Diquark cascade and meson production in diquark-deuteron fragmentation

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(Received 16 November 1983; revised manuscript received 19 June 1984)

A diquark cascade model of meson production in the fragmentation region of the diquark deuteron is proposed. The meson spectra obtained in this model show that, in general, the cross sections are large compared to those occurring in fragmentation of the normal deuteron. It is also shown that the available deuteron data are consistent with the presence of quark clusters in the normal deuteron.

I. INTRODUCTION

The existence of a diquark phase of nuclear matter[1] has been suggested as an explanation of the anomalous stopping property of a fraction of projectiles observed in high-energy nuclear collisions in emulsion.[2] In particular there might exist a long-lived (lifetime $>10^{-10}$ s) $J^P=0^-$ diquark deuteron (δ) with very high reaction cross section which results from strong color fluctuations at the surface. In this paper, we wish to point out that matter in the diquark phase may further be characterized by enhanced meson cross sections in hadron-δ collisions.

The precise object that we calculate in this paper is the inclusive x distribution of soft (low-P_T) mesons produced in the fragmentation region of diquark deuterons and normal deuterons in collisions with hadrons. Since the diquark deuteron is unstable, direct experiment on hadron—diquark-deuteron collisions is obviously ruled out. But it is conceivable that relevant data can be extracted from measurements on the secondary vertices by appropriate selection of events in either emulsion or bubble-chamber experiments, if such experiments can ever be performed to generate sufficiently large number of δ-hadron events.

Irrespective of whether the diquark deuteron exists or not, a diquark is presently an object of interest in hadron physics. According to one view that is gaining popularity, the structure of baryons is best understood when they are treated as being composed of a quark and a diquark, the latter being an entity behaving like a color antitriplet.[3] It may therefore be convenient to describe hadron productions in processes involving baryonic systems directly in terms of fragmentation and/or recombination of quarks and diquarks.

The phenomenological importance of diquark fragmentation as a mechanism of hadron production is now well recognized. Information about it comes mostly from leptoproduction data[4] and data on hadronic collisions with a large-P_T trigger.[5] Calculations of the diquark fragmentation functions using essentially a cascade-type approach[6] have been carried out by Sukhatme, Lassila, and Orava[7] and Bartl, Fraas, and Majerotto.[8] There are two basic processes by which hadrons can appear in a jet initiated by a diquark. Firstly, a diquark as a whole may go into forming a baryon leaving behind an antiquark: $(qq)\rightarrow B+\bar{q}$. Secondly, a diquark may emit a meson by letting one of its constituent quarks fragment: $(qq)\rightarrow M+(q'q)$. If the first one were the only allowed process, a diquark jet would always start with emission of a primary baryon and the antiquark left behind would have to carry on the cascading further. With the second process, a diquark can continue to cascade through several stages, emitting mesons and undergoing appropriate change in its flavor at every stage until it disappears into a baryon. Such an evolution of a diquark will be called a diquark cascade in this paper. It has been established in Refs. 7 and 8 that the existing experimental data on leptoproduction require the inclusion of the second process and hence of the diquark cascade.

In this paper we are interested in studying the role of diquarks in low-P_T hadron production in hadron-deuteron and hadron-δ collisions. In order to calculate the inclusive cross sections, one needs a model for soft-particle production in hadron collisions (see, for example, Capella, Sukhatme, and Tran Thanh Van[9]). The model used in this paper is fashioned after the single-quark-cascade (SQC) model of Fukuda and Iso,[10] according to which the valence quarks of the incident hadrons produce mesons by fragmentation and finally recombine into baryons [Fig. 1(a)]. Integration of the evolution equation corresponding to this cascade enables one to calculate the various cross sections. The Fukuda-Iso model is a simple model which uses arguments of fairly general nature and which has the virtue of being able to predict the correct behavior of most observable cross sections in a variety of processes without having to introduce such artifices as the "held-back effect," in contrast to other, less sophisticated fragmentation models.

