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MASS REVERSAL AND COMPOUND MODEL OF ELEMENTARY PARTICLES

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Abstract

The consequences that follow from the invariance of the Lagrangian of interacting elementary particles with respect to transformation of the mass reversal: $\psi \rightarrow \gamma_5 \psi$, $m \rightarrow -m$ for each particle separately, are examined. In interactions which conserve parity owing to mass reversal invariance elementary particles cannot be created nor destroyed singly. Thus conservation of strangeness and conservation of parity are interrelated.

In electromagnetic interactions mass reversal invariance results in the principle of minimal electromagnetic interaction. Extension of the invariance to strong interactions results in an elementary particle model in which the truly elementary particles are either Ξ^-, Ξ^0, Λ, or p, n, Λ (Sakata's model). In the framework of this model the peculiarities of strong interaction of strange particles and their systematization are discussed qualitatively.

For weak interactions, as has been shown earlier by other authors, invariance with respect to mass reversal results in non-conservation of parity, in the $V-A$ type of interaction and in conservation of combined parity.

Besides, in the case of weak interactions, a number of strangeness and isotopic spin selection rules arise. Within the framework of the Sakata's model there naturally arises

non-renormalization of the β-decay vector coupling constant with allowance for strong interaction.

1. The question of the chirality transformation

$$\psi \to \gamma_5 \psi \quad , \quad \bar{\psi} \to -\bar{\psi}\gamma_5 \tag{1}$$

meaning, essentially, a change of inner parity of the particle, and of the consequences of the invariance of the Lagrangian of interaction with respect to this transformation has lately become a point of extensive discussion /1-7/. Tiomno /1/ noticed that the Lagrangian of a free Dirac particle and of a Dirac particle in an electric field is invariant with respect to this transformation, if the latter is supplemented by the substitution $m \to -m$. Indeed, in this case the Lagrangian has the form:

$$\bar{\psi}(\hat{p} - e\hat{A} - m)\psi$$

and, as can easily be seen, is not changed by the transformation

$$\psi \to \psi' = \gamma_5 \psi, \quad \bar{\psi} \to \bar{\psi}' = -\bar{\psi}\gamma_5 \quad , \quad m \to -m \tag{2}$$

Tiomno suggested the term mass reversal to describe transformation (2).

Marshak and Sudarshan /4/ and Sakurai /5/ investigated the limitations imposed on the Lagrangian of weak interaction by invariance with respect to transformations (1) or (2), and arrived at the $V-A$ coupling in weak interactions.

But in the above papers the strong interactions were not invariant with respect to (2). How weak interactions could satisfy an invariance if strong interactions disturb it remained unclear.

We shall extend mass reversal invariance to strong interactions as well and find what conclusions result from this

2. Let there be a system of elementary particles between which there exists an interaction of an arbitrary type (electromagnetic, weak or strong). We require that the Lagrangian of this system be invariant with respect to transformation (2) for <u>each elementary particle separately</u>. Namely, we require that

$$\mathcal{L} \rightarrow \mathcal{L}' \equiv \mathcal{L}$$

if

$$\begin{aligned} &\psi_i \rightarrow \psi_i' = \gamma_5 \psi_i, && \bar{\psi}_i \rightarrow \bar{\psi}_i' = -\bar{\psi}_i \gamma_5, && m_i \rightarrow -m_i \\ &\psi_k \rightarrow \psi_k' = \psi_k, && \bar{\psi}_k \rightarrow \bar{\psi}_k' = \bar{\psi}_k, && m_k \rightarrow m_k \\ &i, k = 1, 2, 3 \ldots N; && && k \neq i \end{aligned} \tag{3}$$

Let us find the limitations imposed by condition (3) on the Lagrangians of electromagnetic, strong and weak interactions, under the restrictive assymption that the constants of these interactions are not changed by transformation (3).

