WEAK INTERACTIONS

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WEAK INTERACTIONS AND *CP* VIOLATION

I. Kobzarev

1. Introduction

The situation briefly summarized, seems to look like this:
1. The weak *CP* even Lagrangian of the form

$$L_W = \frac{G}{\sqrt{2}} J_i \cdot J_i^+, \tag{1}$$

where

$$J_i = J_i^l + J_i^h$$

$$J_i^l = \bar{\mu}\gamma_i (1 + \gamma_5) \nu_\mu + \bar{e}\gamma_i (1 + \gamma_5) \nu_e$$

$$J_i^h = \cos\theta J_i^{1-2i} + \sin\theta J_i^{4-i5}, *$$

agrees with experiment for the first order effects in G in all the cases when it was possible to extract unique predictions from it. The form (1) is however a far going extrapolation. The terms corresponding to $J_i^l J_i^{l+}$ and $J_i^h J_i^{h+}$ are still badly known and their structure may appear to be more complex. The main difficulties in comparison of L_W with experiment are connected with our inability to calculate matrix elemens of bilinear products of the currents $J_i^h J_i^{h+}$.

The most striking qualitative fact following from the current × current hypothesis is the existence of P odd nuclear forces and $\nu_e e$, $\nu_\mu\mu$-scattering.

The existence of P odd nuclear forces seems now to be proved **.

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* The usually adopted set of assumptions referring to hadronic currents has been summarized in the rapporteur talks by Cabibbo [1] and Wolfenstein [2].

** For summary of the experimental data see [3].

The last result by Reines [4] for $\bar{\nu}_e e$ scattering

$$\sigma_{\bar{\nu}e} < 4\sigma^{\text{Theor}}_{\bar{\nu}e}$$

is at least in no contradiction with the theory.

2. In the low energy region there is a fact — the validity of the $T = 1/2$ rule for hadronic decays — which does not follow directly from L_W in the form (1). Maybe, it is an indication that the Lagrangian L_W has a more complex structure.

3. There is a phenomenon, CP violation, which is explicitly off our scheme. Almost all the facts available are in agreement with the Wolfenstein model. Within this model CP is violated due to CP and T noninvariant and CPT invariant $\Delta S = 2$ interaction with a dimentionless constant of the order $10^{-15\pm2}$. CP violation not only means the end of the accepted belief that there is no difference between right and left in laws of the Nature but also demonstrates that our picture of the weak interactions is evidently incomplete.

4. It is absolutely unknown how to calculate the next corrections in G. Maybe, the problem in such a form is formulated completely incorrectly and L_W is only a phenomenological approximation.

2. Leptonic Decays of Hadrons

2.1. CABIBBO THEORY AND EXPERIMENT

The choice of the form of hadronic current in L_W is based on the agreement with the experiment of the description given by Cabibbo for leptonic decays of hadrons [1]. It is supposed that

$$J^\alpha_k = V^\alpha_k + A^\alpha_k \tag{1}$$

where the currents V^α_k, A^α_k form the vector and axial SU_3 octets and the vector current is normalized so that

$$V^\alpha = \int V^\alpha_0 d^3x \tag{2}$$

are SU_3 generators. (In particular, $V^{1\pm2i}$ and V^3 are the generators of the isospin group.)

Using only these assumptions, it is possible to describe the leptonic decays of pseudoscalar mesons $M \to l\nu$, $M \to M'l\nu$ and baryons $B \to B'l\nu$ in the limit of small momentum transfers q in terms of three parameters: the angle θ, contained directly in L_W and phenomenological parameters of F and D coupling, which determine the axial constants $g_1(0)$ in baryon decays. The vertex in the limit $q = 0$ has the form

$$\Gamma_i = \bar{u}_{B'}\,[f_1(0)\,\gamma_i + g_1(0)\,\gamma_i\gamma_5]\,u_B. \tag{3}$$

From (2) it follows immediately (see the discussion in Sect. (2.2) that up to terms of the order ε_8^2 (where ε_8 is the SU_3 violation parameter) the constants $f_1(0)$ are expressed in terms of the angle θ and the Clebsch — Gordan coefficient of SU_3.

How does all this agree with the experiment? Let us begin with π and K meson decays [1, 2].

The angle θ can be determined from K_{e_3} decays. With the account for the kinematical factors

$$W_{K^+_{e_3}} = 7{,}43 \cdot 10^7 \sin^2\theta \cdot sec^{-1}. \tag{4}$$

Using $W_{K^+_{e_3}} = 4.0 \cdot 10^6\ sec^{-1}$ [5] we obtain $\sin\theta = 0.23$ and $\theta \simeq 0.23$. This value of θ coincides with that given in [3]. When determining θ we did not take into account the correction due to the formfactor of the K_{e_3} decay. In fact, this correction has the value of the order ε_8^2, thus its inclusion exceeds the accuracy with which the angle θ can be determined. In [3] the value of θ was also obtained by taking into account this correction, (this value was cited also in [4]) but the correction there has the incorrect sign and value.

If we calculate now with $\sin\theta = 0.23$ the ratio of probabilities of K_{μ_2}, π_{μ_2} decays, which is equal to $1{,}76\ \mathrm{tg}^2\theta\,\frac{f_K^2}{f_\pi^2}$, where f_K, f_π are the formfactors of K_{μ_2}, π_{μ_2} decays, then

$$f_K/f_\pi = 1.16 \tag{5}$$

while in the SU_3 limit $f_K/f_\pi = 1$.

The agreement is exceptionally good taking into consideration the large mass difference of K and π mesons.

SU_3 interpreted naïvely predicts also that $\xi \ll 1$, where $\xi = f_-/f_+$ and the K_{l_3} vertex have the form (for K^+ decay)

$$\Gamma_i = \frac{1}{\sqrt{2}}\left[f_+(q^2)(p^K + p^\pi)_i + f_-(q^2)(p^K - p^\pi)_i\right]. \tag{6}$$

The experimental situation is inconclusive. In the review by M. K. Gaillard and L. M. Chounet [6], where the experimental data available before the Conference were jointly treated,

$$\xi(0) = -0.85 \pm 0.20. \tag{7}$$

Experimental papers [7] were submitted at this conference where large values of $\lambda_+ : \lambda_+ \simeq 0.08$ were obtained; here λ_+ is determined by $f_+(q^2) = 1 + \lambda_+ \frac{q^2}{m_\pi^2}$.

If we introduce a correction due to λ_+ into (4) despite of the above mentioned inconsistency, we obtain $f_K/f_\pi = 1.30$. Such large λ_+ are however difficult to understand unless vector particles of the type K^* with small mass are assumed to exist.

The paper [4] submitted to the Conference gives the fit of the data on baryonic decays according to the Cabibbo theory. Good agreement with the experiment has been obtained; the value $\theta = 0.24$ obtained from baryonic decays being in good agreement with the value $\theta = 0.23$ determined from $K_{e_3}^+$ decay.

It should be however emphasized that the ratios $g_1(0)/f_1(0)$ being the most critical for the theory are not well known yet.

According to [4] the value of $g_1(0)/f_1(0)$ for the decay $\Lambda \to pe^-\bar{\nu}$ is equal to 0.72. The mean value of the results of three papers presented at the Conference by Althoff et al. [8], Lindquist et al. [9], Baggett et al. [10] is equal [11] to $g_1(0)/f_1(0) = 0.62 \pm 0.06$ but the agreement between the results of different groups is unsatisfactory.

