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Weak decays of hadrons reveal compositeness of quarks

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Considering the latest available data from the Particle Data Group this work shows that leptonic, semileptonic and nonleptonic weak decays of hadrons reveal the compositeness of quarks and provides a reasonable explanation for the apparent null results of quark compositeness and argues that, actually, primons (prequarks) have already been found by some important experiments such as EMC, SMC, SLAC E143 and HERMES.

Keywords: prequarks; new SU(2), hadronic weak decays, Kobayashi-Maskawa matrix.

1. INTRODUCTION

Cabibbo[1] theory and its extensions (GIM mechanism[2] and Kobayashi-Maskawa matrix[3]) describe very well the weak decays of hadrons. It even became common practice to indicate the so-called Cabibbo factor in particle data of hadronic weak decays.

On the other hand, taking into account the data of Hofstadter and Hermann[4] on the charge distributions in the proton and in the neutron de Souza[5-15] has proposed that quarks are composite under a new SU(2) based on a new hypercharge named Σ whose projections are $\Sigma_3 = 0,-1,+1$ for quarks as shown on the table below

	I_3	Σ_3
c,t	0	+1
u	+1/2	0
d	−1/2	0
s,b	0	−1

(where I_3 is isospin) or by the diagram

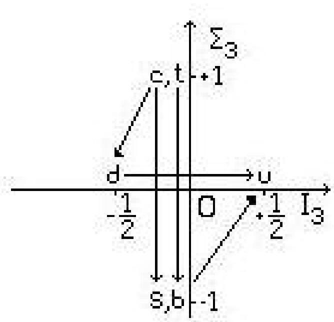

Figure 1. Diagram that shows how the decays of quarks are related to a new hypercharge and to isospin. It is directly related to the Kobayashi-Maskawa matrix.

These values of Σ_3 and I_3 were obtained considering that quarks are composed of primons according to the scheme shown on the following tables

Table.1. Generation of colors from supercolors

	α	β	γ
α		blue	green
Β	blue		red
γ	green	red	

Table 2. Electric charges of primons

Superflavor	charge
p_1	$+5/6$
p_2	$-1/6$
p_3	$-1/6$
p_4	$-1/6$

Table 3. Composition of quark flavors

	p_1	p_2	p_3	p_4
p_1		u	c	t
p_2	u		d	s
p_3	c	d		b
p_4	t	s	b	

By applying the formula

$$Q = I_3 + \frac{1}{2}(B + \Sigma_3) \quad , \qquad (1)$$

for primons with I_3=1/4 and B=1/6 and the above numbers for Q we obtain the Σ_3 assignments for primons which are summarized below

	I_3	Σ_3
p_1	$+\frac{1}{4}$	$+1$
p_j $(j = 2,3,4)$	$+\frac{1}{4}$	-1
	$-\frac{1}{4}$	0

These above values of Σ_3 and I_3 of primons yield the values of Σ_3 and I_3 for quarks shown on the first table.

2. SEMILEPTONIC DECAYS OF LIGHT BARYONS

The Cabibbo factors for the $J^P = \frac{1}{2}^+$ semileptonic decays of baryons (with u, d and s quarks) are shown below. Taking into account the above values of Σ_3 of quarks we obtain that transitions with Cabibbo factor $\cos\theta_c$ have $\Delta\Sigma_3 = 0$ and those with Cabibbo factor $sen\theta_c$ have $\Delta\Sigma_3 = +1$ (all the data below on branching ratios and decay modes were taken from Particle Data Group[16]).

Decay	Cabibbo factor	$\Delta\Sigma_3$
$n \to p$	$\cos\theta_c$	0
$\Sigma^+ \to \Lambda$	$\cos\theta_c$	0
$\Sigma^- \to \Lambda$	$\cos\theta_c$	0
$\Sigma^- \to \Sigma^0$	$\cos\theta_c$	0
$\Lambda \to p$	$\mathrm{sen}\,\theta_c$	+1
$\Sigma^- \to n$	$\mathrm{sen}\,\theta_c$	+1
$\Xi^- \to \Lambda$	$\mathrm{sen}\,\theta_c$	+1
$\Xi^- \to \Sigma^0$	$\mathrm{sen}\,\theta_c$	+1
$\Xi^0 \to \Sigma^+$	$\mathrm{sen}\,\theta_c$	+1
$\Xi^- \to \Xi^0$	$\cos\theta_c$	0

Thus, the selection rule for $J^P = \frac{1}{2}^+$ baryonic semileptonic decays are given by the above values of $\Delta\Sigma_3$ and there is, therefore, a complete relation between $\Delta\Sigma_3$ and the Cabibbo factors.

