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ARE CABIBBO SUPPRESSED DECAYS REALLY SUPPRESSED
IN D^+ DECAYS?

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ABSTRACT

Two classes of proposals have been made to account for the "anomalies" reported in charm decays, namely (a) strong 20-plet dominance and (b) W exchange. It is pointed out that 20-plet dominance leads to rather striking effects for the Cabibbo disfavoured decays of D^+ , namely the absence of strong Cabibbo suppression. The W exchange mechanism does not seem to lead to such effects.

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Recent reports on charm decays¹⁾ are causing some excitement because of their apparent contradiction of previous theoretical expectations²⁾. Three results, listed below, appear to constitute major surprises:

$$\tau(D^+) \sim 5-6 \times \tau(D^0) \quad (1)$$

$$\frac{BR(D^0 \rightarrow K^- \pi^+)}{BR(D^0 \rightarrow \bar{K}^0 \pi^0)} \sim 1-2 \quad (2)$$

$$\frac{BR(D^0 \rightarrow K^+ K^-)}{BR(D^0 \rightarrow \pi^+ \pi^-)} \sim 3 \quad (3)$$

A variety of proposals have been made, not so much to explain these features, but more to accommodate them³⁾⁻⁶⁾. At this point, each of these contains some rather ad hoc assumption which does not seem to be explained by present theoretical understanding of the weak and strong interactions. The aim of this note is to examine the phenomenology of proposals made to account for relations (1) and (2).

We will pursue this goal mainly by considering Cabibbo suppressed decays. At the same time, we will argue that relation (3) may not pose a major problem since SU(3) breaking effects could play an important role in exclusive two-body decays.

One proposal which has been put forward³⁾ assumes a strong "20-plet" dominance in the weak coupling. As is well known, the weak Lagrangian can be decomposed into two parts which transform like a 20-plet and 84-plet under SU(4)³⁾:

$$\mathcal{L} = \frac{G}{\sqrt{2}} \cos^2 \theta_c \{ f_- L_{20} + f_+ L_{84} \} \quad (4a)$$

$$L_{20} \equiv (\bar{s}c)(\bar{u}d) - (\bar{u}c)(\bar{s}d) \quad (4b)$$

$$L_{84} \equiv (\bar{s}c)(\bar{u}d) + (\bar{u}c)(\bar{s}d) \quad (4c)$$

where Lorentz indices and γ matrices have been suppressed and the letters c, d, s, u stand for the corresponding quark fields. Using perturbative QCD one can calculate f_+ and f_- as renormalization coefficients of the four fermion vertex²⁾. Using "reasonable" parameters one obtains $f_-/f_+ \sim 3$ in the leading log limit, i.e., some sizeable "20-plet" enhancement.

Furthermore, when the operator is sandwiched between hadronic matrix elements, one groups the $q\bar{q}$ states into colour singlets thus ignoring final state soft gluon emission^{7),8)}. This standard picture fails to reproduce relations (1) and (2) in a rather striking manner.

One way out of this dilemma has been suggested in Ref. 3):

- i) assume $f_-/f_+ \approx 10$, i.e., much stronger 20-plet enhancement;
- ii) use the same colour matching as in the standard model;
- iii) treat the inclusive decay rate as a quasi-two-body process. Noting the minus sign in Eq. (4b) one then argues that destructive interference can take place.

Thus the authors find that while $\Gamma(D^0)$ is "normal", $\Gamma(D^+)$ is strongly suppressed. A simple consideration points immediately to a crucial test of this ansatz:

$$\tau(F^+) \sim \tau(D^0) \ll \tau(D^+) \quad (5)$$

since F^+ has, like D^0 and in contrast to D^+ , two types of quasi-two-body decay channels, namely

$$F^+ \begin{cases} \rightarrow \eta \pi^+ \\ \rightarrow K^+ \bar{K}^0 \end{cases}$$

Furthermore, in the charmed baryon sector, one does not expect any large differences in lifetimes. Yet triangular relations for the charmed baryons look quite different from those in the standard model⁹⁾, e.g., for $f_-/f_+ \gg 1$:

$$A(\Lambda_c \rightarrow p \bar{K}^0) - \frac{1}{\sqrt{2}} \left[\sqrt{3} A(\Lambda_c \rightarrow \Lambda \pi^+) + A(\Lambda_c \rightarrow \Sigma^0 \pi^+) \right] = 0 \quad (6)$$

It is important to note that in the scheme sketched above one has to apply the analogous analysis to Cabibbo suppressed decays, either in a four flavour scheme or in a six flavour scheme with small mixing angles¹⁰⁾:

$$\mathcal{L}_{\Delta C \neq \Delta S} \approx \frac{G}{\sqrt{2}} \cos \theta_c \sin \theta_c \left\{ \frac{f_-}{2} \left[(\bar{s}c)(\bar{u}s) - (\bar{u}c)(\bar{s}s) - (\bar{d}c)(\bar{u}d) + (\bar{u}c)(\bar{d}d) \right] + \right. \\ \left. + \frac{f_+}{2} \left[(\bar{s}c)(\bar{u}s) + (\bar{u}c)(\bar{s}s) - (\bar{d}c)(\bar{u}d) - (\bar{u}c)(\bar{d}d) \right] \right\} \quad (7)$$

where the renormalization coefficients f_+ are the same as before. Thus we assume $f_-/f_+ \sim 10$.

