LETTERS TO THE EDITOR

DECAY CONSTANTS OF THE "CHARMED" D AND F MESONS

By B. Bagchi* and V. P. Gautam

Department of Theoretical Physics, Indian Association for the Cultivation of Science, Calcutta**

(Received January 14, 1978)

Following current algebra ideas, the semi-leptonic decays of D and F mesons are studied. An estimate of the ratio of the decay constants of these mesons is obtained which agrees fairly well with other theoretical predictions.

It has been pointed out recently [1], by considering a spin analysis of charmed mesons produced in e^+e^- annihilation, that the expected spin values of D and D^* are respectively 0 and 1. An alternative spin arrangement of 1 and 0 has been ruled out by these authors. Previous to this, a new neutral state with mass 1.865 GeV was identified [2] with the the s-wave singlet state D^0. Moreover, clear evidence for a peak at 1.876 GeV corresponding to the charmed mesons D^+ and D^- were found in the charged $K\,2\pi$ channels. Recent analysis shows that F-meson production is not suppressed [3].

In this letter, we study the semi-leptonic decays of D and F mesons in relation to their "old" counterpart. The semi-leptonic decays of "charmed" pseudoscalar mesons were investigated by Montvay and Urban [4] in a quark model with phenomenological quark confinement. The assumptions involved were identical to those of the CERN bag model. $D \to K^* l\nu_l$ and $F \to \phi l\nu_l$ were found to dominate the D-meson and F-meson semi-leptonic decays respectively. This was quite contrary to the results obtained by Ali and Yang [5] who concluded that $D \to Ke\nu_e$ was the dominant decay mode with $D \to K\pi e\nu_e \sim 50\% \, (D \to Ke\nu_e)$, optimistically. Their calculations were based on well known current algebra methods, generalised to SU(4) symmetry.

We start by reviewing briefly the assumptions involved in the study [6] of the semi-leptonic decays of K meson. By generalising these assumptions to the semi-leptonic decays of the D-meson and F-meson we are able to obtain an estimate of the ratio of the decay

* CSIR Junior Research Fellow.

** Address: Department of Theoretical Physics, Indian Association for the Cultivation of Science, Calcutta 700 032, India.

constants of F and D mesons which is in good agreement with other theoretical predictions.

The kaon decay chain viz. $Kl_3 \leftrightarrow Kl_2$ was linked together by current algebra soft pion theorems. Thus the form factors of the semi-leptonic decay of the K into two leptons plus a pion could be related to the decay constant of the K-meson decay into two leptons [7] as

$$f_+(m_K^2)+f_-(m_K^2) = \frac{f_K}{f_{\pi^+}}, \tag{1}$$

where f_+ and f_- are the form factors for the Kl_3 decay. However, the physical values of t ran between 0 and $(m_K - m_\pi)^2$, neglecting the lepton masses, so that the form factors above referred to an unphysical value of t. Moreover, the observed form factors referred to the physical value of $q^2 = m_\pi^2$ while those in (1) were evaluated at $q^2 = 0$.

To get around this problem, an extrapolation [8] in the two variables q^2 and t was needed in order to reach the physical point. By assuming a linear variation of $f_\pm$ form factors with t, one could write

$$f_\pm(t) = f_\pm(0)(1+b_\pm t), \tag{2}$$

where $b_\pm = \lambda_\pm/m_\pi^2$. By looking at the μ meson polarization or at the $\Gamma_{\mu 3}/\Gamma_{e3}$ ratio an overal fit was possible as [6, 8]

$$\xi(0) = -0.85\pm0.20, \quad \lambda_+ = 0.045\pm0.012, \quad \lambda_- = 0, \tag{3}$$

where $\xi(t) = f_+(t)/f_-(t)$. On the other hand, a combination of $K_{\mu 3}$ and Kl_3 measurements for λ_+ gave

$$\lambda_+ = 0.034\pm0.06$$

for which

$$\xi(0) = -0.65\pm0.20 \tag{4}$$

for $\lambda_- = 0$. In what follows, we shall extend the above approach to the case of D and F mesons and examine the consequences. The charm changing hadronic weak current in the GIM model [9] can be written as

$$h_\mu^c = \cos\theta\bar{c}\gamma_\mu(1-\gamma_5)s - \sin\theta\bar{c}\gamma_\mu(1-\gamma_5)d, \tag{5}$$

where u, d, s and c are the quark fields and $\theta = \sin^{-1}(0.23)$ [4] is the Cabibbo angle. For our present purpose we shall consider the following decays only:
in $\sin\theta$ order