3. NONLEPTONIC DECAYS OF LIGHT BARYONS

The nonleptonic decays of light baryons (with u, d and s quarks) are shown below

Decay	Branching ratio
$\Lambda \to p\pi^-$	63.9%
$\Lambda \to n\pi^0$	35.8%
$\Sigma^+ \to p\pi^0$	51.6%
$\Sigma^+ \to n\pi^+$	48.3%
$\Sigma^- \to n\pi^-$	99.9%
$\Xi^0 \to \Lambda\pi^0$	99.5%
$\Xi^- \to \Lambda\pi^-$	99.9%
$\Omega^- \to \Xi^0\pi^-$	67.8%
$\Omega^- \to \Xi^-\pi^0$	23.6%
$\Omega^- \to \Lambda K^-$	8.6%

All these decays have $\Delta\Sigma_3 = +1$ and $|\Delta I_3| = \frac{1}{2}$. What about the other decays with very small branching ratios? They have different values for $\Delta\Sigma_3$. For example, $\Omega^- \to \Lambda\pi^-$, $\Xi^0 \to p\pi^-$, $\Xi^- \to n\pi^-$ have $\Delta\Sigma_3 = +2$ and $\Delta I_3 = -1$, and $\Xi^0 \to p\pi^-$ has $\Delta\Sigma_3 = +2$ and $\Delta I_3 = 0$.

4. NONLEPTONIC DECAYS OF HEAVY BARYONS

The data of heavy flavors with the b quark are still very scarce. We discuss preliminary results of Λ_b^0 only. With c quark we will consider $\Lambda_c{}^+$, $\Xi_c{}^+$, $\Omega_c{}^0$ and $\Xi_c{}^0$.

4.1. $\Lambda_c{}^+$

Let us first consider the nonleptonic decays of $\Lambda_c{}^+$ with branching ratios larger than 1%:

Decay	Branching ratio
$p\overline{K}^0$	2.3%
$pK^-\pi^+$	5.0%
$p\overline{K}^*(892)^0$	1.6%
$\Lambda(1520)\pi^+$	1.8%
$p\overline{K}^0\pi^0$	3.3%
$p\overline{K}^0\eta$	1.2%
$p\overline{K}^0\pi^+\pi^-$	2.6%
$pK^-\pi^+\pi^0$	3.4%
$pK^*(892)^-\pi^+$	1.1%
$\Lambda\pi^+$	1.01%
$\Lambda\pi^+\pi^0$	3.6%
$\Lambda\rho^+$	<5%
$\Lambda\pi^+\pi^+\pi^-$	2.6%
$\Sigma^0\pi^+$	1.04%
$\Sigma^+\pi^0$	1.0%
$\Sigma^-\pi^+\pi^+$	1.9%
$\Sigma^0\pi^+\pi^0$	1.8%
$\Sigma^+\omega$	2.7%

All these decays have $\Delta\Sigma_3 = -2$ and $\Delta I_3 = +1$ and show that Σ_3 is a very important quantum number. Let us analyze now those decays with very small branching ratios which are listed below

Decay	Branching ratio	$\Delta\Sigma_3$	ΔI_3
$p\pi^+\pi^-$	3.5×10^{-3}	-1	+1/2
$p\phi$	8.2×10^{-4}	-1	+ ½
$\Xi^0 K^+$	3.9×10^{-3}	-2	+1
$\Xi^-\pi^+\pi^+$	4.9×10^{-3}	-2	+1
ΛK^+	7.5×10^{-4}	-1	+1/2
$\Sigma^0 K^+$	5.8×10^{-4}	-1	+1

The data show that up to branching ratio of about 10^{-3} there is still a tendency to have $\Delta\Sigma_3 = -2$ and $\Delta I_3 = +1$. The Cabibbo suppressed decay $pK^+\pi^-$ whose branching ratio is $< 2.3\times20^{-4}$ has $\Delta\Sigma_3 = 0$ and $\Delta I_3 = 0$. Again, we see that the consistency is quite impressive.

