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THEORETICAL IDEAS ON HEAVY FLAVOUR WEAK DECAYS

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Weak decays occur for particles with widely varying mass and over a vast range of lifetimes. An overall view of the known weak decays is given in Fig.1, where decay rates have been plotted against the maximum momentum of decay products.

Although finer points such as Cabibbo suppression, non leptonic enhancement etc. are not visible, the figure brings out clearly the common origin of weak decays, all points falling closely near the line determined by the Fermi constant, $G \simeq 10^{-5}(Mp)^{-2}$.

Interesting investigations are going on about practically all the processes reported in Fig.1. Nuclear β-decays, and closely related processes such as electron capture, are investigated in connection with the neutrino mass; hyperon β-decays, in connection with precise testing of the Cabibbo theory; τ, D and B-decays, to determine the basic properties of these newly discovered particles.

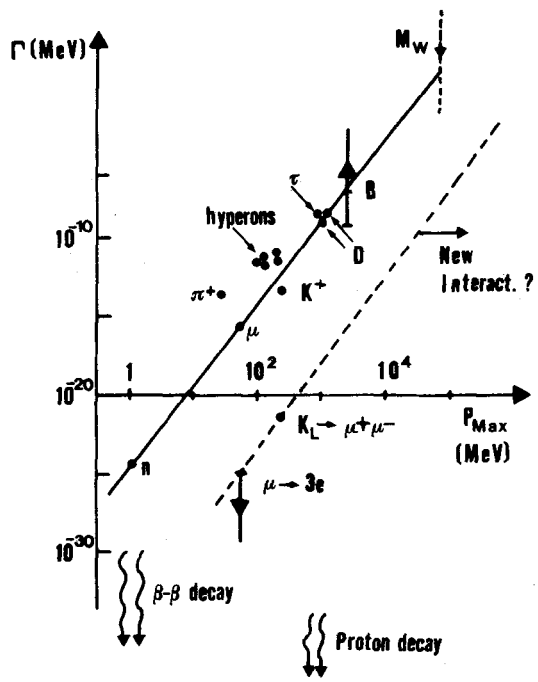

Fig. 1

Also very important is the search for "secondary lines", in the Γ - p plane of Fig.1, whose presence would signal new, weaker interactions: flavour changing neutral currents, double β-decay and, of course, baryon decay. Upper bounds to or measurements of rare decay processes of the known particles, such as $\mu \to 3e$ or $K_L \to \mu^+ \mu^-$, pose already severe constraints on new theoretical ideas (technicolor, preonic models, supersymmetry, etc.).

Most of the above subjects are illustrated elsewhere in this Conference. I have been given the relatively simple task to summarize the present theoretical situation for what concerns the weak decays of heavy particles associated with new flavours. Do we understand τ, charm and beauty decays; what can we say about the mass and decays of the, yet hypothetical, t-quark?

The way in which I have organized my talk goes as follows. Weak decays of τ and of charmed particles are discussed in Sect.1 and in Sects. 3 to 6, respectively. In Sect.2, the issue of the weak decay constants of the pseudoscalar mesons is reviewed. The present situation regarding the Cabibbo-Kobayashi-Maskawa angles is illustrated in Sect.7. B-decays, with respect to "exotic" new interactions are discussed in Sect.8. Finally, the foreseeable properties of the t-quark are summarized in Sect.9.

I have not aimed to a complete review, but I have tried to focus on the more interesting points, at least in my view. It is therefore necessary to close the introduction, giving my apologies to all those whose contributions to this wide field I have not been able to mention.

1. τ - decays. - The decay properties of τ seem quite normal. The standard model, with massless ν_τ and no weak mixing predicts:

$$\tau_\tau = \tau_\mu \left(\frac{m_\mu}{m_\tau}\right)^5 \quad B(\tau \to \nu_\tau e\, \nu) = (2.81 \pm 0.25) \times 10^{-13} s \qquad (1)$$

where the experimental branching ratio /1/ is used:

$$B(\tau^- \longrightarrow \nu_\tau e^- \bar{\nu}_e) = 0.176 \pm 0.016 \qquad (2)$$

In the last year, two experimental determinations of τ -lifetime have been reported /2, 3/. The latest value, reported by the Mark II collaboration at this Conference, is in very good agreement with (1):

$$\tau_\tau = (3.31 \pm 0.57 \pm 0.6)\ 10^{-13}\ s \qquad (3)$$

the first error being statistical, the second the estimated systematic error.

Within the errors, a consistent mixing of ν_τ with a heavier neutrino is still allowed. With a further reduction of the experimental error one could start putting a significant bound to the ν_τ mass. In fact, with $m_{\nu_\tau} = 0.25$ GeV (the present upper bound) the prediction (1) is increased by about 20%, which is quite comparable with the presently quoted statistical error. To complete the picture, I recall

that the branching ratios into a number of Cabibbo allowed and Cabibbo forbidden decay modes of τ have also been measured, always in good agreement with expectation, within errors /4/.

For later use, it is interesting to recall the QCD corrected prediction /5/ for the branching ratio (2):

$$B(\tau^- \longrightarrow \nu_\tau e^- \bar{\nu}_e) = \frac{1}{2 + 3(1 + \frac{\alpha_s(m_\tau)}{\pi})} = 0.19 \qquad (4)$$

(for $\alpha_s = 0.3$). The successful result (4) is obtained if we attribute a very small mass to the final quarks in the semihadronic decay (say, $m < 0.1$ GeV). If we were to endow the $\bar{u}$ and d quarks with the "constituent" quark mass, $m = 0.3$ GeV, a value of B larger than 0.2 would result, in contradiction with the experiment /6/.

We shall make use of this observation in the discussion of charm and beauty decays.

2. $f_{D,F,B}$ and f-meters. - An important role in the weak decays of charmed and beauty particles is played by the weak decay constant of pseudoscalar mesons, defined, e.g. for D^+, by the equation:

$$\langle 0 | \sum_{\text{colours}} \bar{u} \gamma_\mu \gamma_5 c | D^+(q) \rangle = q_\mu f_D \qquad (5)$$

The analogous constant for the pion is usually interpreted as the order parameter whose non vanishing value signals the spontaneous breaking of SU(2) $\otimes$ SU(2) chiral symmetry. For systems involving one heavy quark, however, we are rather far from the chiral limit, and a better intuition on f can be gained with the non relativistic formula:

$$f^2 = \frac{12 |\psi(0)|^2}{M} \qquad (6)$$

M is the heavy quark mass and $\psi(0)$ is the wave function at the origin of the c-$\bar{u}$ bound state. Thus, the value of f_D gives a measure of the size of the pseudoscalar meson.

We do not expect the size of such hadrons to vary much, when we increase the mass of the heavy quark (e.g. replacing c with b-quark), so we expect $|\psi(0)|^2$ to be essentially independent from M, and f to scale accordingly. A nice test of this idea is given by the hyperfine splitting of $J^P = 1^-$ and $J^P = 0^-$ mesons, which, in the non relativistic approximation and with the one-gluon-exchange potential, is given by:

$$\Delta M = M(1^-) - M(0^-) = \frac{32\pi}{9} \alpha_s \frac{|\psi(0)|^2}{M\, m} \qquad (7)$$

Multiplying both sides of this equation by $2M \simeq M(1^-) + M(0^-)$, we see that $|\psi(0)|^2$ is independent from M if the mass-squared splittings do so.

