Remarks on the Possible Existence of Stable or Semistable Charmed Particles in the Three-Triplet Model

J. C. PATI* AND C. H. WOO†
Center of Theoretical Physics, Department of Physics and Astronomy, University of Maryland, College Park, Maryland 20742

(Received 7 October 1970)

The possibility of "charm" being a reasonably good quantum number in the three-triplet model is discussed. The physical differences between the Han-Nambu model and the SUB model of Cabibbo, Maiani, and Preparata are clarified and spelled out in some detail. It is argued that under a variety of circumstances the experimental detection of integrally charged, heavy (in the 2–4-BeV mass region, say), long-lived, charmed particles is quite feasible, provided that the $SU(3)\times SU(3)''$ classification scheme in either model is approximately valid. The lifetimes involved are probably in the range of 10^{-12} to 10^{-8} sec.

I. INTRODUCTION

WHEN energies in the 300-BeV region become available at Batavia, one of the interesting possibilities from an experimental point of view is to look for hitherto undiscovered stable or semistable[1] heavy particles. The existence of such stable particles may arise in the first place from the conservation of baryon[2] number and/or electric charge corresponding to particles such as quarks, diquarks, other triplet particles (such as the triplet of the three-triplet model[3]), etc., all of which have fractional baryon numbers with either fractional or integral electric charge. Such particles, if they exist, will of course include absolutely stable members and will be presumably very heavy. Search for such particles has partially been carried out at least for the fractionally charged ones with no positive candidate as yet. One may presume from this and from crude theoretical estimates that such particles lie, if they exist, in the 5–10-BeV mass region or higher.

The existence of heavy stable or semistable particles could also arise, however, solely from hitherto undiscovered quantum numbers, such as the so-called "charm"[4] quantum number. These particles, in contrast to quarks and other triplets, can have an integral baryon number and integral charge, and could be relatively low-lying compared to the fundamental triplet or triplets. Among theoretical schemes, which contain such a quantum number, the $SU(4)$ scheme[5] is slightly disfavored, since some of the charmed objects belonging to $SU(4)$ multiplets together with the uncharmed ones are expected to lie at rather low energies (around 1 BeV) and have not yet been seen. Furthermore, there does not seem to be any strong *a priori* motivation for such a higher symmetry. The scope for a new internal quantum number is also provided by two other schemes, viz., the two-triplet model[6] and the three-triplet model.[3] The existence of the new quantum number in the latter, however, appears to us to be somewhat more natural than that in the former. We therefore *confine* our discussion in the following to the three-triplet model for providing a framework for the new quantum number.

It is perhaps appropriate to remark briefly here that the motivation for a three-triplet model (compared to a single-triplet model) is many-fold. In the first place, as is well known, it allows one to satisfy the generalized Pauli principle for the 56-plet of $SU(6)$ keeping the constituents in relative S states. Secondly, it allows the possibility of integrally charged fundamental constituents, which to some may have an aesthetic appeal over the fractionally charged ones. The single-triplet model (namely the quark model) with normal statistics cannot incorporate either of the above features. It has also been pointed out[7] that the usual successes of the quark model, such as current algebra and applications to radiative and leptonic decays of vector mesons, etc., can be preserved in the three-triplet model. Furthermore, Adler[8] and Okubo[9] have shown that considerations of the $\pi^0\to 2\gamma$ decay favors the three-triplet model over the two-triplet and quark models.

Thus there appears to be sufficient motivation for

* Supported in part by the National Science Foundation under Grant No. NSF GP 8748.
† Supported in part by the U. S. Air Force Office of Scientific Research under Grant No. AFOSR 68-1453A.

[1] By semistable, we mean particles with lifetime $\gtrsim 10^{-12}$ sec, say, corresponding to weak decays.

[2] T. D. Lee [Nuovo Cimento **35**, 933 (1965)] has discussed in detail such possibilities of stable particle due to baryon conservation in different models.

[3] The three-triplet model was originally proposed by M. Han and Y. Nambu, Phys. Rev. **139**, B1006 (1965). The basic features of this model have been independently proposed by Tavkhelidze *et al.*, in *Proceedings of the Seminar on High-Energy Physics and Elementary Particles* (International Atomic Energy Agency, Vienna, Austria, 1965), p. 763. However, as the Han-Nambu model is rather explicit about the classification scheme, which we adopt, we refer to this model as the Han-Nambu or HN model in the text.

