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YEREVAN PHYSICS INSTITUTE

H.M.ASATRIAN, A.N.IONNISSIAN

RARE B-MESON DECAYS IN $SU(2)_L \times SU(2)_R \times U(1)$ MODEL

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Հ.Մ. ԱՍԱՏՐՅԱՆ, Ա.Ն. ԻՈԱՆՆԻՍՅԱՆ

B-ՄԵԶՈՆԻ ՀԱԶՎԱԳՅՈՒՏ ՏՐՈՀՈՒՄՆԵՐԸ $SU(2)_L \times SU(2)_R \times U(1)$ ՄՈԴԵԼՈՒՄ

Ուսումնասիրվում են B-մեզոնի հազվագյուտ տրոհումները աջ-ձախ համաչափ մոդելում: Հաշվված է սկալյար մասնիկների ներդրումը $b \to s\gamma$ տրոհման ամպլիտուդի համար այդ մոդելում: Ցույց է տրված, որ այդ ներդրումը կարող է բավականաչափ մեծ լինել, նույնիսկ եթե սկալյար մասնիկների զանգվածը մի քանի ՏէՎ-ի կարգի է: Աջ-ձախ համաչափության և սկալյար մասնիկների հետ կապված երևույթները կարելի է առանձնացնել $B \to K^{*}\gamma$ տրոհման ժամանակ առաջացած ֆոտոնի բևեռացումը չափելով:

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Г.М. АСАТРЯН, А.Н. ИОАННИСЯН

РЕДКИЕ РАСПАДЫ B-МЕЗОНА В $SU(2)_L \times SU(2)_R \times U(1)$-МОДЕЛИ

Изучаются редкие распады B-мезона в лево-право симметричной модели. Вычислен вклад скалярных частиц в амплитуду распада $b\to s\gamma$ в этой модели. Показано, что этот вклад может быть достаточно большим даже для масс скалярных частиц порядка нескольких ТэВ. Эффекты, связанные с лево-правой симметрией и со скалярными частицами можно выделить, измерив поляризацию γ-кванта в распаде $B\to K^*\gamma$.

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H.M. ASATRIAN, A.N. IOANNISSIAN

RARE B-MESON DECAYS IN $SU(2)_L \times SU(2)_R \times U(1)$ MODEL

Rare B-meson decays are investigated in the left-right symmetric models. The scalar particle contribution to the amplitude of the $b \to s\gamma$ decay is calculated. It is shown that this contribution can be essential even for the scalar particles masses of about several TeV. The effects due to the left-right symmetry and scalar particles can be detected by measuring the photon polarization in the decay $B \to K^* \gamma$.

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Though the predictions of the standard model define no contradictions with experiment, the ideas beyond its framework are always attracting. One of such ideas is construction of a theory with primary left-right symmetry, the simplest realization of which is the model with the $SU(2)_L \times SU(2)_R \times U(1)$ gauge symmetry. Such a theory supposes a new scale with parity violation, when the group $SU(2)_L \times SU(2)_R \times U(1)$ is violated to $SU(2)_L \times U(1)_Y$.

The existence of a new scale in the theory leads to new particles and interactions. The effects due to the left-right symmetry can be also observed in the interactions of known particles. We are more interested in the study of rare decays of particles, as they are more sensitive to such effects. In this paper we'll consider the contribution of scalar particles in the rare B-meson decays in left-right- symmetric models.

Let us now describe the model. We are considering a theory with the $SU(2)_L \times SU(2)_R \times U(1)$ symmetry which in a certain scale $M_R \gg M_W$ is violated to $SU(2)_L \times U(1)_Y$. This violation may occur, e.g., when the neutral component of the $SU(2)_R$-triplet scalar field, which is included in the representation (1.3)+(3.1) of the group $SU(2)_L \times SU(2)_R$ (also see refs [1,2]), acquires a vacuum expectation value (v.e.v.). As this violation takes place, the right W_R boson acquires a mass, whereas the ordinary fermions and the W,Z bosons remain massless. The masses of these particles arise due to the interaction with the scalar fields in the representation (2.2), the v.e.v. of which violates $SU(2)_L \times U(1)_Y$ to $U(1)_{e.m.}$. Fermions do not interact with other scalar fields. In the simplest case one can assume that there is only one scalar field Φ in the representation (2.2), which can interact with quarks [2]. The most general Lagrangian of interaction of quarks $\Psi_{L;R}$ in the representations (2.1) and (1.2) with that field, has the form:

