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ON THE ROLE OF K^*K INTERMEDIATE STATES IN OZI-RULE VIOLATING REACTIONS OF ANTIPROTON ANNIHILATION

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1. The recent experimental data on the $\bar{p}p$ and $\bar{p}n$ annihilation at rest obtained by the ASTERIX, CRYSTAL BARREL and OBELIX groups[1, 2, 3] at LEAR, have shown that the branching ratios of the reactions $\bar{p}p \to \phi\pi^0$, $\bar{p}n \to \phi\pi^-$ and $\bar{p}p \to \phi\gamma$ are much bigger than expected from naive OZI-rule estimations. For example, as follows from the present data on the $\phi\omega$ mixing angle, a ϕ/ω production ratio should be $4\cdot 10^{-3}$ or less while in practice[1, 2, 3]

$$Br(pp \to \phi\pi^0)/Br(pp \to \omega\pi^0) = 0.14 \pm 0.004\,, \tag{1}$$

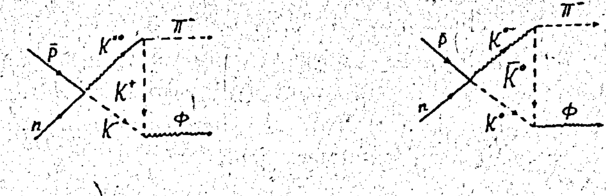
$$Br(\bar{p}n \to \phi\pi^-)/Br(\bar{p}n \to \omega\pi^-) = 0.16 \pm 0.04\,, \tag{2}$$

$$Br(\bar{p}p \to \phi\gamma)/Br(\bar{p}p \to \omega\gamma) = 0.33 \pm 0.15\,. \tag{3}$$

The interest to the reactions violating the OZI-rule is connected with expectations that these reactions may give evidence of the existence of exotic states such as hybrids and glueballs and of the considerable admixture of strange quarks in the nucleon (see for example the discussion in refs.[4, 5]). For this reason it is important to investigate whether some of the reactions violating the OZI rule can be explained by usual mechanisms. In particular, the authors of ref.[6] have shown that the data on the reaction $\bar{p}p \to \phi\phi$ can by explained by the triangle mechanism with K mesons in the intermediate state. These authors also claim that their estimate for the branching ratio of $\Phi\pi$ using the same mechanism with K^* and K mesons in the intermediate state is of the same order as the experimental values[1, 2], but no calculations of the $\Phi\pi$ branching ratio in ref.[6] were given.

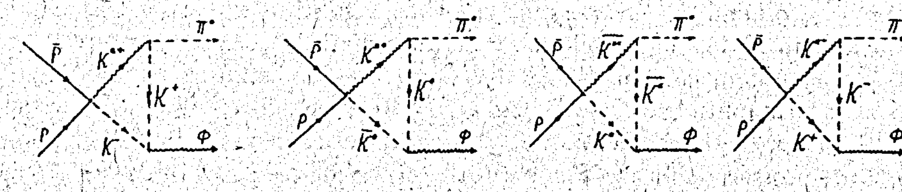
In the present paper we explicitly calculate in the on-shell approximation the contribution of the K^*K intermediate states to the reactions $\bar{p}p \to \phi\pi^0$, $\bar{p}n \to \phi\pi^-$ and $\bar{p}p \to \phi\gamma$ assuming that the initial antiproton and nucleon are at rest and their orbital angular momentum is equal to zero. It is easy to show that to conserve the C, G and P parities in this case, the antiproton-nucleon system should annihilate into $\phi\pi$ only from the state with the spin $S = 1$ and the final $\phi\pi$ system is in the state with $l = 1$, while the $\bar{p}p$ annihilation into $\phi\gamma$ occurs only from the state with $S = 0$.