We propose to modify this model by allowing the diquarks to retain their status as dynamical entities undergoing evolution through diquark cascade (DC) until they end up as baryons by recombination process [Fig. 1(b)]. In Sec. II, we present the SQC model as applied to the deuteron regarded as an assembly of six quarks $(3u+3d)$

(Ref. 11). Our treatment of the model is slightly different from that in Ref. 10; we adopt an algebra which is direct and simple. In Sec. III, we present the diquark-cascade model worked out for diquark-deuteron fragmentation as well as for normal-deuteron fragmentation with the normal deuteron regarded as an assembly of two quarks and two diquarks $[u+d+2(ud)]$. In Sec. IV, the cross sections calculated for these cases are compared with each other. The concluding section contains some comments on our result.

II. SINGLE-QUARK CASCADE

We retain the notation of Ref. 10 to denote the probability of $u \to d+\pi^+$ and $d \to u+\pi^-$ by a, that of $u \to s+k^+$ and $d \to s+K^0$ by b and that of $s \to u+K^-$ and $s \to d+\bar{K}^0$ by b'. Furthermore, $u(x,t)$, $d(x,t)$, and $s(x,t)$ denote the distribution of u, d, and s quarks evolving in time. If x denotes the Feynman variable, the evolution of the u-quark distribution is governed by the equation

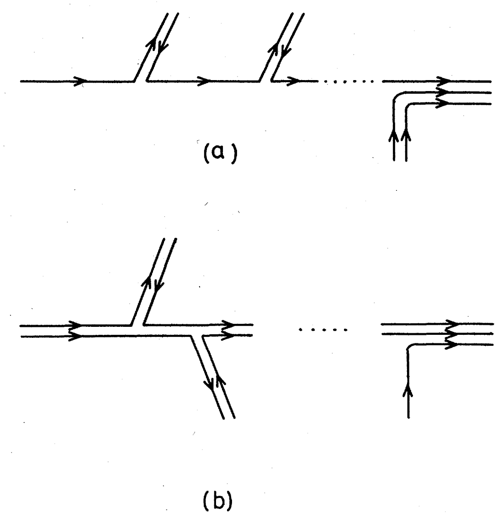

FIG. 1. (a) Single-quark cascade in the model of Fukuda and Iso (Ref. 10). (b) Diquark cascade.

$$\frac{d}{dt}u(x,t) = -(\lambda_1+\lambda_1')u(x,t)+\lambda_1\int_x^1 dx' f(x,x')[(1-a-b)u(x',t)+ad(x',t)+b's(x',t)] , \tag{2.1}$$

where λ_1 and λ_1' are the decay constants for decay of a single quark accompanied by production of mesons and baryons, respectively, and $f(x,x')$ denotes the probability of an initial quark with longitudinal momentum fraction x' going over into a final quark with x after emission of a meson with $x'-x$. The function $f(x,x')$ has a normalization

$$\int_0^{x'} f(x,x')dx = 1 . \tag{2.2}$$

The distributions $d(x,t)$ and $s(x,t)$ obey equations of evolution similar to (2.1). The deuteron being an isosinglet, we have to consider only the combinations $X_1 = u(x,t)+d(x,t)$ and $X_2 = s(x,t)$. The diffusion equation for

$$X = \begin{bmatrix} X_1 \\ X_2 \end{bmatrix}$$

can then be written as

$$\frac{d}{dt}X = M_1 X , \tag{2.3}$$

where

$$M_1 = \begin{bmatrix} -(\lambda_1+\lambda_1')+\lambda_1 D(1-b) & 2\lambda_1 b'D \\ \lambda_1 bD & -(\lambda_1'+C\lambda_1)+\lambda_1 D(1-2b') \end{bmatrix} . \tag{2.4}$$