The most interesting prediction of the theory, the sign alteration of $g_1(0)/f_1(0)$ for $\Sigma^- \to ne^-\nu$ decay as compared to the sign of $g_1(0)/f_1(0)$ for other decays is still not proved experimentally. In the paper [12] for $\Sigma^- \to ne^-\nu$ decay the value $\frac{g_1(0)}{f_1(0)} = 0.2 \pm 0.28$ was obtained while theoretical predictions give 0.31. Thus the problem of the comparison of the Cabibbo theory with the experiment cannot be considered to be definitely solved.

2.2. PROPERTIES OF THE VECTOR CONSTANTS

A main feature of the vector constants for $\Delta S = 1$ transitions is the absence of renormalization in the first order in ε_8 which was proved by Ademollo and Gatto [13].

In fact there are two theorems on nonrenormalizability of $f_1(0)$ with different regions of applicability.

The first is the Ademollo — Gatto theorem. The second might be called as the theorem by Behrends — Sirlin [14], Terentyev [15], Bouchiat — Meyer [16], Fubini — Furlan [17]. According to the theorem 1 $f_1(0)$ is not renormalized, if a) the current $V_i^{\alpha}(x)$ and, in particular $V_i^{4\pm 5i}(x)$ is contained in one octet with $V_{i(x)}^{\text{el.—m.}}$, and b) the symmetry breaking interaction belongs to octet.

The theorem II is the statement that $f_1(0)$ is not renormalized if a′) the operator V^{α} is the generator of a certain symmetry and b′) the symmetry breaking interaction acts at one point only (e. g. locally), the type of symmetry being inessential. Particularly, the papers [14, 15] deal with isotopic symmetry.

Therefore, the applicability regions of the theorems I and II are of the form of Fig. 1.

Let us, for example, consider the case when the SU_3 breaking would be due to interaction of the SU_3 singlet meson φ_0 having the form

$$\varepsilon_8 J_8 \varphi_0 + J_0 \varphi_0.$$

Then SU_3 is violated in the vertex $J_8\varphi_0$, i. e. at one point. Therefore, this model belongs to the region B. In the models where integer change triplet SU_3 representations are considered, the condition Ia is violated due to the presence of the SU_3 scalar in $J^{\text{el}}(x)$ [18]. This model does not belong to the regions A, B, C. The region, as defined, (A) may contain only dynamical models of the octet enhancement.

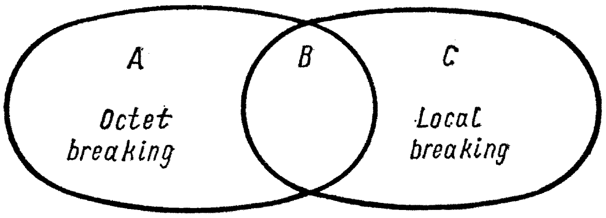

Fig. 1.

The violation of theorem I is possible if the enhancement mechanism generating the octet breaking for masses stops working for weak vertices.

One may obtain the relation between $f_1(0)$ which is valid in the order ε_8^2 and substantially depends on the octet character of the SU_3 breaking. It has the form [19]

$$-\sqrt{6}\,(f_{\Xi^-\Lambda} + f_{\Lambda p}) = f_{\Xi^0\Sigma^+} + f_{\Sigma^- n}. \tag{8}$$

Note that in exact SU_3 limit both parts of eq. (8) vanish. The methods for the proof of the theorem II allows one to make some conclusions on possible accuracy of nonrenormalizability of the vector constants.

The simplest proof is given in [15]. Its main ideà is that up to kinematic corrections of the order $o(\varepsilon^2)$

$$f_{1AB}(q^2) = \langle A \mid V^{\alpha} \mid B \rangle; \tag{9}$$

here $|A\rangle$ and $|B\rangle$ must be taken up to ε^2, i. e.,

$$|A\rangle = |A_0\rangle + \sum_n \varepsilon \, \frac{\langle n \mid H' \mid A_0 \rangle}{E_0 - E_n} \, |n\rangle, \tag{10}$$

where $H = H_0 + \varepsilon H'$, ε is the symmetry breaking parameter; the states A, B belong to the same multiplet of H_0, $|n\rangle$ are the eigenfunctions of H_0. Then as V^{α} is the symmetry generator, $\langle A \mid V^{\alpha} \mid n \rangle = 0$ and terms linear in ε give no contribution. The states A, B have equal momenta $\vec{p}$, thus $q^2 = \left(\sqrt{m_A^2 + \vec{p}^2} - \sqrt{m_B^2 + \vec{p}^2}\right)^2$, where q^2 varies from $(m_A - m_B)^2$ to 0 when $\vec{p}$ varies from 0 to ∞.

Therefore, the nonrenormalizability statement may refer both to points $q^2 = 0$ and $q^2 = (m_A - m_B)^2$. This does not contradict the meaning of the theorem as $(m_A - m_B)^2 \sim \varepsilon_8^2$.

However, in reality if we use experimental formfactors, $f_1(q^2)$ may be considerably different at the points $q^2 = 0$, $q^2 = (m_A - m_B)^2$.

A pessimistic point of view would be that the variation of $f_1(q^2)$ in going from $q^2 = 0$ to $q^2 = (m_A - m_B)^2$ should be considered as a measure of accuracy of nonrenormalizability statement. For example, for K^+ mesons with $\lambda_+ = 0.02$ we obtain the accuracy of order $\pm$ 16%. If we assume that the formfactor of the decay $\Sigma^- \to ne^-\nu$ is determined by the K^* (890) pole then for $f_1(0)$ we obtain the accuracy of order 8%.

The accuracy may be much better if the point $\vec{p} = \infty$ would be physically preferable. The arguments in favour of this were given in [17].

Theoretical papers where attempts were made to calculate the difference of $f_+(0)$ from 1 (for K^+ mesons in normalization corresponding to (6)) give also results much different from $f_+(0) = 1.06$ [20] up to $f_+(0) = 0.80$ [21]. Only the complete set of the experiments on all leptonic decays can give the answer what is the real accuracy with which the values of the vector constants coincide with the SU_3 predictions.

3. $\Delta T = 1/2$ Rule and P Odd Nuclear Forces ($\mathcal{L}_h$)

It is still not proved that the hadronic part $\mathcal{L}_h$ of the weak Lagrangian really has the structure which resulting from the weak Lagrangian (1.1). The doubts are mainly connected to the experimental fact of existence of the $\Delta T = 1/2$ rule and its SU_3 generalization (octet dominance). Important information on the structure of $\mathcal{L}_h$ may be obtained by an investigation of the isotopic structure of P odd nuclear forces.

3.1. $\Delta T = 1/2$ RULE AND EXPERIMENT

The $\Delta T = 1/2$ rule for hadronic transitions with $\Delta S = 1$ does not follow from conventional $J_i J_i^+$ theory: it is well known that such Lagrangian contains both $\Delta T = 1/2$ and $\Delta T = 3/2$ transitions. In experiment the $\Delta T = 3/2$ transitions are small. For baryon decays, according to the most precise recent measurements by Overseth et al. [1—3], the ratios of P and S wave amplitudes with $\Delta T = 3/2$ and $\Delta T = 1/2$ for $\Lambda \to N\pi$ decays * are

$$S_3/S_1 = 0{,}03 \pm 0{,}01$$
$$P_3/P_1 = 0{,}02 \pm 0{,}04 \tag{1}$$

and for Σ-hyperons

$$S_3/S_- = -0{,}04 \pm 0{,}05$$
$$P_3/P_+ = -0{,}04 \pm 0{,}05 \tag{2}$$

where S_- and P_+ are the amplitudes of the appropriate Σ-decays, satisfying the $\Delta T = 1/2$ rule.

