YU ISSN 0015—3206
FZKAAA 21 (2) 199 (1989)

PRODUCTION BEHAVIOURS OF OPEN-CHARM PARTICLES AND SUPPRESSION OF Σ_c-PRODUCTION

SUMITA DHAR and PARTHASARATHI MUKHOPADHYAY

Physics Department, Jadavpur University, Calcutta 700 032, India

Received 8 December 1988

UDC 539.12

Original scientific paper

Production behaviours of the open-charm particles described by $SU_f(4)$ symmetry have been investigated in this paper. It accounts for observed suppressed productions of the charm baryon Σ_c, the strange-cum-charm meson D_s (F in the notation of Gaillard et al.) and its excited state D_s^* (F^*). Also, it has been pointed out that suppression witnessed in Σ_c-production must be stronger than that in D_s-production. Furthermore, this paper predicts which ones of the so far unobserved $\frac{1}{2}^+$ charm baryons will be freely produced and which ones of them will undergo suppressed production.

1. Introduction

As is well known, charm particles[1] are described by flavour symmetry[2] $SU_f(N)$ of hadrons with $N > 4$. Obviously, $SU_f(4)$ predicts minimum number of such particles. For convenience of discussions, we shall restrict ourselves to the open-charm particles described by the $SU_f(4)$ symmetry scheme. This scheme, needless to mention, has already achieved some brilliant successes through the experimental discoveries[3] of quite an appreciable number of charm particles predicted by the same. The important point to be recognized about these observed charm particles is that *not* all of them are freely produced. To be more specific, suppressions are witnessed in productions of the 0^- strange-cum-charm mesons D_s and its excited D_s^*. A similar remark is also true for the $\frac{1}{2}^+$ charm hyperon

Σ_c. It is worth noting in this context that there are no provisions for suppressions of any particle within the framework of $SU_f(4)$ symmetry. The above mentioned experimental facts inspired one of us (P. M.) to investigate production behaviours of the $SU_f(4)$-predicted charm particles in earlier papers[4,5]. The same problem has been re-examined in the present paper in a more systematic as well as refined way making use of the up-to-date experimental information on charm particles.

In order to prepare the necessary background for further discussions we may note the following points. From the observed production cross section of a particle one cannot ascertain whether it is freely produced or it undergoes suppressed production. This is because, as is well known, a particle is regarded as a freely produced one if the theoretical value of its production cross section is in close agreement with the observed value of the same. On the other hand, a particle is considered to undergo suppressed production if σ (expt.), the observed value of its production cross section, is found to be appreciably lower than σ (theo.), the theoretical value of its production cross section. Obviously, in this case production behaviour of the particle concerned is not satisfactorily described by the theory appropriate for the interaction responsible for its production. The situation, however, is saved by invoking suitable constraint (*s*) according to which the production of the particle is forbidden. The role of the constraint (*s*) is to reduce the value of σ (theo.) and consequently the existing gap between σ (theo.) and σ (expt.) is narrowed down. What we are trying to emphasize is that production behaviour of a particle is satisfactorily described by the relevant theory by exploiting suitable constraint (*s*). This point is so well known that we need not elaborate it further.

In the above we have highlighted the crucial role played by constraints in the matter relating to production behaviour of a particle. In fact, much insight is gained in regard to production behaviour of a particle with the help of the constraints operative in its production. In this paper we shall investigate production behaviours of the charmed particles by making use of the constraints which suit our purpose. In order to select these constraints it is important to be aware of the following points. In the literature there is not a single constraint which is exclusively meant for particle production. Needless to mention, the familiar constraints which are applicable in particle production also find their use in particle decays. On the other hand, there are some constraints which cover particle decays only (such as, for example, $\Delta I = \frac{1}{2}$ rule in weak decays). Furthermore, the conventional constraints are valid in specific interactions and not in all interactions. For example, the quark duality diagram constraint i. e. the OZI rule is operative in strong and electromagnetic interactions but not in weak interactions. Obviously, then, this rule is not applicable in particle productions through neutrino induced reactions. The above considerations prompted one of us (P. M.) to suggest two non-dynamical constraints[4-9] which are exclusively meant for hadron production. As these constraints (to be discussed below) are non-dynamical ones, they are applicable in production of a hadron irrespective of the nature of interactions responsible for its production mechanism. This apart, these constaints are exclusively meant for production and as such they are expected to deliver vital infoımation regarding production behaviours of hadrons. This is really the case as evident from earlier papers[4-9]. It is worth mentioning here that the two constraints have already been employed in isolation for investigating production behaviours of charm particles[4,5]. In the present paper both the constraints have been considered jointly for the same purpose. The individual predictions of these constraints on the nature of production of the 0^-, 1^- and $\frac{1}{2}^+$ charm particles described by $SU_f(4)$ have been shown in Table 1. The overall nature of production of these particles has been displayed in the last column of the same table.