$$L=A_{ik}\bar{\Psi}_{Li}\Phi\,\Psi_{Ri}+B_{ik}\,\bar{\Psi}_{Ri}\,\tilde{\Phi}\,\Psi_{Lk}+\text{c.c.}$$

$$\Phi=\begin{pmatrix}\eta^{o} & \xi^{+}\\ \eta^{-} & -\xi^{o*}\end{pmatrix}\qquad \tilde{\Phi}=\begin{pmatrix}\xi^{o} & \eta^{+}\\ \xi^{-} & -\eta^{o*}\end{pmatrix}\tag{1}$$

$$\Psi_{L;R1}=\begin{pmatrix}u\\ d\end{pmatrix}_{L,R};\quad \Psi_{L;R2}=\begin{pmatrix}c\\ s\end{pmatrix}_{L,R};\quad \Psi_{L;R3}=\begin{pmatrix}t\\ b\end{pmatrix}_{L,R}$$

From here on we'll assume there is only one $SU(2)_L$ doublet with a nonzero v.e.v. connected with the violation of the $SU(2)_L\times U(1)_Y$ symmetry. In the general case the field η' is a combination of the doublets η and ξ and its mass must be of order M_W. And the combination ξ' orthogonal to it, with a zero v.e.v., has a mass of order M_R, in accordance with the Higgs survival hypothesis [3]:

$$\begin{aligned}\eta &= \eta'\cos\theta+\xi'\sin\theta\\ \xi &= -\eta'\sin\theta+\xi'\cos\theta\\ \langle\eta'^{o}\rangle &= 175\ \text{GeV},\qquad \langle\xi'^{o}\rangle=0,\end{aligned}\tag{2}$$

where for simplicity we assume that the mixing matrix is a real one.

What can one say about the mixing angle θ?

One can obtain some constraints on this angle by considering the mixing of the usual (left) W boson with the right W_R boson. The angle of this mixing is proportional to the magnitude $2\left(M_W/M_{W_R}\right)^2\cdot tg\theta$ [2]. This angle is experimentally restricted to <0.004 [3]. Hence, at quite large (about 1.5-2 TeV) masses of the W_R boson, $tg\theta$ can be a considerable quantity, e.g., when $M_{W_R}=2$ TeV, for $tg\theta$ we obtain the condition of $tg\theta<1.2$.

Let us derive from the eqs (1) and (2) expressions for the up and down quark mass matrices

$$M_u = (A\cos\theta - B\sin\theta)\,\langle\eta'^{\circ}\rangle$$
$$M_d = (-A\sin\theta + B\cos\theta)\,\langle\eta'^{\circ *}\rangle \tag{3}$$

The quarks interaction with the doublet ξ' is defined by the mass matrices M_u, M_d and the angle θ:

$$L_{\xi'} = \bar{\Psi}_L\left\{\frac{M_u}{\langle\eta'^{\circ}\rangle}\,tg2\theta + \frac{M_d}{\langle-\eta'^{\circ *}\rangle}\,(tg^2 2\theta + 1)^{1/2}\right\}u_R\,\xi' +$$
$$+\bar{\psi}_L\left\{\frac{M_u}{\langle\eta'^{\circ}\rangle}\,(tg^2 2\theta + 1)^{1/2} + \frac{M_d}{\langle-\eta'^{\circ *}\rangle}\,tg2\theta\right\}d_R\,\xi' + h.c. \tag{4}$$

The mass matrices (3) are reduced to a diagonal form by means of the biunitary transformation:

$$u_{L,R} = V_{L,R}\,u^{\circ}_{L,R}\,, \qquad d_{L,R} = T_{L,R}\,d^{\circ}_{L,R} \tag{5}$$