3. It should be pointed out that condition (3) in combination with parity conservation in electromagnetic interactions leads to the so-called principle of minimal electromagnetic interaction /8/. According to this principle the only interaction between the electromagnetic field and the particles is the interaction with the electrical charges of the latter. Indeed, other gauge-invariant interactions would have the form

$$\ell_1 \bar{\psi}_i \gamma_\mu \gamma_\nu \psi_i F_{\mu\nu} \tag{4}$$

$$\ell_2 \bar{\psi}_i \gamma_\mu \gamma_\nu \psi_k F_{\mu\nu} \tag{5}$$

where the subscripts i and k refer to different particles.

However transformation (3) reverses the sign of the first of these expressions and the sign and parity of the second. (It may be pointed out that the value of ℓ, is proportional to m in the expression for the anomalous magnetic moment of the fermion appearing as a result of radiative corrections, and so condition (3) is not violated). The absence of terms of type (5) accounts, in particular, for the conservation of strangeness in electromagnetic interactions. (These terms might have led to decays of the types $\Sigma^+ \to p + \gamma$, $\Lambda^0 \to n + \gamma$, $\mu \to e + \gamma$ etc.).

4. It can easily be seen that the strong meson-barion interaction usually employed does not satisfy condition (3). Terms of type $\bar{\Psi}_i \gamma_5 \Psi_i \varphi$ (for example, $\bar{\Psi}_p \gamma_5 \Psi_p \varphi$) reverse, their sign under transformation (3), while terms of type $\bar{\Psi}_i \gamma_5 \Psi_k \varphi$ (say $\bar{\Psi}_p \gamma_5 \Psi_n \varphi$) change their parity as well. This difficulty can be overcome by assuming that strongly interacting mesons (π and K) are not elementary particles but bound states of barions and antibarions, as was done by Fermi and Yang /9/ and by Markov /10/. If we accept this viewpoint the mesons should be excluded from the initial Lagrangian and the latter should be substituted by a Lagrangian containing only interacting fermions.

If we confine ourselves to four-fermion interactions it will easily be seen that not every strong interaction between fermions satisfies condition (3). Indeed, in the case of terms of the type

$$(\bar{\Psi}_i O \Psi_k)(\bar{\Psi}_\ell O \Psi_\ell),\ (\bar{\Psi}_i O \Psi_\ell)(\bar{\Psi}_k O \Psi_\ell),\ (\bar{\Psi}_i O \Psi_k)(\bar{\Psi}_\ell O \Psi_m) \qquad (6)$$

condition (3) and conservation of parity are incompatible. But it is precisely such terms that describe fast parity conserving processes such as

$$\Sigma^0+n\to\Lambda+n,\quad \Xi^-+p\to\Lambda+\Lambda,\quad \Sigma^++n\to\Lambda+p$$

To overcome this difficulty we are obliged to assume that not all known barions are truly elementary particles[x)] and to confine ourselves to the interaction of truly elementary barions only.

The selection of elementary barions is somewhat arbitrary at present. There are two possibilities, which satisfy condition (3). As a first one, the Λ-hyperon and the Ξ^- and Ξ^0 hyperons can be selected as elementary particles. Another possibility is to select a Λ-hyperon, a proton and a neutron. A composite model with p, n and Λ as the elementary particles, was suggested by Sakata /12/ and examined afterwards by a number of authors /13-16/. That is the model we shall deal with in the following.

5. The following strong four-fermion interactions satisfying condition (3) and the laws of conservation of charge and number of barions, are possible between the Λ-hyperon, the proton and the neutron:

$$(\bar\Psi_p O\Psi_p)(\bar\Psi_p O\Psi_p),\quad (\bar\Psi_n O\Psi_n)(\bar\Psi_n O\Psi_n),\quad (\bar\Psi_\Lambda O\Psi_\Lambda)(\bar\Psi_\Lambda O\Psi_\Lambda) \tag{7}$$

$$(\bar\Psi_p O\Psi_p)(\bar\Psi_n O\Psi_n),\quad (\bar\Psi_p O\Psi_p)(\bar\Psi_\Lambda O\Psi_\Lambda),\quad (\bar\Psi_n O\Psi_n)(\bar\Psi_\Lambda O\Psi_\Lambda) \tag{8}$$

$$(\bar\Psi_\Lambda O\Psi_n)(\bar\Psi_n O\Psi_n) \tag{9}$$

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x) Judging by the note added in proof to /11/ a similar programme has been developed in an unpublished paper by K.Iwata and K.Fujii.

where O are known operators of four-fermion interaction. Expressions of the type $(\bar{\psi}_p O \psi_n)(\bar{\psi}_n O \psi_p)$ can be represented by means of Fierz's relationships /17/ as a linear combination of terms of type (8).