The plan of this paper is as follows. In Sec. 2 the derivation of the two constraints for hadron production has been outlined. In Sec. 3 these constraints have been exploited to investigate production behaviours of the open-charm particles described by $SU_f(4)$. It has been shown in this section that these constraints, considered jointly, can satisfactorily account for the observed suppressed production of D_s, D_s^* and Σ_c. The same constraints have also been employed in this section to predict production behaviours of the $\frac{1}{2}^+$ charm baryons which are yet to be discovered. In Sec. 4, i. e. in *Conclusions*, it has been emphasized that the predictions of the constraints of our interest on the nature of productions of the open-charm particles are valid in all production mechanisms as the constraints concerned are non-dynamical.

2. *Two constraints for hadron production*

We now proceed to discuss the two constraints referred to above. One of them is of restricted validity whereas the other one is of general validity. For convenience of discussions, we first confine our attention on the former constraint which is applicable for production of a hadron having an odd-half integral isospin or (and) actual spin. To formulate this constraint we assume flavour symmetry[1] of hadrons to be $SU_f(4)$ as we shall limit ourselves to the charm particles described by $SU_f(4)$. To start with we consider a hadron specified by its actual spin J and $SU_f(4)$ quantum numbers I (isospin), S (strangeness) and C (charm); I or (and) J being odd-half integral. With this hadron we associate the quantity $(-1)^{K_1 I}$ where K_1 is a c-number in isospace. If we do not invoke super-symmetric transformations[10] (i. e. Poincaré transformations as well as the transformations which generate fermions from bosons or vice versa)*, then, the quantity mentioned above may be treated as a rotational invariant in isospace. With the same hadron we can also associate the quantity $(-1)^{K_2 J}$ where K_2 is a c-number in actual spin space. This quantity may be regarded as a rotational invariant in actual spin space in absence of supersymmetric transformations. If, further, K_1 and K_2 are so chosen that both of them are c-numbers in isospace and actual spin space as well, then, the following conclusions may be drawn regarding the combination $(-1)^{K_1 I} + (-1)^{K_2 J}$. Obviously, the first term of this combination is an invariant under rotational transformations in isospace to which the second term does not respond and as such the latter term may be treated as a constant quantity. On the other hand, under rotational transformations in actual spin space the first term of the above mentioned combination behaves as a constant quantity whereas the second term is an invariant. It is worth recalling in this context that invariance property

*The most general supersymmetric transformations[10] affect the actual spin as well as the internal quantum numbers of a particle.