Then, the quarks interaction with the charged component of the doublet ξ' is expressed by:

$$L_{ch} = \xi^{+}\left\{\bar{u}_R^{\circ}\left[\left(\frac{M_u^{\circ}}{\langle\eta'^{\circ}\rangle}\right)^{+}K_L\,tg2\theta + K_R\left(\frac{M_d^{\circ}}{\langle-\eta'^{\circ *}\rangle}\right)^{+}(tg^2 2\theta + 1)^{1/2}\right]d_L^{\circ} +\right.$$
$$\left.+\bar{u}_L^{\circ}\left[K_L\,\frac{M_d^{\circ}}{\langle-\eta'^{\circ *}\rangle}\,tg2\theta + \frac{M_u^{\circ}}{\langle\eta'^{\circ}\rangle}\left[K_R(tg^2 2\theta + 1)^{1/2}\right]\right]d_R^{\circ}\right\} + h.c. \tag{6}$$

where K_L is the Kobayashi-Masakawa matrix; K_R is an analogous mixing matrix for the right currents:

$$K_L = V_L^{+}\,T_L\,, \qquad K_R = V_R^{+}\,T_R\,. \tag{7}$$

If the matrices M_u and M_d are symmetric ones, then $K_R = K_L^{*}$.

The neutral component of the field ξ is a complex field:

$\xi^{c}=\frac{1}{\sqrt{2}}\left(\xi_{1} + i\xi_{2}\right)$. After the violation of $SU(2)_L\times U(1)_Y$ is taken into account, this field is reduced to two real scalar fields ξ_1 and ξ_2 with different masses. The interaction of d-quarks with these fields is defined by:

$$\frac{1}{\sqrt{2}}\,\xi_1\left\{\bar{d}_L\left[K_L^{+}\,\frac{M_u^{o}}{\langle\eta^{o}\rangle}\,K_R(tg^2 2\theta + 1)^{1/2} + \frac{M_d}{\langle-\eta'^{\,o*}\rangle}\,tg2\theta\right]d_R + \right.$$

$$+ \left.\bar{d}_R\left[K_R^{+}\left(\frac{M_u^{o}}{\langle\eta^{o}\rangle}\right)^{+}K_L(tg^2 2\theta + 1)^{1/2} + \left(\frac{M_d}{\langle-\eta'^{\,o*}\rangle}\right)^{+}tg2\theta\right]d_L\right\} + \tag{8}$$

$$+ \frac{1}{\sqrt{2}}\,i\,\xi_2\left\{\bar{d}_L\left[K_L^{+}\,\frac{M_u^{o}}{\langle\eta^{o}\rangle}\,K_R(tg^2 2\theta + 1)^{1/2} + \frac{M_d}{\langle-\eta'^{\,o*}\rangle}\,tg2\theta\right]d_R - \right.$$

$$\left.\bar{d}_R\left[K_R^{+}\left(\frac{M_u^{o}}{\langle\eta^{o}\rangle}\right)^{+}K_L(tg^2 2\theta + 1)^{1/2} + \left(\frac{M_d}{\langle-\eta'^{\,o*}\rangle}\right)^{+}tg2\theta\right]d_L\right\}.$$

Clearly, the masses of the fields ξ^{+}, ξ_1, ξ_2 differ only by the magnitude of violation of $SU(2)_L\times U(1)_Y$, i.e. the difference in the masses of these fields is much smaller than the masses themselves.

Interaction of quarks with the neutral fields ξ_1 and ξ_2 (7) yields flavor-changing neutral currents, in particular, to the transitions $K_o - \bar{K}^{o}$, $B^{o} - \bar{B}^{o}$, etc. The aspects connected with such neutral currents have been considered in refs [2,4,5] and others. Clearly, the masses of ξ_1 and ξ_2, hence, the scale M_R too, must be large enough not to lead to results contradicting the theory. Most severe constraints on the masses of ξ_1 and ξ_2 gives the consideration of their contribution to the difference in the masses of K^{o} and $\bar{K}^{o}$ mesons. The lower limit of the mass m_ξ (we assume that $m_{\xi_1}=m_{\xi_2}=m_\xi$) obtained hence depends on the t-quark mass [5] and the angle θ [2]:

$$\begin{aligned} m_\xi &> (2.3 - 4.0)\ \text{TeV} \quad \text{for} \quad m_t = 100\ \text{GeV} \\ m_\xi &> (1.6 - 2.8)\ \text{TeV} \quad \text{for} \quad m_t = 150\ \text{GeV} \end{aligned} \tag{9}$$

We shall further assume that the same constraint takes place for the mass of the ξ^+-particle too.

Note, that considering the contribution of the right W_R boson to the difference in the masses of $K^\circ - \bar{K}^\circ$, it is possible to obtain constraints on the mass of the W_R boson: $M_{W_R} > 1.6$ TeV [4]. These constraints show that the $SU(2)_R$-symmetry must be broken at gauges of about 1÷2 TeV and higher.