* The accuracy for the check of the $\Delta T = 1/2$ rule in [1—3] is such that radiative corrections appear to be essential [4, 5]. The analysis with such an accuracy is somewhat ambiguos, as these corrections contain divergences and, strictly speaking, cannot be calculated. Similar is the situation also in the $K \to 3\pi$ decay.

From the $K^+ \to \pi^+\pi^0$ decay (if one assumes that the $\Delta T = 5/2$ transition is small) it follows that in standard normalization

$$A_{3/2}/A_{1/2} = 0{,}044, \qquad (3)$$

where $A_{3/2}$, $A_{1/2}$ are the reduced amplitudes of the $K \to 2\pi$ decays. The mean value of results 6—8 submitted at the Conference of measurements of the $K_S \to \pi^+\pi^-$ and $K_S \to \pi^0\pi^0$ decay probability ratio is

$$R = \frac{W(K_S \to \pi^+\pi^-)}{W(K_S \to \pi^0\pi^0)} = 2{,}22 \pm 0{,}05. \qquad (4)$$

If we make use of the experimental value of the scattering phase shifts [9]

$$|\delta_2 - \delta_0| = 30^0 \pm 10^0 \qquad (5)$$

then we get for the ratio of the amplitudes of $A_{5/2}$, $A_{3/2}$ transitions

$$A_{5/2}/A_{3/2} \simeq 0.2 \pm 0.1. \qquad (6)$$

This estimate for the $A_{5/2}/A_{3/2}$ ratio is very rough and the present knowledge of the phase shifts δ_2, δ_0 and R do not permit to obtain reliable estimate of this quantity. The precise value of $A_{5/2}/A_{3/2}$ is of great interest. If the amplitudes $A_{3/2}$, $A_{5/2}$ would be of comparable magnitude then it would prove the electromagnetic nature of the $\Delta T = 1/2$ rule violation.

The agreement with the $\Delta T = 1/2$ rule in $\Xi \to \Lambda\pi$ decays 16 was checked with lower accuracy. The situation with $K \to 3\pi$ decays is still less clear both theoretically and experimentally.

General picture both for the total probabilities and for slopes qualitatively corresponds to predictions of the $\Delta T = 1/2$ rule. It is possible that the real violation of the $\Delta T = 1/2$ rule in weak amplitudes is not more then 5% (see, however, below the discussion of the $K \to 3\pi$ decays).

3.2. $\Delta T = 1/2$ RULE AND PCAC

If we do not change $\mathcal{L}_h$, while introducing neutral currents, then we need a mechanism which explains the smallness of the $\Delta T = 3/2$ transitions. An interesting example of suppression of the $\Delta T = 3/2$ transitions is given by the hypothesis of partially conserved axial current (PCAC). Here it is possible to get the suppression of the $\Delta T = 3/2$ amplitude for S waves in $\Lambda \to N\pi$, $\Xi \to \Lambda\pi$ and $K \to 2\pi$, 3π decays. It is not, however, possible to deduce the $\Delta T = 1/2$ rule for S waves of the $\Sigma \to N\pi$ decays and for P waves in all nonleptonic hyperon decays (without considering special models for the amplitudes). Moreover, the PCAC explanation of the $\Delta T = 1/2$ rule uses extrapolation in kinematical variables which is especially questionable for the $K \to 2\pi$ decay. In this decay the application of PCAC essentially implies the 4-momentum nonconservation. If one considers, as it was done by T. D. Lee [11], the contribution to the amplitude linearly depending on possible invariants (at $p_K \neq p_{\pi_1} + p_{\pi_2}$)

$$M = \alpha(p_K p_{\pi_1}) + \beta(p_K p_{\pi_2}) + \gamma(p_{\pi_1} p_{\pi_2}) + \delta \qquad (7)$$

then it can be easily seen that for three $K \to 2\pi$ decays it is possible to construct the amplitudes not satisfying the $\Delta T = 1/2$ rule at physical points but satisfying all the conditions which follow from PCAC. Thus, we see that it is impossible to deduce the $\Delta T = 1/2$ rule for $K \to 2\pi$ decay amplitudes if they contain contributions of the form of (7). Similar statements were also made earlier [12, 13].

Even in the cases when the $\Delta T = 1/2$ rule follows from PCAC, the accuracy with which it is satisfied seems to be, in general, higher than that with which PCAC is satisfied experimentally. Therefore, at present there is no explanation for the $\Delta T = 1/2$ rule.

3.3. AMPLITUDES OF $\Delta T = 1/2$ AND $\Delta T = 3/2$ TRANSITIONS AND SO-CALLED «DISCONNECTED» AMPLITUDES

More quantitative picture can be obtained by calculating 14—16 (within the current—current model) the so called «disconnected» diagrams which have for $K \to 2\pi$, $B \to B'\pi$ decays the form of Fig. 2 (of course, W boson is not necessary present here). There are several types of diagrams for the $K \to 3\pi$ decays. It is important that the amplitudes corresponding to such diagrams may be expressed directly through observable constants of leptonic decays. Comparing the values thus obtained with the experimental data, one can easily see that experimentally the $\Delta T = 1/2$ amplitude is approximately an order of magnitude larger, and the $\Delta T = 3/2$ amplitude is 2 — 3 times less than that given by the diagrams of Fig. 2.

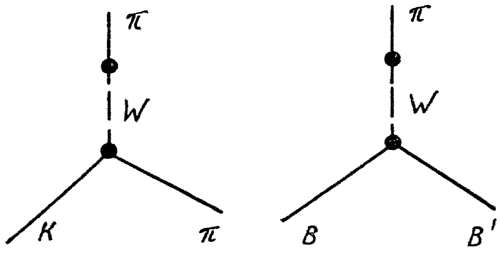

Fig. 2.

Therefore, if $\mathcal{L}_h$ has the conventional structure, then two mechanisms must exist: suppression of $\Delta T = 3/2$ and enhancement of $\Delta T = 1/2$ amplitudes. As was noted by Haan and Stech [14] PCAC cannot serve as the first mechanism for the contributions of disconnected diagrams as the diagrams 2 do satisfy it automatically.

3.4. DECAYS $K \to 3\pi$

In $K \to 3\pi$ decays there are usually compared with experiment predictions of the $\Delta T = 1/2$ ule for the total probabilities and slopes determined from the linear matrix element

$$M \sim 1 + \frac{g}{m_\pi^2}(s^2 - s_0) \tag{8}$$

where $s_3 = (p_K - p_\pi)^2$ corresponds to the «odd» meson and the value of S_0 corresponds to the center of the Dalitz plot. As it is shown in [17, 18], uncertainties which are due to electromagnetic mass difference of $\pi^\pm$, π^0-mesons and pion-pion scattering, do not allow us to interpret unambiguously the total widths data. As was shown by Anisovich, Dakhno and Likhoded [17], one can obtain a relation between the probabilities of the $K \to 3\pi$ decays R^{++-}, R^{+00}, R^{000}, R^{+-0} which does not contain uncertainties due to electromagnetic mass difference and is valid when the $\Delta T = 7/2$ transitions are absent. This relation is of the form

$$\frac{R^{++-}}{4R^{+00}} - \frac{3R^{+-0}}{2R^{000}} = -\frac{175}{162}\left(1 - \frac{3\sqrt{3}}{2\pi}\right)(a_2 - a_0)^2 m_\pi Q + \text{terms of higher order in } Q, \tag{9}$$

where Q is the energy release and a_2, a_0 are the $\pi\pi$ scattering lengths. In the paper by Anisovich and Volkovitsky, submitted to the Conference [19], the right-hand part of this relation is calculated up to terms $Q^{5/2}$ using the experimental values of terms linear in energy in the matrix element. The result obtained is used to determine the values of a_0, a_2.