In fact, experimentally the K^* - K and the D^* - D mass-squared splittings agree with each other by better than 10%.

Using $\Delta M^2(D^*, D)$ with $\alpha_s = 0.3$, $m = 0.3$ GeV, we obtain from (6) and (7) the value:

$$(f_D)_{\text{h-f-splitt.}} = 0.38 \text{ GeV} \qquad (8)$$

not too dissimilar from $f_\pi = 0.14$ GeV.

The constants f_D, f_F and f_B have been estimated by various authors, with different theoretical approaches. Table 1 gives a list of the predicted values (or upper bounds). All the methods used support a decreasing behaviour of f with increasing M, roughly in agreement with eq.(6) with constant $\psi(0)$, and indicate that the value (8) may be regarded as a safe upper bound.

Table 1
Theoretical estimates of the weak decay constants (in GeV) of D, F and B mesons.

Method		f_D	f_F	f_B
Potential models,	Ref. /7/	0.15	0.21	0.12
	Ref. /8/	0.15	0.18	---
QCD sum rules	Ref. /9/	0.22	---	0.14
	Ref. /10/	0.28	0.37	---
Bag Model	Ref. /11/	0.15	---	0.10

A measurement of the weak constant f for D, F and B mesons is extremely important to test our understanding of quark-dynamics and to make a more realistic discussion of inclusive non leptonic weak decays (see Sect. 4), so it is appropriate to discuss here which are the most promising processes to be used as f-meters.

The best process is:

$$F^+ \longrightarrow \tau^+ \nu_\tau \qquad (9)$$

whose rate gives f_F. This process is Cabibbo allowed, and it has a rather large branching ratio due to the large τ mass: $B(F \to \tau\nu_\tau) = 1.4\%$ for $f_F = 0.15$ GeV. To measure f_D is much harder. One should be able to detect the Cabibbo suppressed modes:

$$D^+ \to \mu^+ \nu_\mu \qquad (10)$$

$$D^+ \to \tau^+ \nu_\tau \qquad (11)$$
$$\tau^+ \to \mu^+ \nu_\mu \bar{\nu}_\tau$$

The branching fraction of (10) is about 10^{-4}; process (11) has a somewhat larger branching fraction (for $m_{\nu_\tau} = 0$), but if τ is observed through the μ^+, the overall branching ratio comes down to about 0.5×10^{-4}. Process (11) would give additional and much valued information on ν_τ mass: its mere observation implies $m_{\nu\tau} < 82$ MeV and a 20% accurate measurement of the ratio of the rates (11) and (10) would be sensitive to $m_{\nu\tau} = 60$ MeV, substantially improving on the present bound (*).

The above branching fractions may seem discouraging, but it has been argued(*) that the observation of (10) and (11) may not be entirely forbidden, because these processes are associated to events with a very clear signature. In fact, the processes:

$$e^+ e^- \to \psi'' \to D^+ D^-$$
$$D^+ \to \text{hadrons}$$
$$D^- \to \mu^+ \nu_\mu \text{ or } \tau^+ \nu_\tau$$
$$\tau^+ \to \mu^+ \nu_\mu \nu_\tau$$

observed as:

$$e^+ e^- \to \mu^+ + \text{hadrons}$$

have the characteristic signatures:

$$E(\text{hadrons}) = \frac{E_{\text{total}}}{2}$$

$$M(\text{hadrons}) = M(D)$$

Furthermore, they can be obviously distinguished from each other by the kinematical properties of the observed muon.

Another possibility to measure f_D, which may become available in the near future, is to measure the form factors of the decay:

$$D \to K e \nu$$

and to use soft-kaon theorems to extract f_D /12/.

Finally the non-strange B meson weak coupling could be measured in the reaction:

$$B \to \tau \nu_\tau \qquad (12)$$

(*) This observation is due to N.Cabibbo, University of Rome report (unpublished).

at the γ''' resonance, with a similar strategy as that indicated for f_D. The reaction (12) is suppressed by a small K-M angle, which should be measured independently to get f_B, so this seems really for the future.

3. Semileptonic inclusive decays of $D^{+,o}$ and Λ_c. - A good approximation to the semileptonic inclusive decays of D's and Λ_c is thought to be given by the parton model approximation. The decay of the hadron is simply described by the β-decay of the charmed quark. In this approximation, the total decay rate is given by /13/:

$$\Gamma_{SL} = \frac{G^2 M_c^5}{192\,\pi^3}\, g\left(\frac{m_s}{M_c}\right)\left[1 + \frac{2\,\alpha_s(M_c)}{3\,\pi}\, f\left(\frac{m_s}{M_c}\right)\right] \cos^2\gamma \qquad (13)$$

and:

$$\Gamma_{SL}(D^+) = \Gamma_{SL}(D^\circ) = \Gamma_{SL}(\Lambda_c) \qquad (14)$$

M_c, m_s are the masses of the charmed and the strange quark (I am setting $\cos\,\Theta_c = 1$); g is a phase space factor and f embodies first-order QCD corrections. The total rate is multiplied by the Kobayashi-Maskawa weak-mixing factor, $\cos^2\gamma$, which could be considerably smaller than one, see Sect. 7. In principle, $\cos^2\gamma$ could be determined by comparing (13) with the experimental rate.

Eq. (13) is of little use, however, until we have a precise idea about the value of M_c: a 15% uncertainty in M_c corresponds to an uncertainty in Γ of a factor 2. Also, we need to estimate the effect of the binding, theoretically a very difficult question, involving corrections to the parton picture.

Time ago, it was proposed to use the shape of the charged lepton spectrum in the same reaction, to obtain information on both points /13, 14, 15/. This question has been reanalyzed recently /16/, using a model which relates the effective charmed quark mass to the mass of the D-meson and to the average momentum spread of the $\bar{u}$ quark in the initial bound state, p_F. A good fit to the electron spectrum in D decay is obtained, for values of p_F ranging from zero to 0.15 GeV and using "current" type light quark masses ($m_{u,d} = 0 \div 0.15$ GeV; $m_s = 0.5 \div 0.3$ GeV). In correspondence, the effective charmed quark mass to be used in (13) ranges from the D-mass down to about 1.7 GeV, and one obtains:

$$\Gamma_{SL} = (2 \div 4)\ 10^{11}\ \cos^2\gamma\ (\mathrm{sec})^{-1} \qquad (15)$$

Assuming a 15% semileptonic branching ratio for the D^+ /17, 18/ one thus predicts:

$$\cos^2\gamma\ \tau(D^+) = (2.5 \div 5)\ 10^{-13}\,\mathrm{sec} \qquad (16)$$

in general agreement with the present world average /4/:

$$\tau(D^+) = (9.3^{+2.7}_{-1.8})\ 10^{-13}\text{s}$$

with perhaps the suggestion that $\cos^2\gamma$ may be appreciably smaller than one.

If we use the same rate (15) for the semileptonic decay of Λ_c^+ and combine it with the recently measured /19/ semileptonic branching ratio of about 5%, we obtain:

$$\cos^2\gamma\ \tau(\Lambda_c) = (1.2 \div 2.5)\ 10^{-13}\text{s} \qquad (17)$$

The present world average is /4/:

$$\tau(\Lambda_c) = (2.2^{+0.9}_{-0.5})\ 10^{-13}\text{s}$$

in agreement with the expectation.