The contribution of the triangle mechanism with K^* and K mesons in the intermediate state to the reaction $\bar{p}n \to \Phi\pi^-$ is described by the two graphs in fig.1, and such a contribution for the reaction $\bar{p}p \to \phi\pi^0$ is described by the four graphs in fig.2. Taking into account the isotopic invariance it easy to show



a) b)

Fig. 1



a) b) c) d)

Fig. 2

that if $S = 1$ and $I = 1$ (where I is the isospin), then the contributions of the graphs 1a and 1b are equal to each other and the contributions of all the four graphs in fig.2 are also equal to each other. In addition, the amplitude of the reaction $\bar{p}n \to \phi\pi^-$ is by $\sqrt{2}$ times bigger than the amplitude of the reaction $\bar{p}p \to \phi\pi^0$.

The contribution of the triangle mechanism with K^* and K mesons in the intermediate state to the reaction $\bar{p}p \to \Phi\gamma$ is described by the same graphs as in fig.2 but π^0 is replaced by γ. If $S = 0$ then in this case the contribution of the graph a) is equal to that of the graph d) and the contributions of the graphs b) and c) are also equal to each other. However since the isotopic invariance doesn't take place in the process $K^* \to K\gamma$, we cannot relate directly the graphs a) and b).

2. At the conditions specified above there exists only one relativistically invariant amplitude for the reaction $\bar{p}n \to \phi\pi^-$:

$$A_{\bar{p}n\to\phi\pi^-} = f_{\bar{p}n\to\phi\pi^-}(\bar{\Psi}_-\gamma^\mu\Psi)e_{\mu\nu\rho\sigma}e^{\nu*}p_1^\rho p_2^\sigma = (2m)^2 f_{\bar{p}n\to\phi\pi^-}(\varphi'^T\sigma_2\sigma_i\varphi)e_k^* e_{ikl}p_l\,. \tag{4}$$

Here $f_{\bar{p}n\to\phi\pi^-}$ is some constant, Ψ is the Dirac byspinor describing the initial neutron, Ψ_- is the Dirac byspinor with the negative energy describing the initial antiproton, e^ν is the polarization vector of the ϕ meson, p_1 is the 4-momentum of π^-, p_2 is the 4-momentum of ϕ, m is the nucleon mass, φ is the usual spinor describing the neutron, σ_i ($i = 1,2,3$) are the Pauli matrices, φ'

is the charge conjugated spinor describing the antiproton, the index T means the transposed spinor, $\mathbf{p}$ is the momentum of π in the c.m.frame of the $\phi\pi$ system, $e_{\mu\nu\rho\sigma}$ and e_{ikl} are the absolutely antisymmetric tensors and a sum over repeated indices is assumed. The Greek indices take the values 0,1,2,3 and the Latin indices take the values 1,2,3. A standard calculation using Eq. 4 gives:

$$Br(\bar{p}n \to \phi\pi^-) = \frac{(2m)^3}{4\pi} \mid f_{\bar{p}n\to\phi\pi^-} \mid^2 p^3 C_{\bar{p}n}, \qquad (5)$$

where $p = \mid \mathbf{p} \mid$ and $C_{\bar{p}n}$ is some constant which is fully determined by the total cross section of the $\bar{p}n$ annihilation from the state with $l = 0$.

The $\bar{p}n$ system can annihilate into $K^{*0}K^-$ from both states with $S = 1$ and $S = 0$. The amplitude corresponding to $S = 1$ can be written by analogy with Eq. 4. Let $\mathbf{p}'_1$ be the momentum of K^{*0} and $\mathbf{p}'_2$ be the momentum of K^-. The amplitude corresponding to $S = 0$ can be proportional only to $(\bar{\Psi}_-\gamma^5\Psi)(e^*P)$ where e is the polarization vector of K^* and $P = p'_1 + p'_2$. Therefore, as follows from (4)

$$A_{\bar{p}n\to K^{*0}K^-} = (2m)^2[f^{(1)}_{\bar{p}n\to K^{*0}K^-}(\varphi'^T\sigma_2\sigma_i\varphi)e^*_k e_{ikl}p'_l + \sqrt{2}m^* f^{(0)}_{\bar{p}n\to K^{*0}K^-}(\varphi'^T\sigma_2\varphi)e^*_0], \qquad (6)$$

