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ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ
YEREVAN PHYSICS INSTITUTE

S.V.ESAYBEGYAN, S.N.TAMARYAN

MASS CORRECTIONS TO THE STATIC CHARACTERISTICS OF A PSEUDOSCALAR MESONS OCTET IN THE INSTANTÓN VACUUM MODEL

ЦНИИатоминформ
ЕРЕВАН—1988

Նախատիպ ԵՖԻ-1090(53)-88

Ս.Վ. ԵՍԱՅԲԵԳՅԱՆ, Ս.Ն. ԹԱՄԱՐՅԱՆ

ՓՍԵՎԴՈՍԿԱԼՅԱՐ ՄԵԶՈՆՆԵՐԻ ՕԿՏԵՏԻ ՍՏԱՏԻԿ ԲՆՈՒԹԱԳՐԵՐԻՆ ԱՐՎԱԾ ՋԱՆԳՎԱԾԱՅԻՆ ՈՒՂՂՈՒՄՆԵՐԸ ԻՆՍՏԱՆՏՈՆԱՅԻՆ ՎԱԿՈՒՈՒՄԻ ՄՈԴԵԼՈՒՄ

Ցույց է տրված, որ քվարկների հոսանքային զանգվածների հաշվառմամբ կարելի է մոդելի կիրառելիությունը ընդլայնել մինչև $P \leqslant m_K$ իմպուլսների: Գտնված են K^+, K^0 մեզոնների էլեկտրամագնիսական շառավիղները, հաշված է K_{e3} տրոհման ձևի գործոնը:

Երևանի ֆիզիկայի ինստիտուտ
Երևան 1988

Препринт ЕФИ-1090(53)-88

С.В.ЕСАЙБЕГЯН, С.Н.ТАМАРЯН

МАССОВЫЕ ПОПРАВКИ К СТАТИЧЕСКИМ ХАРАКТЕРИСТИКАМ ОКТЕТА ПСЕВДОСКАЛЯРНЫХ МЕЗОНОВ В МОДЕЛИ ИНСТАНТОННОГО ВАКУУМА

Показано, что применимость модели можно расширить до импульсов $P \leq m_K$ при включении токовых масс кварков. Найдены электромагнитные радиусы K^+, K^0 мезонов, вычислен формфактор K_{e3} распада.

Ереванский физический институт
Ереван 1988

Preprint YERPHI-1090(53)-88

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MASS CORRECTIONS TO THE STATIC CHARACTERISTICS OF A PSEUDOSCALAR MESONS OCTET IN THE INSTANTON VACUUM MODEL

It is shown that when including the current masses of quarks, the model can be applicable to up to $p \leqslant m_K$. The electromagnetic radii of K^+, K^0 mesons are found and the form factor of K_{e3} decay is calculated.

Yerevan Physics Institute

Yerevan 1988

It is well known that the spontaneous breakdown of chiral symmetry (SBCS) results in the production of a nonet of massless pseudoscalar mesons. The SBCS mechanism was proposed in refs.[1,2] . So, the "instanton fluid" vacuum model allowed to quantitatively describe such low-energy characteristics of pions as the constant f_π in the decay $\pi\to\mu\nu$, $\langle r_\pi^2\rangle$ - the RMS radius of the charge, and reproduced the results of the algebra of currents [3]. Just the SBCS mechanism seems to govern over the low-energy physics of particles of pseudoscalar octet.

The account of masses of light quarks (u,d,s) must, in principle, allow one to describe the other static characteristics of the octet. It should be noted, that one is to take the anomalous contributions to the singlet axial current [4,5] into account to find the characteristics of η and η' mesons.

In our previous work [6] mass corrections to the effective Green functions in the instanton vacuum were found and the mass spectrum of the pseudoscalar octet was determined. In the present work we shall find the electromagnetic radii of the strange mesons $r^2_{K^+}$, $r^2_{K^0}$ (at the same time, there will be corrected the formula for the constant f_K found in ref.[6]), and the form factor $f_+(q^2)$ of K_{e3} will be described.

All calculations are carried out in the leading over the

the packing parameter ρ/R approximation, ρ being the mean radius of instantons, R - the average distance between the pseudoparticles.

Besides, assumptions directly connected with the disregard of nonzero modes are made:

a) there is ignored the quark loop contribution proportional to N_f/N_c. When a strange quark engaged, N_f/N_c is already not low. But it should be noted, that the loops must be taken into account simultaneously with the nonzero modes, as they are correlated by a renormalization procedure [7] ;

b) only linear terms will be taken into account via the current masses of quarks. For three light quarks (u,s,d) the condition $m\rho \ll 1$ is satisfied and expanded over the small parameter $m\rho$, but the account of the highest orders over m again requires the nonzero modes to be engaged.

