On the $\tau \to VP\nu_\tau$ decays

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The $\tau \to VP\nu_\tau$ decays of the τ lepton are studied using the method of phenomenological chiral Lagrangians. The expressions of weak hadronic currents between pseudoscalar and vector meson states and the strong interaction Lagrangian between axial-vector, vector, and pseudoscalar mesons are obtained. Calculated partial widths for these decays are compared with the available theoretical and experimental data.
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In this paper the $\tau \to VP\nu_\tau$ decays of the τ lepton are studied using the method of phenomenological chiral Lagrangians (PCL's) [1]. Such decay channels are a unique ''laboratory'' for verification of weak hadron currents between pseudoscalar and vector meson states. The main uncertainty in the study of these decays is connected with this weak hadron current and so investigation of these decays is of interest. Note that the hadron decays of the τ lepton up to three pseudoscalar mesons in the final state have been studied also in the framework of this method [2,3].

In the PCL, the weak interaction Lagrangian has the form

$$L_W = \frac{G_F}{\sqrt{2}} J^h_\mu l^+_\mu + \text{H.c.}, \tag{1}$$

where $G_F \simeq 10^{-5}/m_P^2$ is the Fermi constant, $l_\mu = \overline{u_l}\gamma_\mu(1+\gamma_5)u_{\nu_l}$ is the lepton current, and hadron currents have the form [1]

$$J^h_\mu = J^{1+i2}_\mu \cos\Theta_c + J^{4-i5}_\mu \sin\Theta_c,$$

where Θ_c is the Cabibbo angle.

Weak hadron currents between pseudoscalar and vector meson states are obtained by including the gauge fields of these mesons in covariant derivatives [4]:

$$\partial_\mu \to \partial_\mu + igv_\mu V + iga_\mu A, \tag{2}$$

where v^i_μ and a^i_μ are the fields of the 1^- and 1^+ mesons, $V_i = \lambda_i I/2$, and $A_i = V_i\gamma_5$ are the vector and axial-vector generators of the $SU(3)\times SU(3)$ group, respectively.

The weak hadron currents we obtained in this way have the form

$$J^i_\mu = F_\pi g v^a_\mu \varphi^b f_{abi}, \tag{3}$$

where $F_\pi = 93$ MeV, g is the ''universal'' coupling constant which is fixed from the experimental $\rho \to \pi\pi$ decay width

$$\frac{g^2}{4\pi} \simeq 3.2,$$

and φ^b represent the fields of the 0^- mesons.

Axial-vector and vector meson currents are defined as

$$J^i_\mu = \frac{m_v^2}{g} v^i_\mu + \frac{m_a^2}{g} a^i_\mu, \tag{4}$$

where m_v and m_a are the masses of vector and axial-vector mesons, respectively.

The strong interaction Lagrangian of axial-vector mesons with vector and pseudoscalar mesons is obtained also by this way and has the form [2]

$$L_S(1^+,1^-,0^-) = -F_\pi g^2 f_{klm} a^k_\mu v^l_\mu \varphi^m. \tag{5}$$

In the PCLM, the strong interaction Lagrangian of vector mesons with vector and pseudoscalar mesons has the form

TABLE I. The partial widths (in 10^9 sec^{-1}) for the $\tau \to VP\nu_\tau$ decays.

Decays	I	II	III	Experiment [7]
$\tau^- \to \rho^0\pi^-\nu_\tau$	0.22×10^2	0.306×10^2	0.306×10^2	$(1.77\pm0.56)\times10^2$ [8]
$\tau^- \to K^{*0}K^-\nu_\tau$	2.2	1.3	7.82	$6.9\pm1.7\pm1.4$
$\tau^- \to \overline{K}^{*0}\pi^-\nu_\tau$	0.48	7.85	9.52	$8.6\pm3.4\pm1.7$
$\tau^- \to K^{*-}\pi^0\nu_\tau$	0.24	1.76	2.61	
$\tau^- \to \rho^-\overline{K}^0\nu_\tau$	0.23	1.18	2.12	
$\tau^- \to \rho^0K^-\nu_\tau$	0.12	0.6	1.08	
$\tau^- \to \omega K^-\nu_\tau$	0.32	1.68	1.83	

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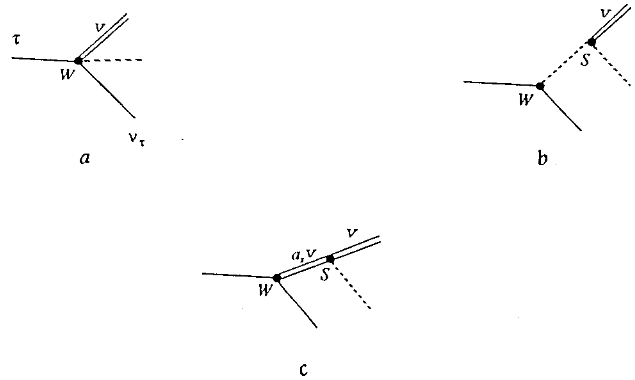

FIG. 1. Diagrams for the $\tau \rightarrow VP\nu_\tau$ decays, here W and S are the vertices of weak and strong interactions, respectively. (a) and (b) are without the pole contribution of $1^{\pm}$ mesons and (c) includes these pole contributions.

$$L_s(vv\varphi) = -g_{vv\varphi}\varepsilon_{\mu\nu\alpha\beta}Sp(\partial_\mu \hat{V}_\nu \partial_\alpha \hat{V}_\beta \hat{\varphi}), \qquad (6)$$

where $g_{vv\varphi} = 3g^2/16\pi^2 F_\pi$ is the coupling constant, $\hat{V}_\mu = (1/2i)\lambda_i v^i_\mu$, and $\hat{\varphi} = \frac{1}{2}\lambda_i \varphi^i$.

