# Nature of weak hadron currents

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The form of weak hadron currents, both charged and neutral, is obtained within the framework of $SU(4)$ symmetry with allowance for the experimental situation. The currents for charmed particles have a form that differs significantly from that previously assumed.

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The introduction of unitary symmetry into hadron physics has led to the Cabibbo theory for weak interactions, which describes well the experimental data. We recall that the main premises of the Cabibbo theory were the hypothesis that the weak currents belong to the $SU(3)$ octet, the hypothesis of charge algebra, and the hypothesis of universality of weak interactions for leptons and hadrons. This makes it possible to fix the scale of the coefficients of the currents with different transitions relative to the weak lepton-current constant $G$. Any weak-interaction theory must also satisfy the principles indicated above. The indirect experimental indications of the existence of the charmed quark $p'$ uncover a large class of new phenomena in elementary-particle physics. Among the possibilities of including charm in the hadron scheme, one of the principal ones is the $SU(4)$ group. It is natural here to consider also weak interactions within the framework of this group. Such a program was carried out in[1]. Namely, we assume that weak hadron currents belong to a regular representation of $SU(4)$, and that it is also possible to mix the singlet and the 15-plet when constructing the diagonal (in the sense of $SU(4)$) neutral currents. The basic premise is contained in the algebra of the zeroth components of the currents within the framework of the $SU(4)\times SU(4)$ group. In the language of transformation properties, two types of weak hadron currents were obtained. We shall henceforth refer to the solutions (7) and (7′) of[1] as solutions I and II, respectively. In case I, automatic absence of a strangeness-changing neutral current was demonstrated. By the same token, a certain artificiality of the introduction of $p'$ to suppress $J^3_{8\mu}$, as was done in the GIM model, was eliminated. In the proposed analysis, it is also possible to take into account a wider class, for example, to include in the scheme currents with violation of $CP$ invariance, i.e., currents in the form $J^3_{7\mu}$ and $J^3_{10\mu}$. This can be done by allowing the coefficients a, b, c, and d to be complex. The results of the analysis will be published elsewhere.

In the Cabbibo analysis, the $V{-}A$ variant of hadron currents is taken as a natural assumption. We do not introduce this limitation and investigate the following form of the current:

$$J^{\pm}_{\mu} = a V_{\mu}^{1\pm i2} + a' A_{\mu}^{1\pm i2} + b V_{\mu}^{4\pm i5} + b' A_{\mu}^{4\pm i5} + c V_{\mu}^{11\mp i12}$$

$$+ c' A_\mu^{11 \mp i12} + d V_\mu^{13 \mp i14} + d' A_\mu^{13 \mp i14} \quad . \tag{1}$$

The requirements imposed on the form of the current (1) are the same as in[1]. It is useful to introduce the following combinations of the coefficients:

$$A = \frac{1}{2}(a + a'),\quad B = \frac{1}{2}(b + b'),\quad C = \frac{1}{2}(c + c'),\quad D = \frac{1}{2}(d + d'),$$
$$A_1 = \frac{1}{2}(a - a'),\quad B_1 = \frac{1}{2}(b - b'),\quad C_1 = \frac{1}{2}(c - c'),\quad D_1 = \frac{1}{2}(d - d'). \tag{2}$$

As a result of the foregoing requirements, we obtain for the coefficients (2) two independent systems of equations, one for the set $\mathfrak{A} \equiv \{A, B, C, D\}$ and the other for the set $\mathfrak{A}_1 \equiv \{A_1, B_1, C_1, D_1\}$. There are two nontrivial solutions for each of the sets $\mathfrak{A}$ and $\mathfrak{A}_1$. Both solutions, obviously, are the same as solutions I and II. There are therefore four sets of coefficients in the current (1). The requirement governing the choice between the sets will be, as before, the best possible agreement with the present-day experimental situation. Again, just as in[1], it is convenient for the subsequent analysis to represent the coefficients in the form of trigonometric quantities. *Taking solution* I *for* $\mathfrak{A}$ *and* $\mathfrak{A}_1$, *we obtain variant* I *of*[1], *or the* GIM *model, whereas the solution* II *for* $\mathfrak{A}$ *and* $\mathfrak{A}_1$ *gives solution* II *of*[1].

Let us consider now the following combination of solutions: II for $\mathfrak{A}$ and I for the set $\mathfrak{A}_1$. As a result we obtain for the coefficients in the expression for the current the following set:

$$\begin{aligned}
a &= \cos\alpha\cos\beta + \cos\theta_c, & c &= \cos\alpha\sin\beta - \sin\theta_c,\\
a' &= \cos\alpha\cos\beta - \cos\theta_c, & c' &= \cos\alpha\sin\beta + \sin\theta_c,\\
b &= \sin\alpha\cos\beta + \sin\theta_c, & d &= \sin\alpha\sin\beta + \cos\theta_c,\\
b' &= \sin\alpha\cos\beta - \sin\theta_c, & d' &= \sin\alpha\sin\beta - \cos\theta_c.
\end{aligned} \tag{3}$$

The designation $\theta_c$ (the Cabbibo angle) will be justified below. One of the main requirements imposed on the structure of the current (1) is conservation of the Cabbibo current for ordinary particles. In this case currents of charmed particles do not remain arbitrary, and the requirement indicated above imposes on them definite limitations. We shall satisfy this requirement by putting $\beta = \pi/2$ in (3).