However, here it was assumed, that in the first nonvanishing approximation the nonzero modes can be ignored which may be proved as follows. For true saddle-point solutions the nonzero modes must lead to renormalization of physical values [7]. On the other hand, the instanton-antiinstanton configurations in the leading over ρ/R approximation, are saddle-point solutions. That is why, when both the next orders over ρ/R and m and the effects of renormalization are ignored, then the contribution of nonzero modes vanishes. The versatility of the ansatz (vacuum-superposition of instanton-antiinstanton fluctuations) lies in the fact that this probe configuration is close to the saddle-point solutions, whereas it is necessary to deviate from stationary solutions to stabilize the testing of the model applicability within this range, which will be shown in the analyses of the electromagnetic form factors and of the Ademollo-Gatto theorem [9].

In the previous work [6] the algorithm of calculation of correlation functions which must be expressed through the found functions $f(P)$ and $d(P)$ is considered in details

$$f(P) = 2i\,\frac{N_c R^4}{m^2 \varepsilon}\;\frac{M(P)}{P^2 - 2mM + M^2\,\frac{P^2+m^2}{P^2}}\,,$$

$$d(P) = 2i\,\frac{N_c R^4}{m^2 \varepsilon}\;M(P)\,\frac{-m + M(P)\,\frac{P^2+m^2}{P^2}}{P^2 - 2mM + M^2\,\frac{P^2+m^2}{P^2}}\,, \tag{1}$$

where

$$\varepsilon(m) = \frac{\varepsilon_0}{\sqrt{1+\left(\frac{m\varepsilon_0}{2}\right)^2} + \frac{m\varepsilon_0}{2}} \qquad \varepsilon_0 = \varepsilon(0) \approx const\, N_c^{1/2}\,\frac{R^2}{\rho} \approx (100\ \text{MэB})^{-1}$$

To find the three-point correlator

$$T_\mu(x,y) = \langle 0 | \Psi^+(x)\gamma_5 t \Psi(x),\ \Psi^+(0)\gamma_\mu Q\Psi(0),\ \Psi^+(y)\gamma_5 t^+ \Psi(y) | 0 \rangle, \tag{2}$$

where t is the flavour matrix and Q is the charge one, one must sum up the bound diagrams shown in fig.1 . After cumbersome computations the Fourier form of the correlator

$$T_\mu(P_1,P_2) = \int d^4x \int d^4y\, e^{iP_1x - iP_2y}\, T_\mu(x,y)$$

is obtained to be

$$T_\mu = N_c\left(\frac{2VN_c}{N}\right)^2\,\frac{\Gamma_I(P_1)}{R-(P_1)}\,\frac{\Gamma_I(P_2)}{R-(R_2)}\int\frac{d^4K}{(2\pi)^4}$$

$$\Big\{ (S_p Q t t^+) \frac{\sqrt{M_1 M_2}}{K_1^2 \, K_2^2} \Big(1 + i m_1^2 \varepsilon_1 \frac{N}{2VN_c} d(K_1)\Big)\Big(1 + i m_1^2 \varepsilon_1 \frac{N}{2VN_c} d(K_2)\Big)$$

$$S_p \, \gamma_\mu \left[\hat{K}_1 + \frac{m_1^2 \varepsilon_1 \frac{N}{2VN_c} f(K_1) K_1^2}{1 + i m_1^2 \varepsilon_1 \frac{N}{2VN_c} d(K_1)} \right] \gamma_5 m_2^2 \varepsilon_2 \frac{N}{2VN_c} \left[d(K_3) - i f(K_3) \hat{K}_3 \right] \gamma_5 \qquad (3)$$

$$\left[\hat{K}_2 + \frac{m_1^2 \varepsilon_1 \frac{N}{2VN_c} f(K_2) K_2^2}{1 + i m_1^2 \varepsilon_1 \frac{N}{2VN_c} d(K_2)} \right] + \left(t \leftrightarrow t^+ ; \; p \leftrightarrow -p ; \; m_2 \leftrightarrow m_2 \right) \Big\}$$