[4] The word "charm" was originally introduced by Bjorken and Glashow [Phys. Letters **11**, 255 (1964)] in connection with $SU(4)$ symmetry.

[5] P. Tarjanne and V. L. Teplitz, Phys. Rev. Letters **11**, 447 (1963). See also D. Amati, H. Bacry, J. Nuyts, and J. Prentki, Phys. Letters **11**, 190 (1964) and Ref. 4.

[6] Y. Nambu, in *Proceedings of the Second Coral Gables Conference on Symmetry Principles at High Energy* (W. H. Freeman, San Francisco, 1965); H. Bacry, J. Nuyts, and L. van Hove, Phys. Letters **9**, 279 (1964).

[7] See, for example, N. Cabibbo, L. Maiani, and G. Preparata, Phys. Letters **B25**, 132 (1967).

[8] S. Adler, Phys. Rev. **177**, 2426 (1969).

[9] S. Okubo, Phys. Rev. **179**, 1629 (1969).

the three-triplet model to be considered as a candidate for providing the fundamental constituents of hadrons. It is of great interest, therefore, to examine whether experiments in the near future could shed light on certain distinguishing features of this model, namely, on the existence of charmed particles, together with the uncharmed ones, forming multiplets in the three-triplet way. The purpose of this paper is to point out certain possibilities of the above nature in the three-triplet model that suggest that a search for such particles should indeed be feasible. While most of these remarks are relatively straightforward, to our knowledge they have not explicitly been discussed in the literature and should be helpful from an experimental point of view.

II. TWO VERSIONS OF THREE-TRIPLET MODEL

In order to make our discussion fairly self-contained, it is helpful first to review briefly the main features of the three-triplet model, as proposed originally by Han and Nambu,[3] and a second version of the three-triplet model (to be referred to as the *SUB* model) introduced by Cabibbo, Maiani, and Preparata.[10] Contrary to common impression, these two different versions do possess physical differences, which, however, does not seem to have been emphasized or discussed in the literature. Below we discuss the two models and their main differences.

The HN three-triplet model consists of a set of nine fundamental fields $t_{\alpha i}$ ($\alpha=1, 2, 3$ and $i=1, 2, 3$) with integral charges and baryon number $\frac{1}{3}$. They allow one to define a group $SU(3)'$ acting on the index α and a second $SU(3)$ group called $SU(3)''$ acting on the index i such that the fields $t_{\alpha i}$ provide a representation (3,3*) of the group $G=SU(3)'\times SU(3)''$. The triplets $t_{\alpha 1}$ and $t_{\alpha 2}$ form an $SU(2)''$ doublet and $t_{\alpha 3}$ a $SU(2)''$ singlet. The familiar $SU(3)$ group (whose generators F_i have eigenvalues corresponding to the observed quantum numbers such as I, I_3, and Y, etc.) is identified with the diagonal subgroup of $SU(3)'\times SU(3)''$. Thus, the F_i's are given by the sum of the generators of $SU(3)'$ and $SU(3)''$, i.e., $F_i=F_i'+F_i''$. The usual Gell-Mann–Nishijima formula,

$$Q=I_3+\tfrac{1}{2}Y=(I_3'+\tfrac{1}{2}Y')+(I_3''+\tfrac{1}{2}Y'')=Q'+Q'', \quad (1)$$

leads to integral charges for these nine objects owing to the fact that Q is a sum of two $SU(3)$ charges Q' and Q'' (each of which is, of course, fractional), corresponding to **3** and **3*** representations, respectively. This could also be seen by noting that the nine objects transform as an octet plus a singlet under the usual $SU(3)$ group (rather than as triplets).

Table I shows the $SU(3)'$, $SU(3)''$, and $SU(3)$ quantum numbers of the nine objects in the HN model. One

TABLE I. Quantum numbers of the HN model. The nine objects $t_{\alpha i}$ are assumed to transform as (3,3*) under $SU(3)'\times SU(3)''$. The charges are given by the usual Gell-Mann–Nishijima formulas, i.e., $Q'=I_3'+\frac{1}{2}Y'$, $Q''=I_3''+\frac{1}{2}Y''$, $Q=Q'+Q''=I_3+\frac{1}{2}Y$. Charm is identified with $3Q''$.