4. Non leptonic inclusive rates of $D^{+,\circ}$ and Λ_c. - The parton model prediction of equal non leptonic rates and therefore of equal lifetimes for all charmed particles seems not to be supported by the data. Earlier experimental results indicated a ratio of D^+ to D° lifetime of about 10 and this has prompted a large number of conventional and less conventional explanations.

The situation has become much clearer in the last year. For one thing, the experimental value of the lifetime ratio has steadily decreased, the present world average being /4/:

$$\frac{\tau(D^+)}{\tau(D^\circ)} = 2.2^{+0.9}_{-0.6}$$

Also, the theoretical picture has been somewhat clarified. There is now a widespread consensus that the deviation from unity of the lifetime ratio is due to preasymptotic corrections, i.e. to the fact that the charmed quark mass is not large enough to make the parton rate completely dominating over non-parton contributions. The main sources of corrections to the parton picture have been furthermore identified as follows:

(i) Interaction of the c-quark with the spectator quark or antiquark (Fig.2). This process is Cabibbo allowed for D° and Λ_c, and Cabibbo suppressed for D^+, so its effect is to decrease D° and Λ_c lifetime /20, 21/. Note that the interaction has to take place in a state with J = 1, to avoid helicity suppression from the small final state quark masses. In the case of D° a substantial admixture of the bare $c\bar{u}$, J = 0 state with states containing valence gluons is thus required.

(ii) Identical particle effects in D^+ decay /22/, where the $\bar{d}$ quark emitted in c-decay can have a negative interference with the spectator $\bar{d}$ (in earlier works /23/ this mechanism was referred to as "color clustering"). This effect increases the D^+ lifetime above its parton value.

(iii) The use of "constituent" quark masses for the final states ($m_{u,d}$ = 0.3 GeV; m_s = 0.5 GeV) suppresses the D^+ decay, which has a three body final state, more than the D° or Λ_c decays, provided that the latter are dominated by mechanism (i) and thus lead to a two body final state /24/.

In what follows, I shall discuss only (i) and (ii), which seem to me the most likely explanations of the lifetime ratio.

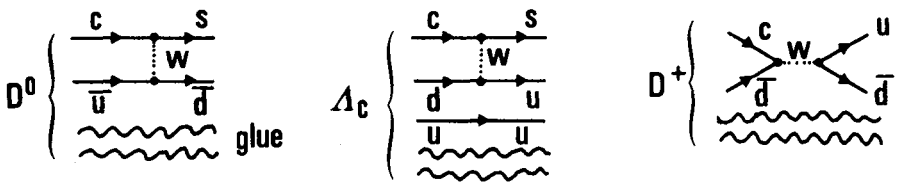

Fig.2
Processes involving the spectator quark in D^+, D° and Λ_c decay.

Mass effects as in (iii) may also play some role; however we have seen that such effects are not present in τ-decay, so to attribute them a leading role in c-decay seems somewhat doubtful.

Alternative theoretical pictures of charmed particle decays have also been proposed. Most are based on the difference between final states in D^+ and D° decays (D° decay may lead to I = 1/2 final states while D^+ leads only to exotic configurations) /25/; others invoke new dynamical ideas /26/.

I will not discuss these attempts at any length since the conventional picture seems already to work well. In the long run, these approaches may well turn out to be equivalent to the parton picture, with the preasymptotic corrections included.

Consider D^+ first. In the non-relativistic approximation, with final state masses and Cabibbo suppressed contributions ignored, one finds the very simple formula /22/:

$$\Gamma_{NL}(D^+) = \Gamma_{c\text{-decay}} + \Gamma_{interf} =$$

$$= \left(2C_+^2 + C_-^2 \right) \frac{G^2 M_c^5}{192\pi^3} - \left(C_-^2 - 2C_+^2 \right) \frac{G^2 M_c^2}{\pi} |\psi(0)|^2 \qquad (18)$$

where $C_\pm$ are the leading-log-corrected coefficients of the weak hamiltonian ($C_+ = 1$ for $\alpha_s = 0$) and $\psi(0)$ is the wave function at the origin of the c-$\bar{d}$ system. (Here and in the following I am omitting the K-M mixing factor, $\cos^2\gamma$, which can be reinserted at will and, in any case, drops out from lifetime ratios).

Working in the same approximation, one finds for D°:

$$\Gamma_{NL}(D^\circ) = \Gamma_{c\text{-decay}} + \Gamma_{q\text{-int}}$$

$$\Gamma_{q\text{-int}} = \left(\frac{C_+ + C_-}{2}\right)^2 \frac{G^2 M^2}{3\pi} |\psi^{(8)}(0)|^2 P^{(8)} \qquad (19)$$

$$\Gamma_{c\text{-decay}}(D^\circ) = \Gamma_{c\text{-decay}}(D^+)$$

$P^{(8)}$ is the probability for finding the $c\text{-}\bar{u}$ pair in a $J = 1$, color octet state, and $\psi^{(8)}(0)$ the corresponding wave function at the origin.

D° decay from $J = 1$, color singlet state could also be considered, but the corresponding rate is suppressed by the small combination $|(2C_+ - C_-)/3|^2$.

Eqs. (18) and (19) show clearly that the effects (i) and (ii) are both determined by the size of the bound state. Furthermore these equations imply that the deviations from unity of the lifetime ratio should disappear for heavier quarks, since we expect (Sect. 2):

$$\frac{|\psi(0)|^2}{M^3} \to 0$$

for $M \to \infty$.

To see whether the effects (i) and (ii) really explain the data, we need a more precise evaluation of the rates and, in particular, a more precise definition of the phenomenological parameters which appear in the above equations. This can be done in the case of the D^+, in that one can express <u>both</u> $\Gamma_{c\text{-decay}}$ and Γ_{interf} in terms of the <u>same</u> parameter, p_F, which determines the shape of the electron spectrum in the semileptonic decay. Thus, at least in principle, a precise measurement of the latter can provide a precise prediction of the total non leptonic rate.

The result of this calculation /27/ is reported in Table 2, where the range of values for $\Gamma_{c\text{-decay}}(D^+)$ and $\Gamma_{interf}(D^+)$ reflects the present uncertainty on p_F. It is seen that the interference effect gives a suppression of less than 10% of the total rate; thus this effect can play only a minor role in increasing the D^+ lifetime.

The D° case is less favorable, in that we need to know both $P^{(8)}$ and $\psi^{(8)}(0)$, which are not related to other processes. $P^{(8)}$ has been computed perturbatively /21/ (one gluon emission from the initial light quark):

$$P^{(8)} = \frac{\alpha_s}{18\pi}\left(\frac{M_D}{m}\right)^2 \simeq 0.2 \qquad (20)$$

for $\alpha_s = 0.3$ and $m = 0.3$ GeV.

The presence of the $1/m^2$ factor strongly suggests that the low momentum region dominates, casting some doubts on the relevance of the perturbative calculation. It is, in fact, quite possible that $P^{(8)}$ is of order unity.