For slopes the $\Delta T = 1/2$ rule predicts:

$$-\frac{g_{+00}}{2g_{++-}} = 1$$
$$-\frac{g_{+-0}}{2g_{++-}} = 1. \tag{10}$$

The experimental data on the slopes g are now contradictory. There are the data which are in good agreement with (10) but there are also experiments which give considerably larger values for corresponding quantities (see Rapporteur talk by V. M. Lobashov).

It is interesting that large deviations from (10) are predicted by the PCAC hypothesis. With this it is possible to relate the $\Delta T = 1/2$ rule violation in $K \to \to 3\pi$ decays with $A_{3/2}$ amplitude for $K \to 2\pi$ [21, 22].

The calculation [22] gives

$$-\frac{g_{+00}}{2g_{++-}} = -\frac{g_{+-0}}{2g_{++-}} \cong 1{,}5. \qquad (11)$$

The existing data do not allow one to make a choice between (10) and (11).

3.5. $\Delta S = 0$ TRANSITIONS AND NEUTRAL CURRENTS

The $\Delta T = 1/2$ rule can be easily obtained if neutral octet currents will be included into $\mathcal{L}_h$ (and the number of W mesons respectively increased). The models of this type were discussed at this Conference in the papers by Marshak et al. and by Tomozawa (see Sect. 4).

It is obvious that if the neutral currents exist, the structure of the weak Lagrangian corresponding to $\Delta S = 0$ may be changed as compared with the usual one.

A general treatment of this problem is given in the paper by Albraight and Oakes [23]. The authors discuss, in particular, the hypothesis according to which $\mathcal{L}_h^{\Delta S=0}$ satisfies the selection rule $\Delta T = 0$. (In the scheme with charged currents $\mathcal{L}_h^{\Delta S=0}$ contains transitions with $\Delta T = 0, 1, 2$.) The proposed $\mathcal{L}_h$ has a simple form (previously obtained by Lee and Yang in shizon model):

$$\mathcal{L} = \frac{G}{\sqrt{2}} [J_i^{(+)} J_i^{(+)+} + J_i^{(0)} J_i^{(0)+}] \qquad (12)$$

where $J_i^{(+)}$ is the conventional Cabibbo current and

$$J_i^{(0)} = \cos\theta J_i^3 - \sin\theta J_i^{6+7i}. \qquad (13)$$

In principle, other pure cases: $\Delta T = 1$, and $\Delta T = 2$ are also possible, but then, as it was shown in [23], the part of $\mathcal{L}_h$ depending on the charged currents must be also changed.

As $\Delta T = 1$ part of $\mathcal{L}_h$ is sensitive to different models of $\mathcal{L}_h$ direct experimental study of $\Delta T = 1$, $\Delta S = 0$ transitions is very interesting. As is known, $\Delta T = 1$, $\Delta S = 0$ transitions are responsible for γ-quanta asymmetry in the capture of polarized neutrons [24].

It can be mentioned that calculations of P odd nuclear potentials [25] seem to give an indication to the absence or smallness of $\Delta T = 1$ part of $\mathcal{L}_h$. The smallness of $\Delta T = 1$ takes however place not only for $\mathcal{L}_h$ in the form $J_i^{(+)} J_i^{(+)+}$ but also, e. g. for $\mathcal{L}_h$ of the type (12), thus it is not by itself an argument against the existence of the neutral currents, as it is sometimes stated.

4. *CP* Violation

4.1. WOLFENSTEIN MODEL

The main fact which has now became clear is that almost all the CP violation data available for K^0, $\bar{K}^0$ are in agreement with the Wolfenstein model [1]. In this model CP is violated due to transitions of Fig. 3.

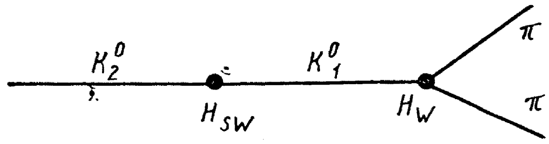

Fig. 3.

where H_{SW} is the superweak interaction giving $\Delta S = 2$ transitions with dimensionless constant $\sim 10^{-13} \div 10^{-17}$. It can be said in other words that in this model CP is violated (only) due to the admixtures of K_1 and K_2 in K_L, K_S states

$$K_L = K_2 + \varepsilon K_1$$
$$K_S = K_1 + \varepsilon K_2 \tag{1}$$

where the phase of ε is determined uniquely

$$\varepsilon = \frac{im_{12}}{\Delta m - \frac{i}{2}(\Gamma_S - \Gamma_L)}$$

$$\Delta m = m_S - m_L, \tag{2}$$

where m_{12} is a real constant.

It is obvious that in this model the relation

$$\eta_{+-} = \eta_{00} = \varepsilon \tag{3}$$

is always valid (independently of $\Delta T = {}^1/_2$). Here

$$\eta_{+-} = \frac{\langle \pi^+\pi^- | T | K_L \rangle}{\langle \pi^+\pi^- | T | K_S \rangle} \tag{4}$$

$$\eta_{00} = \frac{\langle \pi^0\pi^0 | T | K_L \rangle}{\langle \pi^0\pi^0 | T | K_S \rangle}. \tag{5}$$

The charge asymmetry in μ_3, e_3 decays of K_L determined as

$$\delta_l = \frac{N_{l^+} - N_{l^-}}{N_{l^+} + N_{l^-}} \qquad (l = e, \mu) \tag{6}$$

is equal to

$$\delta_l = 2\,\mathrm{Re}\,\varepsilon \tag{7}$$

if the selection rule $\Delta Q = \Delta S$ is valid.

Thus the model contains only one new parameter m_{12} and given $|\eta_{+-}|$, one may predict all other effects. From existing data on Δm and Γ_S we obtain

$$\varphi_{+-} = \arg \eta_{+-} = \varphi_{00} = \arg \eta_{00} = 43.0^0 \pm 0.2^0 \tag{8}$$

and with $|\eta_{+-}| = (1{,}95 \pm 0{,}05) \cdot 10^{-3}$ we obtain

$$\mathrm{Re}\,\varepsilon = (1{,}42 \pm 0{,}04) \cdot 10^{-3}. \tag{9}$$

Recent experimental data are in good agreement with these predictions. New exact data [2] on $m_L - m_S$ allow us to determine with high accuracy φ_{+-} from vacuum interference experiments. The results are in agreement with the data of regeneration experiments and give the mean value

$$\varphi_{+-} = 44^0 \pm 4^0. \tag{10}$$

Recent data on asymmetries δ_e, δ_μ correspond to

$$\mathrm{Re}\,\varepsilon = (1{,}61 \pm 0{,}20) \cdot 10^{-3}. \tag{11}$$

The data on $|\eta_{00}|$ were so far contradictory. The recent data by the ITEP group [3] are in agreement with the results by Cronin et al. [4] and Budagov et al. [5]. The mean value for [3—5] is equal to

$$|\eta_{00}| = (2{,}10 \pm 0{,}17) \cdot 10^{-3}. \tag{12}$$

Thus within the accuracy achieved ($\sim$ 10%) the data (10) — (12) are in agreement with the model [1].

$\varphi_{00} = \arg \eta_{00}$ was measured in only one work [6]; the result obtained has low accuracy

$$\varphi_{00} = 51^0 \pm 30^0. \tag{13}$$

The value of the phase of η_{00} is of great interest and its accurate measurement is very important.