where m^* is the mass of K^*, e_0 is the time component of e_μ, f's are some constants and $\mathbf{p}'$ is the momentum of K^{*0}. A standard calculation gives then:

$$Br(\bar{p}n \to K^{*0}K^-) = \frac{(2m)^3}{4\pi} p'^3 (\mid f^{(1)}_{\bar{p}n\to K^{*0}K^-} \mid^2 + \mid f^{(0)}_{\bar{p}n\to K^{*0}K^-} \mid^2) C_{\bar{p}n}, \qquad (7)$$

where $p' = \mid \mathbf{p}' \mid$ and $C_{\bar{p}n}$ is the same constant as in (5). Then as follows from (5)

$$\frac{Br(\bar{p}n \to \phi\pi^-)}{Br(\bar{p}n \to K^{*0}K^-)} = (\frac{p}{p'})^3 \frac{\mid f_{\bar{p}n\to\phi\pi^-} \mid}{\mid f^{(1)}_{\bar{p}n\to K^{*0}K^-} \mid^2 + \mid f^{(0)}_{\bar{p}n\to K^{*0}K^-} \mid^2}. \qquad (8)$$

It is well known that if the vector meson with the mass M decays into pseudoscalar mesons with the 4-momenta q_1 and q_2 then the amplitude of such a decay can be written as

$$A = g(q_1 - q_2)_\mu e^\mu \qquad (9)$$

and the width of the vector meson relative to such a decay is

$$\Gamma = \frac{\mid g \mid^2}{6\pi M^2} k^3, \qquad (10)$$

where k is the magnitude of the momenta of the pseudoscalar mesons in their c.m.frame. As follows from the facts that K^* in almost 100% cases decays into $K\pi$ and ϕ in 87% cases decays into $K\bar{K}$, if g_1 is the constant entering into the amplitude $K^{*0} \to \pi^-K^+$ and g_2 is the constant entering into the amplitude $\phi \to K^+K^-$ then:

$$\frac{\mid g_1 \mid^2 p^3_{\pi K}}{6\pi m^{*2}} = \frac{2}{3}\Gamma^* \qquad \frac{\mid g_2 \mid^2 p^3_{K\bar{K}}}{6\pi m^2_\phi} = \frac{1}{2}0.87\Gamma_\phi, \qquad (11)$$

where $p_{\pi K}$ is the momentum in the c.m. frame of the $K\pi$ system created in the decay of K^*, $p_{\bar{K}K}$ is the momentum in the c.m. frame of the $K\bar{K}$ system created in the decay of ϕ, Γ^* is the full width of K^* and Γ_ϕ is the full width of ϕ.

The amplitude of the decay $K^* \to K\gamma$ has the form :

$$A_{K^*\to K\gamma} = f_{K^*\to K\gamma} e_{\mu\nu\rho\sigma} e^{\mu *} E^\nu P^\rho k^\sigma, \qquad (12)$$

where e^μ is the polarization vector of the photon, E is the polarization vector of the K^* meson, P is the 4-momentum of the K^* meson and k is the 4-momentum of the photon. The amplitude (12) is gauge invariant and automatically ensures the gauge invariance of the amplitude $\bar{p}p \to \phi\gamma$. Let $p_{K\gamma}$ be the magnitude of the momentum in the c.m.frame of $K\gamma$, and Γ^*_γ be the radiative width of K^*. Then, as follows from (12)

$$\Gamma^*_\gamma = \frac{p^3_{K\gamma}}{12\pi} \mid f_{K^*\to K\gamma} \mid^2. \qquad (13)$$

3. We have done all the preparatory work for calculating the graphs in figs.1,2. However it is easy to see that these graphs diverge if no form factors are introduced into the vertices since K^* is the vector meson. At the same time the imaginary part of these graphs can be calculated rather reliably. Consider for example the imaginary part of the graph in fig.1a. The amplitude $\bar{p}n \to K^{*0}K^-$ enters into this graph when all the particles are on their mass shells, and in the amplitudes $K^{*0} \to \pi^-K^+$ and $K^+K^- \to \phi$ only K^+ isn't on the mass shell. However, as can be seen from a simple numerical estimate, the mass of the virtual K^+ meson doesn't differ considerably from the mass of the real K^+ meson. Therefore with a good accuracy all the amplitudes in the vertices can be taken in the same form as for real particles. Then, as can be shown by a straightforward calculation, *the integrals defining the imaginary part of the graphs in figs.1,2 can be calculated analytically.*