In Table 2, I have also reported the predictions for $\Gamma_{q\text{-int}}(D^\circ)$ obtained by Eq.(19) with $P^{(8)} = 1$, and with three different estimates of the wave function, always under the assumption that:

$$| \psi^{(8)}(0) |^2 = | \psi(0) |^2$$

the r.h.s. being the wave function for the color singlet, J = 0 or J = 1, c - $\bar{u}$ system.

Table 2

Non leptonic rates for D^+ and D° for $\cos\Theta_c = \cos\gamma = 1$ and $P^{(8)} = 1$ (see text); P_F is the momentum spread of the c-quark in the meson (in GeV) and the two values considered correspond to the range allowed by a fit to the electron spectrum in the semileptonic decay , see Sect.3. The values of α_s, c_+ and c_- used are given in Eq. (23). Next-to-leading QCD corrections to c-decay /28/ have been included. Rates are in units of $10^{12} s^{-1}$.

	P_F	$\Gamma_{c\text{-decay}}$	Γ_{interf}	$\Gamma_{q\text{-int}}$
D^+	0.00	1.6	0.00	-
	0.15	1.1	0.06	-
D°	same	same	-	$3.0^{(a)}$
				$0.4^{(b)}$
				$1.3^{(c)}$

The three estimates correspond to:

a. $| \psi(0) |^2$ obtained from D-D^* splitting, via Eq.(7), which gives:

$$\Gamma_{q\text{-int}}(D^\circ) = \left(\frac{C_+ + C_-}{2}\right)^2 \frac{G^2}{64\pi^2} \frac{3 M^2 m \left[M(D^*)^2 - M(D)^2\right]}{\alpha_s} \qquad (21)$$

b. using Eq.(6) with $f_D = 0.15$ GeV;

c. relating the D rate to the $\psi \to \mu^+ \mu^-$ rate, via SU(4) symmetry, which gives:

$$\Gamma_{q\text{-int}}(D^\circ) = \left(\frac{C_+ + C_-}{2}\right)^2 \frac{G^2}{24\pi^2 \alpha^2} M_D^4 \; \Gamma(\psi \to \mu^+ \mu^-) \qquad (22)$$

The numerical values are obtained with:

$\alpha_s = 0.3$, $C_+ = 0.75$, $C_- = 1.75$

and using in (a) and (b) the (large) mass values:

$m = 0.3$

$M = M_D = 1.86$ GeV

to be on the safe side.

It is encouraging that different estimates give rather close results. The conclusion is that even with $P^{(8)} = 1$, quark interaction cannot dominate completely over the quark decay rate but, at best, it can be about equally important. The relative importance of q-interaction vs c-decay can be increased by reducing M_c, but then, too long lifetimes would result. Without major modifications, the present picture implies that:

$$\frac{\tau(D^+)}{\tau(D^\circ)} < 4$$

and most likely the ratio to be between 1.5 and 2. This is well within the present range of the experimental uncertainty.

If the Cabibbo-suppressed annihilation diagram in D^+ decay is not very much enhanced, we can expect a branching ratio for the Cabibbo suppressed modes not much greater than the naive expectation $B \sim \sin^2\theta_C = 5\%$. There may be a problem here, in that the present data for the Cabibbo allowed modes of D^+ and D° seem to be smaller that expected, although with a large uncertainty /18/:

$$\frac{\Gamma(D^+ \to \bar{K} + \ldots)}{\Gamma(D^+ \to \text{all})} = (60 \pm 18)\ \%$$

$$\frac{\Gamma(D^\circ \to \bar{K} + \ldots)}{\Gamma(D^\circ \to \text{all})} = (53 \pm 21)\ \%$$

More precise data are needed to clarify this very important issue.

Other conclusions one can draw from the above discussion can be summarized as follows.

i) While the theoretical predictions for the total D^+ rate are considerably affected by the poor knowledge of the wave function momentum spread, p_F, the semileptonic branching ratio is much better determined. Ref./27/ estimates:

$$B_{SL}(D^+) = (14.5 \pm 3.5)\ \%$$

quite compatible with data, the theoretical uncertainty being essentially due to value of α_s.

ii) A precise prediction of the total D° rate is, at present, beyond reach. A direct measurement of f_D (or f_F), would be of the greatest value, in that it would give an upper bound to $\Gamma_{q\text{-int}}$, much firmer than that given in Table 2.

iii) The c-d pair in Λ_c has a $J = 1$ component even in the valence quark approximation. The quark-interaction rate is thus determined mainly by the wave function overlap. Theoretical calculations /29/ seem to give values in general agreement with the observed lifetime. A comparison of D and Λ_c lifetime can tell how difficult it is to emit a further gluon, and whether or not $P^{(8)}$ is of order unity.

iv) Finally, it is clearly suggested that for B-mesons:

$$\tau(B^+) = \tau(B^\circ)$$

We wait eagerly for the result of this crucial test. An amusing suggestion about how this can be done has been given in Ref./30/.

5. F-decays. - Non leptonic decays of F differ from D° decays in that the annihilation of the $c\bar{s}$ in J = 1 color octet state is considerably suppressed by the structure of the weak hamiltonian, while annihilation from J = 1, color singlet state, is fully allowed. The latter state can be obtained by radiation of at least two gluons. However if the probability for one gluon emission (i.e. $P^{(8)}$) is large, the probability for finding the $c-\bar{s}$ pair in a J = 1, color singlet state, $P^{(0)}$, could also be large /31/. Thus we expect:

$$\tau(F^+) \simeq \tau(D^+) \qquad (P^{(0)} \text{ small})$$

$$\tau(F^+) \simeq \tau(D^\circ) \qquad (P^{(0)} \text{ large})$$

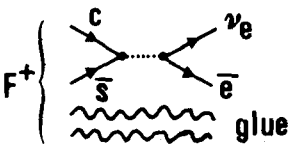

Fig.3: Quark annihilation in F semileptonic decay. The initial pair is in a J = 1, color singlet, state.

In the latter case, the semileptonic decays of F^+ would also be affected, in that they would receive contributions from the diagram of Fig.3. No helicity suppression is present, since the annihilation proceeds from a J = 1 state so this mechanism yields as many electrons as muons, and we expect:

$$\Gamma_{SL}(F^+) > \Gamma_{SL}(D^+) \qquad (P^{(0)} \text{ large})$$

with the possibility of very interesting hadronic final states made out of pure glue.

6. Exclusive charm decays. - There is no new experimental information on hadronic, exclusive, charm decays since the Madison Conference (see the review paper /18/), and very little new theoretical developments on the subjects, so I will limit myself to a few comments.

In early works, assuming complete c-decay dominance and the free quark model rules for color recombination, predictions of the rates for the two body decays of D^+, D° and F have been derived /32/, in terms of very few phenomenological parameters. Most notably, an almost complete suppression of the neutral decay modes of D° was predicted:

$$\frac{B(D^\circ \to \bar{K}^\circ \pi^\circ)}{B(D^\circ \to K^- \pi^+)} \simeq \frac{1}{40} \qquad (23)$$

Eq. (23) turned out to be incompatible with the experimental result /18/:

$$\frac{B(D^\circ \to \bar{K}^\circ \pi^\circ)}{B(D^\circ \to K^- \pi^+)} = 0.73 \pm 0.39 \qquad (24)$$

The result (24) supports in fact the idea that q-interaction dominates over quark decay, the former process leading to the acceptable ratio of 1/2 as a consequence of pure I = 1/2 final states.