It can easily be seen that expressions (7) and (8) conserve strangeness which in the model under consideration equals minus the number of Λ-hyperons. Expression (9) changes strangeness by two. Hence the impossibility of changing the strangeness by one in strong interactions is a direct consequence of the model under consideration and condition (3), and is not related to the isotopic properties of strong interactions. This makes it possible to introduce new elementary particles into the model if such necessity arise in the future.

6. Now let us consider the limitations imposed within the framework of the Sakata's model on the operators in (7), (8), (9) and on the coupling constants of strong interaction by condition (3), by the requirement of isotopic invariance and by the Pauli principle. The most general isotopic invariant expression for the strong interaction Lagrangian has the form:

$$\mathcal{L}^S = \mathcal{L}^S_{NN} + \mathcal{L}^S_{N\Lambda} + \mathcal{L}^S_{\Lambda\Lambda} = \sum_i \{ f_i (\bar{\chi} \vec{\tau} O_i \chi)(\bar{\chi} \vec{\tau} O_i \chi) + g_i (\bar{\chi} O_i \chi)(\bar{\chi} O_i \chi) + h_i (\bar{\chi} O_i \chi)(\bar{\varphi} O_i \varphi) + e_i (\bar{\varphi} O_i \varphi)(\bar{\varphi} O_i \varphi) \}, \tag{10}$$

where $\chi = \begin{pmatrix} \psi_p \\ \psi_n \end{pmatrix}$ is the isotopic spinor and $\varphi = \psi_\Lambda$ is the isotopic scalar. $i = S, V, T, A, P$.

Making use of the conceptions of the Yukawa interactions the terms in (9) proportional to g, h and e correspond to exchange of a neutral meson which is an isotopic scalar, while the terms proportional to f correspond to exchange of isotopic vector mesons.

It should be pointed out that expression (9) and hence fast processes with $\Delta S = \pm 2$ prove to be forbidden already on the strength of isotopic symmetry, because there is no such interaction for the proton.

Writing down (10) in explicit form we have:

$$\sum_i \Big\{ f_i (\bar\Psi_p O_i \Psi_p - \bar\Psi_n O_i \Psi_n)^2 + 4 f_i (\bar\Psi_p O_i \Psi_n)(\bar\Psi_n O_i \Psi_p) + \tag{11}$$
$$+ g_i (\bar\Psi_p O_i \Psi_p + \bar\Psi_n O_i \Psi_n)^2 + h_i (\bar\Psi_p O_i \Psi_p + \bar\Psi_n O_i \Psi_n)(\bar\Psi_\Lambda O_i \Psi_\Lambda) +$$
$$+ e_i (\bar\Psi_\Lambda O_i \Psi_\Lambda)(\bar\Psi_\Lambda O_i \Psi_\Lambda) \Big\}$$

Now we modify the second addend in (11):

$$(\bar\Psi_p O_i \Psi_n)(\bar\Psi_n O_i \Psi_p) = -\sum_k a_{ik} (\bar\Psi_p O_k \Psi_p)(\bar\Psi_n O_k \Psi_n) \tag{12}$$

where a_{ik} are the known Fierz factors /17/. Substituting (12) into (11) and requiring invariance of (11) with respect to each of the transformations $\Psi_p \to \gamma_5 \Psi_p$, $\Psi_n \to \gamma_5 \Psi_n$, $\Psi_\Lambda \to \gamma_5 \Psi_\Lambda$, separately, we obtain the following relations

$$\begin{aligned} &2 g_S - 2 f_S - (f_S + 4 f_V + 6 f_T + 4 f_A + f_P) = 0 \\ &2 g_T - 2 f_T - (f_S - 2 f_T + f_P) = 0 \\ &2 g_P - 2 f_P - (f_S - 4 f_V + 6 f_T - 4 f_A + f_P) = 0 \\ &h_S = h_P = h_T = 0 \end{aligned} \tag{13}$$

