Classification and J^{PG} Selection Rules for Weak Currents

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(Received 24 July 1987)

Four categories are defined of exotic and nonexotic first-class and second-class weak currents, three of which are suppressed in the standard model. Hadronic final states produced through various symmetry-breaking mechanisms are subject to selection rules which govern their allowed values of J^{PG}. We show that there are four types of suppressed transitions and give examples of each.

PACS numbers: 12.15.Ji, 11.30.Er, 13.35.+s, 13.38.+c

It is well known that weak charged currents can be classified as first or second class according to their transformation under G parity, and that second-class currents are suppressed in the standard model.[1] The standard model describes the coupling of the W and Z^0 bosons to the quark sector by an operator which is bilinear in the quark fields and describes the decay of a weak boson into a quark-antiquark pair. This coupling cannot create a state in the quark sector with quantum numbers that do not exist in the quark-antiquark system and cannot be produced by any bilinear product of quark fields. Such states have been called "exotic" in hadron spectroscopy; they do not exist in the quarkonium spectrum, and there is still no evidence in the hadron spectrum for states with these quantum numbers.

There has been extensive discussion of possible weak transitions in the hadronic sector with the quantum numbers of a second-class current, produced by various symmetry-breaking mechanisms.[2-4] However, there has been little if any discussion of exotic suppression and the role of the exotic-nonexotic classification in hadronic symmetry breaking. In this paper we consider the G parity and exotic classifications of weak currents together and show that useful selection rules are obtained for the different symmetry-breaking mechanisms.

We first note that only first-class nonexotic currents are found in lowest order in the standard model, and that three different kinds of suppressed transitions can be defined; namely first-class exotic, second-class nonexotic, and second-class exotic. Such suppressed transitions can be produced by various symmetry-breaking mechanisms, including radiative corrections, quark mass differences, and isospin violation in the hadronic sector. We do not consider CP nonconservation here, as it is a small effect and we are concerned with the possible existence of suppressed CP-conserving transitions at a level considerably higher than the observed CP nonconservation.

Since W decays can produce mesonic states with values of total angular momentum $J=0$ and $J=1$, we now consider all possible $J=0$ and $J=1$ states and classify them into the following four categories: First-class nonexotic (allowed):

$$J^{PG}=0^{--}\ (\pi),$$
$$1^{-+}\ (\rho),$$
$$1^{+-}\ (a_1).$$

First-class exotic (suppressed):

$$J^{PG}=0^{++}\ (p\text{-wave } \omega a_0).$$

Second-class nonexotic (suppressed):

$$J^{PG}=0^{+-}\ (a_0),$$
$$1^{++}\ (b_1).$$

Second-class exotic (suppressed):

$$J^{PG}=0^{-+}\ (s\text{-wave } \pi a_0),$$
$$1^{--}\ (p\text{-wave } \eta\pi).$$

We have noted examples of the meson states with each particular set of J^{PG} quantum numbers.

We now consider weak decay processes in which a W creates a hadronic state with these quantum numbers out of the vacuum. The most probable symmetry-breaking mechanisms in the hadronic sector which can lead to any of these three types of suppressed transitions can be divided into two categories: (1) Symmetry breaking at the weak vertex, due to the u-d mass difference, radiative corrections, or any other effect which breaks the symmetry of a three-point $Wq\bar{q}$ vertex but leaves the transition proceeding via an intermediate $q\bar{q}$ state. We do not consider symmetry breaking by a complicated weak vertex which is not bilinear in the quark fields and which can

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give rise to all three types of suppressed transitions. (2) Symmetry breaking in the hadronization process by which the initial quark-antiquark pair produced at the weak vertex is transformed by QCD interactions into a multihadron state with additional $q\bar{q}$ pairs.

We now note the following selection rules for these two types of symmetry breaking: Symmetry breaking at the weak vertex can produce states with the quantum numbers of a nonexotic second-class current. Such symmetry breaking cannot produce states with exotic quantum numbers. Thus weak-vertex symmetry breaking can produce states with the second-class nonexotic quantum numbers $J^{PG}=0^{+-},1^{++}$ but not with the second-class exotic quantum numbers $J^{PG}=0^{-+},1^{--}$ nor first-class exotic quantum numbers $J^{PG}=0^{++}$. (2) Symmetry breaking in the hadronization process can produce states with exotic quantum numbers as well as states with quantum numbers of second-class currents. However, since the strong interactions of QCD conserve J and P, they cannot produce states with J and P quantum numbers suppressed for the weak vertex. Thus, if there is no symmetry breaking at the weak vertex, states with $J^P=0^+$ cannot be produced by hadronization.

