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Inclusive studies of charmed-meson decays and SU(4) 20-plet dominance model

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Inclusive branching ratios to states containing kaons in D^0, D^+, and F^+ decays are studied on the basis of an SU(4) 20-plet dominance model, where strangeness-changing decays of D^+ are strongly suppressed.

Recently measurements of inclusive branching ratios to states containing kaons in D^0 and $D^\pm$ decays, $B(D\to KX)$, have been reported by Vuillemin *et al.*[1] from inclusive studies of the D-meson decays at the $\psi(3772)$. A very surprising result is that the sum of the branching ratios to states containing charged and neutral kaons in the D^+ decays is only about $\frac{1}{2}$ although this sum in the D^0 decays is nearly 1.

In the conventional scheme, dominant modes in charm decays are strangeness-changing modes. Only when there exists some selection rule which suppresses the Cabibbo favored modes ($\Delta S=1$) in the D^+ decays can we explain the observed large branching ratio to "no kaon" state in the D^+ decays, $B(D^+\to \text{no } K)$. We have already known an example of such a selection rule. An SU(4) 20-plet dominance for the weak interaction of current-current type leads to the suppression of $D^+\to \overline{K}{}^0\pi^+$.[2]

In a previous paper,[3] Katuya and the author have pointed out that studies of $B(D\to l\nu X)/B(D\to K\pi)$ and $B(D\to K\pi\pi)/B(D\to K\pi)$ based on quantum chromodynamics (QCD) lead to "moderate" $\underline{20}$ enhancement, i.e., $c_-\simeq 4$ and $c_+\simeq 0.5$, where c_- and c_+ are the enhancement factor for $\underline{20}$ and the suppression factor for $\underline{84}$, respectively, and QCD one-loop calculation gives $c_-c_+^2=1$.[4] They have also predicted $\Gamma(D^+\to \text{all})/\Gamma(D^0\to \text{all})\simeq 0.05$.[5]

The purposes of this paper are to understand the data of the inclusive branching fractions in the D^0 and $D^\pm$ decays from the standpoint of the "moderate" $\underline{20}$ enhancement suggested in Ref. 3, and to predict inclusive branching fractions in F^+ decays and lifetimes of the charmed mesons thereby.

The prediction $\Gamma(D^+\to \text{all})/\Gamma(D^0\to \text{all})\simeq 0.05$ in Ref. 3 has been derived from an estimate of $\Gamma(D\to K\pi)$ and the experimental values of $B(D\to K\pi)$. On the other hand, an estimate based on a naive quark-parton model leads to $\Gamma(D^+\to \text{all})=\Gamma(D^0\to \text{all})$, because we take the incoherent sum of all the diagrams.

In order to reconcile the quark-parton picture with the conclusion $\Gamma(D^+\to \text{all})\ll\Gamma(D^0\to \text{all})$ in Ref. 3, we assume that in the charmed meson decays caused by charm-quark decay $c\to s+u+\overline{d}$ the final-state quark system dissociates into two color-singlet hadron "jets." This assumption has been proposed by Ellis, Gaillard, and Nanopoulos,[6] and they have obtained the semileptonic branching ratios $B(D^0\to l\nu X)=B(D^+\to l\nu X)=B(F^+\to l\nu X)=[3(X_+^2+X_-^2)+2]^{-1}$, where $X_\pm=(2c_+\pm c_-)/3$. Figures 1(a) and 1(b) illustrate two types of D decays, $D\to h(\overline{d}u)+h(\overline{q}s)$ and $D\to h(\overline{d}s)+h(\overline{q}u)$, respectively, where $\overline{q}$ is spectator, i.e., $\overline{q}=\overline{u}$ ($\overline{q}=\overline{d}$) for D^0 (D^+), and $h(\overline{d}u)$ means the color-singlet hadron jet produced by the color-singlet quark pair ($\overline{d}u$) [hereafter we write $h(\overline{d}u)$ as $h(\pi^+)$]. The amplitudes for the decays (a) and (b) are proportional to the factors X_+ and X_-, respectively. Note that in the D^+ decays the flavor configuration of the jets in the type (a) is identical with that in the type (b). We assume that such diagrams (a) and (b) are coherent, and $\Gamma(D^+\to h(\overline{K}{}^0)+h(\pi^+))$ is given by substituting a factor $3(X_++X_-)^2$ for the factor $3(X_+^2+X_-^2)$ in the $\Gamma(D^0\to h(K^-)+h(\pi^+))+\Gamma(D^0\to h(\overline{K}{}^0)+h(\overline{u}u))$.

Similar assumptions are applied to the Cabibbo-suppressed decays $c\to d+\overline{d}+u$ and $c\to s+\overline{s}+u$, too.