The operator D is defined as

$$Dq(x,t) = \int_x^1 dx' f(x,x')q(x',t) . \tag{2.5}$$

The constant C in (2.4) is a parameter incorporating SU(3) violation. The inclusive meson cross sections can be calculated once we know the quantity

$$\bar{X}(x) = \int_0^\infty dt\, X(x,t) . \tag{2.6}$$

Integration of (2.3) leads to

$$\bar{X}(x) = -M_1{}^{-1}X(t=0) . \tag{2.7}$$

The initial quark distribution $X(t=0)$ in the deuteron which contains six quarks may be fixed by the following considerations. The initial momenta of all the quarks add up to the total deuteron momentum. Normalization of the total probability to 1 then means

$$1 = N\int dx_0' \int dx_0'' \cdots \int dx_0^{vi}\delta(x_0'+x_0''+\cdots+x_0^{vi}-1) = \frac{N}{24}\int_0^1 dx_0'(1-x_0')^4 , \tag{2.8}$$

giving $N=120$. If a quark starts cascading at $t=0$ with a typical value x_0 of the Feynman parameter, the initial distribution is represented by

$$X(t=0)=5\int_0^1 dx_0(1-x_0)^4\delta(x-x_0)\begin{bmatrix}3\\0\end{bmatrix} . \tag{2.9}$$

The operation with M_1^{-1} can be carried out conveniently by separating each element $(M_1^{-1})_{ij}$ into partial fractions

$$(M^{-1})_{ij}=\sum \frac{R_{ij}^{(n)}}{1-\beta_{ij}^{(n)}D} \tag{2.10}$$

and using the formula

$$D^n\delta(x-x_0)=\frac{f(x,x_0)}{(n-1)!}\left[(h+1)\ln\left[\frac{x_0}{x}\right]\right]^{n-1} \tag{2.11}$$

if we choose

$$f(x,x')=\frac{1+h}{x'}\left[\frac{x}{x'}\right]^h \tag{2.12}$$

in accordance with Fukuda and Iso.[10]

The smallness of K/π and $\bar{K}/\pi$ ratios implies relative smallness of b and b'. The consequent smallness of the off-diagonal elements of M_1 allows one to invert M_1 by iteration. The result is

$$\bar{X}_1(x)=\frac{1}{\lambda_1}R^{(1)}H_1(\beta^{(1)},x) , \tag{2.13}$$

$$\bar{X}_2(x)=\frac{1}{\lambda_2}\frac{bR^{(1)}R^{(2)}\beta^{(1)}\beta^{(2)}}{\beta^{(1)}-\beta^{(2)}} \times[H_1(\beta^{(2)},x)-H_1(\beta^{(1)},x)] , \tag{2.14}$$

where we have put

$$R^{(1)}=1/(1-b),\ R^{(2)}=1/(1-2b') ,$$
$$\beta^{(1)}=(1+r_1)/(1-b),\ \beta^{(2)}=(c+r_1)/(1-2b') , \tag{2.15}$$
$$r_1=\lambda_1'/\lambda_1 ,$$

and with the choice $h=1$ which agrees with the dimensional-counting rule,

$$H_1(\beta^{(i)},x)=15(1-x)^4 +30\beta^{(i)}\int_x^1\frac{(1-x_0)^4}{x_0}\left[\frac{x}{x_0}\right]^{1-2\beta^{(i)}}dx_0 . \tag{2.16}$$

The meson spectra resulting from single-quark cascade are given by

$$\pi^{\pm}(x)=\lambda_1 a\int_x^1\bar{X}_1(x')f(x'-x,x')dx' , \tag{2.17}$$

$$K^+(x)=K^0(x) =\lambda_1 b\int_x^1\bar{X}_1(x')f(x'-x,x')dx' , \tag{2.18}$$

$$K^-(x)=\bar{K}^0(x) =\lambda_1 b'\int_x^1\bar{X}_2(x')f(x'-x,x')dx' \tag{2.19}$$

with $\bar{X}_1$ and $\bar{X}_2$ calculated from (2.13) and (2.14).