These considerations lead to a classification of four types of suppressed transitions: (1) States with the second-class exotic quantum numbers $J^{PG}=0^{-+},1^{--}$ can be produced only by symmetry breaking in the hadronization process. (2) States with the second-class nonexotic quantum numbers $J^{PG}=0^{+-}$ can be produced only by symmetry breaking at the weak vertex. (3) States with the second-class nonexotic quantum numbers $J^{PG}=1^{++}$ can be produced either by symmetry breaking at the weak vertex or by symmetry breaking in the hadronization process. (4) States with the first-class exotic quantum numbers $J^{PG}=0^{++}$ cannot be produced by a single simple symmetry-breaking mechanism. Both symmetry breaking at the weak vertex and symmetry breaking in the hadronization process are required.

One example of the use of these selection rules is immediately seen in the decay $\tau \rightarrow \nu_\tau \eta\pi$. The s-wave $\eta\pi$ state has the second-class nonexotic quantum numbers $J^{PG}=0^{+-}$ and can be produced only by symmetry breaking at the weak vertex and not by subsequent hadronization. The p-wave $\eta\pi$ state has the second-class exotic quantum numbers $J^{PG}=1^{--}$ and cannot be produced by symmetry breaking at the weak vertex but only by subsequent hadronization.

So far we have considered only the charged weak current and W decays, where suppressed second-class transitions can be introduced by nonconserving GP without CP nonconservation. A similar treatment is possible for the neutral current and Z^0 decays; however, a GP nonconservation in the neutral sector requires CP nonconservation and can only be considered together with CP-nonconserving mechanisms. This is easily seen explicitly by expressing the G-parity classification of first- and second-class currents in terms of the operators $GP(-1)^J$ and $CP(-1)^J$.

First-class isovector currents couple to spin-zero and spin-one states which are eigenstates of the operator $GP(-1)^J$ with the eigenvalue $+1$, while second-class isovector currents couple to states with the eigenvalue -1. Neutral isovector eigenstates of GP are also eigenstates of CP with the opposite eigenvalue. Thus, states coupled to the isovector neutral currents are also eigenstates of the operator $CP(-1)^J$ with the eigenvalues -1 for first-class currents and $+1$ for second-class currents. If both types of charged currents are present, a state with a positive eigenvalue of $GP(-1)^J$ can go into a state with a negative eigenvalue via an intermediate W state which couples to both. Since J is always conserved, this implies a change in the eigenvalue of GP; i.e., a GP nonconservation. If both types of neutral currents are present, a state with a positive eigenvalue of $CP(-1)^J$ can go into a state with a negative eigenvalue via an intermediate Z^0 state which couples to both, thereby introducing CP nonconservation. Only states with $CP(-1)^J=-1$ are coupled to the Z^0 in the standard model, and CP is conserved in this coupling. The experimentally observed CP nonconservation is assumed to originate elsewhere; e.g., in the Kobayashi-Maskawa matrix.

The first-class exotic neutral current with the quantum numbers $J^{PC}=0^{+-}$ does not introduce CP nonconservation and can be expected to be suppressed on the same basis as the corresponding charged current. However, such states cannot be produced in the charged sector by a single symmetry-breaking mechanism as discussed above. GP symmetry breaking at both the weak vertex and in the hadronization process are required. In the neutral sector this GP nonconservation implies CP nonconservation. Thus, the first-class exotic neutral transitions to states with the quantum numbers $J^{PC}=0^{+-}$ can occur without CP nonconservation only via a complicated weak vertex which is not bilinear in the quark fields and produces exotic states directly.

The classification of weak transitions as exotic and nonexotic applies also to decays of baryonic states; e.g., to nuclear β decay and hyperon decays, since the J, P, and C quantum numbers carried by the weak current are required by crossing to be the same for spacelike and timelike momentum transfers. The same classification applies also to treatments of nuclear β decay using an effective weak interaction Lagrangean which couples the weak current directly to nucleons described by phenomenological Dirac spinors. Currents carrying exotic quantum numbers and not describable by a bilinear product of quark field variables also cannot be described by a bilinear product of phenomenological nucleon field variables.

This work was supported by the U.S. Department of Energy, Division of High Energy Physics, Contract No.

W-31-109-ENG-38.

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