4.2. WHAT FOLLOWS FROM EXPERIMENTAL DATA AVAILABLE?

Statements that will be made here are not new and mainly contained in the papers [7, 8] and in the rapporteur talks [9—11]. Nevertheless, in existing situation it seems to me useful to summarize them. Though the Wolfenstein model may be easily disproved experimentally, the agreement with its predictions is not a proof of its validity. The fact is that up to 10% accuracy an analogous statement may be valid for millistrong model. There is also a number of models, though somewhat artificial, the predictions of which coincide with predictions of the Wolfenstein model with the accuracy up to 10^{-3} or better.

This follows easily from the general theory of K^0, $\bar{K}^0$. From general principles of quantum mechanics it follows that if the strong interaction spectrum does not contain any degenerated states other them K^0 and $\bar{K}^0$, then due to weak interaction two exponentially decaying states K_L, K_S will result being of the form

$$\begin{aligned} K_L &= pK^0 - q\bar{K}^0 \\ K_S &= rK^0 + s\bar{K}^0 \end{aligned} \tag{14}$$

and

$$\begin{aligned} K_L(t) &= \exp(-i\lambda_L t)\,|K_L\rangle \\ K_S(t) &= \exp(-i\lambda_S t)\,|K_S\rangle \end{aligned} \tag{15}$$

where

$$\lambda_{L,S} = m_{L,S} - \frac{i}{2}\Gamma_{L,S}.$$

The observed amplitudes of $K_{L,S} \to 2\pi$ decays are expressed through the following parameters: p, q, r, s; the amplitudes of K^0, $\bar{K}^0$ decays into stationary waves with $T = 0$, $T = 2$ A_0, A_2, $\bar{A}_0$, $\bar{A}_2$; the phase shifts of $\pi\pi$ scattering in the states with $T = 0,2$: δ_0 and δ_2, appearing in the amplitudes $\langle 2\pi, T = 0,2\,|\,T\,|\,K_{L,S}\rangle$ after transition to outgoing waves. As it was shown in the paper by Wu and Yang [7], it follows from this general consideration that:

$$\begin{aligned} \eta_{+-} &= \varepsilon + \varepsilon' \\ \eta_{00} &= \varepsilon - 2\varepsilon' \end{aligned} \tag{16}$$

where

$$\varepsilon = \frac{im_{12}}{\Delta m - i\dfrac{\Gamma_S - \Gamma_L}{2}}, \quad \varepsilon' = \frac{i}{\sqrt{2}} \cdot \frac{\operatorname{Im} A_2}{A_0} e^{i(\delta_2 - \delta_0)} \tag{17}$$

and

$$p = r = 1 + \varepsilon, \quad q = s = 1 - \varepsilon.$$

Formulae (16) and (17) follow from very plausible assumptions: 1) CPT invariance; 2) $\Delta T = {}^1/_2$ rule for CP even $K_S \to 2\pi$ decays; 3) CP violation in other decays of K_L, K_S is of the same order as in the 2π channel.

Formulae (16) and (17) are written in the gauge (always possible) where $\mathrm{Im}\, A_0 = 0$. Further assuming $\Delta Q = \Delta S$ rule in phenomenological theory the relations

$$\delta_\mu = \delta_e = 2\, \mathrm{Re}\, \varepsilon$$

are also valid.

The assumption 2) is experimentally fulfilled with not very high accuracy (it follows from the K_S^0 data that Re $A_2/A_0 \cong 0.03$). This violation of the $\Delta T = {}^1/_2$ rule may be easily taken into account [9, 11, 12] the results being not changed essentially. Corrections appear in terms ε' (different in η_{+-} and η_{00}) and a correction to ε determined with good accuracy by equation

$$\mathrm{Im}\, \varepsilon = \mathrm{Re}\, \varepsilon - \frac{\mathrm{Im}\, A_2 \cdot \mathrm{Re}\, A_2}{A_0^2}. \tag{18}$$

It is evident from formulae (16), (17), that under reasonable assumption the phenomenological theory results in appearance in expressions for η_{+-}, η_{00} of only one new parameter: Im A_2. Therefore, any model in which Im A_2 is small will give the same results as the Wolfenstein model. It can be readily seen that, e. g. in millistrong model [13—15] always Im $A_2 \sim \varepsilon\, \mathrm{Re}\, A_2$. This is due to the fact that the A_2 amplitude must appear in this case as a result of two transitions: *CP* violating millistrong with $\Delta T = 0$ and *CP* conserving weak transitions with $\Delta T = {}^3/_2$. Thus, in millistrong model η_{+-}, η_{00} coincide with (3) up to 10%.

(Let us note, that although $\Delta T = 0$ [17] for *CP* violating vertices in the *a*-particle model by T. D. Lee [18], $\Delta T = 0{,}1$ for *CP* even vertex and thus in this model virtual photons give both $\Delta T = {}^1/_2$ and $\Delta T = {}^3/_2$ transitions).

As for the milliweak models, we have various possibilities including also $\frac{\mathrm{Im}\, A_2}{A_0} \ll 10^{-3}$. There is a wide class of models in which there is no direct *CP* violation in $K \to 2\pi$ amplitudes at all (e. g. *CP* violation in *P* even $\Delta S = 1$ amplitudes [18], in $\Delta Q = -\Delta S$ [19] transitions, in weak electromagnetic [20] $\Delta S = 1$ *P* even interactions). In these models $\mathrm{Im}\, A_2 = 0$, ε' term (17) and the correction to the phase (18) are absent. The accuracy of the coincidence with (3) depends on the accuracy of fulfillment of the assumption (3) and may be of order 10^{-3} and higher.

It follows from the above mentioned that if the accuracy in φ_{+-} would achieve 1°, then it would exclude with reasonable plausibility such models as millistrong.

Further progress may be achieved only by looking for the *CP* violating effects outside the K^0, $\bar{K}^0$ system. It seems that the measurement of the neutron dipole moment with the accuracy of order $d_n \leqslant e \cdot 10^{-25}$ *cm* would be the most important experiment. If it is absent it will be a strong argument in the favour of the Wolfenstein model.

If the superweak interaction alongside with $\Delta S = 2$ component has $\Delta S = 0$, $P = -1$ component, it must give the neutron dipole moment of order $e \times 10^{-28\pm 2}$ *cm* [21] and thus the further improvement of accuracy might give positive result even in the case of superweak model.

4.3. *T* VIOLATION

The phenomenological theory allows one to consider a case when *T* is conserved while *CP* is violated [21—29].

The experimental data analysis shows however that such possibility is now hardly acceptable. Thus it is possible to demonstrate directly the *T* violation in K^0, $\bar{K}^0$ decays independently of the CPT theorem, the latter being based on an assumption that the field theory is valid. A complete proof of T violation would be achieved if the more accurate data on arg η_{00} would be obtained.

For simplicity, let us retain, following 25—26, the assumptions 2, 3 of sec. 4.2, made when deriving the Wu — Yang formulae.

Then

$$\begin{aligned} \eta_{+-} &= \bar{\varepsilon} + \bar{\varepsilon}' \\ \eta_{00} &= \bar{\varepsilon} - 2\bar{\varepsilon}' \end{aligned} \qquad (19)$$

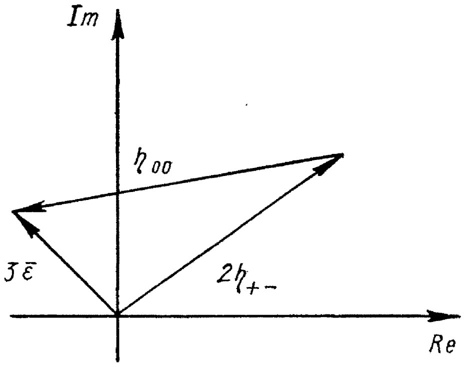

Fig. 4.

where $\bar{\varepsilon}$ and $\bar{\varepsilon}'$ differ from (17) by a factor i (see Fig. 4).