TABLE 1

Charm particle	Quark content	J	Nature of production predicted by relation (7)	Nature of production predicted by relation (8)	Overall nature of production
D^+	$c\bar{d}$	0	free	free	free
D^0	$c\bar{u}$	0			
$\bar{D}^0$	$\bar{c}u$	0			
D^-	$\bar{c}d$	0			
F^+ (D_s^+)	$c\bar{s}$	0	....	suppressed	suppressed
F^- (D_s^-)	$\bar{c}s$	0			
D^{*+}	$c\bar{d}$	1	free	free	free
D^{*0}	$c\bar{u}$	1			
$\bar{D}^{*0}$	$\bar{c}u$	1			
D^{*-}	$\bar{c}d$	1			
F^{*+} (D_s^{*+})	$c\bar{s}$	1	....	suppressed	suppressed
F^{*-} (D_s^{*-})	$\bar{c}s$	1			
C_1^{++} (Σ_c^{++})	cuu	$\frac{1}{2}$	suppressed	free	suppressed
C_1^+ (Σ_c^+)	cud	$\frac{1}{2}$			
C_1^0 (Σ_c^0)	cdd	$\frac{1}{2}$			
C_0^+ (Λ_c^+)	cud	$\frac{1}{2}$	....	free	free
A^+ (Ξ_c^+)	csu	$\frac{1}{2}$	free	free	free
A^0 (Ξ_c^0)	csd	$\frac{1}{2}$			
S^+	csu	$\frac{1}{2}$	free	free	free
S^0	csd	$\frac{1}{2}$			
T^0 (Ω_c^0)	css	$\frac{1}{2}$	....	suppressed	suppressed
X_u^{++}	ccu	$\frac{1}{2}$	free	free	free
X_d^+	ccd	$\frac{1}{2}$			
X_s^+	ccs	$\frac{1}{2}$	....	suppressed	suppressed

The predictions on the nature of production of the 0^-, 1^- and $\frac{1}{2}^+$ charm particles by the constraints described by relations (7) and (8). The particle symbols and the quantum numbers have been taken from Ref. 1. The particle symbols in parenthesis have been taken from Ref. 3.

of a quantity is not affected if we add to it a constant term. This in turn implies that

$$(-1)^{K_1 I} + (-1)^{K_2 J} \equiv \text{invariant} \tag{1}$$

under rotations in isospace or actual spin space provided we do not consider supersymmetric transformations.

In order that the invariant, defined by relation (1), may be physical it has to possess a real value. This in turn means that both K_1 and K_2 occuring in relation (1) can only admit non-zero even integral values as we are considering a hadron having odd-half integral I or (and) J. Obviously, the minimum value for both K_1 and K_2 is 2. If, however, we set $K_1 = K_2 = 2$, then, the invariant concerned remains real as desired. However, for this choice of the values for K_1 and K_2 the invariant involves I and J which are not sufficient for specifying a non-ordinary hadron. Therefore, in order that the invariant may be useful for ordinary hadron as well as non-ordinary hadrons, one of the quantities K_1 and K_2 should be expressed in terms of the scalar quantum numbers[4,6-9] as indicated below

$$K_1 = |(B + S + C + X)| \text{ and } K_2 = 2 \tag{2}$$

where B denotes baryon number, S strangeness and C charm. The non-zero quantity X is necessary for the reality of the invariant, given by relation (1), as well as to ensure a non-zero value of K_1. These points become immediately transparent from the following examples. For K^+ meson (with $B = 0$, $S = 1$, $C = 0$, $I=\frac{1}{2}$, $J = 0$), the invariant has an imaginary value if K_1 does not involve X. The importance of the quantity X is further revealed if we consider, for example the $\frac{1}{2}^+$ strange baryons Λ and Σ for both of which $B = 1$, $S = -1$ and $C = 0$. Clearly, K_1 for these particles turns out to be zero unless it involves the quantity X which does not admit the value 0. The admissible values of X may be obtained by exploiting the above mentioned conditions along with the more explicit form[4,6-9] of the invariant shown below.

$$(-1)^{|(B+S+C+X)|(I)} + (-1)^{2J} \equiv \text{invariant.} \tag{3}$$

Now, taking into account the quantum numbers of the well known hadrons which are spinors in isospace or (and) actual spin space, it is easy to check that the allowed values of X are given by[4,6-9]

$$X = \pm 2, \pm 4, \pm 6, \ldots \text{ for isobosons}$$

$$= \pm 1, \pm 3, \pm 5, \ldots \text{ for isofermions} \tag{4}$$

where + sign refers to a particle and − sign to an antiparticle.