In particular, using Eqs. 6 and 9 it can be shown that the imaginary part of the graphs in fig.1 contributes to the amplitude $\bar{p}n \to \phi\pi^-$ as follows:

$$iA_{\bar{p}n\to\phi\pi^-} = -\frac{mp'^2}{4\pi p} f^{(1)}_{\bar{p}n\to K^{*0}K^-} g_1 g_2 (\varphi'^T\sigma_2\sigma_1\varphi) e_{ikl} p_k e^*_l (2a - (1+a^2) ln\frac{a+1}{a-1}), \qquad (14)$$

where $a = (2E^*E_\pi + m_K^2 - m_\pi^2 - m^{*2})/2pp'$, $E^* = (m^{*2} + p'^2)^{1/2}$, $E_\pi = (m_\pi^2 + p^2)^{1/2}$. It is important that the kinematical conditions are such that $a > 1$ and therefore the integrals defining the imaginary part of the amplitudes $\bar{p}n \to \phi\pi^-$ and $\bar{p}p \to \phi\pi^o$ don't contain singularities (the same is true for the case $\bar{p}p \to \phi\gamma$). Comparing equations 4 and 14 we find that:

$$f_{\bar{p}n\to\phi\pi^-} = \frac{ig_1g_2p'^2}{16\pi mp} f^{(1)}_{\bar{p}n\to K^{*0}K^-}(2a - (1+a^2)ln\frac{a+1}{a-1}) \qquad (15)$$

and therefore, as follows from Eqs. 8 and 11:

$$\frac{Br(\bar{p}n \to \phi\pi^-)}{Br(\bar{p}n \to K^{*0}K^-)} = 0.87\frac{3}{64}\frac{pp'm^{*2}m_\phi^2\Gamma^*\Gamma_\phi}{m^2(p_{\pi K}p_{KK})^3}\frac{|f^{(1)}_{\bar{p}n\to K^{*0}K^-}|^2}{|f^{(1)}_{\bar{p}n\to K^{*0}K^-}|^2 + |f^{(0)}_{\bar{p}n\to K^{*0}K^-}|^2}$$
$$(2a - (1+a^2)ln\frac{a+1}{a-1})^2 \qquad (16)$$

Analogous calculations give that:

$$\frac{Br(\bar{p}p \to \phi\pi^0)}{Br(\bar{p}p \to K^{*0}K^-)} = 0.87\frac{3}{32}\frac{pp'm^{*2}m_\phi^2\Gamma^*\Gamma_\phi}{m^2(p_{\pi K}p_{KK})^3}\frac{|f^{11}|^2}{|f^{(1)}_{\bar{p}p\to K^{*+}K^-}|^2 + |f^{(0)}_{\bar{p}p\to K^{*+}K^-}|^2}$$
$$(2a - (1+a^2)ln\frac{a+1}{a-1})^2 \qquad (17)$$

Here we have introduced the notation f^{IS} for the part of the constant $f^{(S)}_{\bar{p}p\to K^{*+}K^-}$ corresponding to the contribution of the isospin I. Using the numerical values of the quantities entering into Eqs. 16 and 17 we can rewrite these expressions in the form:

$$Br(\bar{p}n \to \phi\pi^-) = 0.38\frac{|f^{11}|^2}{|f^{11}+f^{01}|^2 + |f^{10}+f^{00}|^2}Br(\bar{p}n \to K^{*0}K^-), \qquad (18)$$

$$Br(\bar{p}p \to \phi\pi^0) = 0.76\frac{|f^{11}|^2}{|f^{11}+f^{01}|^2 + |f^{10}+f^{00}|^2}Br(\bar{p}p \to K^{*+}K^-). \qquad (19)$$