4.2. Ξ_c^+

Let us consider the data with branching ratios above 0.1%

Decay	Branching ratio
$\Sigma(1385)^+\overline{K}^0$	1.0%
$\Lambda K^-\pi^+\pi+$	0.323%
$\Sigma^+ K^-\pi^+$	0.94%
$\Sigma^+\overline{K}^*(892)^0$	0.81%
$\Sigma^0 K^-\pi^+\pi^+$	0.29%
$\Xi^0\pi^+$	0.55%
$\Xi^-\pi^+\pi^+$	1%
$\Xi^0\pi^+\pi^0$	2.34%

All the above decays have $\Delta\Sigma_3 = -2$ and $\Delta I_3 = +1$ showing once more the same consistency. The Cabibbo suppressed modes

Decay	Branching ratios	ΔI_3
$pK^-\pi^+$	0.21%	-1/2
$p\overline{K}^*(892)^0$	0.12%	+1/2
$\Sigma^+K^+K^-$	0.15%	+1/2
$\Sigma^+\phi$	<0.11	+1/2

have $\Delta\Sigma_3 = -1$, and ΔI_3 as shown above.

4.3. $\Xi_c^{\ 0}$

In this case the branching ratios are not known yet. The modes listed below have been seen and thus, most probably they are Cabibbo allowed decays: $pK^-K^-\pi^+$, $\Lambda\overline{K}^0\pi^+\pi^+$, $\Xi^-\pi^+$, Ω^-K^+, $\Lambda K^-\pi^+\pi^+\pi^-$, $\Xi^-\pi^+\pi^+\pi^-$, $pK^-\overline{K}^*(892)^0$. These decays have also $\Delta\Sigma_3 = -2$ and $\Delta I_3 = +1$. The other nonleptonic decay that has been seen ΛK_S^0 is either incomplete or is Cabibbo suppressed because it has $\Delta\Sigma_3 = 0$.

4.4. Ω_c^0

In this case also the branching ratios have not yet been determined and thus the following decays that have been seen are, probably, Cabibbo allowed decays because all of them have $\Delta\Sigma_3 = -2$ and $\Delta I_3 = +1$: $\Sigma^+K^-K^-\pi^+$, $\Xi^0K^-\pi^+$, $\Xi^-K^-\pi^+\pi^+$, $\Omega^-\pi^+$, $\Omega^-\pi^+\pi^0$, $\Omega^-\pi^-\pi^+\pi^+$.

4.5. Λ_b^0

There are just some known decays and just some of them have known branching ratios. The nonleptonic decays that have been established (but without definite branching ratios) are $\Lambda_c^+\pi^-$ and $\Lambda_c^+a_1(1261)^-$ with $\Delta\Sigma_3$=+2, $\Delta I_3 = -1$. This is consistent with Fig. 1.1 and with what has been discussed up to now. Therefore, we expect that the other yet to be found nonleptonic decays will follow this pattern. The other three known nonleptonic decays $p\pi^-$, pK^- and $\Lambda J/\Psi(1s)$ which have $\Delta\Sigma_3 = +1$, 0 and 0, respectively, have branching ratios below 10^{-3} %.

The two known semileptonic decays $\Lambda_c^+l^-\overline{\nu}_l$ and $\Lambda_c^+\pi^+\pi^-l^-\overline{\nu}_l$ have branching ratios of 5% and 5.6%, respectively and $\Delta\Sigma_3 = +2$, $\Delta I_3 = 0$. We also expect the other semileptonic decays to behave in the same way.

5. LEPTONIC, SEMILEPTONIC AND NONLEPTONIC DECAYS OF MESONS

The decays of mesons also reveal what was shown above with distinct features depending on the nature of the decay, either leptonic or nonleptonic.

5.1. LEPTONIC AND NONLEPTONIC DECAYS of light UNFLAVORED MESONS

All the decays either leptonic or nonleptonic of light unflavored mesons have $\Delta\Sigma_3 = 0$, $\Delta I_3 = 0$.

5.2. LEPTONIC AND NONLEPTONIC DECAYS of KAONS

All the decays of K^+, K^-, K^0 and $\overline{K}^0$ either leptonic, semileptonic or nonleptonic have $|\Delta\Sigma_3| = +1$, $|\Delta I_3| = 1/2$.

5.3. LEPTONIC AND NONLEPTONIC DECAYS of CHARMED MESONS

Charm quark decays may be either leptonic ($c \to sl^+\nu_l$, $c \to dl^+\nu_l$) or nonleptonic ($c \to su\bar{d}$, $c \to du\bar{d}$, $su\bar{s}$, $c \to du\bar{s}$) as shown on the table below in which we are indicating also the values of $\Delta\Sigma_3$ and ΔI_3.