To proceed further we may note that the numerical value of the invariant can be either 0 or 2. Now we demand that a hadron, which is a spinor in isospace or(and) actual spin space, to be freely produced it is essential (but not sufficient) that the invariant must have the value 0 i. e.

$$(-1)^{|(B+S+C+X)|(I)} + (-1)^{2J} = 0 \tag{5}$$

which can be recast as

$$(-1)^{|(B+S+C+X)|(I)} = -(-1)^{2J} = (-1)^{2J+1}. \tag{6}$$

This relation clearly indicates that as the bases are unity we cannot in general demand the equality of the powers of the same. However, for the special class of particles specified below the equality of the powers of both sides of relation (6) i. e.

$$|(B+S+C+X)|(I) = 2J+1, \quad I \neq 0 \tag{7}$$

may be achieved with a proper choice of the value of X from its admissible values gives by relation (4). It can be easily checked that relation (7) is invariably satisfied for *freely produced* hadrons which are spinors in either isospace or/and actual spin space having $I \neq 0$. This point becomes transparent from the following examples. For strange measons $K^{+,0}$ (for which $B = 0$, $S = 0$, $C = 0$, $I = 0$, $J = 1/2$) relation (7) is satisfied with $X = +1$. A similar remark is also true for their antiparticles (having $S = -1$) for which, however, $X = -1$ must be chosen. The same relation is also found to be valid for the $\frac{1}{2}^+$ strange baryon $\Sigma^{+,0,-}$ (for which $B = 1$, $S = -1$, $C = 0$, $I = 1$, $J = \frac{1}{2}$) with the choice $X = +2$. In fact, relation (7) holds true without a single exception for the freely produced hadrons having I and J as specified above. This in turn means that the relation concerned enjoys the status of a constraint for free productions of the special class of hadrons referred to above. For such a hadron relation (7) must hold true in order that it may be freely produced. Otherwise its production must be forbidden and consequently suppressed. We shall return to this point in Sec. 3.

As the constraint discussed above is of restricted validity, we require another constraint which should be applicable in productions of all hadrons without a single exception. To formulate this constraint we consider, as before, flavour symmetry of hadrons to be $SU_f(4)$ for the reason already mentioned. For the moment, however, we confine our attention on the hadrons belonging to the 0^-, 1^-, $\frac{1}{2}^+$, $\frac{3}{2}^+$ multiplets of $SU_f(3)$. For these particles we consider the linear combination $(2I + |S|)$, I denoting isospin and $|S|$ the magnitude of strangeness. This combination exhibits the following interesting property for the hadrons referred to above. Its value is odd integral for all the particles of the $\frac{1}{2}^+$ and $\frac{3}{2}^+$ multiplets and the same is even integral for all the particles of the 0^- and 1^- multiplets. To be more specific, its values for the particles which are well known for their *free production* are given by[8,9]

$$\begin{aligned} 2I + |S| &= 1 \text{ for an actual fermion having } I = 0 \\ &= 1 \text{ or } 3 \text{ for an actual fermion having } I \neq 0 \\ &= 0 \text{ for an actual boson having } I = 0 \\ &= 2 \text{ for an actual boson having } I \neq 0. \end{aligned}$$

From the above considerations, we now demand that a hadron may be freely produced if its $SU_f(4)$ quantum numbers satisfy the following constraint[5-9]

$$\begin{aligned} 2I + |S| + |C| &= 1 \text{ for an actual fermion having } I = 0 \\ &= 1 \text{ or } 3 \text{ for an actual fermion having } I \neq 0 \\ &= 0 \text{ for an actual boson having } I = 0 \\ &= 2 \text{ for an actual boson having } I \neq 0 \end{aligned} \tag{8}$$

where $|S|$ and $|C|$ denote, respectively, the magnitude of strangeness and charm; I representing isospin. The applications of this constraint will be discussed in Sec. 3.

One interesting feature shared by both the constraints discussed above is that they are of non-dynamical origin. This is reflected in the fact that they involve the internal quantum numbers (I, S, C) but not their variations (i. e. ΔI, ΔS, ΔC). Needless to state that dynamical constraints are expressed in terms of the variations of the internal quantum numbers (like $\Delta I = 0$, $\Delta S = 0$, $\Delta C = 0$ in strong interactions, for example). It may be stressed that non-dynamical constraints have a special advantage over dynamical ones as the former, being independent of interactions, are applicable in all interactions. Therefore the constraints of our interest will be operative in all possible production mechanisms for a hadron. One important remark is in order here. The striking difference between the two constraints is that one of them, given by relation (7), involves internal (i. e. I, S, C) as well as external (J) quantum numbers whereas the other, described by relation (8), involves only internal quantum numbers. This has the implication that the former constraint is more stringent than the latter one. The bearing of this point will be evident from our discussions on Σ_c-production in the next section.