It follows from (19) and relation $\bar{\varepsilon}' = \frac{1}{3}(\eta_{+-} - \eta_{00})$ that if T invariance is valid, then

I) $|\eta_{00}| \geqslant 2\,|\eta_{+-}|$

II) arg η_{00} lays in the third quadrant.

III) $\delta_2 - \delta_0$ lays in the first quadrant.

Consequence I contradicts most of the data on $|\eta_{00}|$. If we however reject the assumption (3) of Sect. 4.2, then it may be possible to reconcile the relation $|\eta_{00}| \simeq |\eta_{+-}|$ with the T conservation [29].

In this case however η_{00} — just as in fig. 4 — must lay in the third quadrant. Thus, if in accordance with [6] η_{00} lays in the first quadrant, then the possibility of T conservation is excluded. Consequence III) contradicts the results of $\pi\pi$ scattering phase shift analysis [30], according to which $\delta_2 - \delta_0 = -(30° \pm \pm 10°)$.

One may consider the general case of phenomenological description assuming neither CPT nor T conservation. Then the wave functions K_L, K_S may be written in the form

$$\begin{aligned} K_S &\sim (1 + \varepsilon + \tilde{\varepsilon})\,K^0 + (1 - \tilde{\varepsilon} - \varepsilon)\,\bar{K}^0 \\ K_L &\sim (1 + \varepsilon - \tilde{\varepsilon})\,K^0 - (1 - \varepsilon + \tilde{\varepsilon})\,\bar{K}^0 \end{aligned} \qquad (20)$$

$\tilde{\varepsilon} = 0$ corresponds to the CPT invariant case and $\varepsilon = 0$ to the T invariant case. In the paper [31] submitted to the Conference, the authors using the data on arg η_{00}, have obtained that $|\tilde{\varepsilon}| \leqslant \frac{1}{3}\varepsilon$. A similar limit is also obtained for possible CPT violation in the amplitudes A_0, A_2.

4.4. MODELS AND EXPERIMENT

The CP violation mechanism may be determined only when CP violation in other processes except K^0, $\bar{K}^0$ decays is observed (or its absence is proved). Such effects have not yet been definitely found. However, so far mainly the electromagnetic model by Lee, Bernstein, Feinberg was checked.

The absence of the neutron dipole moment [32]

$$d_n < e \cdot 5 \cdot 10^{-23}\ cm \qquad (21)$$

and of decay $\eta_0 \to \pi^0 e^+ e^-$ [33]

$$R = \frac{\Gamma(\pi^0 e^+ e^-)}{\Gamma(\eta^0)} < 10^{-4} \qquad (22)$$

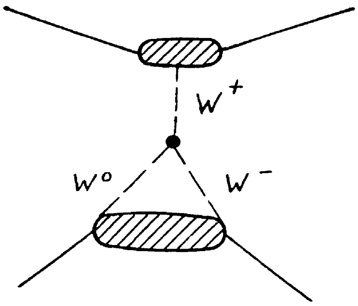

Fig. 5.

as compared to initially expected $d_n \sim 10^{-19} \div 10^{-21} e \cdot cm$ and $R \sim 4 \cdot 10^{-2}$ (for existing value of Γ_{η^0}) is difficult (though not impossible) to reconcile with electromagnetic hypothesis. There are data which might be interpreted in favour of electromagnetic model, such as possible existence of asymmetry in $\eta^0 \to \pi^+\pi^-\pi^0$ decay [34] and the data on the T violation in reaction [35]

$$\gamma + d \leftrightarrow n + p.$$

However these data have not been confirmed in other experiments. New measurements were not presented at the Conference.

As for the checking most other models, in no one of the experiments a necessary accuracy was achieved.

The most critical condition for various models is now the equality $\eta_{+-} = \eta_{00}$. In particular, this equality, generally speaking, is not fulfilled in the model by R. E. Marshak, J. V. Yang and J. S. Rao [36]. In this model weak interactions appear due to CP odd interaction of W^+, W^0, W^- boson triplet (there are in fact six W bosons as for such theory $\overline{W^0} \neq W^0$, $W^- \neq \overline{W^+}$ is essential) with the octet of hadronic currents $j^{\alpha}_{\beta}(x)$ and usual charged leptonic currents with the constant g. Also, a triple CP even vertex with a constant $f \sim 1$ is introduced (see fig. 5).

The one W exchange gives usual CP even interaction in g^2 order. CP is violated due to the diagrams of Fig. 5. It is obvious that for $K_L \to 2\pi$ decays both $\Delta T = {}^1/_2$ and $\Delta T = {}^3/_2$ transitions may appear. The model predicts large CP odd effects in the weak-electromagnetic type processes, such as $K^+ \to \pi^+e^+e^-$ decay, resulting from g^2e^2 and g^3 amplitude interference.

Another model of CP violation in the scheme of weak interactions with nonet (or octet) of W mesons is considered by Tomozawa [37]. In this model complex constants are chosen so as to exclude $\Delta S = 2$ transitions for equal W-masses. These transitions can reappear due to the mass differences of neutral W mesons. Supposing these differences to appear in order αg^4, the author obtains experimentally required CP violation in the mass matrix of K^0, $\overline{K}^0$. In the paper by Filippov [38], where a concrete variant of the weak-electromagnetic hypothesis (with P conservation) is discussed, estimates of the $K_L^0 \to \pi^0e^+e^-$ decay width are given. The existence of this decay with relative probability $\sim 10^{-5}$ is critical for such scheme.

The paper [39] proposes a model of strong (~ 1) C violation at $\rho\eta\pi$ vertex with $\Delta T = 0$ and $\Delta T = 2$ transitions appearing due to electromagnetic corrections in order to describe the data [34]. The authors explain the smallness of ε in K_L by the absence of intermediate real states with needed properties and by low cut-offs in virtual momenta. The question of compatibility of such a model with the absence of C violation in strong interaction up to 1% is not discussed.

5. High Energy Weak Interactions, W Bosons

5.1. SOME PROPERTIES OF HIGH ENERGY WEAK INTERACTIONS

During the last few years the problem of the behaviour of the weak interaction at high energies attracts more and more attention. In the end, the solution of this problem is the solution of the problem of nonrenormalizable interaction. This section is devoted to papers which consider more restricted problems.

The paper by I. Ya. Pomeranchuk which was published posthumously deals with the restrictions which are imposed by analiticity on the increase of the weak interaction cross sections. The perturbation theory leads to cross sections of weak processes increasing as s. At the unitary limit when the perturbation theory fails, the cross section is still small

$$\sigma \sim G.$$

Now the question of the behaviour of the weak cross section at the energies above the unitary limit may be investigated. It appears that its increase is limited in the sence that the cross section may become large only at very high energies. Paper [1] deals with νe scattering. The invariant amplitude at low energies is supposed to be of usual form

$$f_{\nu e} = 4\sqrt{2}\,Gs. \tag{1}$$

If the weak interaction cross section tends to constant, then one may write for the positive signature amplitude $f_+(s)$ the dispersion relation with one subtraction (for $t = 0$)

$$f_+(s) = f_+(0) + \frac{2s^2}{\pi}\int \frac{\sigma(s')\,ds'}{s'^2 - s^2} \tag{2}$$

where $\mathrm{Im}\, f(s) = s\sigma(s)$.