	Y'	I_3'	Q'	Y''	I_3''	$Q''=\frac{1}{3}C$	Y	I_3	Q
t_{11}	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{2}{3}$	$-\frac{1}{3}$	$-\frac{1}{2}$	$-\frac{2}{3}$	0	0	0
t_{21}	$\frac{1}{3}$	$-\frac{1}{2}$	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{2}$	$-\frac{2}{3}$	0	-1	-1
t_{31}	$-\frac{2}{3}$	0	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{2}$	$-\frac{2}{3}$	-1	$-\frac{1}{2}$	-1
t_{12}	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{2}{3}$	$-\frac{1}{3}$	$\frac{1}{2}$	$\frac{1}{3}$	0	1	1
t_{22}	$\frac{1}{3}$	$-\frac{1}{2}$	$-\frac{1}{3}$	$-\frac{1}{3}$	$\frac{1}{2}$	$\frac{1}{3}$	0	0	0
t_{32}	$-\frac{2}{3}$	0	$-\frac{1}{3}$	$-\frac{1}{3}$	$\frac{1}{2}$	$\frac{1}{3}$	-1	$\frac{1}{2}$	0
t_{13}	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{2}{3}$	$\frac{2}{3}$	0	$\frac{1}{3}$	1	$\frac{1}{2}$	1
t_{23}	$\frac{1}{3}$	$-\frac{1}{2}$	$-\frac{1}{3}$	$\frac{2}{3}$	0	$\frac{1}{3}$	1	$-\frac{1}{2}$	0
t_{33}	$-\frac{2}{3}$	0	$-\frac{1}{3}$	$\frac{2}{3}$	0	$\frac{1}{3}$	0	0	0

may define the charm quantum number C in this model by

$$\tfrac{1}{3}C=Q''=I_3''+\tfrac{1}{2}Y'', \quad (2)$$

where (as may be seen from Table I) C has eigenvalues -2, 1, and $+1$ for the three $SU(3)'$ triplets $t_{\alpha 1}$, $t_{\alpha 2}$, and $t_{\alpha 3}$, respectively. Assuming that the $SU(3)''$ group may not be a bad symmetry for the classification of baryons and mesons, Han and Nambu suggested a possible mechanism by which the mass formula for the mesons and baryons could contain a dominant term corresponding to the eigenvalue of the $SU(3)''$ quadratic Casimir operator with a large positive coefficient. In this case, the low-lying states of baryons and mesons will correspond to $SU(3)''$ singlet states, while the higher representations [$SU(3)''$ octets, decuplets, etc.] may lie higher starting with the 2–3-BeV mass region,[11] say. For $SU(3)''$ singlet states, $SU(3)$ operations clearly coincide with that of $SU(3)'$. It is also clear that the (56,1)-plet of $SU(6)'\times SU(3)''$ built out of three triplets satisfy the Pauli principle with S-state triplets, since the $SU(3)''$-singlet wave function is totally antisymmetric, while the $SU(6)'$ 56-plet is totally symmetric.

The so-called *SUB* model, introduced by Cabibbo, Mainani, and Preparata as a version of the three-triplet model, has many features similar to the above and is yet quite different from it. The main difference between them may be traced to the fact that in the *SUB* model, the $SU(3)$ group (corresponding to observed quantum numbers) replaces the $SU(3)'$ group of the HN model; thus the operations of the $SU(3)$

[10] See Ref. 7. We abbreviate the authors of this paper as CMP in the text.

[11] Although, strictly speaking, there is no clearly known scale at present to indicate the separations between different $SU(3)''$ representations, one may get an idea of such separations from certain attempts of mass fittings, as, for example, those extensively carried out by O. W. Greenberg and C. A. Nelson [Phys. Rev. Letters **20**, 604 (1968)]. The above work has certain difficulties at present with regard to the prediction for the Z particles; nevertheless it probably indicates the scale of separation correctly. It suggests that the lowest $SU(3)''$ nonsinglet states may lie in the 2- to 3-BeV region. Some of these states have probably been produced singly (and therefore seen) if $SU(3)''$ is broken by something like medium-strong interaction, say. We will discuss this in the text.