Now, our purpose is to calculate the contribution of the scalar field ξ^+ to the $b \to s\gamma$ decay amplitude. The corresponding B°-meson decay $B \to K^* \gamma$ is not discovered yet, but it is a matter of the nearest future, since at present the experimental upper limit for the branching of this decay differs from the theory predictions only several times.

The b-quark radiative decay in the standard model was calculated in ref.[6]. In refs [7-9] the case with two $SU(2)_L$ Higgs doublets was considered and the extra contribution to that process was calculated. The decay $b \to s\gamma$ in the left-right symmetric model was considered in ref.[1], where the contribution due to the W_R-boson exchange was calculated. We shall study the scalar particle contribution to the process $b \to s\gamma$ in the left-right symmetric model, which, as will be seen, is quite an appreciable one.

Interaction of quarks with the charged scalar field ξ^+ is described by the Lagrangian (6). It contains an independent parameter - the angle θ. As was noted, this angle is not a small one. The value of, e.g., $tg\theta = 1$ is in agreement with the experiment.

The amplitude of the transition $b \to s\gamma$ in the general case has the form:

$$f = (f_1 \bar{s}_L \sigma_{\mu\nu} b_R + f_2 \bar{s}_R \sigma_{\mu\nu} b_L) F^{\mu\nu}, \qquad (10)$$

where $F^{\mu\nu}$ is the electromagnetic field strength tensor.

To the amplitude of the decay $b \to s\gamma$ with particle exchange contribute the diagrams of fig.1 . The amplitudes f_1 and f_2 which correspond to the decays $b_R \to s_L\gamma$ and $b_L \to s_R\gamma$, have the form:

$$f_1 = (K_L^+)_{si}(K_R)_{ib}\ tg2\theta\ (tg^2 2\theta + 1)^{1/2} \frac{m_i}{\langle\eta\rangle^2} g(x) \qquad (11)$$

$$f_2 = (K_L^+)_{bi}(K_R)_{is}\ tg2\theta\ (tg^2 2\theta + 1)^{1/2} \frac{m_i}{\langle\eta\rangle^2} g(x) \qquad (12)$$

where i=u,c,t.

The function g(x) is obtained from the calculation of a particular diagram. For the diagram 1a (1c) we obtain:

$$\sim \frac{1}{(1-x)^2} \left[1 + x + \frac{2x}{1-x} \ln x\right], \qquad (13)$$

and for the diagram 1b (1d) we obtain:

$$\sim \frac{2}{3} \frac{1}{(1-x)^2} \left(-3 + x - \frac{2}{1-x} \ln x\right], \qquad (14)$$

where $x = m_t^2 / m_{\xi^+}^2$. Here we assume that the main contribution to (1), (12) we obtain when i=t due to $m_t \gg m_u$, m_c. As a result we obtain:

$$g(x) = \frac{x}{2(x-1)^3} \left[(x-1) \left[\frac{5}{6} x - \frac{1}{2}\right] - \left[x - \frac{2}{3}\right] \ln x\right] . \qquad (15)$$

The our obtained results are to be compared with the results of ref.[6] obtained in the standard model.

For simplicity we'll assume that the mixing matrix elements in the left and right currents K_L and K_R are equal to each other (by the absolute value). Then, the contributions from the scalar field ξ^+ to the amplitudes of $b_R \to s_L \gamma$ and $b_L \to s_R \gamma$ are also equal to each other. But in the standard model only the amplitude of $b_R \to s_L \gamma$ can be different from zero (the amplitude of $b_L \to s_R \gamma$ is suppressed as compared to it by the relation m_s / m_b). Thus, the standard model yields:

$$f_1^{SM} = \frac{e}{16\pi^2} (K_L)_{st} (K_L)_{tb} \frac{m_e}{\langle\eta\rangle^2} g'(y), \qquad f_2^{SM} \approx 0 , \qquad (16)$$

where $y=m_t^2/M_W^2$, and $g'(y)$ has the form [6,8]:

$$g'(y)= - \frac{y}{2(y-1)4}\left\{(y-1)\left(\frac{2}{3}y^2+\frac{5}{12}y-\frac{7}{12}\right)-\left(\frac{3}{2}y^2-y\right)\ln y\right\} \quad (17)$$

It should be noted that the fact of a strong suppression of the amplitude of $b_L \to s_R \gamma$ takes place not only in the standard model with one Higgs doublet, but also in the model $SU(2)_L \times U(1)_Y$ with two and more Higgs doublets, where this amplitude is also suppressed [8].

