[4] A. D. Sakharov, JETP Letters 3, 439 (1966), transl. p. 288.
[5] Ya. B. Zel'dovich and S. S. Gershtein, JETP Letters 4, 174 (1966), transl. p. 120.

QUARK-MUONIC CURRENTS AND VIOLATION OF CP INVARIANCE

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Submitted 23 September 1966
ZhETF Pis'ma 5, No. 1, 36-39, 1 January 1967

In [1] we postulated, from cosmological considerations, the existence of quark-muonic currents whose interaction constant g_a with the fractional-charge vector field $a_{i\alpha}$ of the order of $137^{-3/2}$. In this note we consider a hypothesis in which the violation of CP invariance in $K_{0,L}$ decay (see [2]) is ascribed to the difference between the phase constants $g_a\exp(i\varphi)$ for the ordinary and strange quarks.

We assume interaction Lagrangians with maximum phase difference for ordinary and strange quarks *) and with P-parity conservation:

$$L = \sum_{\alpha,\, q,\, \mu} g_a [(\bar{\Psi}_{-q} a_{i\alpha} \gamma^i \Psi_\mu) + \text{h.c.}],$$
$$L = i\sum_{\alpha,\, \mu} g_{a\lambda} [(\bar{\Psi}_{-\lambda} a_{i\alpha} \gamma^i \Psi_\mu) - \text{h.c.}], \tag{1}$$
$$\alpha + q + \mu = \alpha + \lambda + \mu = 0;$$

α, q, λ, and μ are the indices of the electric charge and take on the values $q = -1/3, +2/3$; $\lambda = -1/3$; $\mu = 01, 0$; $\alpha = -2/3, +1/3, +4/3$.

Generally speaking, the constant g_a can depend on the index α, but we shall not consider these variants.

Figure 1 shows the main diagrams for the transformation of $K_0 = \bar{\lambda}n$ into $\bar{K}_0 = \lambda\bar{n}$. The

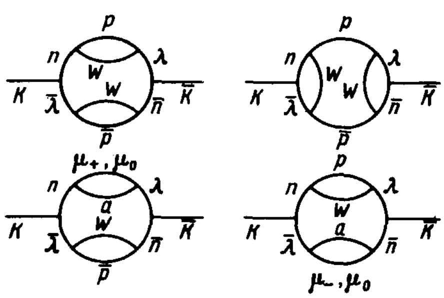

Fig. 1

matrix element of the transition, $V_{12} = (K_0|V|\bar{K}_0)$, is complex:

$$V_{12} \sim 2 g_W^2\, g_{W\lambda}^2 + i g_W\, g_{W\lambda}\, g_a\, g_{a\lambda};$$

g_W is the constant for the interaction of the weak current with the W boson,

$$\frac{4\pi g_W^2}{m_W^2} = \frac{G}{\sqrt{2}} = \frac{10^{-5}}{\sqrt{2 m_p^2}},$$

where m_W is the W-boson mass. In the expression for V_{12} we neglected the possible differences between the masses m_a and m_W, which enter in diverging expressions. The eigenfunction of the mass operator are proportional to

$$K_o V_{12} \pm \bar{K}_o |V_{12}|,$$

and in particular

$$K_L = \cos\nu \cdot K_2 + i \sin\nu \cdot K_1,$$

where

$$\nu = \frac{1}{2} \frac{\mathrm{Im}\, V_{12}}{\mathrm{Re}\, V_{12}} = \frac{1}{4} \frac{g_a g_{a\lambda}}{g_W g_{W\lambda}}.$$

The difference between K_L and K_2 determines completely the amplitude of the decay $K_L \to \pi^+\pi^-$, since the "direct" decay $K_2 \to \pi^+\pi^-$ is forbidden by P-parity conservation in the a-interaction. Therefore

$$\nu = \left| \frac{A(K_L \to \pi^+\pi^-)}{A(K_s \to \pi^+\pi^-)} \right| = 2\cdot 10^{-3}.$$

Using the value $g_a^2 = (137)^{-3}$ from [1], we get $g_W^2 = (137)^{-2}$ and

$$m_W \sim 10\, m_P \sim 137\,(m_\pi/2) = 137^2 m_e.$$

m_a remains unknown.

The qμ currents, as well as the quark-electronic currents which are possible in principle, should change the ratio of the yields of the two channels of $\pi^\pm$-meson decay

$$R = \left| \frac{A(\pi^+ \to e^+\nu)}{A(\pi^+ \to \mu^+ \mu^o)} \right|^2.$$

The experimental value is $R = (1.24 \pm 0.03) \times 10^{-4}$ (see [3]) and agrees within the limits of measurement accuracy both with the theoretical value of R_W given by the V - A theory with electromagnetic corrections (see [4]), and with the possible value of R_{W+a} measured as a result of the presence of qμ currents $[(R_{W+a} - R_W)/R_W] \sim \pm 0.01(m_W^2/m_a^2)$. We use the formula

$$R_W = \left(\frac{m_e}{m_\mu}\right)^2 \left(\frac{m_\pi^2 - m_e^2}{m_\pi^2 - m_\mu^2}\right)^2 \frac{f_e^2}{f_\mu^2} = 1{,}21\cdot 10^{-4}.$$

f takes into account the electromagnetic correction to the nonrelativistic approximation, as an effect that is due to the attraction of the charged particles in the neutral channel and depends on their relative velocity v:

$$f = \left| \frac{\Psi(o)}{\Psi(\infty)} \right| = \left[\frac{2\pi e^2}{v[(1 - \exp(-2\pi e^2/v)]} \right]^{1/2}, \quad \frac{f_e^2}{f_\mu^2} = 0{,}945.$$