group are independent of those of the $SU(3)''$ group. In the HN model, on the other hand, the $SU(3)$ group is the diagonal subgroup of $SU(3)' \times SU(3)''$ group. Thus in the *SUB* model the nine fundamental constituents form three $SU(3)$ triplets called S, U, and B [in the HN model they form an $SU(3)$ octet plus singlet]. These three triplets are transformed into each other by the $SU(3)''$ group; S and U form an $SU(2)''$ doublet and B and $SU(2)''$ singlet. Each of S, U, and B possess baryon number $\frac{1}{3}$ and consists of three $SU(3)$ partners having the (I, I_3, and Y) values the same as those of a quark triplet. They are allowed to have integral charges, however, by a *modification*[12] of the Gell-Mann–Nishijima formula to the form

$$Q=I_3+\tfrac{1}{2}Y+\tfrac{1}{3}C, \tag{3}$$

where C is the so-called charm operator transforming as a (1,8) operator under $(SU(3), SU(3)'')$; its eigenvalues are 1, 1, and -2 for the S, U, and B triplets, respectively (see Table II).

Since CMP choose (S, U, and B) to transform as a **3** (rather than as **3***)[13] under $SU(3)''$, it is easy to see that one must identify C in this case with $3Y''$, i.e.,

$$C=3Y''. \tag{4}$$

For the $SU(3)''$ singlet states, C is necessarily zero; hence the usual Gell-Mann–Nishijima formula holds.

Some of the main differences between the two versions of the three-triplet model may thus be noted as follows. In the HN model it is possible to have the so-called exotic Z particles with $Y=2$ and baryon number equal to 1 as bound states of ttt, while in the *SUB* model they can arise as bound states of $tttt\bar{t}$, $tttttt\bar{t}\bar{t}$, etc. This is because the nine objects transform as an $SU(3)$ octet plus a singlet in the HN model, while they form three $SU(3)$ triplets in the *SUB* model. For the same reason it is possible to construct an $SU(3)$ 27-plet current carrying $I=2$ (for example) with bilinear combination of $t\bar{t}$ in the HN model; this is not possible in the *SUB* model. Another striking difference between the two models arises, of course, through the relationship of the electric charge to $(I_3+\frac{1}{2}Y)$. Such a difference can be noticeable if and when the charmed particles are discovered (provided that $I_3+\frac{1}{2}Y$ and therefore charm are at least reasonably good quantum numbers in the *SUB* model). Another obvious difference is, for example, that in the HN model, Y has integral values for the constituents and therefore strangeness has fractional values (since baryon number for them is $\frac{1}{3}$), while in the *SUB* model the situation is reversed.

The above discussion regarding the two versions of the three-triplet model naturally raises the following question: How well is the charm quantum number expected to be conserved in either scheme? Let us first consider this question in the *SUB* model. In this case, since the Gell-Mann–Nishijima formula relates C to Q, and since isospin and Y are known to be well conserved separately (at least for the low-lying levels), it appears safe to assume that charm is conserved at least by the strong and medium-strong interactions. If the electromagnetic current transforms the same way as the charge given by Eq. (3) under the $SU(3)$ and $SU(3)''$ group operations, then electromagnetism will also conserve C, I_3, and Y separately. It is, of course, possible that there may exist as yet undetected interactions[14] of strength similar to that of electromagnetism or lower, which could violate both C and I_3 (for example), but conserve Y and Q. In the present paper, however, we will ignore[15] such possibilities. Turning to weak

TABLE II. Quantum numbers of the *SUB* model. The nine objects (S_i, U_i, and B_i) are assumed to transform as (3,3) under $SU(3) \times SU(3)''$. Charm is identified with $3Y''$.

	Y	I_3	$Y''=\frac{1}{3}C$	I_3''	$Q=I_3+\frac{1}{2}Y+\frac{1}{3}C$
S_p	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{2}$	1
S_n	$\frac{1}{3}$	$-\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{2}$	0
S_λ	$-\frac{2}{3}$	0	$\frac{1}{3}$	$\frac{1}{2}$	0
U_p	$\frac{1}{3}$	$\frac{1}{2}$	$\frac{1}{3}$	$-\frac{1}{2}$	1
U_n	$\frac{1}{3}$	$-\frac{1}{2}$	$\frac{1}{3}$	$-\frac{1}{2}$	0
U_λ	$-\frac{2}{3}$	0	$\frac{1}{3}$	$-\frac{1}{2}$	0
B_p	$\frac{1}{3}$	$\frac{1}{2}$	$-\frac{2}{3}$	0	0
B_n	$\frac{1}{3}$	$-\frac{1}{2}$	$-\frac{2}{3}$	0	-1
B_λ	$-\frac{2}{3}$	0	$-\frac{2}{3}$	0	-1