To estimate the relative contribution of scalar fields to the amplitude of $b \to s\gamma$ in the left-right symmetric model, let us consider the relation

$$R = \frac{f_1^\xi}{f_1^{SM}} = \frac{m_t}{m_b}\, tg2\theta\, (tg^2 2\theta + 1)^{1/2}\, \frac{g(x)}{g'(y)} \,. \quad (18)$$

It is in a strong dependence with the scalar-field mass as well as with m_t and $tg2\theta$. We have already seen that the values of $tg\theta$ near unity are not in contradiction with the experiment, so that $tg2\theta$ can easily reach several units. The values of R for m_t=100 and 150 GeV and for the values of m_ξ equal to the lower limits (9) and by 25% higher than that limit, are presented in Table 1. The values of $tg2\theta$ vary within 0.5 and 5.

From Table 1 is seen that for m_t=100 GeV already at $tg2\theta=1$ the contribution of the amplitude f_1 becomes essential (50% of the standard amplitude). For m_t=150 GeV, already at $tg2\theta=0.5$, f_1^ξ makes 100% of the standard, and at $tg2\theta=1$ exceeds it almost three times.

These considerations already show that the contribution of the fields ξ^+ to the amplitude of the decay $b \to s\gamma$ is an essential one. It should be also noted that the real contribution of the field ξ^+ to the decay amplitude is higher, since there is still an equal contribution from the amplitude of $b_L \to s_R \gamma$, whereas in the model $SU(2)_L \times U(1)_Y$ that amplitude is practically equal to zero.

From this point of view, it would be very desirable to make a polarization analysis of the photons discovered in the experimental study of the decay $B \to K^* \gamma$ (when it will be discovered). It will give a valuable information about the existence of a left-right symmetry and about the scale of violation of $SU(2)_R$.

Indeed, if there is no such symmetry, or the scale of its violation M_R is far from the TeV region (tens of TeV and higher), then there is only the amplitude of $b_R \to s_L \gamma$ and the photon helicity will be only negative. And if the $SU(2)_R$-symmetry-violation scale M_R is in the region of several TeV, then also photons with positive helicity will be discovered with a comparable relative probability. They originate due to the contributions of the scalar ξ^+-particle (11) and the gauge W_R boson [1]. Note that the contribution of ξ^+ to this amplitude is not lower, but, when $m_{\xi^+} = m_{W_R}$, is even higher than that of the W_R boson.

The ratio of the amplitudes of photons with negative and positive helicity depends on $tg2\theta$, the scale of violation M_R and the mixing angles in the left and right currents. If, e.g., assumed that $K_L = K_R$ (this takes place for the Hermitian mass matrices), then in the standard model, as is seen from Table 1 and (10)-(16), the contribution of ξ^+ to the amplitude of $b_R \to s_L \gamma$ may completely or partially reduce the amplitude of the same decay. Then (if, say, $M_{W_K} > m_{\xi^+}$ and the contribution of W_R boson can be ignored) photons with positive helicity will dominate in the decay $B \to K^* \gamma$.

In our work we have not considered the questions connected with the QCD corrections, the relation between the amplitudes of $b \to s\gamma$ and $B \to K^* \gamma$, and those connected with an experimental detection of the decay (see ref.[10] and the references in it). The points concerning the decays $b \to se^+e^-$ and $b \to sg$ (gluon) will be considered elsewhere.

In conclusion it can be said that our calculations of scalar particle contributions to the rare B-meson decays in the left-right symmetric models allows us to conclude that the study of rare B-meson decays, especially that of the photon polarization in the decay $B \to K^{*}\gamma$, will give us an important information about the presence and the scale of the left-right-symmetry violation.