It is easy to see that for symmetrical (in the q-number theory) couplings -

$$V - A \quad , \quad V + A - 2(S - P) \quad , \quad S + P - T \; -$$

and their linear combinations one has

$$(\bar\chi \vec\tau O_i \chi)(\bar\chi \vec\tau O_i \chi) = (\bar\chi O_i \chi)(\bar\chi O_i \chi)$$

For antisymmetrical couplings -

$$V + A + 2(S - P) \quad , \quad 3(S + P) + T \; -$$

and their linear combinations one has

$$(\bar{\chi}\vec{\tau}O_i\chi)(\bar{\chi}\vec{\tau}O_i\chi) = -6(\bar{\psi}_p O_i \psi_p)(\bar{\psi}_n O_i \psi_n) = -3(\bar{\chi}O_i\chi)(\bar{\chi}O_i\chi)$$

In the latter case terms like $(\bar{\psi}_p O_i \psi_p)(\bar{\psi}_p O_i \psi_p)$ are equal zero.

The existence of exchange forces in p-k interaction implies that the Lagrangian (10) contains both symmetrical and antisymmetrical couplings.

7. Now let us turn to composite particles in the Sakata's model and enumerate the possible isotopic states.

<u>Mesons</u>

Pions are bound states of a nucleon and an antinucleon:

$$\pi^+ = p\bar{n}, \quad \pi^- = \bar{p}n, \quad \pi^0 = \frac{1}{\sqrt{2}}(p\bar{p}+n\bar{n}), \quad T=1$$

K-mesons are bound states of a nucleon and an anti-hyperon (or an antinucleon and a Λ-hyperon).

$$K^+ = p\bar{\Lambda}, \quad K^0 = n\bar{\Lambda}, \quad K^- = \bar{p}\Lambda, \quad \bar{K}^0 = \bar{n}\Lambda, \quad T = 1/2$$

Besides, two more neutral mesons are possible with zero strangeness and isotopic spin: ρ_1^0 and ρ_2^0. These mesons are mixtures of the states:

$$\frac{1}{\sqrt{2}}(p\bar{p}-n\bar{n}) \quad \text{and} \quad \Lambda\bar{\Lambda}, \quad T=0$$

There are two more singly-charged mesons for which there are empty spaces in the Gell-Mann scheme /8/. These are the ω^+ and ω^--mesons. The strangeness of the first of them is +2 and of the second -2. These mesons can be represented as follows

$$\omega^+ = \frac{1}{\sqrt{2}}(pn-np)\bar{\Lambda}\bar{\Lambda}, \quad \omega^- = \frac{1}{\sqrt{2}}(\bar{p}\bar{n}-\bar{n}\bar{p})\Lambda\Lambda, \quad T=0$$

Hyperons

The known hyperons can be represented as follows:

$$\Sigma^+=p\bar{n}\Lambda,\quad \Sigma^-=\bar{p}n\Lambda,\quad \Sigma^0=\frac{1}{\sqrt{2}}(p\bar{p}+n\bar{n})\Lambda\ ,\quad T=1$$

$$\Xi^-=\bar{p}\Lambda\Lambda,\quad \Xi^0=\bar{n}\Lambda\Lambda\ ,\quad T=1/2$$

Besides there are empty spaces in the Gell-Mann scheme /6/ for two singly-charged hyperons:

$$Z^+=\frac{1}{\sqrt{2}}(pn-np)\bar{\Lambda}\ ,\qquad T=0$$

$$\Omega^-=\frac{1}{\sqrt{2}}(\bar{p}\bar{n}-\bar{n}\bar{p})\Lambda\Lambda\Lambda\ ,\qquad T=0$$

The strangeness of the first of these equals +1 and of the second -3.

The question as to why not all the particles enumerated above exist will be discussed below.