Decay	Cabibbo factor	Examples	$\Delta\Sigma_3$	ΔI_3
(leptonic) $c \to sl^+\nu_l$	$\cos^2\theta_C$	$D^+ \to \bar{K}^0 l^+\nu_l$, $D^0 \to K^- l^+\nu_l$, $D_s^+ \to l^+\nu_l$	-2	0
(leptonic) $c \to dl^+\nu_l$	$\sin^2\theta_C$	$D^+ \to l^+\nu_l$, $D_s^+ \to K^0 l^+\nu_l$	-1	-1/2
(nonleptonic) $c \to su\bar{d}$	$\cos^4\theta_C$	$D^+ \to \bar{K}^0(n\pi)^+$, $D^0 \to K^-(n\pi)^+, \bar{K}^0(n\pi)^0$, $D_s^+ \to \eta\pi^+$	-2	+1/2
(nonleptonic) $c \to du\bar{d}$, $su\bar{s}$	$\sin^2\theta_C\cos^2\theta_C$	$D \to n\pi$, $D_s^+ \to K\pi$	-1	+1/2
(nonleptonic) $c \to du\bar{s}$	$\sin^4\theta_C$	$D^+ \to K^+\pi^0$, $K^0(n\pi)^+$, $D^0 \to K^+(n\pi)^-$, $K^0(n\pi)^0$, $D_s^+ \to K^+K^0$	0	0

We note again a quite strong consistency with what was presented above and we observe again that there is a clear and direct correlation between the Cabibbo factors and the values of $\Delta\Sigma_3$ and ΔI_3. Again we see that the most favorable decays have $\Delta\Sigma_3 = -2$.

5.4. DECAYS of beauty MESONS

5.4.1. B^+ and B^0

A better analysis demands more experimental data but we expect modes with $\Delta\Sigma_3 = -2$ to be favored. And indeed the decays $B^+ \to \bar{D}^0 l^+\nu_l$, $B^+ \to \bar{D}^*(2007)^0 l^+\nu_l$, which have $\Delta\Sigma_3 = -2$, $\Delta I_3 = 0$ have high branching ratios (2.15% and 6.5%, respectively), and $B^+ \to \bar{D}^0\rho^+$ which has $\Delta\Sigma_3 = -2$ and $\Lambda I_3 = +1$ has a branching ratio of 1.34%. And moreover, between the two inclusive decays $B^+ \to D^0 X(\Delta\Sigma_3 = 0)$ and $B^+ \to \bar{D}^0 X(\Delta\Sigma_3 = -2)$ we expect the latter to be favored for $\Delta\Sigma_3(X) = 0$ and indeed their branching ratios are, respectively, 9.8% and 79%. The same holds between the inclusive modes

$B^+ \to D^+ X\,(\Delta\Sigma_3 = 0)$ and $B^+ \to D^- X\,(\Delta\Sigma_3 = -2)$ whose branching ratios are 3.8% and 9.8%, respectively, and between the inclusive decays $B^+ \to cX\,(\Sigma_3 = 0)$ and $B^+ \to \bar{c}X\,(\Delta\Sigma_3 = -2)$ that have branching ratios 33% and 98%, repectively.

The same behavior is observed for B^0. The two semileptonic decays $D^*(2010)^- l^+ \nu_l$ and $\overline{D}{}^0 \pi^+ l^= \nu_l$, with respective branching ratios of 2.12% and 5.35%, have $\Delta\Sigma_3 = -2$. And the inclusive modes present the same behavior: $\overline{D}{}^0 X\,(\Delta\Sigma_3 = -2)$ is favored with respect to $D^0 X\,(\Delta\Sigma_3 = 0)$ and this goes hand in hand with respect to their branching ratios which are, respectively, 51% and 6.3%. The same holds for the inclusive modes $B^0 \to \bar{c}X\,(\Delta\Sigma_3 = -2)$ and $B^0 \to cX\,(\Delta\Sigma_3 = 0)$ whose branching ratios are 104% and 24%, respectively. The inclusive mode $B^0 \to K^\pm anything$ has a branching ratio of 78% but, since $B^0 \to K^+ anything$ has $\Delta\Sigma_3 = 0$ while $B^0 \to K^- anything$ has $\Delta\Sigma_3 = -2$ the latter should be favorable with respect to first one whenever $\Delta\Sigma_3(anything) = 0$.

