Hadronic decays of the τ lepton in the virton-quark model

M. Dineĭkhan, G. V. Efimov, and E. A. Nogovitsyn
Joint Institute for Nuclear Research

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The hadronic decays of the heavy τ lepton, $\tau^- \to \pi^- \nu_\tau, \rho^- \nu_\tau, K^- \nu_\tau, \overset{*}{K}{}^- \nu_\tau$, $\pi^- \rho^0 \nu_\tau, \pi^- \pi^0 \nu_\tau, K\pi\nu_\tau, \omega\pi^- \nu_\tau$, and $\rho^- \eta(\eta')\nu_\tau$, are analyzed in the virton-quark model. The results are in complete agreement with the experimental data available.

The success of the virton-quark model in describing various phenomena in hadron physics[1] suggests that this model, which has only two adjustable parameters, will work well in the quark-confinement region.

Let us examine the hadronic decays of the heavy τ lepton ($M = 1807$ MeV): $\tau^- \to \pi^- \nu_\tau, \rho^- \nu_\tau, K^- \nu_\tau, \overset{*}{K}{}^- \nu_\tau, \pi^- \rho^0 \nu_\tau, \pi^- \pi^0 \nu_\tau, K\pi\nu_\tau, \omega\pi^- \nu_\tau, \rho^- \eta(\eta')\nu_\tau$. The widths of the decays having a single hadron in the final state have been detected experimentally, but the widths of decays with two final-state hadrons have not yet been detected (except for the reaction $\tau^- \to \pi^- \rho^0 \nu_\tau$).

According to the standard theory of electroweak interactions, the Lagrangian of the interaction of the W boson with quark and lepton fields is

$$\mathcal{L}_{\rm lep} = \frac{g}{\sqrt{2}} (\bar{\tau}_L \gamma_\mu \nu_{\tau L}) W_\mu^- + \text{H.a.}$$

$$\mathcal{L}_{\rm quark} = \frac{g}{\sqrt{2}} [(\bar{d}_L \gamma_\mu u_L) \cos\theta_K + (\bar{s}_L \gamma_\mu u_L) \sin\theta_K \tag{1}$$

$$+ (\bar{s}_L \gamma_\mu c_L) \cos\theta_K - (\bar{d}_L \gamma_\mu c_L) \sin\theta_K] W_\mu^- + \text{H.a.}$$

Here u, d, s, and c are the quark fields; $\psi_L = \frac{1}{2}(1-\gamma_5)\psi$; θ_K is the Cabibbo angle; $g^2 = 8M_W^2 G_F/\sqrt{2}$;$G_F$ is the Fermi constant; and M_W is the mass of the W boson.

The Lagrangian of the interaction of the meson fields with quark fields is written

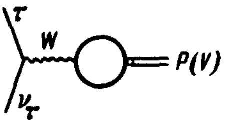

FIG. 1. Feynman diagram of the corresponding two-particle decays.

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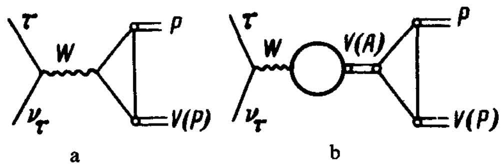

FIG. 2. Feynman diagrams of the three-particle decays.

in the form[1]

$$\mathcal{L}_M = \frac{h}{\sqrt{2}} \phi^j (\bar{q} \Gamma \lambda^j q), \quad j = 1, \ldots, 8, \tag{2}$$

where the ϕ^j are the meson fields;

$$q = \begin{pmatrix} u \\ d \\ s \end{pmatrix}$$

are the quark fields; $\Gamma = i\gamma_5, \gamma_\mu$, and $\gamma_5 \gamma_\mu$ for pseudoscalar, vector, and axial vector fields, respectively; and the λ^j are the Gell-Mann matrices. The coupling constants describing the coupling of the meson fields with the quark fields are determined from the connectedness condition[1] and have the following numerical values:

$$\lambda_P = \frac{h_P^2}{(4\pi)^2} = 0.13\,; \quad \lambda_V = \frac{h_V^2}{(4\pi)^2} = 0.13; \quad \lambda_A = \frac{h_A^2}{(4\pi)^2} = 0.38$$

(for pseudoscalar, vector, and axial vector mesons, respectively).

TABLE I.

Mode	Experimental width[3] (%)	Theoretical width (%)	Theoretical width ($\times 10^{-10}$ MeV)
$\tau \to \pi^- \nu_\tau$	10, 7 ± 1, 6	12	1, 8
$\rho^- \nu_\tau$	21, 6 ± 3, 6	25	3, 8
$K^- \nu_\tau$	1, 3 ± 0, 5	0, 72	0, 1
$K^{*-} \nu_\tau$	1, 7 ± 0, 7	1, 9	0, 28
$\pi^- \rho^0 \nu_\tau$	5, 4 ± 1, 7	4, 1	0, 58
$\pi^- \pi^0 \nu_\tau$	—	1, 4	0, 2
$K\pi\nu_\tau$	—	$4,2 \cdot 10^{-2}$	$0,6 \cdot 10^{-2}$
$\omega\pi^- \nu_\tau$	—	0, 5	0, 072
$\rho^- \eta \nu_\tau$	—	0, 042	$0,6 \cdot 10^{-2}$
$\rho^- \eta' \nu_\tau$	—	$4,3 \cdot 10^{-6}$	$0,62 \cdot 10^{-6}$

The quark-virton propagator is[1]

$$G(\hat{p}) = L \exp [\xi \frac{L}{2}\hat{p} + \frac{L^2}{4}p^2] . \tag{3}$$

Here $L = 1/(320\ \text{MeV})$ and $\xi = 1.4$ are parameters of the model, which have been fixed previously and which do not change in any of the processes described by this model.

The diagram in Fig. 1 corresponds to the decays $\tau^- \to \pi^- \nu_\tau, K^- \nu_\tau, \rho^- \nu_\tau$, and $\overset{*}{K}{}^- \nu_\tau$. The two diagrams in Fig. 2 contribute to the amplitudes of the decays $\tau^- \to \pi^- \rho^0 \nu_\tau, \pi^- \pi^0 \nu_\tau, K\pi\nu_\tau, \omega\pi^0\nu_\tau$, and $\rho^- \eta(\eta')\nu_\tau$. In other words, the W boson may initially become a ρ meson [the decays $\omega\pi^-\nu_\tau, \rho^-\eta(\eta')\nu_\tau$], an A meson ($\pi^-\rho^0\nu_\tau$), or a $\overset{*}{K}$ meson ($K\pi\nu_\tau$), each of which would then decay into ($P + V$) or ($P + P$). The need to consider such diagrams was pointed out by Ivanov.[2] The amplitudes were calculated in the standard way for the virton-quark model.[1] We should point out that in Lagrangian (1) we used a conserved local quark current,[1] which does not violate the gauge invariance of the electroweak interactions.

The numerical values of the partial widths are listed in Table I. The results are in complete agreement with the available experimental data.

[1]G. V. Efimov and M. A. Ivanov, Fiz. Elem. Chastits At. Yadra. **12**, 1220 (1981) [Sov. J. Part. Nucl. **12**, 489 (1981)].
[2]A. N. Ivanov, Yad. Fiz. **32**, 1687 (1980) [Sov. J. Nucl. Phys. **32**, 873 (1980)].
[3]Particle Data Group, Phys. Lett. **111B**, 1 (1982).

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