The result of the analogous calculation for $Br(\bar{p}p \to \phi\gamma)$ is the following:

$$Br(\bar{p}p \to \phi\gamma) = (10^{-3}\frac{1.1\,|f^{10}-f^{00}|^2 + 0.5\,|f^{10}+f^{00}|^2}{|f^{10}+f^{00}|^2 + |f^{11}+f^{01}|^2}$$
$$+10^{-3}\frac{1.4\cos\alpha\,|f^{10}-f^{00}||f^{10}+f^{00}|}{|f^{10}+f^{00}|^2 + |f^{11}+f^{01}|^2})$$
$$Br(\bar{p}p \to K^{*+}K^-), \qquad (20)$$

where α is the (unknown) difference of phases between the graphs **a)** and **b)** in fig.2 for the case $\bar{p}p \to \phi\gamma$.

4. Let us now discuss the obtained results. As follows from Eqs. 18-20, even in the on-shell approximation the branching ratios under consideration aren't expressed only in terms of observable quantities since we should know additionally the quantities f^{IS}. The analysis carried out by different authors has shown that the channel with $I = S = 1$ is preponderant. For example, according to ref.[7]:

$$|f^{11}|^2 = (23.4 \pm 2.0)\ 10^{-4}, \qquad |f^{01}|^2 = (6.6 \pm 2.7)\ 10^{-4}$$
$$|f^{10}|^2 = (1.7 \pm 1.0)\ 10^{-4}, \qquad |f^{00}|^2 = (8.4 \pm 1.4)\ 10^{-4}. \qquad (21)$$

The quantities given in ref.[8] do not differ significantly from these ones. If we assume additionally that the quantities f^{0S} and f^{1S} don't interfere with each other (this isn't a crucial assumption) and do not take into account the uncertainty in Eq. 21 then:

$$Br(\bar{p}n \to \phi\pi^-) = 0.22Br(\bar{p}n \to K^{*0}K^-)$$
$$Br(\bar{p}p \to \phi\pi^0) = 0.44Br(\bar{p}p \to K^{*+}K^-) \qquad (22)$$
$$Br(\bar{p}p \to \phi\gamma) = 0.25 \cdot 10^{-3}(1.6 + 1.4\cos\alpha)Br(\bar{p}p \to K^{*+}K^-).$$

A direct comparison between the first expression in Eq. 22 and the experimental data isn't possible since $Br(\bar{p}n \to K^{*0}K^-)$ hasn't been measured so far. At the same time, the second expression is in good agreement with the data (see Table 1) if we take into account that according to ref.[9]:

$$Br(\bar{p}p \to K^{*+}K^-) = (0.70 \pm 0.04) \cdot 10^{-3}. \qquad (23)$$

TABLE 1

Reaction	$\bar{p}p \to \phi\pi^0$	$\bar{p}n \to \phi\pi^-$	$\bar{p}p \to \phi\gamma$	$\bar{p}p \to \phi\eta$	$\bar{p}p \to \phi\rho^0$	$\bar{p}p \to \phi\omega$
I, S	1, 1	1, 1	$S = 0$	0, 1	1, 0	0, 0
Theory	3.1 ± 0.2	7.7 ± 0.5	$0.5\ 10^{-2}$	1.0 ± 0.1	1.10^{-2}	0.5
Experiment	7.8 ± 1.0	12.41 ± 0.88	0.22 ± 0.06	0.94 ± 0.28	3.4 ± 1.0	5.3 ± 2.2

Comparison of our results obtained by calculating the contribution of the triangle mechanism with K^*K intermediate states to the branching ratios of different reactions with the experimental data of refs. [1-3]. The theoretical value for the $Br(\bar{p}p \to \phi\gamma)$ is the upper bound for Eq. 20, the value of $Br(\bar{p}p \to \phi\eta)$ is calculated assuming the SU(3) symmetry relation between the constants $K^{*-} \to K^-\pi^0$ and $K^{*-} \to K^-\eta$, and the values for $Br(\bar{p}p \to \phi\rho^0)$ and $Br(\bar{p}p \to \phi\omega)$ are the rough estimations. All the branching ratios are given in units 10^{-4}.