3. *Production behaviours of the SU (4)-predicted open-charm particles*

In this section we shall investigate production behaviours of the $SU_f(4)$-predicted 0^-, 1^-, $\frac{1}{2}^+$ open-charm particles by exploiting the two constraints discussed in Sec. 2. With this end in view we first consider the constraint given by relation (7). This constraint, as can be easily checked, is satisfied for the charm mesons

$D^{+,0}$ (for which $B = 0$, $S = 0$, $C = 1$, $I = \frac{1}{2}$, $J = 0$) with $X = +1$ as well as for their antiparticles (having $C = -1$) with $X = -1$. A similar remark is also true for the charm hyperons $\Xi_c^{+,0}$ (or $A^{+,0}$ in the notation of Ref. 1 with $B = 1$, $S = -1$, $C = +1$, $I = \frac{1}{2}$, $J = \frac{1}{2}\Big)$ with the choice $X = +3$. These hadrons are, therefore, expected to be freely produced according to the constraint under considerations. The same constraint, on the other hand, is not satisfied for the charm baryons $\Sigma_c^{++,+,0}$ (with $B = 1$, $S = 0$, $C = 1$, $I = 1$, $J = \frac{1}{2}\Big)$. This is because for Σ_c, which is an isoboson, one cannot find any value of X from its allowed values for isobosons indicated in relation (4) for which the constraint i. e. relation (7) may be satisfied. Consequently, Σ_c-production is forbidden according to this constraint and as such suppressed. The predictions of this constraint on the nature of production of the 0^-, 1^- and $\frac{1}{2}^+$ open-charm particles have been shown in Table 1. In passing we may note that this constraint is not valid for the particles like D_s, D_s^*, Λ_c^+ for which $I = 0$.

We now shift our attention to the other constraint i. e. relation (8) which is of general validity. It is a simple matter to check that D and D^* mesons (having $I = \frac{1}{2}$, $S = 0$, $|C| = 1$) are predicted to be freely produced by this constraint which holds true for these charm particles. The same constraint, however, is not satisfied for D_s (or F in the notation of Ref. 1) and D_s^* (or F^*) having $I = 0$, $|S| = 1$, $|C| = 1$ as can be easily verified. Consequently, productions of these hadrons are forbidden by the constraint concerned. This in turn means inhibited productions of these hadrons. This constraint is satisfied for Σ_c (having $I = 1$, $S = 0$, $|C| = 1$) which, therefore, is expected to be freely produced. This expectation, however, cannot be materialized as we have already noted that Σ_c-production is forbidden by the other constraint given by relation (7). It may be emphasized in this connection that the predictions of a constraint are more reliable for its forbidden processes rather than for its allowed ones. This is because a process allowed by a particular constraint may be forbidden (and as such suppressed) by other constraint(s). In passing we may also note that if production of a particle is forbidden by any one of a set of constraints operative in its production, then, the overall status of its production turns out to be that of a suppressed particle even if its production is allowed by the rest of the constraints. This point will be utilized in our following discussions. The predictions of the constraint, given by relation (8), on the nature of productions of the 0^-, 1^-, $\frac{1}{2}^+$ open-charm particles have been indicated in Table 1.

For convenience of further discussions, we first concentrate on the already observed charm particles[3)]. As evident from Table 1 the charm mesons D and D^* are predicted to be freely produced by both the constraints. A similar remark is also true for the strange-cum-charm hyperon Ξ_c^+ (or A^+ in the notation of Ref. 1). Also, as reflected in Table 1, Λ_c^+ is predicted to be freely produced by the constraint given by relation (8); the other constraint described by relation (7) being not applicable for production of Λ_c^+ for which $I = 0$. These predictions are in conformity with the so far available data[2] on productions of these charm particles. In sharp contrast to the above mentioned particles, D_s (or F in the notation of Ref. 1), D_s^* (or F^*), Σ_c and Ω_c^0 (or T^0) must exhibit inhibited production. A look into Table 1 reveals that D_s, D_s^* and Ω_c^0 are predicted to undergo suppressed production by the constraint given by relation (8) whereas Σ_c-production is predicted to be suppressed by the other constraint described by relation (7). At this point one important observation may be made. Σ_c-production should be more strongly suppressed than D_s-production. This is because the constraint given by relation (7) is more stringent than the constraint given by relation (8) for the reason pointed out earlier.