More in general, the experimental result (24) prompted a reconsideration of the whole subject. The role of the final state interactions has been investigated in various papers /33, 34/, the color combination rules have been questioned in Ref. /35/, the use of the "vacuum insertion" approximation has been also criticized /36/, as well as the very use of the QCD corrected effective hamiltonian /37/. More recently, phenomenological pictures of two body decays (2 pseudoscalar, PP, or pseudoscalar plus vector, PV, final states) incorporating both the q-interaction mechanism and the identical particle interference effects have been developed /38/.

The situation remains confuse, and a clarification must wait for more precise data.

In connection with the puzzle posed by Eqs (23) and (24), however, the following observation can be useful. The neutral PV decay modes of D° have also been observed, with the results /18/:

$$B(D^\circ \to \bar{K}^\circ \rho^\circ) = 0.1^{+0.6}_{-0.1} \ \% \qquad (25)$$

$$B(D^\circ \to K^{*\circ} \pi^\circ) = 1.4^{+2.3}_{-1.4} \ \% \qquad (26)$$

to be compared with the observed branching ratios of the charged modes:

$$B(D^\circ \to K^- \rho^+) = 7.2 \pm 3 \ \% \qquad (27)$$

$$B(D^\circ \to K^{*-} \pi^+) = 3.6 \pm 1.3 \ \% \qquad (28)$$

The neutral mode suppression is very well borne out by (25) vs (27), and the result (26) is also compatible with zero. This implies that the q-interaction mechanism does not contribute to the PV decay modes. If this is the case, and if the q-interaction mechanism was completely dominant in total rates, one would expect an overall suppression of PV decay modes, which is not borne out at all by the data, e.g.:

$$\begin{aligned} B(D^\circ \to \bar{K}^\circ \rho^\circ) + B(D^\circ \to K^- \rho^+) &\simeq 7 \ \% \\ B(D^\circ \to \bar{K}^\circ \pi^\circ) + B(D^\circ \to K^- \pi^+) &\simeq 5 \ \% \end{aligned} \qquad (29)$$

The near equality of PP and PV modes supports nicely what found in Sect.4, namely that q-interaction and c-decay contribute about equally in D° decay. A convincing explanation of q-decay dominance in

PV decays remains entirely to be found, of course. However, if we assume this to be true, the branching ratios (27) and (28) determine the unknown parameters in the analysis of Ref. /32/, and lead to univocal predictions for the other PV modes. In particular, one finds:

$$B(F \to \phi\pi) = \frac{\tau(F)}{\tau(D^\circ)} \quad B(D^\circ \to K^{*-} \pi^+) \simeq 3\ \% \tag{30}$$

for about equal F and D° lifetimes. A test of this simple relation can be very interesting.

7. Weak mixing angles. - The quark-charged weak current in the standard model, has the form:

$$J^+_\mu = \bar{u}\ \gamma_\mu (1 - \gamma_5)\ Ud \tag{31}$$

where u = (u, c, t, ...), d = (d, s, b, ...) and U is a NxN unitary matrix for N generation of quark doublets (i.e. 2N quark flavours). If $N \geq 3$, U contains one or more CP-violating phases /39/.

The present information on the matrix elements of U has been summarized at this Conference by S.Pakvasa, whose talk may be consulted for more details.

The matrix elements U_{ud} and U_{us} are well determined from hyperon and kaon β-decays (for a recent analysis see Ref./40/). In earlier works, information about U_{cd} and U_{cs} was obtained from calculations of the $K_L - K_S$ mass difference and of the $K_L \to \mu^+ \mu^-$ rate. These calculations, however, suffer from many ambiguities and the corresponding bounds should be taken with some suspicion. Fortunately, as pointed out recently /41, 42/, similar, but more reliable, information may now be obtained from neutrino dimuon data /43/ and from the present information on B-decays.

Table 3 summarizes the situation for what concerns the present knowledge about the matrix elements of U. If three generations are assumed, weak but significant bounds can be obtained for the t-quark couplings, from the unitarity conditions.

In the three generation model, U can be parametrized in terms of the Cabibbo angle, θ_c, and of three other parameters: two real angles and one CP-violating phase.

To first order in all mixing angles, the form of U is uniquely determined to be:

$$U = \begin{pmatrix} 1 & \theta & \beta \\ -\theta & 1 & \gamma \\ -\beta & -\gamma & 1 \end{pmatrix} \tag{32}$$

Table 3

Present information on the matrix elements of the Kobayashi-Maskawa matrix.
(a) from hyperon and kaon β-decays, Ref. /40/;
(b) from dimuon, neutrino and antineutrino data, CDHS Collaboration, Ref. /43/;
(c) from the upper limit of B-lifetime, JADE Collaboration, Ref. /44/, combined with the CUSB result, Eq. (36);
(u) from the unitary conditions, for three generations only.

$U_{ud} = 0.9737 \pm 0.0025^{(a)}$	$U_{us} = 0.225 \pm 0.005^{(a)}$	$0 \leqslant \lvert U_{ub}\rvert \leqslant 0.09^{(u)}$
$U_{cd} = 0.24 \pm 0.03^{(b)}$	$0.59^{(b)} \leqslant \lvert U_{cs}\rvert \leqslant 0.97^{(u)}$	$0.044^{(c)} \leqslant \lvert U_{cb}\rvert \leqslant 0.78^{(u)}$
$0 \leqslant \lvert U_{td}\rvert \leqslant 0.11^{(u)}$	$0 \leqslant \lvert U_{ts}\rvert \leqslant 0.78^{(u)}$	$0.62^{(u)} \leqslant \lvert U_{tb}\rvert \leqslant 1$

A comparison with Eq.(31) shows that $\Theta = \Theta_c$, and gives a simple interpretation for the other two angles: β determines the b-u (or t-d) transition amplitude and γ determines the b-c (or t-s) one. To this order, no CP-violation can be present. The form resulting for U when we allow arbitrary values for Θ, β, γ as well as for the CP-violating phase δ, has been given in Ref. /45/ and is:

$$U = \begin{pmatrix} c_\beta c_\Theta & c_\beta s_\Theta & s_\beta \\ -c_\gamma s_\Theta - s_\gamma s_\beta c_\Theta e^{i\delta} & c_\gamma c_\Theta - s_\gamma s_\beta s_\Theta e^{i\delta} & s_\gamma c_\beta e^{i\delta} \\ -c_\gamma s_\beta c_\Theta + s_\gamma s_\Theta e^{-i\delta} & -c_\gamma s_\beta s_\Theta - s_\gamma c_\Theta e^{-i\delta} & c_\gamma c_\beta \end{pmatrix} \quad (33)$$

and where $c_\beta = \cos\beta$ etc., and the conditions:

$$0 \leqslant \sin\beta \leqslant 1, \quad -1 \leqslant \sin\gamma, \quad \sin\delta \leqslant 1$$

are understood.

The bounds to the matrix elements of U summarized in Table 3 imply an allowed region in the $\sin\beta$ - $\sin\gamma$ plane (here and in the following I set, for simplicity, $\delta = 0$), as shown in Fig. 4. We see at once from Table 3 that $\sin\beta \ll 1$ so that I have used in the figure the variable $\sin\beta / \tan\Theta_c$ rather than $\sin\beta$ itself.