The quantities $Br(\bar{p}p \to \phi\pi^0)$ and $Br(\bar{p}n \to \phi\pi^-)$ can be related to each other as follows. Since $Br(\bar{p}p \to \phi\pi^0) = \sigma_{\bar{p}p\to\phi\pi^0}/\sigma_{\bar{p}p}$, $Br(\bar{p}n \to \phi\pi^-) = \sigma_{\bar{p}n\to\phi\pi^-}/\sigma_{\bar{p}n}$, where $\sigma_{\bar{p}p}$ and $\sigma_{\bar{p}n}$ are the total cross sections of the $\bar{p}p$ and $\bar{p}n$ annihilations, and the amplitude $\bar{p}n \to \phi\pi^-$ is by $\sqrt{2}$ times bigger than the amplitude $\bar{p}p \to \phi\pi^0$, then:

$$Br(\bar{p}n \to \phi\pi^-)/Br(\bar{p}p \to \phi\pi^0) = 2\sigma_{\bar{p}p}/\sigma_{\bar{p}n} \cdot \tag{24}$$

According to the analysis of data made in ref.[10], the ratio $\sigma_{\bar{p}p}/\sigma_{\bar{p}n}$ for the S wave annihilation near threshold is 1.25. Therefore $Br(\bar{p}n \to \phi\pi^-) = 2.5\ Br(\bar{p}p \to \phi\pi^0)$, and, as follows from Table 1, our result for $Br(\bar{p}n \to \phi\pi^-)$ is in good agreement with the data. At the same time, as follows from (23), even the upper bound for $Br(\bar{p}p \to \phi\gamma)$ is by the order of magnitude less than the experimental quantity (see Table 1).

Some deviation from the OZI-rule (though not so strong as in the above cases) has been also observed in the reactions $\bar{p}p \to \phi\eta$, $\bar{p}p \to \phi\rho^0$ and $\bar{p}p \to \phi\omega$[1, 2]. The contribution of the considered mechanism to these reactions is described by the graphs in fig.2 where the π^0 meson is replaced by the η, ρ^0 and ω mesons respectively. The value of $Br(\bar{p}p \to \phi\eta)$ can be calculated by analogy with the calculation for $Br(\bar{p}p \to \phi\pi^0)$, and $Br(\bar{p}p \to \phi\rho^0)$ and $Br(\bar{p}p \to \phi\omega)$ can be calculated by analogy with $Br(\bar{p}p \to \phi\gamma)$. The results of such calculations are the following

$$Br(\bar{p}p \to \phi\eta) = 0.64\frac{|f^{01}|^2}{|f^{11}|^2}\frac{|g_{K^{*+}\to K^+\eta}|^2}{|g_{K^{*+}\to K^+\pi^0}|^2}Br(\bar{p}p \to \phi\pi^0)\,, \tag{25}$$

$$Br(\bar{p}p \to \phi\rho^0) = 0.15\frac{|f^{10}|^2}{|f^{11}|^2}\frac{|g_{K^{*+}\to K^+\rho^0}|^2}{|\tilde{g}_{K^{*+}\to K^+\pi^0}|^2}Br(\bar{p}p \to \phi\pi^0)\,, \tag{26}$$

$$Br(\bar{p}p \to \phi\omega) = 0.15\frac{|f^{00}|^2}{|f^{11}|^2}\frac{|g_{K^{*+}\to K^+\omega}|^2}{|\tilde{g}_{K^{*+}\to K^+\pi^0}|^2}Br(\bar{p}p \to \phi\pi^0)\,, \tag{27}$$