We now turn our attention to production behaviours of the $\frac{1}{2}^+$ charm baryons which still remain to be discovered. From a glance at Table 1 it is clear that S^+, S^0, X_{uu}^{++} and X_d^+ are expected to be freely produced as their productions are allowed by both the constraints of our interest. These expectations will be materialized in future experiments provided productions of these hadrons are not forbidden by any other constraint(s). It is also evident from Table 1 that X_s^+ is predicted to undergo suppressed production by the constraint given by relation (8). This prediction must turn out to be true in future experiments for the reason discussed earlier.

4. *Conclusions*

In this paper we have discussed two non-dynamical constraints which are exclusively meant for hadron production. These constraints have been exploited to investigate production behaviours of the 0^-, 1^-, $\frac{1}{2}^+$ open-charm particles predicted by $SU_f(4)$ symmetry. These constraints, considered jointly, can account for the observed suppressed productions of D_s (or F), D_s^* (or F^*), Σ_c, Ω_c^0 (or T^0). It has also been underlined that Σ_c-production should be more strongly suppressed than D_s (or F)-production. The other observed charm particles are predicted to be freely produced by the constraints concerned. These predictions are well supported by the so far accumulated experimental information on productions of these particles. The same constraints have also been utilized to predict production behaviours of the $\frac{1}{2}^+$ charm baryons which still remain to be discovered. We conclude this paper with the final remark. The predictions of the constraints on the nature of production of the charm particles are valid irrespective of their production mechanisms as the constraints are of non-dynamical origin.

References

1) M. K. Gaillard, B. W. Lee and J. L. Rosner, Rev. Mod. Phys. **47** (1975) 277;
2) C. A. Heusch, Proceedings of the 1982 SLAC Summer Institute on Particle Physics;
3) Particle Data Group, Review of Particle Properties (1986);
4) P. Mukhopadhyay, Phys. Lett. B98 (1981) 96;

5) P. Mukhopadhyay, Acta Phys. Pol. **B10** (1979) 237;
6) P. Mukhopadhyay, Hadronic Journal **7** (1984) 867;
7) P. Mukhopadhyay, Hadronic Journal **8** (1985) 317;
8) P. Mukhopadhyay, the paper entitled *Production Behaviours of Open-Bottom Hadrons and Suppression of Λ_b^0-Production* (to be published in Mod. Phys. Lett. A);
9) P. Mukhopadhyay, Acta Phys. Pol. **B19** (1988) 589;
10) P. Fayet and S. Ferrara, Phys. Rep. **C32** (1977) 249.

PONAŠANJE PRODUKCIJE ČESTICA OTVORENOG ŠARMA I POTISNUĆE PRODUKCIJE Σ_c

SUMIT DHAR i PARTHASARATHI MUKHOPADHYAY

Physics Department, Jadavpur University, Calcutta 700 032, India

UDK 539.12

Originalni znanstveni rad

U ovom radu proučavano je ponašanje produkcije čestica otvorenog šarma u okviru $SU_f(4)$ simetrije, koje objašnjava opaženo potisnuće produkcije šarmantnog bariona Σ_c, stranog šarmantnog mezona D_s (F u notaciji Gaillardove i ostalih) te njegovog probuđenog stanja D_s^* (F^*). Također je ukazano da potisnuće kod Σ_c produkcije mora biti jače nego kod D_s produkcije. Ovaj rad, osim toga, predviđa koji od dosad neopaženih $\frac{1}{2}^+$ šarmantnih bariona će se proizvoditi slobodno a koji od njih će trpiti potisnuće.