There are other diagrams as shown in Fig. 2. (Hereafter we refer to the decays illustrated in Figs. 1 and 2 as types I and II, respectively.) We assume that the final-state quark system in diagram II decays into one color-singlet hadron jet h', and the diagrams I and II incoherent. We define the ratio of the contribution from diagram II to that from diagram I as R. The value of R is very sensitive to the masses of the ordinary quarks; therefore, we deal with R as a free parameter.

Under these assumptions, we get the total decay

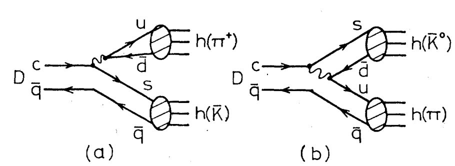

FIG. 1. Diagrams for D-meson decays caused by charm-quark decay $c\to s+u+\overline{d}$. Amplitudes for diagrams (a) and (b) are proportional to factors $X_+\equiv(2c_++c_-)/3$ and $X_-\equiv(2c_+-c_-)/3$, respectively, which result from gluon corrections.

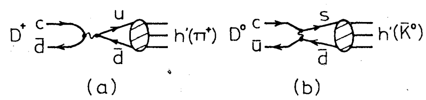

FIG. 2. Diagrams for D-meson decays where the incoming $C \neq 0$ $q\bar{q}$ pair annihilates to produce a $C=0$ $q\bar{q}$ pair which subsequently evolves into ordinary hadrons. Amplitudes for diagrams (a) and (b) are proportional to factors X_+ and X_-, respectively, apart from the Cabibbo-angle factors.

widths

$$\begin{aligned}\Gamma(D^0 \to \mathrm{all})/\cos^4\theta_C\,\Gamma_0 &= 3(X_+^2+X_-^2)(1+2\tan^2\theta_C) \\ &\quad + 3RX_-^2 + 2/\cos^4\theta_C\,, \\ \Gamma(D^+ \to \mathrm{all})/\cos^4\theta_C\,\Gamma_0 &= 3(X_+ + X_-)^2(1+\tan^2\theta_C) \\ &\quad + 2/\cos^4\theta_C \\ &\quad + 3\tan^2\theta_C(X_+^2+X_-^2+RX_+^2)\,,\end{aligned} \qquad (1)$$

where $\Gamma_0 = (m_C/m_\mu)^5\Gamma(\mu \to e\nu\bar{\nu})$ and we take into account up to the Cabibbo-suppressed modes of the order of $(\sin\theta_C\cos\theta_C)^2$.

Furthermore, we parametrize the inclusive D-meson decays as follows: (i) Hadron jets produced from nonstrange-quark pairs, $(\bar{d}u)$ and so on, one-strange-quark pairs, $(\bar{u}s)$ and so on, and two-strange-quark pair $(\bar{s}s)$ belong to no-, one- and two-kaon states, respectively. (ii) Hadron jet $h(K)$ consists of one-body state K with the fraction $1-\alpha$ and many-body state $h^m(K)$ with the fraction α. For simplicity, we assume $h'(K) \simeq h^m(K)$.

TABLE I. Semileptonic branching ratios and fractions of charged and neutral kaons in D^0, D^+, and F^+ decays, where we assume $X_+ = \frac{5}{3}$, $X_- = -1$, $\alpha = 0.8$, and $\beta = \frac{1}{3}$.

	$R=10$	$R=8$	$R=6$	Experiments
$B(D^0 \to l\nu X)$	0.03	0.03	0.03	average
$B(D^+ \to l\nu X)$	0.13	0.15	0.16	0.098±0.014
$B(F^+ \to l\nu X)$	0.01	0.01	0.02	
$B(D^0 \to K^- X)$	0.42	0.44	0.45	0.35±0.10
$B(D^0 \to K^+ X)$	0.01	0.01	0.01	
$B(D^0 \to \bar{K}^0 X)$	0.56	0.55	0.53	0.57±0.26
$B(D^0 \to K^0 X)$	0.00	0.01	0.01	
$B(D^+ \to K^- X)$	0.13	0.15	0.16	0.10±0.07
$B(D^+ \to K^+ X)$	0.05	0.05	0.06	0.06±0.06
$B(D^+ \to \bar{K}^0 X)$	0.35	0.38	0.43	0.39±0.29
$B(D^+ \to K^0 X)$	0.02	0.03	0.03	
$B(F^+ \to K^- X)$	0.06	0.07	0.09	
$B(F^+ \to K^+ X)$	0.10	0.12	0.14	
$B(F^+ \to \bar{K}^0 X)$	0.07	0.09	0.11	
$B(F^+ \to K^0 X)$	0.08	0.09	0.11	