$$D_- \to l_-\bar{\nu}_l, \tag{6}$$

$$F_- \to \bar{K}_0 l_-\bar{\nu}_l, \tag{7}$$

and in $\cos\theta$ order

$$F_- \to l_-\bar{\nu}_l \tag{8}$$

and

$$D_- \to K_0 l_-\bar{\nu}_l. \tag{9}$$

Writing the matrix elements corresponding to the decays (6) and (9) as

$$\langle 0|A_\mu^V|D^-(p)\rangle = ip_\mu f_D \tag{10}$$

and

$$\langle K_0(q)|V_\mu^V|D^-(p)\rangle = \frac{1}{\sqrt{2}}[(q+p)_\mu f_+(t)+(p-q)_\mu f_-(t)], \tag{11}$$

where $t=(p-q)^2$, p and q being the four momenta of D and K^0 mesons respectively, one gets, after reducing the kaons in a similar manner as in Eq. (1)

$$f_+(m_D^2)+f_-(m_D^2) = -\frac{f_D}{f_K}\frac{\alpha_K}{\sqrt{2}}, \tag{12}$$

where α_K is the soft meson correction factor for the kaons. Such a correction factor becomes necessary as the extrapolation is to be made from $q^2=0$ to $q^2=m_K^2$.

Similarly, by considering the decays (7) and (8) we get

$$f_+(m_F^2)+f_-(m_F^2) = -\frac{f_F}{f_K}\frac{\alpha_K}{\sqrt{2}}. \tag{13}$$

From Eqs. (12) and (13) we get a relation of the form

$$\frac{f_+(m_D^2)+f_-(m_D^2)}{f_D} = \frac{f_+(m_F^2)+f_-(m_F^2)}{f_F}. \tag{14}$$

If we next assume a linear variation of the form factor $f_\pm$ having the same slope as in (2) we obtain

$$\frac{f_F}{f_D} = \frac{f_+(0)\,(1+b_+m_F^2)+f_-(0)}{f_+(0)\,(1+b_+m_D^2)+f_-(0)}. \tag{15}$$

Thus corresponding to the fits given in Eqs. (3) and (4) we get an estimate of the ratio f_F/f_D to be ~ 1.2. Although experimental numbers for f_F and f_D are not available at present, our estimated ratio is in good agreement with other theoretical predictions [10].

A knowledge of this ratio enables one to estimate chiral $SU(4)\times SU(4)$ symmetry breaking parameters[1] as well. Using experimental values for $f_K/f_\pi = 1.26$, $m_D = 1.85$ GeV and taking $m_F = 2$ GeV, it can be easily shown that [12]

$$\frac{\langle 0|v_K|K\rangle}{\langle 0|v_\pi|\pi\rangle} \approx 2.4 \quad \text{and} \quad \frac{\langle 0|v_F|F\rangle}{\langle 0|v_D|D\rangle} \approx 1.2. \tag{16}$$

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[1] Assuming SU(3) invariance, we have shown [11] the validity of the following relations:

$$\frac{\langle 0|v_C|C\rangle}{\langle 0|v_N|N\rangle} = \frac{m_C+\hat{m}}{2\hat{m}}$$

and

$$\frac{f_C M_C^2}{f_N M_N^2} = \left(\frac{m_C+\hat{m}}{2\hat{m}}\right)^2$$

where $N \equiv (\pi, K, \eta)$ and $C \equiv (D, F)$ mesons; m denotes the quark masses and M the meson masses.

REFERENCES

[1] H. K. Nguyen et al., SLAC-PUB-1946, LBL-6424, June 1977.
[2] G. Goldhaber et al., *Phys. Rev. Lett.* **37**, 255 (1976); I. Peruzzi et al., *Phys. Rev. Lett.* **37**, 569 (1976).
[3] B. Humpert et al., SLAC-PUB-1856, Dec. 1976.
[4] I. Montvay, L. Urban, KFKI-1977-5, Hungarian Academy of Sciences.
[5] A. Ali, T. C. Yang, *Phys. Lett.* **65B**, 275 (1976).
[6] For a review of the theory see, e.g., M. K. Gaillard, L. M. Chounet, *Phys. Lett.* **32B**, 505 (1970).
[7] C. G. Callan, S. B. Treiman, *Phys. Rev. Lett.* **16**, 153 (1966); V. S. Mathur, S. Okubo, L. Pandit, *Phys. Rev. Lett.* **16**, 371 (1966).
[8] See, for a discussion, *Currents in Hadron Physics*, by V. De Alfaro, S. Fubini, G. Furlan and C. Rossetti, North-Holland Publishing Company, 1973.
[9] S. Glashow, J. Illiopoulos, L. Maini, *Phys. Rev.* **D2**, 1285 (1970).
[10] e.g., M. Singer, *Phys. Rev.* **D14**, 2349 (1976).
[11] V. P. Gautam, B. Bagchi, *Prog. Theor. Phys.* **58**, 1049 (1977).
[12] V. P. Gautam, B. Bagchi, IACS Preprint, submitted for publication.