Here $\quad K_2 = K - \frac{q}{2} \qquad K_2 = K + \frac{q}{2} \qquad K_3 = K - P$

$$p = \frac{P_1 + P_2}{2} \qquad q = P_1 - P_2 \qquad P_1^2 = P_2^2 = -m_K^2$$

V is a four-dimensional volume, $N/2$ is the number of instantons. The functions $\Gamma_I(P)$ and $R_-(P)$ too were found in the previous work

$$\Gamma_I(0) = \frac{\sqrt{\varepsilon_1 \varepsilon_2}}{\varepsilon_0} \; \frac{\langle \bar{\Psi} \Psi \rangle}{2N_c}$$

$$R_-(P) = 1 + m_1^2 \varepsilon_1 m_2^2 \varepsilon_2 \frac{N}{VN_c} \int \frac{d^4 P_1 \, d^4 P_2}{(2\pi)^4} \delta^4(P_1 - P_2 - P) (d_1 d_2 + P_1 P_2 \, f_1 f_2). \qquad (4)$$

The indices 1 and 2 throughout mean dependence on the corresponding arguments, e.g.,

$$d_1 = d(P_1, m_1).$$

The physical amplitude A_μ is obtained by extraction of two mesonic poles out of the three-point correlator T_μ

$$T_\mu = \frac{2\langle \bar{\Psi} \Psi \rangle}{f_K} \; \frac{1}{P_1^2 + m_K^2} \; A_\mu \; \frac{1}{P_2^2 + m_K^2} \; \frac{2\langle \bar{\Psi} \Psi \rangle}{f_K}, \qquad (5)$$

After algebraic transformations

$$A_\mu = \frac{N_c}{\pi^2}\ \frac{1}{f_K^2}\int_0^1 dx \int_0^1 2y\,dy \int \frac{d^4K}{\pi^2} M(K_3)\sqrt{M(K_2)\,M(K_2)}\ \cdot$$

$$\Big\{(S_p Q t t^+)\Big[\Big(\frac{q^2}{2}+m_K^2\Big)K_\mu + \Big(K^2+M_1^2-\frac{q^2}{4}\Big)P_\mu -$$

$$- m_1 M\Big(\frac{1}{K_1^2}+\frac{1}{K_2^2}\Big)\Big(\frac{q^2}{2}K_\mu + \Big(K^2-\frac{q^2}{4}\Big)P_\mu\Big)\Big]\cdot\big[(K-\ell)^2+S\big]^{-3} + \qquad (6)$$

$$+ (t \leftrightarrow t^+;\ P \leftrightarrow -P;\ m_1 \leftrightarrow m_2)\Big\},$$

where

$$\ell_\mu = (1-y)P_\mu + y\frac{2x-1}{2}q_\mu$$

$$S = y^2 x(1-x)q^2 - y(1-y)m_K^2 + y(M_1^2-2m_1M) + (1-y)(M_3^2-2m_2M).$$

The amplitude A_μ relates to the electromagnetic form factor $F(q^2)$ as:

$$A = 2P_\mu F(q^2).$$

Now, the main criterion of checking of our assumptions is the correct normalization of F(o) : F(o)=1 for K^+ and F(o)=0 for K^0 and K^0 mesons.

In the leading over ρ/R approximation the derivatives of the function M(K) must be omitted, after which the integral can be calculated as follows [10]. Substitute M(K) by M(o) and take the upper cutoff of the integral $|K| = 1/\rho$ (note, that M(K) sharply decreases in this scale), which conforms to retention of only large logarithmic terms of $\sim \ln R/\rho$. Then

$$F(0)=\frac{N_c}{2\pi^2}\,\frac{M^2(0)}{f_K^2}\int_0^1 2y\,dy\left\{\ln\frac{1}{\rho^2 S_0}(S_p Q t t^+)-(t\leftrightarrow t^+;\, m_1\leftrightarrow m_2)\right\}. \quad (7)$$

$S_0 = S(q^2=0)$

To calculate f_K^2 , represent $R_-(P)$ as

$$R_-(P)=\frac{2VN_c}{N}\int\frac{d^4P_1\,d^4P_2}{|2\pi|^4}\,\delta^4(P_1-P_2-P)\,\frac{(M_1P_{2\mu}-M_2P_{2\mu})^2}{(P_1^2-2m_1M_1+M_1^2)(P_2^2-2m_2M_2+M_2^2)}+ \quad (8)$$

$$+O(m^2)g(P)+\text{const}.$$

On the other hand, from the algebra of currents it follows [3] that

$$R_-(P)=\frac{V}{N}f_K^2\,(P^2+m_K^2) \quad (9)$$

whence

$$f_K^2=\frac{N_c}{2\pi^2}M^2(0)\int_0^1\ln\frac{1}{\rho^2 S_0}\,dy. \quad (10)$$

After integration one has

$$F(0)=S_p(Qtt^+)-S_p(Qt^+t)+$$

$$+O(m^2)\left[S_p(Qtt^+)+S_p(Qt^+t)\right] \quad (11)$$

That is to say, in the linear over m approximation the form factor coincides with the total charge of the system, which just proves our approximation and the related statement that the model is applicable for up to $P\sim m_K$.