8. Now let us turn to the question of parity of elementary and composite particles.

It is easy to see that the transformation $\psi\to\gamma_5\psi$ corresponds to transition to a particle with a different inner parity. Indeed, if $\beta\psi=\pm\psi$ where β is the parity operator, then $\beta(\gamma_5\psi)=\mp(\gamma_5\psi)$. Therefore requirement (3) infers that the physical processes do not depend on the inner parity of the elementary particle. This is actually the case. In strong and electromagnetic parity conserving processes ψ -operators of elementary particles occur twice. In weak processes where particles are created or destroyed singly parity is not conserved. Thus not only the absolute inner parity of elementary particles, but their relative parity as well, lack physical sense, as they cannot be determined by experiment. For brevity we shall in the following accept the parity of all elementary particles as equal to +1. Then the parity of all antiparticles will equal -1.

Unlike elementary particles, the parity of composite particles is a physically measurable quantity. If we assume that the elementary particles contained in the composite particles are in the S-state we find that the parity of π, K ρ-mesons and Σ, Ξ and Z-hyperons should be equal to -1 while the parity of ω-mesons and the Ω-hyperon equals +1.

9. There are no arguments at present against the existence of ρ_1^0 and ρ_2^0-mesons. If they had a zero spin these mesons would be analogues of the π^0-meson. The assumption /18/ that the masses of ρ^0-mesons coincide with the mass of the π^0-meson should be rejected if we take into account the strong dependence of nuclear interactions on the isotopic spin.

It is also very improbable that their masses are at all comparable with the mass of π-mesons, as in such a case the presence of ρ-mesons would tell on the results of phase analysis of the interaction of pions with nucleons. Besides, such ρ-mesons would arise during K-meson decay. It is possible that the ρ-mesons (or one of them) are responsible for the existence of the maximum in π^--meson scattering in the 900 Mev region. In this case the masses of the ρ-mesons (or one of them) should be close to the mass of the nucleon.

The fast decay of pseudo-scalar ρ -mesons into 2π-mesons is forbidden on the strength of parity conservation. The rapid decay of pseudo-scalar ρ-mesons into 3π-mesons is forbidden on the strength of the isotopic and charge conjugation invariance of strong interactions /19/ (this forbiddance is not indicated in /16/). Apparently the most probable decays of ρ -mesons must be the fast decays $\rho \to \gamma\pi$ $\rho \to 2\pi + \gamma$.

10. It is known that no multicharged elementary particles exist in nature. It is known also that nature has not filled all the vacancies in the Gell-Mann scheme within the framework of singly-charged particles: Ξ and Ω -hyperons and ω -mesons are evidently absent. What qualitative conclusions concerning the nature of the interaction between truly elementary barions can be drawn from the fact that composite elementary particles of one kind exist and composite elementary particles of other kinds do not ? From the existence of pions and K-mesons it should be concluded that there is a very strong attraction between elementary barions and antibarions at small distances. Furthermore, from the fact that the mass of the K-meson is considerably greater than that of the pion, it follows that the attraction between the nucleon and the anti-hyperon is weaker than the attraction between the nucleon and the anti-nucleon (at least in the state with $T = 1$) or has a smaller radius. From the absence of composite particles of high strangeness and charges greater than unity it should be concluded that there is

a strong repulsion between two barions (or between two anti-barions) at small distances. This conclusion is in agreement with the widely known data on the existence of a "hard core" in the interaction of two nucleons. The repulsion between two Λ -hyperons is obviously weaker than that between two nucleons, as a particle containing two Λ-hyperons exists (the Ξ -hyperon), whereas particles containing even two nucleons (such particles would be ω -mesons, Ω and Z -hyperons, and doubly-charged particles), do not.

11. The above considerations give grounds to believe that nucleon-nucleon interaction $\mathcal{L}^{S}_{NN}$ is stronger or has a larger radius than nucleon- Λ interaction $\mathcal{L}^{S}_{N\Lambda}$ and Λ-Λ interaction $\mathcal{L}^{S}_{\Lambda\Lambda}$.

Let us see what conclusions the symbolical inequality

$$\mathcal{L}^{S}_{NN} > \mathcal{L}^{S}_{N\Lambda} , \mathcal{L}^{S}_{\Lambda\Lambda} \qquad (14)$$

leads to[x)].