If at $s' > s_1$, the cross section becomes large: $\sigma(s') \simeq \sigma_1$, then considering the contribution from the region $s' > s_2$ to the integral (2) one can easily see that

$$\mathrm{Re}\, f_+(s) > \frac{s^2}{\pi} \cdot \frac{\sigma_1}{s_1}. \tag{3}$$

If now we suppose that at $s \sim \frac{1}{G}$ $f_+ \sim f_- \sim 1$, then it is obvious that

$$s_1 > \frac{\sigma_1}{G^2}. \tag{4}$$

The regime corresponding to (3), (4) might be obtained with the interaction radius increasing as $\sqrt{s}$ starting with $s \sim \frac{1}{G}$ and the phase shifts $\delta_l \sim 1$. Then $\mathrm{Im}\, f_+ \sim \mathrm{Re}\, f_+$ increase as $s\sigma(s)$, i. e. as s^2 (all this with logarithmic accuracy).

Hence it follows, in particular that the weak interaction cross section may become of order of strong one only at $s \simeq 10^{10}\ m^2$.

Proceeding from the fact that it is possible to estimate $\frac{\partial f}{\partial t}$ in the first order in G, Pomeranchuk has obtained a more strong restriction on s_1:

$$s_1 > \frac{\sigma_1^2}{32\pi G_1^3}. \tag{5}$$

The paper by Berezinsky [2] discussed the problem how the restriction on cross sections at $s_1 \gg \frac{1}{G}$ depends on the assumptions concerning the interaction radius at $s \sim \frac{1}{G}$. In the paper [3] the authors arrive at the conclusion that approximations usually used in dispersion approach models are nonapplicable in case of nonrenormalizable interaction.

Paper [4] considers the behaviour of weak hadronic processes with one W meson exchange, of the type $\pi^- p \to K^0 n$ in the region $sG \ll 1$. The cross sections of such processes are constant for the diagrams of the type of Fig. 6. (see p. 558) and of order $10^{-40}\ cm^2$ if the electromagnetic formfactors are substituted into vertices. The arguments are given that such diagrams cannot be suppressed by

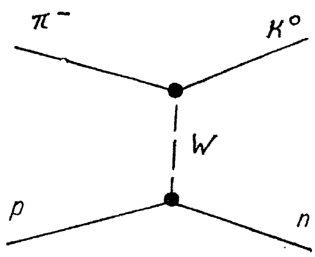

Fig. 6.

strong interactions. Due to the diffraction scattering cone shrinkage the strong interaction phase shifts decrease as $1/\ln s$ at impact parameters $\rho \sim \frac{1}{m_\pi}$ on which the scattering described by the diagram of Fig. 6 occurs. For reactions of the type $\pi^- p \to \pi^0 n$ the decrease of strong amplitudes as compared to the weak one must lead to an increase of P-odd effects at $E \to \infty$; in effect the nucleon longitudinal polarization must increase from $\sim 2.10^{-5}$ at $E_\pi \sim 25$ GeV (lab) up to 10^{-4} at $E_\pi \sim 10^3$ GeV.

The impossibility of suppressing the contributions from the simplest graphs of perturbation theory is proved more rigorously in [4] for the case of electromagnetic two-photon contributions to the scattering processes.

Considerably larger P-odd effects could be observed at large t if the weak amplitudes stop decreasing in this region [5, 6]. Such an assumption (unlike the consideration in [4]) does not follow from usual theoretical notions.

5.2. WHAT DOES THE NONRENORMALIZABILITY OF L_W MEAN?

As was mentioned above, the first order amplitudes of perturbation theory cannot describe weak interactions at high energies as they contradict unitarity. It is also well known that the perturbation theory series for L_W is nonrenormalizable. There are different opinions on the meaning of this.

According to one of them [7] the perturbation theory series has still some meaning and comparing the second order corrections of the type $G^2\Lambda^2$ with the experiment, we can find the limit for Λ. In this approach Λ is interpreted as energy at which new physical phenomena must appear, i. e. new interactions will be turned on and new particles will appear. However, the parameter Λ is related to integration over virtual particles and at best determines in which region the deviations from the mass shell amplitude start to appear. As for the identification of Λ with the real energy, it is a certain hypothesis. Such relation between the cut off for virtual particles and the energy where physical amplitudes change their structure, is directly realized in renormalizable theories of the weak interaction where the nonlocality of the effective four-fermion interaction cuts integrals at $\Lambda^2 \sim M^2$, where M is the mass of heavy particles. However, in general such relation may be absent.

The second possibility is the elimination of divergences due to their cancellation by a special choice of interaction constants. Such possibility would correspond to the picture in which the self-consistency of the theory would be possible due to the existence of some symmetry group providing the cancellation of divergences. It is seen on a number of examples that such possibility does in fact exist. Thus for instance, the quadratic divergence for $\Delta S = 1$ hadronic processes of the type of Fig. 7 and for the processes with $\Delta S = 0$, $P = -1$, which trivially disappears in the $SU_3 \times SU_3$ limit remains zero [8] for a definite choice of the $SU_3 \times SU_3$ violation in the form $[(3,\bar{3}) + (\bar{3},3)]$. As it is shown in the paper [9], submitted to the Conference, corresponding quadratic divergences also do not appear in processes with the additional γ-quanta emission and may also be absent in $\Delta S = 1$, $\Delta S = 0$, $P = -1$ transitions even with the account of radiative corrections.

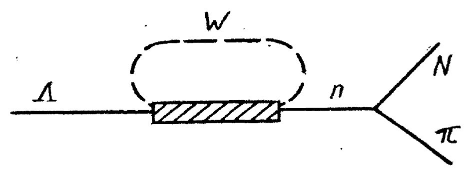

Fig. 7.

Thus, one can see that a definite choice of interaction (in this given case, of strong one) can really result in cancellation of a class of divergences.

And finally it is possible that actual difficulties are simply due to our inability to find the correct method to work with L_W. Before the renormalization theory has emerged it was thought that in electrodynamics it is impossible to calculate the next orders in α in perturbation theory. But in fact neither new constants nor new interactions were needed. It is not impossible that the same will be true for L_W.

An attempt to solve the problem of νe-scattering corresponding to the pointlike νe interaction is contained in a paper by D. A. Kirzhnits and M. A. Livshits [10]. In this paper the solutions of equations of axiomatic field theory are considered. The usual form of the νe-scattering amplitude is used as a boundary condition. Working in two-particle approximation the authors obtain for the S matrix the solutions depending on one free parameter which are finite at all E. These solutions are not unitary at finite time intervals t (unlike usual formal series of perturbation theory) but at $t \to \infty$ the unitarity is reestablished.

The unadmissible growth of the obtained solution in the complex plane may be, in authors opinion, a feature of the approximation used.

5.3. THE MODEL WITH PHYSICAL CUT-OFF

If the current algebra is valid at large momenta, then for the process $K_L \to \mu^+\mu^-$ in the second order in L_W the result [11, 12] is valid

$$\frac{\Gamma(K_L \to \mu^+\mu^-)}{\Gamma(K^+ \to \mu^+\nu)} \simeq G^2\left(\frac{\Lambda}{2\pi}\right)^4 \tag{6}$$

for the model of the local current $\times$ current interaction. In the paper by Clark et al. [13] the upper limit is obtained

$$\frac{\Gamma(K_L \to \mu^+\mu^-)}{\Gamma_L} \leqslant 6 \cdot 10^{-9} \tag{7}$$

that formally corresponds to $\Lambda \leqslant 12$ *GeV*. However, as it was emphasized by B. L. Ioffe (a remark at the Conference), this estimate is in fact very ambiguous as the limit (7) practically coincides with the lower theoretical limit. This latter limit is determined by imaginary part of the amplitude of electromagnetic transition $K_L \to 2\gamma \to \mu^+\mu^-$ and is equal, according to [14], to 5.10^{-9}, which is close to (7). Under these conditions formula (6) is, rigorously speaking, nonapplicable as it refers to the case when the second order weak amplitude G^2 is much larger than the electromagnetic one ($G\alpha^2$).