In a six flavour scheme there are more contributions to $\mathcal{L}_{\Delta C \neq \Delta S}$. Although they are further suppressed by mixing angles which are expected to be small, this could, in principle, be compensated by an enhancement in the matrix elements ("penguin" diagrams). Yet we follow the authors of Ref. 10) in assuming this to be unlikely.

The most interesting case is provided by the D^+ decays, since according to the scheme under study, the Cabibbo allowed decays of D^+ are suppressed. The question arises as to whether this additional suppression holds also for its Cabibbo suppressed decays¹¹⁾.

The answer is negative: there are four quasi two body decay channels for D^+ , namely " $K^+\bar{K}^0$ ", " $\eta\pi^+$ ", " $\eta'\pi^+$ " and " $\pi^+\pi^0$ ". One can derive very easily that only one of these channels will be further suppressed due to negative interference and that it will be the mode $D^+ \rightarrow \pi^+\pi^0$ (" $\pi^+\pi^0$ " = $\pi^+\pi^0$, $\rho^+\pi^0$, etc.) Thus one finds:

$$\begin{aligned} BR(D^+ \rightarrow K^+\bar{K}^0) : BR(D^+ \rightarrow \eta\pi^+) : BR(D^+ \rightarrow \eta'\pi^+) : BR(D^+ \rightarrow \pi^+\pi^0) \simeq \\ \simeq \quad 1 \quad : \quad \frac{2}{3} \quad : \quad \frac{1}{3} \quad : \quad \sim 0 \end{aligned} \quad (8)$$

One derives, from these relations, various interesting consequences:

i) the transition $D^+ \rightarrow \bar{K}^0\pi^+$ is suppressed by a factor ~ 6 , whereas $D^+ \rightarrow K^+\bar{K}^0, \eta\pi^+$ is exclusively Cabibbo suppressed. Therefore:

$$\frac{BR(D^+ \rightarrow K^+\bar{K}^0, \eta\pi^+)}{BR(D^+ \rightarrow \bar{K}^0\pi^+)} \gg \tan^2 \theta_c \sim 0.05 \quad (9)$$

ii) with even more confidence one can make the analogous prediction for inclusive rates:

$$\frac{BR(D^+ \rightarrow \eta + \pi's)}{BR(D^+ \rightarrow K + \pi's)} \gg \tan^2 \theta_c \quad (10a)$$

$$\frac{BR(D^+ \rightarrow K\bar{K} + \pi's)}{BR(D^+ \rightarrow K + \pi's)} \gg \tan^2 \theta_c \quad (10b)$$

i.e., no drastic Cabibbo suppression.

It is at least amusing to note that while kaons appear in almost all D^0 decays, consistent with Cabibbo suppression¹²⁾

$$BR(D^0 \rightarrow K^\pm X) = 35 \pm 10\%$$

$$BR(D^0 \rightarrow K^0 X) = 57 \pm 26\%$$

it could be quite different for D^+ decays¹²⁾:

$$BR(D^+ \rightarrow K^- X) = 10 \pm 7\%$$

$$BR(D^+ \rightarrow K^0 X) = 39 \pm 29\%$$

These numbers are obviously not conclusive, and it is important to obtain more precise data.

Just as an illustration of our point: if $\Gamma_{NL}(D^+ \rightarrow K + \pi's)$ is suppressed by a factor ~ 6 , then $\Gamma_{NL}(D^+ \rightarrow \eta + \pi's)/\Gamma_{NL}(D^+ \rightarrow K^-/\bar{K}^0 + \pi's) \sim 6 \times \tan^2 \theta_c \sim 0.30$ whereas the data above yield: $BR(D^+ \rightarrow \eta + \pi's, K^+ + X, \pi's) \sim 0.50 \pm 0.36$.