III. DIQUARK CASCADE

We shall now derive analogous equations for the meson cross section in fragmentation of a system in which diquarks evolve as cascading entities. With u, d, and s quarks only, we can make six varieties of diquark. Restricting to isosinglet systems, it is necessary to consider the evolution of only four diquark combinations:

$$Y=\begin{bmatrix}Y_1\\Y_2\\Y_3\\Y_4\end{bmatrix}=\begin{bmatrix}(uu)+(dd)\\(ss)\\(ud)\\(us)+(ds)\end{bmatrix} . \tag{3.1}$$

Evaluation of $Y_1,\ldots,Y_4$ involves the various diquark$\rightarrow$diquark transition probabilities defined in Table I. Thus α denotes the probability of the transition $(uu)\rightarrow(dd)$ (accompanied by emission of $2\pi^+$), etc. To simplify calculations we reduce the number of parameters using SU(2) invariance and neglecting processes involving emission of more than one kaon. These approximations are indicated in Table I.

Evolution of individual diquarks can be expressed in terms of these parameters and the diquark decay constants λ_2 and λ_2' (for decays involving meson production and baryon production, respectively). Thus for the (uu) diquark, for example,

$$\frac{d}{dt}(uu)=-(\lambda_2+\lambda_2')(uu)+\lambda_2\int_x^1 dx'f(x,x')[(1-\alpha-\beta-\gamma-\delta-\epsilon)(uu)+\beta(dd)+\gamma(ud)+\delta(us)+\epsilon(ds)] . \tag{3.2}$$

TABLE I. Probabilities for $(q_1q_2)\rightarrow(q_1'q_2')$.

(q_1q_2) \ $(q_1'q_2')$	(uu)	(dd)	(ss)	(ud)	(us)	(ds)
(uu)		α	β' (≈ 0)	γ'	δ'	ϵ'
(dd)	α		β' (≈ 0)	γ	ϵ'	δ'
(ss)	β (≈ 0)	β (≈ 0)		μ' (≈ 0)	θ' $(\approx\delta)$	θ' $(\approx\delta)$
(ud)	γ	γ'	μ (≈ 0)		ν' $(\approx\delta')$	ν' $(\approx\delta')$
(us)	δ	ϵ	θ $(\approx\delta')$	ν $(\approx\delta)$		κ
(ds)	ϵ	δ	θ $(\approx\delta')$	ν $(\approx\delta)$	κ	

The equations for other diquarks can be similarly written down. With the approximations of Table I, all these equations combine into

$$\frac{d}{dt}Y(x,t)=M_2Y(x,t)\ , \tag{3.3}$$

$$M_2=\begin{bmatrix} A_1 & 0 & 2\gamma\lambda_2 D & (\epsilon+\delta)\lambda_2 D \\ 0 & A_2 & 0 & \delta'\lambda_2 D \\ \gamma'\lambda_2 D & 0 & A_3 & \delta\lambda_2 D \\ (\epsilon'+\delta')\lambda_2 D & 2\delta\lambda_2 D & 2\delta'\lambda_2 D & A_4 \end{bmatrix}, \tag{3.4}$$

where D is the same operator as defined in (2.5) and

$$A_1=-(\lambda_2'+\lambda_2)+\lambda_2 D(1-\gamma-\delta-\epsilon)\ , \tag{3.5}$$

$$A_2=-(\lambda_2'+c'\lambda_2)+\lambda_2 D(1-2\delta')\ , \tag{3.6}$$

$$A_3=-(\lambda_2'+\lambda_2)+\lambda_2 D(1-2\gamma'-2\delta)\ , \tag{3.7}$$

$$A_4=-(\lambda_2'+c''\lambda_2)+\lambda_2 D(1-\delta-2\delta'-\epsilon')\ . \tag{3.8}$$

The parameter c' incorporates SU(3) violation for (ss) diquark and c'' does the same for (us) and (ds).