[12] Note that one may retain the familiar Gell-Mann–Nishijima formula, $Q=I_3+\frac{1}{2}Y$, for the *SUB* model, provided that one does not insist on integrally charged constituents. The other features of the *SUB* model regarding the $(SU(3), SU(3)'')$ structure of the multiplets, etc., are not altered by this. Even though this is clearly a possibility and only experiments must eventually decide between integrally and fractionally charged constituents, we do not explicitly discuss this version of the *SUB* model in this paper. It is easy to see that our subsequent discussion regarding the validity of the charm quantum number in the HN model will apply to this alternative version of the *SUB* model.

[13] Note that if one chooses S, U, and B to transform as a **3*** under $SU(3)''$ (as chosen by HN), C should be identified with $3(I_3''+\frac{1}{2}Y'')$ as in Eq. (2) for the HN model. In this case C will possess eigenvalues 1, -2, and 1 for S, U, and B, respectively. Such a choice will have physical differences from that of CMP through $SU(3)''$ quantum numbers of nonsinglet $SU(3)''$ representations. It is worth pointing out that one may also modify the HN model simply by choosing the nine objects $t_{\alpha i}$ to transform as (3,3), under $SU(3)' \times SU(3)''$ rather than as (3,3*). In this case, the $t_{\alpha i}$'s transform as $\mathbf{6}+\mathbf{3}^*$ under $SU(3)$ (instead of as $\mathbf{8}+\mathbf{1}$); integral charges can be realized for them only by modifying the Gell-Mann–Nishijima formula to the form $Q=I_3+\frac{1}{2}Y-\frac{1}{3}C$, where C is now to be identified with $3Y''$ and has eigenvalues 1, 1, and -2 for $t_{\alpha 1}$, $t_{\alpha 2}$, and $t_{\alpha 3}$, respectively. Such a modified HN model also possesses distinct physical differences from the original HN model. Although such modifications do not alter the discussion in our paper, it appears that one may need to keep an open mind about these possibilities, for at present we are totally ignorant of the properties of $SU(3)''$ nonsinglet representations.

[14] For example, interactions of the type proposed recently by one of us [J. C. Pati, Phys. Rev. D 2, 2061 (1970)] to accommodate isospin, charge conjugation, and *CP* violation may also be formulated in the *SUB* model to incorporate charm and I_3 violation.

[15] If such interactions do exist, however, one would expect that those charmed particles, which are described to be stable or semistable in this paper, will in fact decay rather rapidly. However, they may still be *distinguishable* from the $C=0$ particles *by their narrow widths* (less than or of the order of 1 MeV).

interactions, the simplest extension of the present theory of weak interactions to the *SUB* model would suggest[16] that the weak currents commute with I_3'' and Y'', in which case they would conserve C. However, this may be an oversimplification and it is possible that weak interactions may have a piece in them, which could violate both $I_3+\frac{1}{2}Y$ and C in such a manner as to conserve the sum $Q=(I_3+\frac{1}{2}Y)+\frac{1}{3}C$; such an interaction will not have any effect except in higher order for the low-lying $C=0$ particles, and thus may not have been felt. We will thus assume that C is either absolutely conserved or violated only weakly in the *SUB* model (see further remarks in Sec. III).

In the HN model, since the charm is related to charge only through $SU(3)'$ quantum numbers and since we do not have any *a priori* understanding of how well the $SU(3)'$ or $SU(3)''$ quantum numbers are conserved separately, one cannot make the same argument as above for the conservation of the charm quantum number. In fact, if one assumes a strong spin-orbit type of coupling between the $SU(3)'$ and $SU(3)''$ groups, as suggested by Han and Nambu, separate conservations of (I_3', Y', I_3'', and Y'') would be destroyed, and only the sums $I_3=I_3'+I_3''$ and $Y=Y'+Y''$ would be conserved. In this case the "charm" will not be a good quantum number in any sense. However, it seems to us that there is no compelling motivation for postulating such a strong coupling between the two $SU(3)$ groups. There have often been situations with approximate symmetry groups where the diagonal generators are conserved by strong, medium-strong, and electromagnetic interactions, even though the symmetry itself is very poor. If this is any guide, it is possible that I_3'' and Y'' may be well conserved even though $SU(3)''$ is badly broken. Thus that the "charm" may be a good quantum number broken possibly by weak interactions appears to be a simple and attractive possibility even in the HN model. We therefore consider in Sec. III the experimental consequences of the following assumptions.