An interaction $\mathcal{L}^{S}_{N\Lambda}$ is necessarily included in the processes of creation of strange particles (particularly, K-mesons) as a result of collisions of γ -quanta, pions and nucleons with nucleons. This is due to the fact that in the model in question the formation of any strange particles by collisions of ordinary particles passes through a process

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[x)] It seems very attractive to assume that in Lagrangian (10) $f=g=h=e$ and the difference between Λ-Λ, N-Λ and N-N interactions is ~~to~~ of the combinatorial nature and is connected with the presence of matrices τ in $\mathcal{L}^{S}_{NN}$

of creation of the virtual pair $\Lambda+\tilde{\Lambda}$. According to (14) the cross-sections of these processes should be smaller than the cross-sections of the corresponding processes of pion creation. This conclusion is confirmed by abundant experimental material concerning the photocreation of K-mesons and the formation of K-mesons by collisions of pions and nucleons with nucleons.

According to (14) when nucleons are bombarded with nucleons or π-mesons the creation cross-section of the real pair hyperon + anti-hyperon should be smaller than the creation cross-section of the pair nucleon + anti-nucleon, provided both these processes are considered far enough above their thresholds.

On the other hand the processes of scattering and mutual transformation of strange particles may proceed at the expense of strong nucleon-nucleon interactions $\mathcal{L}^{S}_{NN}$. Thus, the formation cross-section of the pair anti-hyperon + nucleon by collisions of K^{+}-mesons with nucleons may prove to be not so small, as in this case the reaction of K^{+}-meson "break down" is possible, this reaction not including the comparatively weak interaction $\mathcal{L}^{S}_{N\Lambda}$:

$$K^{+}+p=(\bar{\Lambda}+p)+p\to\bar{\Lambda}+p+p$$

The same holds also for the scattering cross-sections of K^{+} and K^{-}-mesons. The absorption cross-section of K^{-}-mesons (reactions of the type $K^{-}+p\to\Sigma^{-}+\pi^{+}$) may also be not small

Thus, in the scheme under consideration smallness of the strange particle creation cross-section does not necessarily involve small cross-sections of scattering and transit into other strange particles, as mainly different inte tions are responsible for these processes. This conclu agrees qualitatively with numerous experimental data a ding to which strange particles have small creation cr sections but large scattering and absorption cross-sec

It should be pointed out that this peculiarity of ge particles is not reflected in the model suggested r by Gell-Mann /20/. According to this model the interac of all barions with pions are of equal strength and th interaction with K-mesons is comparatively weak. The clusions obtained on the basis of this model differ sh from those we arrived at above. Particularly, accordin Gell-Mann's model the scattering cross-sections of $K^{\pm}$- and the absorption cross-section of K^{-}-mesons should The formation cross-section of the pair hyperon + anti in a beam of pions or nucleons should be larger than t mation cross-section of the nucleon + anti-hyperon pai beam of K^{+}-mesons.

According to (14) the interaction between two Λ- rons is weaker than that between two nucleons. If this the matrix element of formation of four strange partic should be smaller than that of formation of two strang ticles (at the same time, the matrix element of creati the Ξ-hyperon is smaller than that of creation of Λ Σ-hyperons).

12. In the model under consideration all slow processes are described by weak four-fermion interactions. All slow processes known at present can be described by the following interactions:

$$G^1(\bar{\psi}_p O \psi_n)(\bar{\psi}_e O \psi_\nu) \quad (15) \qquad G^2(\bar{\psi}_p O \psi_n)(\bar{\psi}_\mu O \psi_\nu) \quad (16)$$

$$G^3(\bar{\psi}_p O \psi_\Lambda)(\bar{\psi}_e O \psi_\nu) \quad (17) \qquad G^4(\bar{\psi}_p O \psi_\Lambda)(\bar{\psi}_\mu O \psi_\nu) \quad (18)$$

$$G^5(\bar{\psi}_p O \psi_n)(\bar{\psi}_\Lambda O \psi_p) \quad (19) \qquad G^6(\bar{\psi}_\mu O \psi_\nu)(\bar{\psi}_\nu O \psi_e) \quad (20)$$

Expressions (15), (16), (17) and (18) describe the interaction of barions with leptons. Expression (19) describes a weak interaction between barions responsible for non-leptonic decays of strange particles. Expression (20) describes the interaction responsible for the decay of the μ-meson. It seems reasonable not to go any further in examining other possible types of weak interaction unless necessitated by experiment.

