Decay of a charmed meson into a heavy lepton, and the mass of the ν_τ neutrino

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The probabilities of the decay of the pseudoscalar charmed F and D mesons into a heavy lepton, $F^- \to \tau^- + \bar{\nu}_\tau$ and $D^- \to \tau^- + \bar{\nu}_\tau$ are estimated under the assumption that the mass of the ν_τ neutrino is less than 220 and 58 MeV, respectively. At almost all values of $m(\nu_\tau)$ (up to 219.5 MeV) the probability of the $F \to \tau + \nu_\tau$ decay exceeds the probability of the $F \to \mu + \mu_\nu$ decay. The branching ratio $W(F^+ \to \tau^+ \nu_\tau)/W(F^+ \to \mu^+ \nu_\mu)$ is determined only by the mass of the ν_τ neutrino and is sensitive to this mass.

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This article discusses a number of interesting properties of leptonic decays of the charmed charged pseudoscalar mesons D and F. Since the masses of these mesons ($m_F = 2.03$ GeV[1] and $m_D = 1.865$ GeV[2]) exceed the mass of the heavy τ lepton, which was measured with good accuracy in colliding electron-positron beams ($m_\tau = 1.807$ GeV),[3] decays into the τ lepton and the corresponding neutrino

$$F^\pm \to \tau^\pm + \nu_\tau(\bar{\nu}_\tau), \qquad D^\pm \to \tau^\pm + \nu_\tau(\bar{\nu}_\tau), \tag{1}$$

become allowed for the D and F mesons. In the standard scheme[4] of weak interaction with four quarks (u, d, s, and c), the F-meson decay, unlike the D-meson decay, is not subject to the Cabibbo suppression.

Naturally, the decays (1) can take place only at definite values of the mass of the ν_τ neutrino, namely $m_\nu < 220$ MeV for the $F \to \tau + \nu_\tau$ decay and $m_\nu < 68$ MeV for the $D \to \tau + \nu_\tau$ decay. We note that the estimate $m_\nu < 540$ MeV obtained in experiments with colliding electron-positron beams for the mass of the ν_τ neutrino[5] exceeds the required values of m_ν. Yet an astrophysical estimate[6] gives for the neutrino mass the much smaller value $m_\nu > 30$ eV.

Therefore the very observation of the decays (1) would make it possible to improve by severalfold the estimate of the mass of the ν_τ neutrino. It is also easy to verify that owing to the proximity of the τ lepton mass to the masses of the D and F mesons the probabilities of the decays (1) are sensitive to the value of the ν_τ neutrino mass. Indeed, the probability of the decay $P \to \tau + \nu_\tau$ (P stands for F or D) is determined by the following formula (with allowance for the neutrino mass)

$$w(P \to \tau + \nu_\tau) = |\mathrm{k}|\, G^2 \frac{f_P^2}{4\pi} \, \frac{M^2(m_\tau^2 + m_\nu^2) - (m_\tau^2 - m_\nu^2)^2}{M^2}, \tag{2}$$

where G is the Fermi weak interaction constant, f_p is the constant of the $P \to \tau + \nu_\tau$

decay, M, m_τ, and m_ν are the masses of the P meson, the τ lepton, and the ν_τ neutrino, and **k** is the 3-momentum of the τ lepton. This formula is valid both for the $V-A$ and for the $V+A$ variant of the weak charged current describing the transition $\nu_\tau \to \tau$.

The branching ratio $R_p = u(P \to \tau\ \nu_\tau)/u(P \to \mu\ \nu_\mu)$ is determined only by the mass of the ν_τ neutrino, and there is a noticable dependence of R_p on the mass m_ν. It is seen from Table I that, as expected, the greatest sensitivity of the ratio R_F to the value of m_ν takes place near $m_\nu = 220$ MeV (we have assumed $m_F = 2.03$ and $m_\tau = 1.81$ GeV).

TABLE I.

m_ν, MeV	0	120	160	200	210	215	217	218	219	219,5	219,75
R_F	13,6	12,6	10,7	6,7	5,0	3,5	2,7	2,2	1,6	1,1	0,80

We note that R_F exceeds unity all the way to $m_\nu = 219.5$ MeV, i.e., to $m_F - m_\tau - m_\nu = 0.5$ MeV. For the D-meson decay $R_D = 1.15$ ($m_\nu = 0$), 1.20($m_\nu = 20$ MeV), 1.10($m_\nu = 30$ MeV), 0.94 ($m_\nu = 40$ MeV), 0.67 ($m_\nu = 50$ MeV) and 0.46 ($m_\nu = 55$ MeV), i.e., at zero neutrino mass the probability of the $F \to \mu + \nu$ exceeds the probability of the $D \to \mu + \nu$ decay (despite the small energy release in the former decay). We emphasize once more that these results are equally valid for both the $V-A$ and the $V+A$ variant of the current.

If account is taken of the possible dependence[7] of the constant f_p on the masses of the quarks making up the P meson, then the two-particle decays (1) should be enhanced by $[(m_s + m_c)/(m_u + m_d)]^2 = 11$ and $[(m_u + m_c)/(m_u + m_d)]^2 = 9$ times, respectively, if we use for the effective masses of the quarks the values $m_u = m_d = 300$ MeV, $m_s = 500$ MeV and $m_c = 1500$ MeV.

We have thus shown that the $F \to \tau + \nu_\tau$ decay should be the principal leptonic decay of the F meson. The probability of the $D \to \tau + \nu_\tau$ decay is comparable with the probability of the $D \to \mu + \nu_\mu$ decay, but owing to the Cabibbo suppression the principal leptonic decays of the $D^\pm$ mesons should be three-particle decays with production of K or K^* mesons.

We note in conclusion that the matrix element of the $F^- \to \tau^- + \nu_\tau + \pi^0$ decay does not contain the Cabibbo suppression, but the probability of this decay should nevertheless be substantially suppressed (to the same degree that the probability of $\phi \to 3\pi$ is suppressed in comparison with the probability of the $\phi \to K\bar{K}$ decay).

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