(iii) Fractions to $\bar{K}^0X$ (K^-X) and K^-X $(\bar{K}^0X)$ in the many-body states $h^m(\bar{K}^0)$ $(h^m(K^-))$ are $1-\beta$ and β, respectively. Therefore, fractions to $\bar{K}^0X$ (K^-X) and K^-X $(\bar{K}^0X)$ in the state $h(\bar{K}^0)$ $(h(K^-))$ are $1-\alpha\beta$ and $\alpha\beta$, respectively, where $\bar{K}^0X$ (K^-X) state may contain the one-body state $\bar{K}^0$ (K^-). Hadron jet $h(\bar{s}s)$ consists of K^+K^-X and $K^0\bar{K}^0X$ with equal weights.

Then we obtain the following results:

$$\begin{aligned}\Gamma(D^0 \to K^-X)/\cos^4\theta_C\,\Gamma_0 &= (1-\alpha\beta)[3X_+^2(1+\tan^2\theta_C)+2/\cos^2\theta_C] + 3X_-^2(\alpha\beta+\beta) + 3\tan^2\theta_C X_-^2/2\,, \\ \Gamma(D^0 \to K^+X)/\cos^4\theta_C\,\Gamma_0 &= 3\tan^2\theta_C[(1-\alpha\beta)X_+^2 + X_-^2/2]\,, \\ \Gamma(D^+ \to K^-X)/\cos^4\theta_C\,\Gamma_0 &= \alpha\beta[3(X_+ + X_-)^2 + 3\tan^2\theta_C X_+^2 + 2/\cos^2\theta_C] + 3\tan^2\theta_C X_-^2/2\,, \\ \Gamma(D^+ \to K^+X)/\cos^4\theta_C\,\Gamma_0 &= \Gamma(D^0 \to K^+X)/\cos^4\theta_C\,\Gamma_0\,.\end{aligned} \qquad (2)$$

$\Gamma(D^0 \to \bar{K}^0X)$, $\Gamma(D^0 \to K^0X)$, $\Gamma(D^+ \to \bar{K}^0X)$, and $\Gamma(D^+ \to K^0X)$ are given by the exchange $(1-\alpha\beta) \leftrightarrow \alpha\beta$ and $(1-\beta) \leftrightarrow \beta$ in the results $\Gamma(D^0 \to K^-X)$, $\Gamma(D^0 \to K^+X)$, $\Gamma(D^+ \to K^-X)$, and $\Gamma(D^+ \to K^+X)$, respectively. We also obtain

$$\frac{B(D^0 \to l\nu\bar{K}^0X)}{B(D^0 \to l\nu K^-X)} = \frac{B(D^+ \to l\nu K^-X)}{B(D^+ \to l\nu\bar{K}^0X)} = \frac{\alpha\beta}{1-\alpha\beta}\,. \qquad (3)$$

Parameters in our model are $X_\pm$, R, α, and β. In order to suppress the strangeness-changing decays of D^+, according to Ref. 3, we use $c_- = 4$ and $c_+ = 0.5$, that is, $X_+ = \frac{5}{3}$ and $X_- = -1$. In order to realize to small $B(D^0 \to l\nu X)$ and large $B(D^+ \to \text{no } K)$, we must suppose that R is considerably large ($R = 1$–10), although it is usually considered that R is negligibly small. If $1-\alpha\beta > \alpha\beta$ and $1-\beta > \beta$, we can derive $B(D^+ \to (K^0+\bar{K}^0)X) > B(D^+ \to K^\pm X)$ and $B(D^0 \to (K^0+\bar{K}^0)X) > B(D^0 \to K^\pm X)$, respectively. Since $B(D^0 \to K^-\pi^+) \simeq 2\%$,[7] we suppose $(1-\alpha)^2 \simeq 2\%$, so that $\alpha = 0.8$–0.9. If we assume that the states X in the many-body state $h^m(K) = KX$ belong to $I=0$ and $I=1$ with equal weights, we get $\beta = \frac{1}{3}$.

In Table I, we give the predicted values of $B(D \to l\nu X)$ and $B(D \to KX)$ for $R = 6$, 8, and 10, where we use $\sin\theta_C = 0.22$, $X_+ = \frac{5}{3}$, $X_- = -1$, $\alpha = 0.8$, and $\beta = \frac{1}{3}$. $R \simeq 8$ is favorable. Further detailed determination of the parameters is not so significant at the present experimental status. We also give the predicted values of $B(F^+ \to l\nu X)$ and

$B(F^+ \to KX)$ in Table I, where we put the same assumptions as those in D decays and we neglect the contribution from $F^+ \to \tau\nu_\tau$ decay.