5.4.2. B_s^0

Considering in Fig. 1 the vertical transitions between b and s quarks and since $B_s^0 = s\bar{b}$ has $\Sigma_3 = 0$ in order to have $|\Delta\Sigma_3| = +2$ we expect that the favorable decays to be $B_s^0 \to D_s^- anything$ and $B_s^0 \to D_s^+ anything$ (with $\Delta\Sigma_3(anything) = 0$), and indeed, the decays $B_s^0 \to D_s^- anything$ have a branching ratio of $(90 \pm 30)\%$ and the $D_s^{(*)+} + D_s^{(*)-}$ decays have a branching ratio of $\left(23\begin{matrix}+21\\-13\end{matrix}\right)\%$ because $D_s^- = \bar{c}s$ has $\Sigma_3 = -2$ and $D_s^+ = c\bar{s}$ has $\Sigma_3 = +2$.

6. WHY QUARK COMPOSITENESS HAS NOT YET BEEN ESTABLISHED?

Quark compositeness has not yet been established due to misinterpretations of data because of the strength and solidity of the quark model and of QCD. Hofstadter and Hermann[4] had already shown in 1961 that the proton and the neutron have a common positive core. They were the first to see primons (the name given to the above prequarks) before the discovery of quarks.

The quark model (and QCD) has described hadrons so well since the 1960´s, that it overshadowed Hofstadter and Hermann results. The accommodation of several experimental results with the theory forced the adoption of two kinds of quarks, valence quarks and constituent quarks, the first ones being almost massless.

But the results of SLAC E143 Collaboration[17] and of SMC[18] in 1988 showed that something is not right in the description of the nucleon because quarks account for only half of the total nucleon spin. Their results were also confirmed by the subsequent data of EMC[19] in 1989 and HERMES in 2007[20]. This constitutes the so-called proton spin puzzle. The puzzle is a consequence of the quark model itself, that is, it is a consequence of considering that a nucleon is composed of three massless quarks that acquire mass by some mechanism and thus we have at the same time massless quarks and constituent quarks. These massless quarks are the ones that have been found in DIS experiments surrounded by a quark sea. As has been argued by de Souza[15] we solve the proton spin puzzle and reconcile the Hofstadter and Hermann data with the idea of constituent and valence quarks if we admit that quarks are composed of two primons (prequarks) which are almost massless. The combination of two of them form a particular quark (please, see the picture below). In this picture the proton is composed of two layers of primons, each one having three primons. And thus the inner layer is what high energy DIS experiments have identified as being massless quarks. The other three primons of the outer layer have not been identified because, as they are very light and are somewhat loose, they get blurred into the quark sea. And thus according to this picture constituent quarks are the true quarks and valence quarks are primons, actually. **And the spin puzzle is solved because the outer layer of primons yields the other half of the proton spin. In this way we solve also the problem of the lack of quark momenta in the nucleon.**

How can we interpret the D0 collaboration21 data that concluded that “there is no evidence for quark compositeness below an energy scale of about 2 TeV”? Although D0 says below 2TeV the experiment only probed the very high energy scale, that is, **D0 found that primons are not composite (the three inner primons to be precise)**. According to de Souza´s picture of the proton the average size of u and d quarks is about 0.5fm which agrees well with the results of Povn and Hüfner[22].

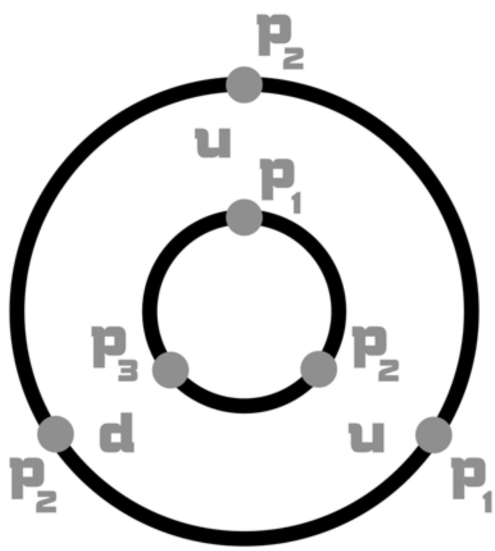

Figure 2. The proton in terms of quarks and primons

7. CONCLUSION

All the various decays above mentioned clearly indicate that Σ_3 is a fundamental quantum number, and together with I_3, describe very well the weak decays of hadrons and is a very important tool for predicting the yet to be found decays of heavier hadrons.

The existence of this quantum number indicates that quarks are composite and thus, taking into account the results of the D0 collaboration we can say that quarks are not small at all. We should probe further the (1-10) GeV scale with more insight taking into account the above picture of the nucleon. At the TeV scale or higher energies maybe we will indirectly find primons too. **The LHC data will produce lots of heavy hadrons and we will see that they will obey selection rules dictated by the values of Σ_3 and I_3.**

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