The quantity of interest

$$\bar{Y}(x)=\int_0^\infty dt\ Y(x,t) \tag{3.9}$$

is again obtained by integrating (3.3). Thus,

$$\bar{Y}(x)=-M_2^{-1}Y(x,t=0)\ . \tag{3.10}$$

If the diquark deuteron initially contains three (ud) diquarks, the total longitudinal momentum is shared by three objects. The initial distribution can then be represented by

$$Y(x,t=0)=2\int_0^1 dx_0(1-x_0)\begin{bmatrix}0\\0\\3\\0\end{bmatrix}\delta(x-x_0)\ . \tag{3.11}$$

One can then calculate M_2^{-1} by iteration, write down each of its elements as a sum of partial functions, and apply (2.12) to obtain

$$\bar{Y}_1(x)=\frac{1}{\lambda_2}\frac{2\gamma G^{(3)}G^{(1)}\gamma^{(3)}\gamma^{(1)}}{\gamma^{(1)}-\gamma^{(3)}} \times[H_2(\gamma^{(3)},x)-H_2(\gamma^{(1)},x)]\ , \tag{3.12}$$

$$\bar{Y}_2(x)=0\ , \tag{3.13}$$

$$\bar{Y}_3(x)=\frac{1}{\lambda_2}G^{(3)}\gamma^{(3)}H_2(\gamma^{(3)},x)\ , \tag{3.14}$$

$$\bar{Y}_4(x)=\frac{1}{\lambda_2}\frac{2\delta' G^{(3)}G^{(4)}\gamma^{(3)}\gamma^{(4)}}{\gamma^{(3)}-\gamma^{(4)}} \times[H_2(\gamma^{(4)},x)-H_2(\gamma^{(3)},x)]\ , \tag{3.15}$$

where we have put

$$G^{(1)}=\frac{1}{(1-\beta-\gamma-\delta-\epsilon)},\quad G^{(3)}=\frac{1}{(1-2\gamma'-2\delta)}\ ,$$

$$G^{(4)}=\frac{1}{(1-\delta-2\delta'-\epsilon')},\quad \gamma^{(1)}=(1+r_2)G^{(1)}\ , \tag{3.16}$$

$$\gamma^{(3)}=(1+r_2)G^{(3)},\quad \gamma^{(4)}=(c''+r_2)G^{(4)}\ ,$$

$$H_2(\gamma^{(i)},x)=6(1-x) +12\gamma^{(i)}\int_x^1 dx_0\frac{(1-x_0)}{x_0}\left[\frac{x}{x_0}\right]^{1-2\gamma^{(i)}}\ . \tag{3.17}$$

In (3.17) we have used the same choice $h=1$ for the power in $f(x,x')$ as used in SQC. The dimensional-counting rule would indicate $h=3$ for diquark fragmentation. However, Bartl, Fraas, and Majerotto[8] found that the dimensional-counting-rule prescription for the momentum-sharing functions does not always lead to good agreement with the existing leptoproduction data. Moreover, the most important part of our paper, namely, the enhancement in the large-x region for diquark-deuteron fragmentation is not affected by any variation in the choice of h. Therefore, for simplicity, we present here our calculation with $h=1$. The inclusive meson cross sections resulting from diquark cascades are given by

$$\pi^{\pm}(x)=\lambda_2\int_x^1[(2\alpha+\gamma'+\epsilon')\bar{Y}_1(x')+\gamma\bar{Y}_3(x')+(\epsilon+\kappa)\bar{Y}_4(x')]f(x'-x,x')dx'\ , \tag{3.18}$$

$$K^0(x)=\lambda_2\int_x^1[\delta'\bar{Y}_1(x')+\delta'\bar{Y}_2(x')+(\epsilon+\delta)\bar{Y}_4(x')]f(x'-x,x')dx'\ , \tag{3.19}$$