In the previous work we used a numerically inaccurate expansion when calculating f_K^2 . The accurate expression following from (10) is

$$f_K^2 = \frac{N_c}{2\pi^2} M^2(0) \left[\ln \frac{1}{\rho|M(0)-m_1|} + \ln \frac{1}{\rho|M(0)-m_2|} \right]. \quad (12)$$

Expanding $F(q^2)$ in powers of q^2

$$F(q^2) = 1 - \frac{r_K^2}{6} q^2$$

one can calculate $r_{K^+}^2$. The current masses of quark make their contribution only through the mass of messons. Since $m_K^2 \gg m_q M$ both parametrically and numerically, then the terms $m_q M$ must be omitted. Eventually,

$$r_{K^+}^2 = \frac{N_c}{2\pi^2} \frac{q_u - q_s}{f_K^2} \left(1 + \frac{1}{5} \frac{m_K^2}{M^2}\right), \quad (13)$$

where q is the electric charge of the quark.

In this approximation the radius of K^0 meson becomes zero, because the masses of mesons symmetrically depend on the current masses of quarks and such terms vanish in virtue of antisymmetric dependence of $r_{K^0}^2$ on the current masses. But since these terms become zero in virtue of symmetry, then the first nonvanishing approximation for $r_{K^0}^2$ are just the small terms $m_q M$ which must be now taken into account. It should be emphasized that this is a very delicate criterion for checking of our assumptions, as this is the very region where only the linear over m_q terms in f and d functions "work". Thus, we have

$$r_{K^0}^2 = \frac{N_c}{2\pi^2} \frac{q_s + q_d}{2 f_K^2} \left(1 + \frac{2 + M_0 \varepsilon_0}{10}\right) \frac{m_s \langle \bar{s} s \rangle - m_d \langle \bar{d} d \rangle}{M_0 \langle \bar{\Psi} \Psi \rangle} \quad (14)$$

Here $\langle \bar{s}s \rangle$, $\langle \bar{d}d \rangle$ are the vacuum averages of s and d quarks, respectively; $\langle \bar{\Psi}\Psi \rangle$ is the quark condensate at m=0

$$\frac{\langle \bar{q}q \rangle}{\langle \bar{\Psi}\Psi \rangle} = \frac{\varepsilon(m_q)}{\varepsilon(0)} .$$

In the model under consideration the value of $M_0 \varepsilon_0$ is independent of the model parameters and must be substituted by its numerical value. Note that since we keep only the first over ρ/R terms, then for M_0 and ε_0 we use values which correspond to that approximation [2,10] :

$$M_0 \approx 300 \text{ MeV} \qquad \varepsilon_0 \approx (100 \text{ MeV})^{-1} \qquad M_0 \varepsilon_0 \approx 3$$

Substituting this value into (14) one has

$$\tau^2_{K^0} = \frac{3}{4} \cdot \frac{N_c}{2\pi^2} \frac{q_s + q_d}{f_K^2} \frac{m_\rho \langle \bar{s}s \rangle - m_d \langle \bar{d}d \rangle}{M_0 \langle \bar{\Psi}\Psi \rangle} . \qquad (15)$$

Another interesting test for the model is its applying to the decay K_{e3} , fig.2 .

The amplitude of the process reads:

$$M = L_\nu M_\nu \varphi_\pi \varphi_K f_+ (q^2).$$

Here L_ν is the leptonic current, $\varphi_\pi(K)$ are the wave functions of mesons, $f_+(q^2)$ is the form factor of the K_{e3} decay.

The calculation, entirely analogous to the former one, yields the following results. The zero form factor does not contain linear over m terms, which, from the point of view of composition of the Ademallo-Gatto theorem, attests to the self-consistency of the assumptions made. Using the accepted parametrization of $f_+(q^2)$

$$f_+(q^2) = 1 + \lambda_+ \frac{q^2}{m_\pi^2}$$

as well as the expressions (13) and that in ref.[10] obtained for $r_{K^+}^2$ and $r_{\pi^+}^2$, respectively, one finds that

$$\lambda_+ = \frac{1}{12} \frac{r_{K^+}^2 f_K^2 + r_{\pi^+}^2 f_\pi^2}{f_K f_\pi} m_\pi^2 , \qquad (16)$$

Closing this paper, we present the numerical values of the quantities found as well as the corresponding experimental data ($m_u \approx 4$ MeV, $m_d \approx 7$ MeV, $m_s \approx 150$ MeV) [11] .