Strict equality is not plausible from the experimental point of view. Moreover, the possibility of making $\cos\beta$ different from zero must be regarded as one of the advantages of the present analysis. In this way we can, for example, obtain a correct ratio of the vector constants $G_\mu$ and $G_n$ of the $\mu$ and $\beta$ decays. In the GIM model, strict equality is essential. The next restriction on the coefficients is obtained by considering the experimental consequences of the neutral current obtained by us in the proposed scheme. This current takes the form

$$\begin{aligned}
J_\mu^3 = {} & V_{3\mu}^3[2(A^2 + A_1^2) + B^2 + B_1^2 + C^2 + C_1^2]\\
& + A_{3\mu}^3[2(A^2 - A_1^2) + B^2 - B_1^2 + C^2 - C_1^2]\\
& - 2V_{6\mu}^3[AB + A_1B_1 + CD + C_1D_1] - 2A_{6\mu}^3[AB - A_1B_1 + CD - C_1D_1]\\
& + V_{8\mu}^3\left[\sqrt{3}(B^2 + B_1^2) - \frac{1}{\sqrt{3}}(C^2 + C_1^2) + \frac{2}{\sqrt{3}}(D^2 + D_1^2)\right]\\
& + A_{8\mu}^3\left[\sqrt{3}(B^2 - B_1^2) - \frac{1}{\sqrt{3}}(C^2 - C_1^2) + \frac{2}{\sqrt{3}}(D^2 - D_1^2)\right]\\
& + 2V_{9\mu}^3[AC + A_1C_1 + BD + B_1D_1] + 2A_{9\mu}^3[AC - A_1C_1 + BD - B_1D_1]\\
& - 2\sqrt{\frac{2}{3}}V_{15\mu}^3[C^2 + C_1^2 + D^2 + D_1^2] - 2\sqrt{\frac{2}{3}}A_{15\mu}^3[C^2 - C_1^2 + D^2 - D_1^2].
\end{aligned} \tag{4}$$

It is known from experiment that processes in which the currents $J_{6\mu}^3$ take part are strongly suppressed. Expressing the coefficients obtained in (4) in terms of trigonometric parameters, we obtain $\sin 2\alpha$ in the current $J_{6\mu}^3$. It is obvious that to satisfy the experimental data we must put $\sin 2\alpha \ll \sin\theta_c$ without contradicting all the facts known concerning weak hadron interaction. We again do not require the strict equality $\alpha = 0$. What can we expect from analogous interactions with participation of charmed particles? Calculating the coefficient of the current $J_{9\mu}^3$ we obtain for it the value $\sin 2\beta$. It turns out that the conditions imposed on the form of the charged current for ordinary particles automatically necessitate strong suppression of neutral interactions with change of charm, since $\beta \approx \pi/2$.

As a result, current (1), which does not contradict the known experiments, has the following coefficient:

$$\begin{aligned}
a &= \cos\theta_c, & a' &= -\cos\theta_c, & b &= \sin\theta_c, & b' &= -\sin\theta_c,\\
c &= 1 - \sin\theta_c, & c' &= 1 + \sin\theta_c, & d &= \cos\theta_c, & d' &= -\cos\theta_c.
\end{aligned} \tag{5}$$

The solution (5) leads to immediate experimental consequences. It alters significantly the proposed picture of creation and decay of charmed particles. In addition, it was assumed that $n \leftrightarrow p'$ transitions are suppressed by the coefficient $\sin\theta_c$, whereas the transi- $p' \leftrightarrow \lambda$ had the coefficient $\cos\theta_c$. From this it was concluded that production of charmed particles must be accompanied by a strange particle. From the expression for the current obtained in the present paper it is seen that weak charmed nonstrange particle production processes, which are proportional to $1 \pm \sin\theta_c$, will proceed at the same intensity as processes with charmed strange particles, where the coefficient is $\cos\theta_c$ as before. The same holds also for the corresponding decays. The consequences for nonleptonic interactions in the "current ⊗ current" scheme are also of interest. In the GIM model all the representations 20″ and 84 remained in the 15 ⊗ 15 expansion. The current with the coefficients (5) has no such property—the representation 15 is present in the expansion of the product of the current. It seems natural now to establish for nonleptonic decays selection rules that are based on 15-dominance, in complete analogy with the octet enhancement of $SU(3)$ theory. Details of the analysis of nonleptonic decays call for a separate investigation.

There is no doubt that the results did not require any model representations whatever and are based on profound and verified principles of the physics of hadron interactions and on contemporary experiments. This gives grounds for hoping that the consequences that follow from the results will be verified experimentally.

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[1]G. G. Volkov, A. G. Liparteliani, and F. F. Tikhonin, Preprint 75–103, Institute of High Energy Physics, Serpukhov, 1975.