The horizontal continuous line indicates the maximum violation of Cabibbo universality ($\lvert U_{ud}\rvert^2 + \lvert U_{us}\rvert^2 = 1$) tolerated in $\Delta S = 1$, 0 β-decays /40/, the dashed lines correspond to the CDHS measurement /43/:

$$\frac{\lvert U_{cd}\rvert}{\sin\Theta_c} = 1.05 \pm 0.14 \ (\text{i.e.} > 0.91) \quad (34)$$

The continuous line around the origin represents the limitation arising from the upper bound to the B-meson lifetime /44/:

$$\tau(B) < 1.4 \cdot 10^{-12}\,\text{s} \quad (35)$$

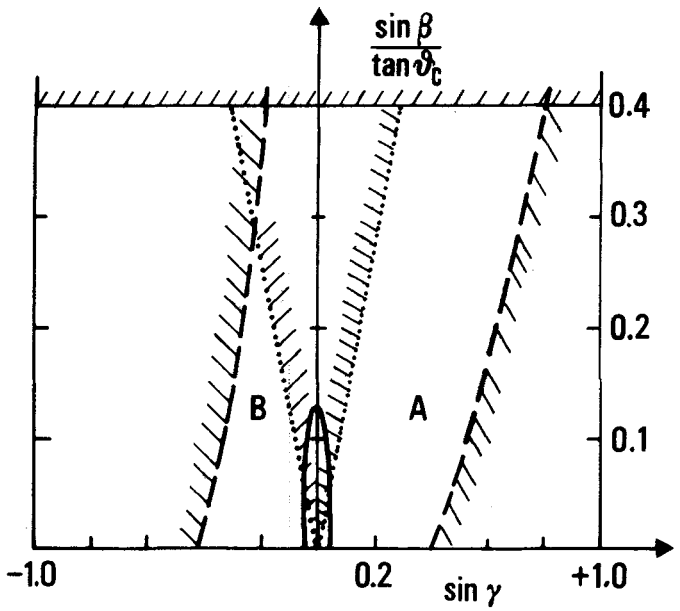

Fig. 4: A,B: regions in the plane $\sin\beta/\tan\Theta_C$ - $\sin\gamma$ allowed by the present experimental results, see text.

Finally the dotted lines correspond to the limit:

$$\frac{|U_{ub}|}{|U_{cb}|} < 0.3 \qquad (36)$$

reported to this Conference by the CUSB Collaboration, see /4/ (a similar limit has been obtained by the CLEO Collaboration). The allowed regions in Fig.4 imply the lower bound for B-lifetime:

$$\tau(B) > 3 \cdot 10^{-14} s.$$

A future strategy for a complete determination of the K-M angles can be outlined as follows:

i) $|\cos\gamma|$ and $|\sin\gamma|$ could be determined from the inclusive semileptonic rates of charmed and beauty mesons respectively, once the momentum spread, P_F, of the bound quark has been determined from an accurate measurement of the lepton spectrum, see Sect. 3;

ii) the ratio $|\sin\beta/\sin\gamma|$ could be determined from an analysis of the end-point spectrum of the electron in B-semileptonic decay /16/. Fig. 5 shows the theoretical spectra for the transitions:

$B \to e + \nu +$ (C = 0)

$B \to e + \nu +$ (C = 1)

normalized to unit couplings. It is clear that an investigation of the spectrum above the $\Delta C = 1$ end-point can provide a sensitive bound - or a measurement if we are lucky - for the relative strength of the two transitions;

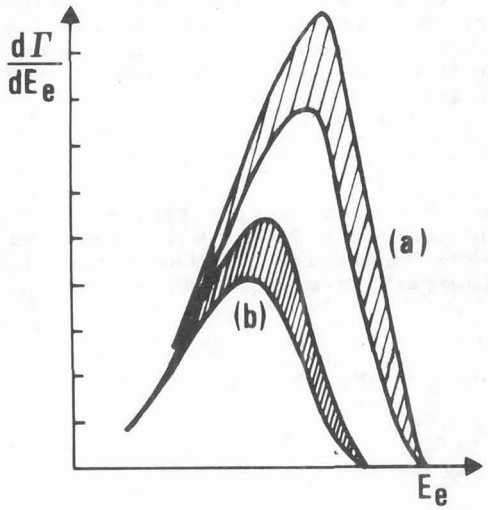

Fig.5: Theoretical curves /16/ for the electron spectrum in: $B \to e^+ \nu$ +(C = 0 states) curve (a) and: $B \to e^+ \nu$ +(C = 1 states) curve (b). The meson B is at rest. The curves include QCD corrections, bound states effects and are normalized to unit coupling. The momentum spread of the b quark, p_F, is taken to be the same as for charmed mesons; shaded areas correspond to $0 \leqslant p_F \leqslant 0.15$ GeV.

iii) the sign of $\sin\gamma$ appears to be more difficult to determine. One possibility is given by $B_o - \bar{B}_o$ mixing /46, 47/, to be measured in the e^+e^- reaction:

$$e^+e^- \quad B^\circ + \bar{B}^\circ + \ldots$$
$$\hookrightarrow e^+ \ldots \text{ (or } e^- + \ldots)$$
$$\hookrightarrow e^- + \ldots \text{ (or } e^+ + \ldots)$$

The fraction of wrong-signature dileptons:

$$Z = \frac{N(e^+e^+) + N(e^-e^-)}{N(e^+e^-) + N(e^+e^+) + N(e^-e^-)} \qquad (37)$$

is very sensitive to the sign of $\sin\gamma$. Explicit calculation shows that there is a line of zeros present in the $\sin\gamma > 0$ region, which strongly suppresses $B_o - \bar{B}_o$ mixing there, while a (perhaps) observable signal is expected, if $\sin\gamma < 0$.

8. Exotics. - The present data on weak decays exclude to a remarkable accuracy the presence of further interactions, besides those of the SU(2) ⊗ U(1) theory. Such effects are usually classified as "exotics", although they are not very much bizarre, within the framework of a unified gauge theory. Here follow some remarks about the most simple possibilities and the way they are excluded.

Charged Higgs particles. Many gauge theories, (and all supersymmetric extensions) require more than one Higgs multiplet, thereby implying the existence of charged scalar particles, not necessarily with large masses. The simplest option, naturally leading to flavour conservation in neutral current interactions /48/, is that of two Higgs doublets, with the charge pattern:

$$\phi = \begin{pmatrix} \phi^{\circ} \\ \phi^{-} \end{pmatrix} \qquad \chi = \begin{pmatrix} \chi^{+} \\ \chi^{\circ} \end{pmatrix}$$

After symmetry breaking, one remains with three neutral fields coupled to Δ flavour = 0 transitions, plus a charged scalar $H^{\pm}$, coupled to flavour changing processes. The Yukawa lagrangian for the latter is uniquely determined by the quark (diagonal) mass matrices, M_u and M_d, and by the K-M matrix U, Eq. (31):

$$L = \frac{e}{2 \sin \theta_w M_w} \{H^{+} | x \bar{u} M_u U (1-\gamma_5) d - \frac{1}{x} \bar{u} U M_d (1+\gamma_5) d | + h.c.\} \quad (38)$$

As before, u = (u, c, t, ...), d = (d, s, b, ...) and x is the ratio of the vacuum values of the two neutral scalar fields.

