

QUARK LINE RULE FOR NON-LEPTONIC DECAYS*

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ADDENDUM

A final point concerns the jet structure of events where heavy new mesons (like "B") are produced and decay weakly. If the picture presented here does apply it would be natural to expect two jets in the decay of the meson, which then would give a multi-jet structure to the overall event. Such a mechanism may play a role in the recently discussed three jet effect in e^+e^- annihilation.

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ABSTRACT

We consider the possibility that the recently reported differences in non-leptonic rates of D^+ and D^0 may be a reflection of a "quark line rule" according to which the final state in a weak non-leptonic decay process must be represented by the same number of quarks and anti-quarks as in the initial state. We look for other possible manifestations of the rule and find interesting cases concerning charmed baryon decays, suppression of certain decay modes of "b" particles, and an odd-even pattern for the pionic decay of the D^- meson.

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Weak non-leptonic decays of hadrons continue to provide surprises. Recently there have been indications from different sources [1] of a substantial difference in the lifetimes of the charmed mesons D^+ and D^0 with perhaps $\tau(D^+)/\tau(D^0) \approx 5$. Such results, if confirmed, would be completely in disagreement with any kind of model where the charmed quark in the D decays independently of the up or down quark, which just plays the role of a "spectator". Such a large lifetime difference would show clearly that the decay rate depends strongly on the accompanying light quark.

Another interesting indication from experiment is the report [2] that $D^0 \rightarrow \bar{K}^0 \pi^0$ exists, and with a rate somewhat smaller than that of $D^0 \rightarrow K^- \pi^+$. This is at variance both with predictions that it should be practically zero [3] or that it should be twice as big [4] as $D^0 \rightarrow K^- \pi^+$.

Both of these facts would be explained by assuming predominance of the (strong) isospin $T = \frac{1}{2}$ in the final state. First of all for $T = \frac{1}{2}$ we have $\bar{K}^0 \pi^0 / K^- \pi^+ = \frac{1}{2}$ which would be consistent with the data, and if we take the Gell-Mann-Nishijima formula

$$Q = \frac{S + B}{2} + T_3 \quad (1)$$

we see that if the D^+ decays into a final state of negative strangeness, it must go into $T_3 = 3/2$ final states. Therefore it cannot go into $T = \frac{1}{2}$ final states, while the D^0 can, so we expect

$$\begin{array}{ll} \Gamma(D^{++}) & \ll \Gamma(D^0) \\ \text{non-leptonic} & \text{non-leptonic} \end{array} .$$

Taking this supposition, that in D decay $T = \frac{1}{2}$ final states are dominant, to be true, we might wonder if it is a manifestation of some rule governing non-leptonic charm decays in general.

One obvious description is that "non-exotic" final states are enhanced. We could arrive at this by postulating a "quark line rule" stating that it should be possible to represent the final state by the same number of quarks and anti-quarks as the initial state. That is those final states not having the quantum numbers of $q\bar{q}$ (a quark and an anti-quark) for mesons or qqq for baryons have a reduced amplitude relative to those that do. Assuming this to be a correct characterization of the situation, it is interesting to see what further manifestations it may have.

For the D mesons, as indicated, we expect dominance of $T = \frac{1}{2}$ in D^0 final states, so we also have $\bar{K}^{*0}\pi^0/K^{*-}\pi^+ = \frac{1}{2}$ and so forth [5]. For singly charmed baryons the rule would tell us that in decays (charm) \rightarrow (strange + X) we can only have $T = 0$ or 1, but not $T = 2$ final states, although $T = 2$ is possible via the GIM Hamiltonian. This gives a number of interesting predictions for Σ_c weak decays. Unfortunately these are probably academic since it is reported that Σ_c decays strongly [6] and in any event we expect $\Sigma_c^+ \rightarrow \Lambda_c^+ + \gamma$. We list some anyway, in case the pattern of masses turns out to be different than presently anticipated. The most striking consequence is that the non-leptonic weak decay of Σ_c^{++} is inhibited relatively, since we see from Eq. (1) that it must lead to $T = 2$ final states. Thus we would expect

$$\begin{array}{ccc} \Gamma(\Sigma_c^{++}) & \ll & \Gamma(\Sigma_c^0) \\ \text{non-leptonic} & & \text{non-leptonic} \end{array} \quad (2)$$

or, correspondingly, that Σ_c^{++} would have the larger leptonic branching ratio (since we see no reason for the leptonic decays to depart from conventional expectations). The relative reduction of $T = 2$ final states

would mean that Σ_c^+ weak decay would be predominantly into $T=1$ final states, since from (1), it cannot go into $T=0$ final states. This implies relations like

$$\Sigma_c^+ \rightarrow \Sigma_c^+ \pi^0 / \Sigma_c^+ \rightarrow \Sigma_c^0 \pi^+ \approx 1 \quad (3)$$

Similarly, the absence or suppression of $T=2$ for Σ_c^0 decays would give, for example, the approximate amplitude relation for the Σ_c^0 final states

$$A(\Sigma_c^- \pi^+) - 2A(\Sigma_c^0 \pi^0) + A(\Sigma_c^+ \pi^-) = 0 \quad (4)$$

For Λ_c^+ decays the GIM non-leptonic Hamiltonian itself restricts the final state to $T=1$ so our rule adds nothing.