	THEORY	EXPERIMENT
$r_{K^+}^2$	0.34	0.28 ± 0.07
$r_{K^0}^2$	-0.037	-0.054 ± 0.026
f_K^2 / f_π^2	1.5	1.49 ± 0.02
λ_+	0.029	0.0300 ± 0.0016

The authors thank S.G. Matinyan for support. One of the authors (S.T.) is grateful to R. Poghossian for some stimulating ideas.

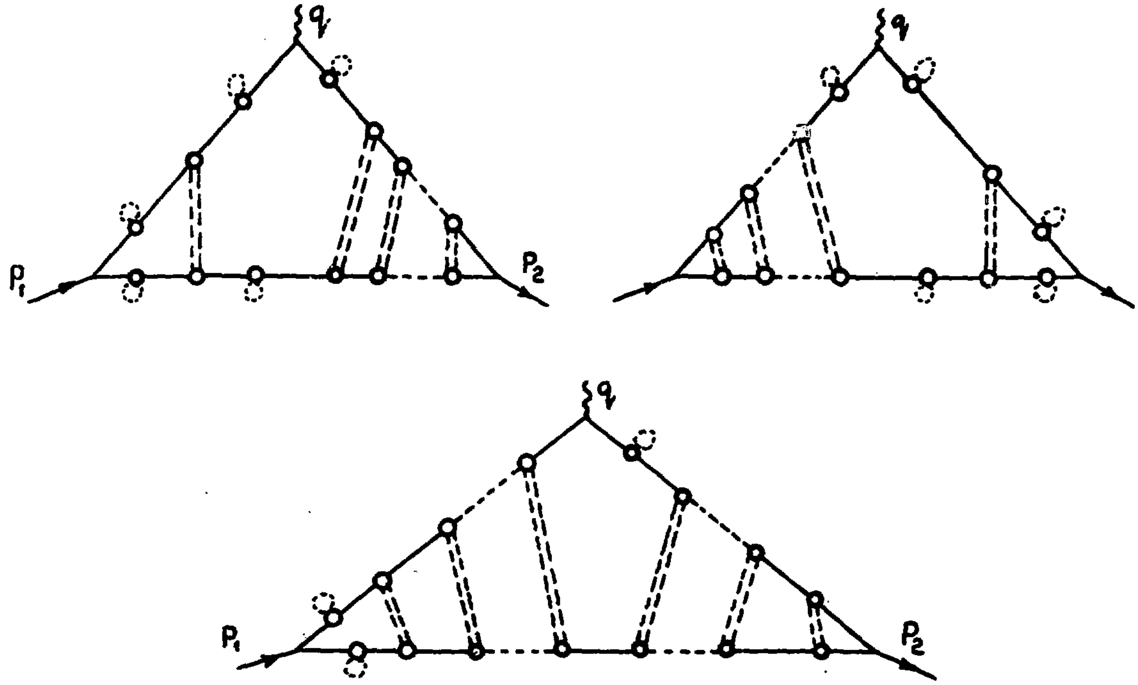

Fig.1

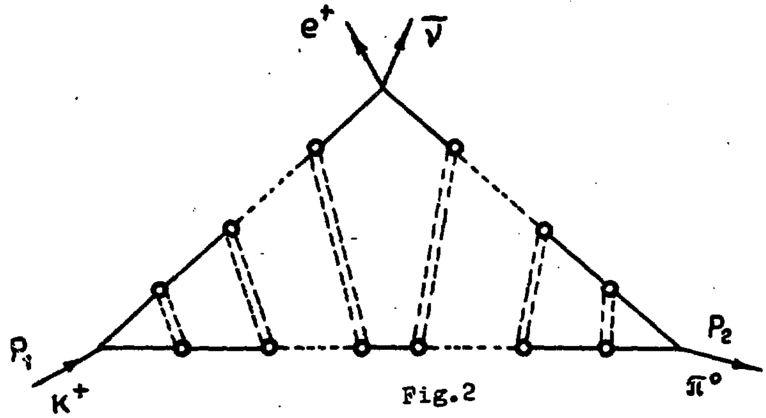

Fig.2

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The manuscript was received 15 April 1988

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