(a) The ($SU(3)$,$SU(3)''$) classification of hadrons is a good one in either scheme, even though both symmetries may be violated (say) by medium-strong interactions.

(b) The charm quantum number in either scheme is either exactly conserved or broken at most by weak interactions, even though $SU(3)''$ may be broken as mentioned above.

(c) The $SU(3)''$ singlet states (as mentioned before) are dynamically favored to be the lowest-lying; the nonsinglet states (with $C=0$ and $C\neq 0$) lie higher, starting possibly with the 2–4-BeV region.

III. EXPERIMENTAL CONSEQUENCES

For the sake of simplicity, we confine our remarks below to only one version of the three-triplet model, viz., the *SUB* model. However, one can make somewhat similar remarks in the HN model as well.

Let us first discuss the production of $C=0$, $SU(3)''$ nonsinglet states. If $SU(3)''$ symmetry is broken by, say, medium-strong interactions, such states can be produced singly with appreciable cross section from the low-lying $SU(3)''$ singlet projectiles consistent with charm conservation. Once produced, they may decay with appreciably large widths[17] to the low-lying singlet states via the $SU(3)''$-breaking interactions. Some of these states could therefore correspond to the already observed baryon and meson resonances in the higher-mass region.

On the other hand, starting from normal particles as projectiles, the $C\neq 0$ particles can be produced only in "associated production" in a manner consistent with C conservation. The production cross section for such particles could be typical of strong interactions, suppressed of course by relevant kinematic factors[18]; one should thus be able to produce such particles without much difficulty with higher available energies. If C is a good quantum number, such charmed particles, under a variety of circumstances, will include electrically charged stable or semistable particles (decaying weakly) as discussed below.

First consider the possibility that charm is absolutely conserved. Let us denote the lowest-lying charmed state by a with $C=C_a\neq 0$, $I_3=I_{3a}$, and $Y=Y_a$. Clearly such a state will be absolutely stable. If a happens to be electrically charged, it will be easily detected and will constitute a striking observation. On the other hand, if it is neutral it will escape detection. However, we can argue that in this case there will always exist a charged charmed object lying higher than a but still either stable or semistable, in so far as the low-lying states (charmed or noncharmed) correspond to bound states of ttt (for baryons) and $t\bar{t}$ (for mesons).

The argument is as follows. Since we confine ourselves to bound states of (ttt) and ($t\bar{t}$), we need to consider only **1**, **8**, and **10** representations for the

[16] If one assumes that the weak vector currents are those that lead to the generators of $SU(3)$, then they of course transform as singlets under $SU(3)''$ in the *SUB* model. If furthermore one imposes that the weak vector and axial-vector charges satisfy Gell-Mann's $SU(3)\times SU(3)$ algebra, one may then convince oneself that the axial-vector currents must transform as certain fixed linear combinations of the identity operator and the diagonal generators F_3'' and F_8'' in the $SU(3)''$ space. While these, in general, allow for $SU(3)''$ nonsinglet currents, nevertheless they conserve I_3'' and Y'' separately and therefore C.

[17] If medium-strong interactions break $SU(3)''$, the $SU(3)''$ classification of states may still be appropriate (as we assume); however $SU(3)''$ selection rules on matrix elements may be badly broken. An analogous situation is known to take place in the case of $SU(3)$ symmetry. The $K_1\rightarrow 2\pi$ matrix element vanishes in the limit of $SU(3)$ and the usual framework of weak interactions; however it appears to have a roughly normal rate.