For the D^0 decays one obtains:

$$BR(D^0 \rightarrow K^+ K^-) : BR(D^0 \rightarrow \bar{K}^0 K^0) : BR(D^0 \rightarrow \pi^+ \pi^-) : BR(D^0 \rightarrow \eta \eta) \approx \quad (11)$$

$$\approx \quad 1 \quad : \quad 0 \quad : \quad 1 \quad : \quad \frac{1}{4}$$

At first glance one might think that this ansatz is already ruled out; it predicts $BR(D^0 \rightarrow K^+ K^-)/BR(D^0 \rightarrow \pi^+ \pi^-) \sim 1$ whereas, experimentally, this ratio is around three! Furthermore, naive phase space corrections would only decrease this ratio. Yet such arguments are quite likely fallacious, since they do not properly take into account SU(3) breaking. The numbers given above should apply best to inclusive rates. In the exclusive two body decays SU(3) breaking should play a more prominent role, exemplified by f_π versus f_K ¹³⁾. One can also look at some "analogous" reactions to see whether or not, at an energy $\sim M_D$, the $K^+ K^-$ exclusive channel occupies a larger fraction of the $K\bar{K}$ inclusive channels than does the $\pi^+ \pi^-$ exclusive channel relative to purely pionic channels¹⁴⁾.

It has been observed¹⁵⁾ at ADONE and DCI that about one out of four multi-hadronic events includes a $K\bar{K}$ pair. On the other hand, at these energies one observes¹⁶⁾ $\sigma(e^+ e^- \rightarrow \pi^+ \pi^-) \sim \sigma(e^+ e^- \rightarrow K^+ K^-)$. Thus:

$$\frac{\sigma(e^+ e^- \rightarrow K^+ K^-)}{\sigma(e^+ e^- \rightarrow K\bar{K} + X)} \sim 3 \cdot \frac{\sigma(e^+ e^- \rightarrow \pi^+ \pi^-)}{\sigma(e^+ e^- \rightarrow \pi's)}$$

A similar relation can be derived from $p\bar{p}$ annihilation almost at rest, where one finds¹⁷⁾

$$\frac{\sigma(p\bar{p} \rightarrow \pi^+\pi^-)}{\sigma(p\bar{p} \rightarrow \pi's)} \sim 0.6\% \quad \frac{\sigma(p\bar{p} \rightarrow K_s K_s)}{\sigma(p\bar{p} \rightarrow K_s + X)} \sim 1\%$$

Assuming equal production for all K channels ($K^0\bar{K}^0$, $K^0K^{\pm}$, K^+K^-) one concludes:

$$\frac{\sigma(p\bar{p} \rightarrow K^+K^-)}{\sigma(p\bar{p} \rightarrow K+X)} \sim 2.5 \times \frac{\sigma(p\bar{p} \rightarrow \pi^+\pi^-)}{\sigma(p\bar{p} \rightarrow \pi's)}$$

We present these numbers not to prove that SU(3) breaking effects alone can produce the factor of three in $BR(D^0 \rightarrow K^+K^-)$ versus $BR(D^0 \rightarrow \pi^+\pi^-)$; we only want to point out that they could quite easily explain a large part of the effect. SU(3) breaking presumably does not affect the relative branching ratio of $D^0 \rightarrow K^+K^-$ and $D^0 \rightarrow \eta\eta$ very much. Therefore, experimental information on the latter decay, although not easy to obtain, might be quite interesting.

Another way to "explain" $\tau_{D^+} \gg \tau_{D^0}$ consists in suggesting that the dominant contribution to charm decay is described by the exchange of a weak boson⁴⁾. Unfortunately, since these schemes are rather vague about the origin of this dominance, it is impossible to predict firmly whether the Cabibbo suppressed decays of the D^0 enjoy the same strong enhancement as the Cabibbo allowed ones. One can only say that the most naive argument would lead to the expectation that the ratio between Cabibbo suppressed and allowed decays of D^0 and D^+ (where W exchange is not operative) is still ruled by $\tan^2\theta_c$.

One can easily derive relative branching ratios applying W exchange to these rare D^0 decays:

$$BR(D^0 \rightarrow K^+K^-) : BR(D^0 \rightarrow \bar{K}^0 K^0) : BR(D^0 \rightarrow \pi^+\pi^-) : BR(D^0 \rightarrow \eta\eta) \simeq 1 : \sim \frac{1}{4} : 1 : \sim 0$$

where one assumes that different $q\bar{q}$ pairs are created from the vacuum in the following ratio: $u\bar{u}:d\bar{d}:s\bar{s} \sim 1:1:1 \sim 1/4$ ¹⁸⁾.

As argued above, the ratio $BR(D^0 \rightarrow K^+K^-)/BR(D^0 \rightarrow \pi^+\pi^-)$ is presumably subject to a sizeable increase due to SU(3) symmetry breaking. Therefore, observation of the decay $D^0 \rightarrow \bar{K}^0 K^0$ would be quite interesting for this scheme; yet the experimental prospect for measuring such a channel is rather pessimistic.

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