Most likely, a light $H^{\pm}$ would have been observed in $e^{+}e^{-}$ processes. At any rate, from weak decays alone, we can conclude that:

i) $c \not\to H + s$: because the lifetime would be too short;
ii) $b \not\to H + c$ (or u): given the measured semileptonic branching ratio, this decay leads to a too low energy associated with charged particles, in contrast with what observed by the CLEO and CUSB collaborations, see /4/.

What about virtual effects? A similar formula to Eq. (38) holds for the H-lepton couplings, so that the best signature would be a departure from e- μ universality in semileptonic decays.

For the H-exchange contribution in such a process, however, we expect:

$$|A_H| \simeq \frac{m_\mu m_q}{M_H^2} |A_{weak}| < \frac{m_\mu m_q}{(M_b - M_c)^2} |A_{weak}| \quad (39)$$

and therefore a very small signal.

In agreement with this consideration, e- μ universality is well tested in τ and b decays.

It has been suggested that the anomalously small ν_e/ν_μ ratio reported in the beam dump experiments /49/ may be due to a Higgs-exchange effect /50/ in c-decays.

Although such an effect would not arise in the simplest scheme, as we have seen, one should keep an open mind to this possibility. An experimental verification of e- μ universality in charm decay, lacking at present, is strongly called for.

Is b-quark different? Investigating a class of models without the t-quark, Georgi and Glashow where led to speculate that the b quark has a new quantum number, conserved in the usual SU(2) $\otimes$ U(1)

interactions, as well as in the additional interactions responsible for b decay /51/.

The new quantum number must also be shared by some other lighter than b-particles, the only possible candidates being τ and ν_τ. If this was the case, the final states in b decay would always involve at least one lepton, and again, given the known value of the semi-leptonic branching ratio, a conflict would arise with the observed charged particle energy fraction.

The naive topless model. It is perfectly admissible that both b_L and b_R are SU(2) singlets (no t-quark needed) and that b decays because of its mixing with s and d. The "raison d'être" of the doublet assignment of b_L is that $\Delta S = 1$ neutral currents would in general be present in the singlet case, leading to a contradiction with e.g. $K \to \mu^+ \mu^-$ suppression.

It is possible, though admittedly unnatural, to tune the mixing angles in Eq. (33) so that the $\Delta S = 1$ neutral current vanishes exactly.

This happens for:

$$\tan\gamma = \frac{\sin\beta}{\tan\theta_C} \tag{40}$$

However, Δ (beauty) $\neq 0$ neutral currents cannot be forbidden at the same time, and it is straightforward to predict /52/:

$$R = \frac{\Gamma(b \to e^+e^- + s)}{\Gamma(b \to e\,\nu + c)} = \frac{1}{4}\left[(1 - 2s^2)^2 + 4s^4\right]\cos^2\gamma \tag{41}$$

$$= 0.126\cos^2\gamma$$

where $s^2 = \sin^2\theta_W = 0.23$, θ_W being the Weinberg-Salam angle (to be safe, I have set to one the phase space ratio which unfavours the normal decay). If $\tan\gamma$ is given by Eq. (40), however, it must satisfy the constraint posed by the observed Cabibbo universality, i.e. $\cos^2\gamma > 0.84$, see Table 3.

Thus Eq. (41) implies the absolute bound:

$$R > 0.105$$

which is contradicted by the CLEO result /4/:

$$R_{exp} < 0.08 \tag{42}$$

The t-quark is thus necessary(*), although a better experimental limit would be, perhaps, desirable.

9. t-quark. - I do not know of any firm prediction of the t-quark mass. In the simplest SU(5) model the masses of the charged leptons are related successfully /54/ to the masses of down-type quarks; in

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(*) A similar chain of arguments has been used earlier to rule out models of τ without its own neutrino, see Ref. /53/.

the simplest O (10) the masses of up-type quarks, such as t, are related to neutrino masses, something we know even less about.

More elaborate grand-unified models yield the prediction /55/:

$$\frac{m_t}{m_c} = \frac{m_\tau}{m_\mu} \qquad (43)$$

which, after renormalization group corrections, (see e.g. /56/) gives:

$$m_t = \frac{M_{t\bar{t}}}{2} \simeq 25 \text{ GeV}$$

The same formula arises in a completely different context, by requiring the Higgs interactions to obey a spontaneously broken, discrete permutational symmetry /57/. Even though not very compelling, the value predicted by Eq. (43) may be a useful target for the next round of experiments.

What about upper bounds? A firm bound to the t-quark mass has been obtained by Veltman /58/ who observed that when the t-b mass splitting increases, one gets an increasingly large, positive correction to the parameter:

$$\rho = \frac{G_{\text{neutral current}}}{G_{\text{charged current}}}$$

In tree level: $\rho = 1$ for the Weinberg-Salam theory, but in addition(*), m_t-independent radiative corrections decrease ρ below one by about 1% /59/. Thus from the experimental value /60/:

$$\rho_{exp} = 1.002 \pm 0.015 \quad (< 1.0017)$$

we obtain:

$$(\Delta\rho)_{t\text{-quark}} = \frac{3G}{8\pi^2} m_t^2 < 2.7\%$$

and:

$$m_t < 200 \text{ GeV} \qquad (44)$$

A similar bound is obtained /61/ in SU(5) if one requires the Yukawa interaction of the t-quark not to leave the perturbative domain before the GUT mass is reached (Yukawa interactions are not asymptotically free).

A much more restrictive bound to the t-quark mass has been obtained from the observed values of the K_L-K_S mass splitting and of the $K_L \to \mu^+\mu^-$ rate /62/. This derivation has been recently criticized on various grounds:

i) it relies heavily on the bag model calculation of $< K^\circ | H_W (\Delta S = 2) | \bar{K}^\circ >$, which has been argued to be extremely dependent upon the values of not well controlled bag parameters /63/;

(*) This point has been brought up by A.Sirlin in the discussion Session.

ii) in the calculation of the $K_L \to \mu^+\mu^-$ amplitude, the dispersive contribution from virtual $\gamma\gamma$ intermediate states has been underestimated as shown by comparison with the analogous $\eta \to \mu^+\mu^-$ decay /64/.

A more complete analysis can be performed /64/, but no really firm bound results, in my opinion.

Rare decay modes of B-mesons are enhanced when the t-quark mass increases. With m_t restricted as in Eq. (44) really low branching ratios are expected, however. As an example, one can easily estimate

$$\frac{\Gamma(B \to e^+e^- + \ldots)}{\Gamma(B \to e\,\nu + \ldots)} = \left(\frac{\alpha}{16\pi \sin^2\theta_W}\right)^2 \frac{|U_{ts}\,U^*_{tb}|^2}{|U_{cb}|^2} \left(\frac{m_t}{M_W}\right)^4 f\left(\frac{m_t^2}{M_W^2}\right) \qquad (45)$$

with:

$$f(x) = \left|1 - \frac{3}{x-1} + \frac{3\,x\,\ln x}{(x-1)^2}\right|^2$$

For m_t = 200 GeV, and with M_W = 80 GeV, $\cos\theta_C = \cos\gamma = 1$, the branching ratio is about: $4\ 10^{-5}$, to be compared with the present experimental limit, Eq. (42). Other rare decay modes such as:

$b \to \gamma + s$

$(b\bar{s}) \to \tau^+ + \tau^-$

$(b\bar{s}) \to \gamma + \gamma$

have been studied in Refs. /47, 65/. Branching ratios are found to depend very steeply from m_t, but again very small branching ratios result.