where the g's are the constants of the corresponding decays and $\tilde{g}_{K^{*+}\to K^+\pi^0}$ is a formal quantity equal to the constant of the decay $K^{*+} \to K^+\pi^0$ in the hypothetical case when π^0 would be a vector particle. Since the processes $K^{*+} \to K^+\pi^0$, $K^{*+} \to K^+\eta$ and $K^{*+} \to K^+\omega$ can be only virtual, we cannot determine experimentally the corresponding decay constants. Assuming the SU(3) symmetry we can connect the quantities $g_{K^{*+}\to K^+\eta}$ and $g_{K^{*+}\to K^+\pi^0}$: $g_{K^{*+}\to K^+\eta} = \sqrt{3}g_{K^{*+}\to K^+\pi^0}$. Then our result for $Br(\bar{p}p \to \phi\eta)$ appears to be in satisfactory agreement with the experimental quantity (see Table 1). At the same time, even assuming the SU(3) symmetry, we cannot determine the constants $g_{K^{*+}\to K^+\rho^0}$ and $g_{K^{*+}\to K^+\omega}$ entering into Eqs. 26 and 27. Assuming that these constants are equal to $\tilde{g}_{K^{*+}\to K^+\pi^0}$ we get for $Br(\bar{p}p \to \phi\rho^0)$ and $Br(\bar{p}p \to \phi\omega)$ the estimations given in Table 1.

We can conclude that our results give strong evidences what the violation of the OZI-rule in the reactions $\bar{p}n \to \phi\pi^-$ and $\bar{p}p \to \phi\pi^0$ can be explained by the mechanism corresponding to the graphs in figs.1,2. At the same time this mechanism cannot explain the strong violation of the OZI-rule observed in the reaction $\bar{p}p \to \phi\gamma$. Let us note that this process cannot be also explained by the triangle mechanism with the K and $\bar{K}$ mesons in the intermediate state since if $l = 0$ then the $\bar{p}p$ system can annihilate into $\bar{K}K$ only from the state with $S = 1$. Therefore the problem of explaining the value of $Br(\bar{p}p \to \phi\gamma)$ remains open.

The result for $Br(\bar{p}p \to \phi\eta)$ has been obtained by using additionally the SU(3) symmetry relation between the constants $\tilde{g}_{K^{*+}\to K^+\eta}$ and $\tilde{g}_{K^{*+}\to K^+\pi^0}$. At the same time, our estimations for $Br(\bar{p}p \to \phi\rho^0)$ and $Br(\bar{p}p \to \phi\omega)$ are much less than the corresponding experimental values. Since the violation of the OZI-rule in the reactions $\bar{p}p \to \phi\rho^0$ and $\bar{p}p \to \phi\omega$ are not so drastic as in the reactions $\bar{p}p \to \phi\pi^0$ and $\bar{p}p \to \phi\gamma$, one might think that the main contribution in the cases of $\phi\rho^0$ and $\phi\omega$ is given not by the mechanism considered above but by the $\phi\omega$ mixing. Let us also note that the $\phi\pi$, $\phi\eta$, $\phi\rho$ and $\phi\omega$ channels in the nucleon-antinucleon annihilation are independent of each other since they correspond to different quantum numbers (I,S) (see Table 1). Therefore there may exist mechanisms of annihilation which contribute to some channels and do not contribute to others.

To better understand the problem of the OZI-rule violation it is necessary to carry out both experimental and theoretical study of this problem. For example, the conclusion about the dominant role of the channel with $I = S = 1$ in the annihilation into K^*K was made only using the indirect data while the direct measurement of the reaction $\bar{p}n \to K^{*0}K^-$ hasn't been made. An interesting theoretical problem is to explain the experimental facts[11] that when the $\bar{p}p$ system annihilates from the $l = 1$ state of the hydrogen-like atom then $Br(\bar{p}p \to \phi\pi^0)$ is small while $Br(\bar{p}p \to \phi\eta)$, $Br(\bar{p}p \to \phi\rho^0)$ and $Br(\bar{p}p \to \phi\omega)$ are of the same order of magnitude as in the case $l = 0$. In this connection it is important to measure the branching ratios of the $\bar{p}p$ annihilation into K^*K states from the state of the hydrogen-like atom with $l = 1$.

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