Experiments show that all the constants G are close to each other in value. Gell-Mann and Feynman /21/ pointed out, for instance, that the β-decay vector coupling constant and the vector coupling constant of decay of the μ-meson equal each other very accurately. There are no data at present on the strict equality of all constants G.

We may point out that in writing down weak interactions in the form of (15) to (20) we tacitly assume that p, n, Λ, μ^-, e^-, ν are particles while $\bar{p}$, $\bar{n}$, $\bar{\Lambda}$, μ^+, e^+, $\tilde{\nu}$ are antiparticles.

As shown by Marshak and Sudarshan /4/ and also by Sakurai /5/ condition (3) results in a unique form of operator O in expressions (15) to (20):

$$O = (1-\gamma_5)\gamma_\mu \tag{21}$$

Gell-Mann and Feynman /21/ arrived at the same form of operator O by a different line of reasoning. Thus, condition (3) results in non-conservation of parity in weak interaction, ensures conservation of combined parity and selects the $V-A$ type of interaction.

13. Now we shall show that the vector coupling constants of the β -decay interaction G_V' and of the interaction between μ -mesons and nucleons G_V^2 do not vary in the model under consideration if allowance is made for strong interaction corrections.

In the conventional theory of interacting pions and nucleons, as Gerstein and Zeldovich /22/ and Feynman and Gell-Mann /21/ have demonstrated, this property of the vector interaction arises only if a direct interaction of pions and leptons is introduced. Taking strange particles into account, direct interaction between these particles and leptons should also be introduced /23/. It is easy to see that in the model under consideration this property of the vector type of weak interaction is a direct consequence of the isotopic invariance of strong interactions. Indeed, neglecting electromagnetic and weak interactions, we have the following expression for the total Lagrangian:

$$\mathcal{L} = \frac{i}{2}\left(\bar{X}\gamma_\mu \frac{\partial X}{\partial x_\mu} - \frac{\partial \bar{X}}{\partial x_\mu}\gamma_\mu X\right) + \frac{i}{2}\left(\bar{\varphi}\gamma_\mu \frac{\partial \varphi}{\partial x_\mu} - \frac{\partial \bar{\varphi}}{\partial x_\mu}\gamma_\mu \varphi\right) - \tag{22}$$

$$- m_N \bar{X}X - m_\Lambda \bar{\varphi}\varphi + \mathcal{L}^s_{int}.$$

where $\mathcal{L}_{int}^{s}$ is the Lagrangian of strong interaction in the form (10). Taking advantage of (22), we can easily prove that for the nucleon current of β-decay interaction $j_\mu^V = G_V^1 \bar{\chi} \tau \gamma_\mu \chi$ the following relation is fulfilled:

$$\frac{\partial j_\mu^V}{\partial x_\mu} = 0 \qquad (23)$$

It was shown in /21,23/ that relation (23) results in the conclusion that the value G_V^1, like an electrical charge, does not change when corrections connected with the strong interaction are taken into account. A similar proof can be given for G_V^2. The above-obtained result is true only in an approximation which makes no allowance for virtual slow and electromagnetic processes.

Unlike the leptonic interaction of nucleons, the leptonic interaction of Λ-hyperons (expressions (17) and (18)), as can easily be seen, does not possess the property of non--renormalizability of the vector coupling constant.

14. From expressions (17) and (18) it follows that if the strangeness of strongly interacting particles changes in leptonic decays of strange particles (as is clear from the foregoing, we attribute no strangeness to leptons), this change can only be $\Delta S = \pm 1$. Here $\Delta S = -1$ corresponds to emission of positively charged leptons, while $\Delta S = +1$ corresponds to the emission of negatively charged leptons.