It should be said that if the weak G^2 amplitude would be negligibly small (if really $\Lambda \sim m_N$) then the near absence of the real part in the electromagnetic amplitude, corresponding to (7) will be still difficult to explain.

In any case, if we assume the physical cut-off hypothesis, the deviations from the pointlike L_W should appear at low energies.

What form do they have? The simplest hypothesis assumes the existence of W boson. But its existence by itself, however, does not make the theory good, it remains nonrenormalizable and the amplitudes of the theory are inconsistent with unitarity at high energies (although the limit on Λ from $K_L \to \mu^+\mu^-$ is increased: $\Lambda \leqslant 25$ *GeV*).

It can be supposed that the physical cut off occurs due to W meson electromagnetic interaction which becomes strong at $E \sim \frac{m_W}{e}$. Such hypothesis seems

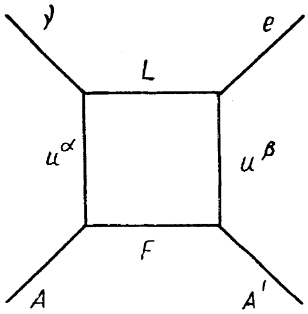

Fig. 8.

to be possible if only

$$\Lambda \geqslant \frac{m_W}{e} \tag{8}$$

and would allow one to obtain the upper limit for m_W. This hypothesis was proposed by B. L. Ioffe but later he has shown [15] that even if (8) is fulfilled, the electromagnetic corrections to weak processes seem to be small. Therefore it is not clear now, how the electromagnetic cut off might work.

Some authors [16—18, 21] discuss schemes in which it is assumed that the real weak interaction is renormalizable. Essentially they discuss variants of the models by Tanikawa and Watanabe [19] and Kummer and Segre [20]. In the models of the type [19] a scalar particle in the s channel with the baryon charge 1 is introduced. The paper [21] considers P odd effects in ep scattering which inevitably appear in models of the type [19]. These effects may achieve tens of percents already at $E_{\text{lab}} \sim 10$ GeV.

In models of the type of [20] weak processes appear in fourth order of perturbation theory due to two scalar meson exchange. In such models hadron-lepton processes are described, e. g. by the diagrams of the type of Fig. 8 where F is the hadronic state, L are heavy leptons, u^α and u^β are scalar bosons, the number of which in different versions of theory is different and A, A' are hadronic states. The papers [16, 18] consider the variants where the Λ, n, p model for usual hadrons is used and the transitions of the heavy neutral baryon F to usual hadrons are forbidden.

In the paper [17] it is noted that the Adler theorem, according to which the parity nonconservation effects disappear in processes of the type of $\nu A \to lA'$ (where A and A' are hadronic states) for parallel configurations $\vec{p}_l \parallel \vec{p}_\nu$ must be violated in renormalizable theories of the Kummer — Segre type, the violation magnitude increasing with energy. Estimates are given in the model [22] with the triplet of scalar bosons. It is obtained that «forbidden» longitudinal proton polarization appears to be of order 10% at $E_\nu \sim 10$ GeV. It is clear that qualitatively the effect is characteristic for all the theories of such type.

For the models of the type [20] difficulties appear in the description of nonleptonic processes with $\Delta S = 1$, $\Delta S = 0$, e. g. $\Delta S = 1$ transitions may appear in g^2 order due to the diagram of the type of Fig. 9.

One can avoid these difficulties if $\bar{u}^0 \neq u^0$. Then the couplings can be arranged in such a way that the diagram of Fig. 9 is absent. The other difficulty connected with the appearance of P odd nuclear forces in g^2 order can be avoided if different U bosons are emitted in scalar and pseudoscalar hadron vertices [18]. In the model [18] hadronic weak interactions appear due to transitions of U bosons one into another, and that introduces a new constant into the theory.

In the paper [16] a peculiar variant is proposed in which the neutral meson U^0 is identified with the combination of neutral pseudoscalar mesons and F is a

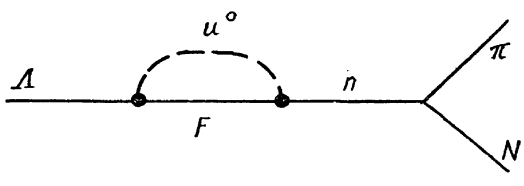

Fig. 9.

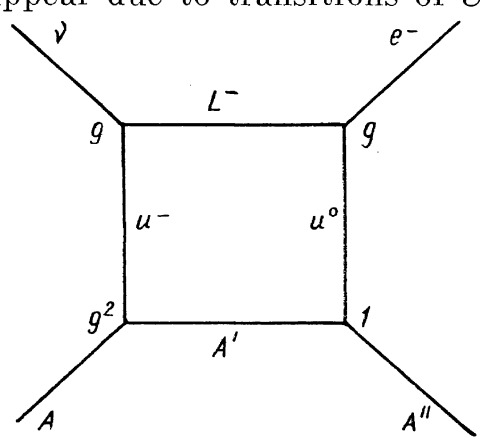

Fig. 10.

usual hadronic state, so that the diagram of Fig. 8 assumes the form where the constants are chosen as is shown in Fig. 10. It is obvious that in this model the neutral currents with $\Delta S = 0$ appear in g^2 order and the problem of *ep* scattering is a difficult one.

All the models of such a type predict the existence of new particles with the masses not larger than 10—20 *GeV*, as it is just at the masses of these particles where the integrals for the processes of the second order in the effective constant *G* are cut off.

Concluding Remarks

Subjects touched upon in this report present a very incomplete selection from a large variety of problems discussed recently and at this Conference. In particular, I have totally omitted the papers on neutrino physics and on the problems of leptonic charge as they were discussed in details at this Conference by B. M. Pontecorvo.

In conclusion I should like to thank B. L. Ioffe, L. B. Okun', I. S. Shapiro for discussions of this report, E. P. Shabalin for useful remarks and N. N. Nikolaev for his help in preparing the report.

DISCUSSION

K h a l f i n:

There is the common misconception that unstable particles decay through a pure exponential law. If one does not make this assumption one can show that the *CP*-violation phenomena may be a result of our seeing the breakdown of the exponential decay law. A crucial experiment for my theory is

$$e- + e+ \to \varphi \to K_S + K_L$$

versus

$$A_2 \to K_S + K_S.$$

I predict no *CP*-violating effect will appear in the second situation where both particles are K_S.

P a t i l:

In our theory we have considered all the processes which involve weak neutral currents. We find that our theory is consistent with all the known processes if the heavy scalar boson mass lies between 1 and 20 *GeV*.

F a i s s n e r:

Regarding the conclusion that *CPT* is valid and *T* is broken I should like to make the following observation: This statement rests on the assumption that the kaon is an isolated system. But you can imagine the kaon interacting with the vacuum, and you may describe this by a complex scalar potential. Of course, this is quite a dramatic assumption, meaning the appearance (or disappearance) of particles (and energy) from the vacuum. But formally such a model is possible. The model violates *CPT* but preserves *T*, and it is not in disagreement with experiment. As a matter of fact it's predictions coincide with those of the Wolfenstein superweak theory, except for the sign of the admixture coefficient ε_S of the short-lived K_S^0, which has a negative sign with respect to the ε_L of K_L^0.

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