The decay amplitudes for these channels can be written as [5]

$$M(\tau(k_\tau) \rightarrow V(p)P(p_1)\nu_\tau(k_\nu)) = G_F \epsilon^\lambda_\mu \overline{U}(k_\nu)\gamma_\mu[f_1 + g_1\gamma_5 + \hat{p}(f_2 + g_2\gamma_5) + \hat{p}_1(f_3 + g_3\gamma_5)]U(k_\tau),$$

where ϵ^λ_μ is the polarization vector of $1^{\pm}$ mesons, f_i and g_i are the form factors that depend on the final state momenta $(q = k_\tau - k_\nu = p + p_1)$, and k_τ, k_ν are the lepton four-momenta $(\hat{p}_i \equiv p_{i\mu}\gamma^\mu)$.

Using these Lagrangians we calculated the partial widths of the $\tau \rightarrow VP\nu_\tau$ decays by means of the TWIST code [6]. The decay diagrams are shown in Fig. 1. The results are shown in Table I. In columns I, II, and III are listed the results without $1^{\pm}$ contribution, with the axial-vector 1^+ contribution, and with the axial-vector 1^+- and vector 1^--meson contributions, respectively. It should be noted that the contribution of Fig. 1(b) to the partial width is about 5% of that of Fig. 1(a).

These decay channels get contributions from the $a_1(1260)$, $K_1(1270)$, and $K_1(1400)$ axial-vector intermediate meson states which have widths of 400, 90, and 174 MeV, respectively. Note that the contribution of the $K_1(1400)$ meson to the partial widths of the $\tau^- \rightarrow (\overline{K}^{*0}\pi^-, K^{*-}\pi^0, \rho^-\overline{K^0}, \rho^0 K^-, \omega K^-)\nu_\tau$ decays is about 60–80 % of that of the $K_1(1270)$ meson.

In these decays vector intermediate meson state contributions have been taken into account also and according to Eq. (6) only the $\tau^- \rightarrow \rho^0\pi^-\nu_\tau$ decay does not get any contributions from such vector meson states. The $\tau^- \rightarrow K^{*0}K^-\nu_\tau$ decay mode gets contributions from the $\rho(770)$-, $\rho(1450)$-, and $\rho(1700)$-vector intermediate meson states which have widths of 151, 310, and 235 MeV, respectively. Note that these contributions dominate those of the axial-vector ones. The $\tau^- \rightarrow (\overline{K}^{*0}\pi^-, K^{*-}\pi^0, \rho^-\overline{K^0}, \rho^0 K^-, \omega K^-)\nu_\tau$ decays get contributions from the $K^{*-}(892)$-, $K^{*-}(1410)$-, and $K^{*-}(1680)$-vector meson states which have widths of 50, 227, and 323 MeV, respectively. Note that in these decays contributions of the $\rho(1450)$-, $\rho(1700)$-, $K^{*-}(1410)$-, and $K^{*-}(1680)$-vector meson states dominate those of the $\rho(770)$ and $K^{*-}(892)$ ones.

Table I shows that the result obtained for the $\tau^- \rightarrow \rho^0\pi^-\nu_\tau$ decay channel lies below the experimental value [8], but is fairly consistent with the chiral perturbation theory prediction [9] $\simeq 0.23 \times 10^{11}$ sec^{-1} ($BR \simeq 0.69\%$). The calculated partial widths of the $\tau^- \rightarrow K^{*0}K^-\nu_\tau$ and $\tau^- \rightarrow \overline{K}^{*0}\pi^-\nu_\tau$ decays are in good agreement with available experimental data [7]. Note that according to Eq. (3) the partial widths of the $\tau^- \rightarrow \omega\pi^-\nu_\tau$ and $\tau^- \rightarrow \phi\pi^-\nu_\tau$ decays are equal to zero in the PCL method; as in Ref. [10], these decay channels can be realized via effects of secondary importance.

Thus, expressions (3), (5), and (6) obtained by including the gauge fields of axial-vector and vector mesons in covariant derivatives allow us to describe the $\tau \rightarrow VP\nu_\tau$ decays in satisfactory agreement with available experimental data. Note, according to Eqs. (2), (4), and (6) we used the same g-coupling constant for all the axial-vector and vector intermediate states and, probably, taking into account corresponding coupling constants would allow us to describe these decays more correctly compared to these calculations. We hope that a new level of precision of future measurements will allow us to evaluate the status of this method and clarify the problems related to weak interactions of hadrons.

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