Finally, the decay:

$$b \to s + \begin{cases} \text{gluon} \\ \\ u\bar{u} \text{ or } d\bar{d} \end{cases}$$

with a $q\bar{q}$ pair created by a virtual gluon, is also sensitive to m_t and may have a reasonable branching ratio /66/. The issue, here, is how to identify this particular final state(*).

In contrast with its mass, present theories make very precise predictions for the decay modes of the t quark, which may be a wonderful source of new particles, if it is heavy enough. Besides the standard decay mode:

$$t \to b + (\text{up fermion}) + (\text{down antifermion}) \qquad (46)$$

the decays:
$t \to b\,H^+$, $b\,W^+$, $(sb) + e^+ + (s\nu)$, (sb) + w-ino, $b + \chi^{++} + \chi^-$ /67/ ...

(*) This could be attempted by looking for B-meson tracks with one break only, as opposed to the normal case where a second break should also be seen, due to charm decay. I thank Dr.Eilam for this observation.

may occur where (sb), (s ν) are the supersymmetric scalar partners of b and ν, χ^{++} and χ^{-} are the scalar mesons predicted by the Gelmini-Roncadelli model /68/ etc. Decay rates are all calculable, within a given model.

An important issue will be the value of t-lifetime. t-lifetime will certainly be too short to be measured directly. In this situation a useful suggestion /69/ is to obtain the t-quark decay rate from a measurement of the toponium ($t\bar{t}$) width (in e^+e^- processes). For sufficiently large m_t, a sizeable, or even dominant, fraction of $t\bar{t}$ decays is due to the weak decay of the t or $\bar{t}$ bound quarks.

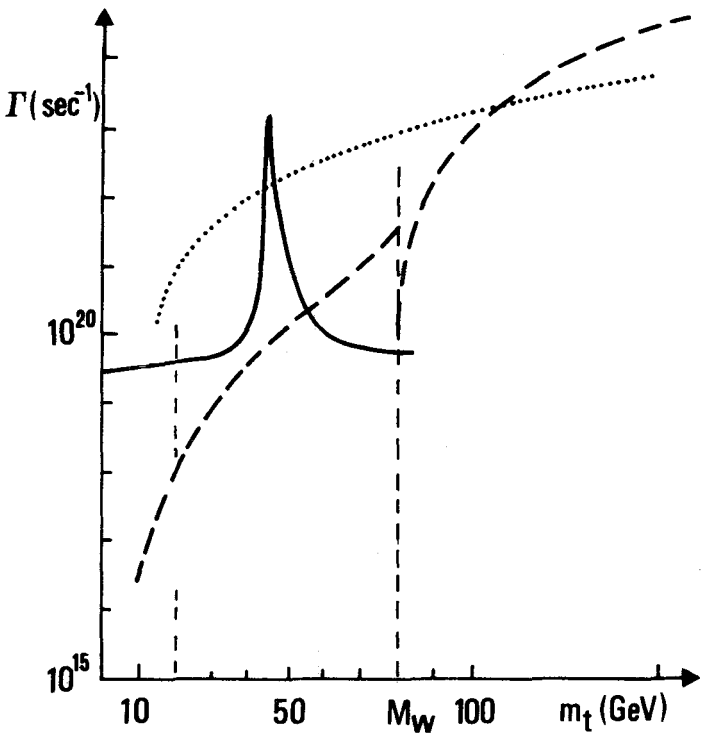

Fig. 6: Continuous line: decay rate for: $t\bar{t} \to \gamma$ or $Z \to f\bar{f}$ as function of m_t. Dashed line: decay rate for the weak decay (46) or for $t \to b + W$. Dotted line: decay rate for $t \to b + H$, with M_H = 10 GeV.

Fig. 6 shows the results of a recent analysis /70/. It is seen that the mode (46) accounts for more than 10% of the total ($t\bar{t}$) decay rate, for $m_t > 25$ GeV (except when $M(t\bar{t})$ is very near M_Z), and it is the dominant mode for $m_t > 60$ GeV. In the event that there is a light charged Higgs (say $M_H = 10$ GeV), the semiweak decay: $t \to b + H^+$ dominates completely, over the entire mass range. Thus, there seems to be some prospect for a measurement of the absolute rate of t-decay, and therefore of process (46).

9. Conclusions. - We have seen that τ decays pose no mistery. Do we understand charm decay? My conclusion is: yes ... but. The theoretical description of non leptonic charm decays is still obscured by uncontrolled strong interaction effects, and a first principle calculation of bound state effects and the like (lattice QCD?) is still not in sight. In the meanwhile, the phenomenological, QCD inspired,

picture I have illustrated seems to work reasonably well, and it may be quite useful, e.g. allowing to extract from the data the values of fundamental parameters such as the weak mixing angles. More precise tests of these ideas are needed, however, before we can be sure that there is really no new dynamics in charm decays, and therefore more precise experiments are called for. A shopping list for the near future includes more precise data on:

(i) charmed particle lifetimes;
(ii) semileptonic inclusive branching ratios and lepton energy spectrum;
(iii) the value of f_F, and f_D;
(iv) branching ratios for inclusive, Cabibbo forbidden decays of D^+ and D°;
(v) e - μ universality.

Data on exclusive decays may also be quite useful.

All indications are that B decays are quite conventional and that the picture developed for charm decay works for B as well. A measurement of B-lifetime is of course crucial. Finally, the discovery of the t-quark within the expected mass range has now become mandatory.

Acknowledgements. - I have discussed the subjects reported here with many theoretical and experimental physicists, whom I would like to thank for having been so helpful. In particular I would like to thank G.Altarelli, N.Cabibbo and P.Bagnaia, G.Ciapetti, E.De Rafael, G.Kalmus, K.Kleinknecht, M.Lusignoli, S.Pakvasa, R.Peccei. Hospitality at CERN, Ecole Normale Supérieure and Rutherford Laboratory, where the manuscript was partly prepared, is gratefully acknowledged. Finally, I thank G.Gori and B.Pellizzoni for skilfully typing a hopeless manuscript.

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Discussion

J.M. FRERE (U.L.B.).- You have insisted on the unitarity of the mixing matrix for quarks ; this however only obtains when one has extracted the correct coupling constant. This is traditionally taken from μ decay ; however if more generations are present, or simply if ν_τ is massive, this rate will be modified. The only way out I know is to compare to the neutral currents. Heavy neutrinos would increase $\rho = (M_W/M_Z \cos\theta)^2$. *One should thus keep an open mind in this direction between different experiments contributing to this fit.*

L. MAIANI. - I have assumed only for simplicity that neutrinos are very light, hence unmixed. In general, I agree with your remark.

A. Sirlin (New York Univ.).- I have a comment regarding the upper bound of m_{top} *by using the Veltman argument. The rest of the radiative corrections (i.e. everything except the Veltman term) decreases* ρ^2_{NC}/ρ^2_{CC}. *If this is taken into account, the derived upper bound for* m_{top} *will increase.*