We note that dominant inclusive decay of F^+ is that into the no-kaon state: We get $B(F^+ \to \text{no } K) = 0.79$, $B(F^+ \to K) = 0.05$, $B(F^+ \to KK) = 0.16$, and $B(F^+ \to KKK) = 0.00$, while $B(D^0 \to \text{no } K) = 0.02$, $B(D^0 \to K) = 0.98$, $B(D^0 \to KK) = 0.02$, $B(D^+ \to \text{no } K) = 0.47$, $B(D^+ \to K) = 0.45$, and $B(D^+ \to KK) = 0.08$, assuming the same parameters as in Table I and $R = 8$.

The predicted lifetimes of the charmed mesons are as follows[8]:

$$\begin{aligned} \tau(D^0) &\simeq 1.4\times 10^{-13}\ \text{sec}, \\ \tau(D^+) &\simeq 7\times 10^{-13}\ \text{sec}, \\ \tau(F^+) &\simeq 0.7\times 10^{-13}\ \text{sec}, \end{aligned} \qquad (4)$$

where we use[9] $\Gamma_0 \simeq 2\times 10^{11}\ \text{sec}^{-1}$. A recent Fermilab experiment[10] using an emulsion-spark-chamber arrangement has found an event which corresponds to the decay of a charged particle with lifetime of $\sim 6\times 10^{-13}$ sec. We would like to identify this particle with the D^+ meson.

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[1]V. Vuillemin *et al.*, Phys. Rev. Lett. 41, 1149 (1978).

[2]T. Hayashi, M. Nakagawa, H. Nitto, and S. Ogawa, Prog. Theor. Phys. 49, 351 (1973); M. K. Gaillard, B. W. Lee, and J. L. Rosner, Rev. Mod. Phys. 47, 277 (1975).

[3]M. Katuya and Y. Koide, Phys. Rev. D 19, 2631 (1979).

[4]M. K. Gaillard and B. W. Lee, Phys. Rev. Lett. 33, 108 (1974); G. Altarelli and L. Maiani, Phys. Lett. 52B, 351 (1974).

[5]One may find a stumbling block for this picture: The average D-meson semileptonic branching ratios measured in e^+e^- annihilation would vary with c.m. energy as the proportion of D^+ and D^0 varies, while data both from SLAC and DESY show no such variation. However, if we admit 2 standard deviations of the data, this picture is still not ruled out experimentally: The value $\Gamma(D^+ \to \text{all})/\Gamma(D^0 \to \text{all}) \simeq 0.05$ leads to $B(D \to e\nu X) = 9.9\%$ and $\simeq 6.6\%$ at $E_{\text{c.m.}} = 3.77$ GeV and at high $E_{\text{c.m.}}$ (4 GeV and above), respectively, where $\sigma(D^0)/\sigma(D^+) = 1.1$ and $\simeq 2.4$, respectively. This has been emphasized by M. Katyua (private communication).

[6]J. Ellis, M. K. Gaillard, and D. V. Nanopoulos, Nucl. Phys. B100, 313 (1975).

[7]I. Peruzzi *et al.*, Phys. Rev. Lett. 39, 1301 (1977).

[8]The present studies of $D \to KX$ lead to $\Gamma(D^+ \to \text{all})/\Gamma(D^0 \to \text{all}) \simeq 0.2$ and consequently weaken the statement $\Gamma(D^+ \to \text{all})/\Gamma(D^0 \to \text{all}) \simeq 0.05$ in Ref. 3 where $D \to K\pi$ and $D \to K\pi\pi$ have been studied. After this work was completed I received a report by Y. Hara [Prog. Theor. Phys. 61, 1738 (1979)] in which $\Gamma(D^+ \to \text{all})/\Gamma(D^0 \to \text{all}) = 0.2$ is concluded from studies of $D \to K\pi$ and $D \to K\pi\pi$ by making use of the current-algebra relations and amplitudes in the dual model. The predicted ratio in Ref. 3 may be excessive.

[9]D. Fakirov and B. Stech, Nucl. Phys. B133, 315 (1978); X. Y. Pham and R. P. Nabavi, Phys. Rev. D 18, 220 (1978); N. Cabibbo and L. Maiani, Phys. Lett. 79B, 109 (1978); M. Suzuki, Nucl. Phys. B145, 420 (1978). These authors have predicted $\Gamma_0 = (1.2\text{–}2.5)\times 10^{11}\ \text{sec}^{-1}$.

[10]A. L. Read *et al.*, Phys. Rev. D 19, 1287 (1979).