Now let us enumerate the decays allowed by (15), (16), (17) and (18) and those forbidden by these interactions:

Allowed:

$$\Lambda \to p + e^-(\mu^-) + \tilde{\nu}, \quad \Sigma^- \to n + e^-(\mu^-) + \tilde{\nu}, \quad \Sigma^- \to \Lambda + e^- + \tilde{\nu}$$
$$\Sigma^+ \to \Lambda + e^+ + \nu, \quad \Xi^- \to \Lambda + e^-(\mu^-) + \tilde{\nu}, \quad \Xi^- \to \Sigma^0 + e^-(\mu^-) + \tilde{\nu}$$
$$\Xi^0 \to \Sigma^+ + e^-(\mu^-) + \tilde{\nu}, \quad K^0 \to \pi^- + e^+(\mu^+) + \nu, \quad \tilde{K}^0 \to \pi^+ + e^-(\mu^-) + \tilde{\nu}$$

Forbidden:

$$\Sigma^+ \to n + e^+(\mu^+) + \nu, \quad \Xi^- \to n + e^-(\mu^-) + \tilde{\nu}, \quad \Xi^0 \to p + e^-(\mu^-) + \tilde{\nu}$$
$$\tilde{\Xi}^0 \to \Sigma^- + e^+(\mu^+) + \nu, \quad K^0 \to \pi^+ + e^-(\mu^-) + \tilde{\nu}, \quad \tilde{K}^0 \to \pi^- + e^+(\mu^+) + \nu$$

We do not claim this list to be exhaustive. The forbiddances arising for K^0_{e3} and $K^0_{\mu 3}$-decays result in a known relationship between the number of $e^+(\mu^+)$-decays and the number of $e^-(\mu^-)$-decays in a beam of neutral K-mesons (see /24, 25, 26, 16/ on this question):

$$\frac{n_{\mu^+}}{n_{\mu^-}} = \frac{n_{e^+}}{n_{e^-}} = \frac{e^{-\frac{t}{\tau_1}} + e^{-\frac{t}{\tau_2}} + 2e^{-\frac{t}{2\tau_1}-\frac{t}{2\tau_2}} \cos \Delta m t}{e^{-\frac{t}{\tau_1}} + e^{-\frac{t}{\tau_2}} - 2e^{-\frac{t}{2\tau_1}-\frac{t}{2\tau_2}} \cos \Delta m t} \quad (24)$$

Here n is the number of corresponding decays per unit time, τ_1 and τ_2 are the lifetimes of K_1^0 and K_2^0-mesons, the first of which has a combined parity of +1 and the second of -1. Δm is the difference of masses of K_1^0 and K_2^0-mesons.

From (17) and (18) it follows that in leptonic decays of strange particles involving strangeness changes the isotopic spin of strongly interacting particles changes by $\Delta T = 1/2$ /27, 26, 16/. This makes it possible to relate the probabilities of decay of K^+ and K^0-mesons /26, 16/:

$$w(K^0 \to e^+(\mu^+) + \nu + \pi^-) = 2\, w(K^+ \to e^+(\mu^+) + \nu + \pi^0) \quad (25)$$

which in its turn results in the relationships /28/:

$$w(K_2^{\circ} \to e^+(\mu^+) + \nu + \pi^-) = w(K_2^{\circ} \to e^-(\mu^-) + \tilde{\nu} + \pi^+) = w(K^+ \to e^+(\mu^+) + \nu + \pi^{\circ}) \qquad (26)$$

In combination with the rule $\Delta T = 1/2$ for non-leptonic decays relation (26) makes it possible to relate the lifetime of the K_2° with the lifetime of the K^+-meson. Taking advantage of data on the lifetime of the K^+-meson and on the frequency of various K^+-meson decays we can estimate the lifetime of the K_2°-meson /23/:

$$\tau_{K_2^{\circ}} \sim 4 \times 10^{-8} \text{ sec.}$$

15. It can easily be seen that interaction (19), which is responsible for the non-leptonic decays of strange particles, allows a change of strangeness of $|\Delta S| = 1$ and forbids a change of strangeness of $|\Delta S| \geq 2$. Non-leptonic decays with $\Delta T > 3/2$ are forbidden by interaction (19). It is not clear, however, how the selection rule $\Delta T = 1/2$ can be obtained from (19), if this interaction is considered as an elementary one.

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