[18] The suppression relative to, say, pion production could be substantial, as is indicated at least to some extent in the case of antideuteron production. See, for example, D. E. Dorfan *et al.*, Phys. Rev. Letters **14**, 999 (1965); **14**, 1003 (1965); F. Binon *et al.*, Phys. Letters **30B**, 510 (1969).

baryons and only **1** and **8** representations for the mesons in both $SU(3)$ and $SU(3)''$ spaces. If a is not an isosinglet, there will be a charged isopartner b of a with the same charm and nearly same mass as a. Such a state will decay via the ordinary weak interaction to a together with leptons if $m_b > (m_a + m_e)$; the corresponding lifetime will be rather long (greater than 10^{-4} sec, say, if $m_b - m_a < 10$ MeV) due to the small phase space available. On the other hand, if a is an isosinglet, Y_a must be nonzero since $C_a \neq 0$ and $Q_a = 0$. There is no isosinglet with $Y \neq 0$ in the **1** and **8** representations of $SU(3)$; in **10** there is only one isosinglet with $Y = -2$. If a corresponds to this state, $Y_a'' = 1$, since $Q_a = (I_3 + \frac{1}{2}Y + Y'')_a = 0$. But whenever $Y'' = 1$ is possible, so is $Y'' = -1$ within the same $SU(3)''$ multiplet. The $Y'' = -1$ quantum number, however, cannot combine with $I_3 = 0$ and $Y = -2$ to make a neutral particle. From this[19] one can argue that if charm is absolutely conserved, there will *always be integrally charged, stable, or very long-lived semistable charmed particles*. On the other hand, there seems to be some experimental evidence against the existence of stable (or metastable with lifetime $\gtrsim 10^{-7}$ sec) charged heavy particles up to 5 BeV, if their production cross section in pair production is comparable to that of the antideuteron (see Ref. 18). This, together with the argument presented above, may be regarded as preliminary evidence against charm being an absolutely conserved quantum number.

Next consider the possibility that charm is violated by a piece of the weak interactions (H_{WK}'), which simultaneously violates $(I_3 + \frac{1}{2}Y)$ so as to conserve Q. In this case, the lowest-lying charmed state a will be semistable[1] and will decay weakly to the lower-lying noncharmed objects via H_{WK}' (provided the selection rules of H_{WK}' allow a transition involving $\Delta C = C_a$). Even if a happens to be neutral, its weak decay to charged components will lead to easy identification of such an object. Furthermore, there should also exist electrically charged charmed objects, which would decay only via H_{WK}' to lower-lying charmed and noncharmed states depending upon the selection rules of H_{WK}'.

Thus, under almost any circumstances, we expect to see heavy integrally charged long-lived particles[20] (which are different from the fundamental constituents) provided charm is a reasonably good quantum number and that the $(SU(3), SU(3)'')$ classification is meaningful. The discovery of a single such state will, of course, be an unequivocal proof of the existence of a new quantum number (such as "charm" as discussed here). However, the possible grouping of such charmed objects together with uncharmed ones into multiplets in the three-triplet manner could establish the validity of the three-triplet model. Simultaneously, the examination of (Q, I_3, Y, and C) quantum numbers of such states will help distinguish between the HN model and the SUB model, as discussed. Finally, if either version of the three-triplet model is true, then in addition to charm, there is the possibility that I_3'' and Y'' are separately well conserved; this will lead to possibly larger number of such long-lived particles. There thus exists interesting experimental possibilities at higher energies to be available in the near future. To conclude: In view of the significance of the three-triplet model as a basis for the fundamental structure of hadrons without statistics difficulty, a search for the long-lived integrally charged charmed particles in the relatively low-mass region (2–4 BeV, say) should indeed be very desirable.

ACKNOWLEDGMENTS

We thank G. A. Snow for raising questions which led to the considerations in this paper and O. W. Greenberg and M. Lévy for very helpful discussions. We also thank G. Preparata for an interesting conversation.

[19] Let us denote by C the state in question with $I=0$, $Y=-2$, and $Y''=-1$. If there is no state lower than C with $Y''=-1$, C will be stable. If, however, there exists a neutral state d with $Y''=-1$ lower than C, then it must have nonzero isospin since zero isospin would imply $Y_d=+2$, which cannot be realized for bound states of (ttt) in the SUB model. The nonisosinglet case, however, is already discussed in the text.

[20] If the negative results found in Ref. 18 are further confirmed, by "long-lived" we will mean lifetimes roughly in the range of 10^{-12}–10^{-8} sec.