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Table 1

Relation R of the absolute values of f_1^{ξ} and f_1^{SM} for different values of tg2θ and m_t and for the mass of ξ on the lower limit ($R^{(1)}$) and by 25% higher than the lower limit

m_t = 100 GeV

tg 2θ	0.5	1	2	3	5
$m_{\xi}^{(1)}$	2.57	3.25	5.14	7.27	11.7
$R^{(1)}$	0.29	0.50	0.72	0.83	0.95
$m_{\xi}^{(2)}$	3.0	4.0	6.5	9	15
$R^{(2)}$	0.24	0.35	0.48	0.57	0.62

m_t = 150 GeV

tg 2θ	0.5	1	2	3	5
$m_{\xi}^{(1)}$	1.79	2.26	3.75	5 05	8.14
$R^{(1)}$	1.06	1.86	2.80	3.35	3.83
$m_{\xi}^{(2)}$	2.2	2.8	4.5	6.25	10
$R^{(2)}$	0.76	1.32	1.91	2.34	2.72

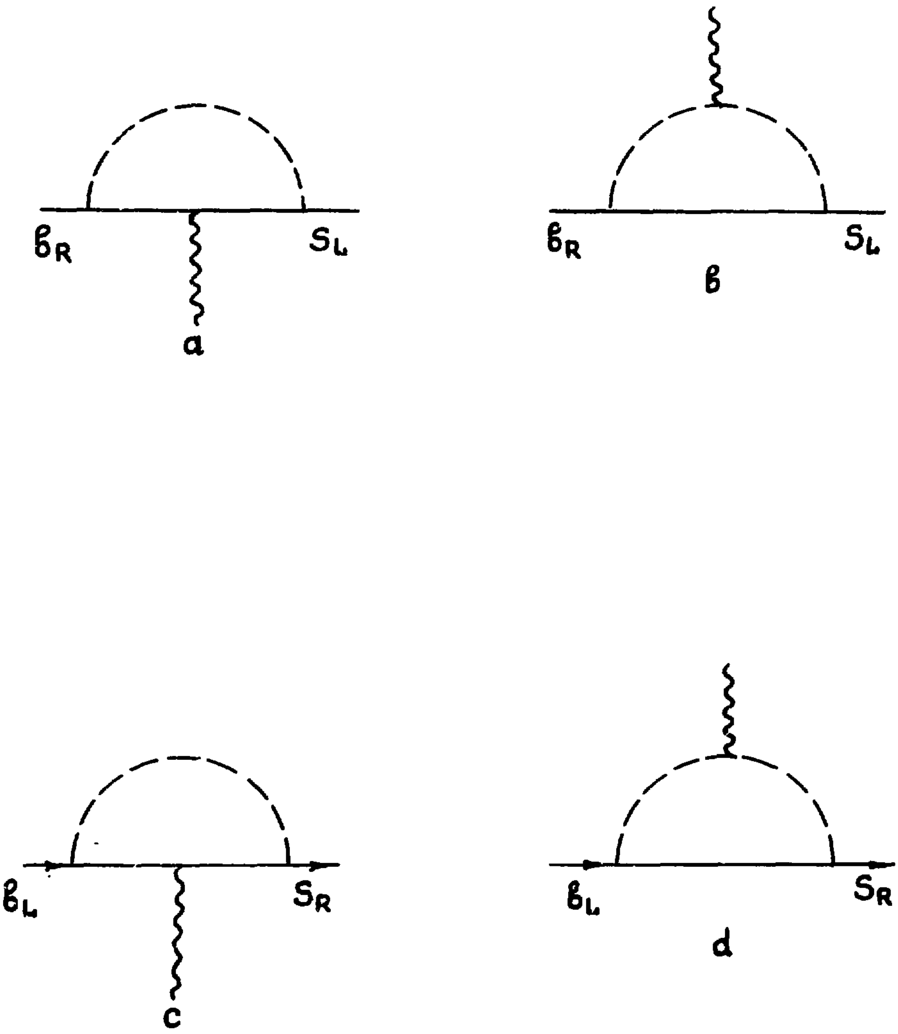

Fig. 1

Diagrams with exchange of the scalar field ξ, which contribute to the amplitude of the decay $b \to s\gamma$.

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Г.М. АСАТРЯН, А.Н. ИОАННИСЯН

РЕДКИЕ РАСПАДЫ В-МЕЗОНА В $SU(2)_L \times SU(2)_R \times U(1)$-МОДЕЛИ

(на английском языке, перевод Г.А. Папяна)
Редактор Л.П. Мукаян
Технический редактор А.С. Абрамян

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The address for requests:
Information Department
Yerevan Physics **Institute**
Alikhanian Brothers 2,
Yrevan, 375036
Armenia, USSR

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