The change in the decay amplitude due to the $q\mu$ currents is

$$A_a = -A_w \frac{g_a^2}{2 g_W^2} \frac{m_W^2}{m_a^2} \frac{m_\pi}{m_\mu} e^{i\phi}$$

(see Fig. 2). The uncertainty in the phase is here a reflection of the uncertainty in the relative phases in the expression (2) for the weak current. Putting $\varphi_1 = \varphi_2$ we get

$$R_{W+a} = R_W \left(1 - \frac{2 m_\pi}{m_\mu} \frac{m_W^2}{m_a^2} \nu\right)^{-2} .$$

We note that the quark-electronic currents of comparable magnitude (for $m_a \sim m_W$ and $\varphi_2 \neq \pi/2$) would change R by several times ten per cent, which is completely excluded by the experiment.

In the case of $K^\pm$ decay, a similar effect of the change in the yield ratio of the two channels is very small ($\sim\nu^2$) when the phases φ coincide, owing to the fact that the a-amplitude is imaginary. An effect on the order of $\nu(m_W^2/m_a^2)$ (i.e., ~1 - 0.1%) must be expected in the expression for the probability of K capture of μ^- in hydrogen and He^3, and in effects of transverse polarization in three-particle decay of K_L.

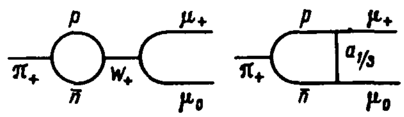

Fig. 2

Particular interest attaches to effects of violation of C symmetry of the partial probabilities in decays with P-parity conservation and change of strangeness, for example, the deviation of the ratio of the partial probabilities

$$\frac{K^+ \to \pi^+ + \pi^+ + \pi^-}{K^- \to \pi^- + \pi^- + \pi^+}, \quad \frac{\Sigma^+ \to N + \pi^+}{\Sigma^- \to N + \pi^-}$$

from unity (the effect of S. Okubo). These effects are also of the order of $\nu(m_W^2/m_a^2)$, but since they depend on the phase differences $\varphi_I \sim (A_a/A_W)$ for different values of the isospin I and on the phases of the strong interaction, their numerical value should be much lower than 0.1%.

As indicated by L. B. Okun' in the course of a discussion, processes of interest from the point of view of checking the theory are those in which pairs of charged mesons are produced, for example $K^+ \to \pi^+ + \mu^+ + \mu^-$ (relative yield $\sim\nu^2$). The processes $K_L \to \mu^+ + \mu^-$ and $K_L \to \mu^+ + \mu^- + \pi^0$ are strongly forbidden, but the processes $K_L \to \mu^+ + \mu^- + \gamma$ and $\Sigma^+ + P^+ + \mu^+ + \mu^-$ are possible (all are $\sim\nu^2$).

The author takes this opportunity to thank L. B. Okun' for a discussion and advice.

[1] A. D. Sakharov, this issue p. 24.

[2] L. B. Okun', UFN 89, 603 (1966), Soviet Phys. Uspekhi 9 (1967), in press.
[3] A. H. Rosenfeld et al., Revs. Modern Phys. 37, 633 (1965) and UCRL-8030, part I, August 1965.

*) The equivalent form of the theory - introduction of complex phases in the expression for the weak current

$$j_W = \bar{e} O \nu + \bar{\mu} O \mu_o e^{i\phi_1} + \bar{n} O p e^{i\phi_2} + \frac{g_{W\lambda}}{g_W} \bar{\lambda} O p e^{i\phi_3} \ldots, \qquad (2)$$

$$\phi_3 - \phi_2 = \pi / 2.$$

ERRATA

Articles by A. D. Sakharov, Vol. 5, No. 1

On page	24,	line	12	from bottom,	read	$\bar{\nu}_\mu = \bar{\mu}_0$	instead of	$\nu_\mu = \mu_0$
" "	24,	"	9	" " ,	"	$\bar{P}$ and $\bar{N}$	" "	P and N
" "	25,	"	7	" top ,	"	$\bar{\Sigma}_-$	" "	Σ_-

On page 25,	line 14	from top ,	read	[3]	instead of	[5].
" " 25,	" 13	" bottom,	"	[4]	" "	[6].
" " 26,	" 4	" top ,	"	[5]	" "	[7].
" " 26,	" 16	" " ,	"	Curl a_i	" "	$R_0 ta_i$.
" " 28,	" 1	" " ,	"	$\sqrt{2}\ m_p^2$	" "	$\sqrt{2m_p^2}$
			"	$K_0 V_{12}^{1/2} \pm \bar{K}_0 V_{21}^{1/2}$	" "	$K_0 V_{12} \pm \bar{K}_0 \lvert V_{12} \rvert$.
" " 29,	last equation		"	$\bar{\Sigma}_- \to \bar{N} + \pi_-$	" "	$\Sigma_- \to N + \pi_-$.