If Σ_c weak decays are unobservable, we must turn to baryon states that are doubly heavy flavored, such as (ccu, ccd) or (csu, csd). Here the rule for decays with the quantum number change $\bar{c} \rightarrow s$ is simple, giving two statements:

(1) The state of the doublet with the lower charge (containing the d quark) has a relatively enhanced non-leptonic decay rate, or equivalently, a small leptonic branching ratio.

(2) This enhanced non-leptonic rate is into states with $T=1/2$.

Thus

$$(\text{csd})^0 \longrightarrow \frac{\Xi_c^- \pi^+}{\Xi_c^0 \pi^0} \sim \frac{\Sigma_c^+ K^-}{\Sigma_c^0 \bar{K}^0} \sim 2 \quad (5)$$

$$(\text{ccd})^+ \longrightarrow \frac{\Sigma_c^+ D^0}{\Sigma_c^0 D^+} \sim \frac{(\text{csd})^0 \pi^+}{(\text{csu})^+ \pi^0} \sim \frac{\Sigma_c^0 K^+}{\Sigma_c^+ K^0} \sim 2$$

The F^+ meson decay is perhaps the most interesting question in the charm complex, since what we expect depends on the interpretation we give to

our rule. It is true that $F^+ \sim (c\bar{s})$ decay can be represented by the final state $(u\bar{d})$ and in that sense might be "allowed". On the other hand, on a graphical level in the usual theory, it involves the annihilation of a quark pair and if we imagine the rule to mean that graphs with through-going quark lines are "allowed", then we would expect suppression. It will be interesting to see what the F^+ lifetime or leptonic branching ratio is.

Thus far we have fixed our attention on charm decays to final states with net strangeness ("Cabibbo allowed decays"). We would like to consider, briefly, the possible extension of the rule to two other cases: meson decays to totally pionic states and decays of particles containing a "b" quark.

If the rule should apply to particles made with "b", a "bottom" quark with charge $-1/3$, a number of interesting results are obtained. We list some of the most salient ones. For the meson doublet $B^- \sim (b\bar{u})$, $B^0 \sim (b\bar{d})$:

(1) The decay $B^- \rightarrow D + \pi$'s is suppressed relative to that for $B^0 \rightarrow D + \pi$ s, since $(c\bar{q})$ cannot have charge (-1) .

(2) The final states in $B^0 \rightarrow D + \pi$'s, $B^- \rightarrow K + \pi$'s and $B^0 \rightarrow K + \pi$'s have dominantly $T = \frac{1}{2}$, with consequences similar to those mentioned under D decay.

(3) Σ_b^- (charm) + (light quarks) cannot be made with three quarks so that $\Sigma_b^- \rightarrow DN\pi$'s $\ll \Sigma_b^0 \rightarrow DN\pi$'s and similarly for other charm decays of Σ_b^- . Here again these Σ may decay strongly, however.

(4) Favored final states with net charm or strangeness have $T \geq 2$ suppressed.

(5) For the doubly heavy flavored doublets [(bbu), (bbd), (bcu), (bcd) ...] a quantum number change involving a decrease in the charge of the isospin-zero quarks ($c \rightarrow s$) favors the non-leptonic decay of the lower (d quark) member of the doublet. While conversely an increase ($b \rightarrow c$) favors the upper member. The favored decays have $T = \frac{1}{2}$. (See the discussion around eq. (5).) For no change ($b \rightarrow s$) both are equally favored and the final state has $T = \frac{1}{2}$.

Finally, let us consider the possibility that the rule applies to totally pionic final states, for decays like $D \rightarrow \pi$'s, $B \rightarrow \pi$'s. Since the states is to be reducible to $\bar{q}q$ it must have $T = 0$ or 1. Since $\pi^+ \pi^0$ in the s-wave has $T = 2$, we would expect $D^+ \rightarrow \pi^+ \pi^0 \ll D^0 \rightarrow \pi\pi$, or $B^+ \rightarrow \pi^+ \pi^0 \ll B^0 \rightarrow \pi\pi$ (with spin zero D and B). Furthermore, $T = 0$ cannot hold for a charged state so D^+ , B^+ pionic final states would be dominantly $T = 1$. We reach an interesting conclusion if we further consider the angular momentum configurations possible for the $\bar{q}q$ pair: 1S_0 and 3P_0 . These both have charge conjugation $C = +$ for the neutral member, so that with $T = 1$, the G parity is odd. Thus for D^+ , B^+ decaying directly into pionic states, odd number of pions should dominate over even numbers.

Concerning "Cabibbo suppressed" decays in general, we note that if the recently discussed "penguin graph mechanism" [7] is taken to dominate, our conclusions will apply, since the mechanism satisfies our rule.

A basic explanation of the "rule" — if it is indeed correct — does not seem entirely obvious. We might suppose that since strong interaction forces are strong and attractive in non-exotic channels that some sort of final state enhancement increases these rates. A factor five seems

rather large for such an explanation, however. On a diagrammatic level the rule could be given by supposing that the graph where the weak W boson is exchanged between the existing quarks is dominant [8]. It is then readily seen that such a graph is allowed for the D^0 but not the D^+ , and that it leads to $T = \frac{1}{2}$ final states. For the two body decay modes in fact none of the other simple graphs give the correct pattern for the three rates involved. This "simple W exchange dominance" on the other hand needs an explanation itself, and if imagined as a general principle, would not explain the $\Delta T = \frac{1}{2}$ rule for strange particles; in fact Σ_S^- decay would be suppressed. On the other hand, the rule that the number of quark lines does not change is compatible with $\Delta T = \frac{1}{2}$ rule phenomenology, although it may not explain it without further assumptions.

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