$$K^+(x)=\lambda_2\int_x^1[(\delta'+\epsilon')\bar{Y}_1(x')+\delta'\bar{Y}_4(x')]f(x'-x,x')dx'\ , \tag{3.20}$$

$$K^-(x)=\lambda_2\int_x^1[\delta\bar{Y}_2(x')+(\delta+\epsilon)\bar{Y}_4(x')]f(x'-x,x')dx'\ , \tag{3.21}$$

$$\bar{K}^0(x)=\lambda_2\int_x^1[\epsilon'\bar{Y}_1(x')+\delta\bar{Y}_2(x')+(\delta+\epsilon)\bar{Y}_4(x')]f(x'-x,x')dx'\ . \tag{3.22}$$

A picture of the normal deuteron which fits with the diquark model of baryon[3] is the one in which the deuteron is an assembly of two quarks and two diquarks. The meson spectra resulting from fragmentation of such a system can also be obtained in our model. The total momentum in this case is shared by four objects and the initial quark and diquark distributions have $(1-x)^2$ dependence on x. The cross sections are obtained as $\pi^{\pm}=\pi_1^{\pm}+\pi_2^{\pm}$, etc., where $\pi_1^{\pm}$ is the $\pi^{\pm}$ cross section calculated from (2.17) and (2.14)–(2.16) with H_1 replaced by

$$H'_1(\beta^{(i)},x)=3(1-x)^2 + 6\beta^{(i)}\int_x^1 \frac{(1-x_0)^2}{x_0}\left[\frac{x}{x_0}\right]^{1-2\beta^{(i)}} dx_0 \quad (3.23)$$

and $\pi_2^{\pm}$ is the $\pi^{\pm}$ cross section calculated from (3.18) and (3.12)—(3.15) with H_2 replaced by $2H'_1(\gamma^{(i)},x)$.

IV. COMPARISON OF MESON SPECTRA IN THE FRAGMENTATION REGION OF NORMAL DEUTERON AND DIQUARK DEUTERON

While the detailed values of each cross section over the range $0 \le x \le 1$ depend on the choice of the various parameters occurring in the formulas given above, the large-x behavior is practically independent of these parameters. For $x \lesssim 1$, the leading terms in the expression for each cross section can be easily calculated. It is found that the behavior depends crucially on the initial distribution of the constituents undergoing fragmentation, which in turn depends on the manner in which the total momentum is shared by these constituents. Therefore, remarkably different results are obtained for the three different assemblies under consideration, namely, the assembly of six quarks ($6q$), the assembly of two quarks and two diquarks [$2q+2(qq)$], and the assembly of three diquarks [$3(qq)$]. The large-x cross section always turns out to be the largest for the last system as the average initial momentum of the cascading units for this system is higher than that for the other two systems. We give below the leading terms for $x \to 1$ of the pion cross section in the three cases:

$$6q:\ \pi^{\pm}(x) \sim \frac{a}{1+r_1}\frac{(1-x)^6}{x^2}\,, \quad (4.1)$$

$$2q+2(qq):\ \pi^{\pm}(x) \sim \left[\frac{a}{2(1+r_1)}+\frac{\gamma}{1+r_2}\right]\frac{(1-x)^4}{x^2}\,, \quad (4.2)$$

$$3(qq):\ \pi^{\pm}(x) \sim \frac{2\gamma}{1+r_2}\frac{(1-x)^3}{x^2}\,. \quad (4.3)$$

The pion cross section in the fragmentation of the diquark deuteron indeed shows dramatic enhancement for large x (Fig. 2). The kaon cross sections from fragmentation of the $6q$ system are similarly suppressed in comparison with those from fragmentation of the $2q+2(qq)$ and $3(qq)$ systems. For the $6q$ system, K^+ and K^0 go like $(1-x)^6/x^2$ and K^- goes like $(1-x)^7/x^3$. For the $2q+2(qq)$ system, K^+ and K^0 cross sections behave like $(1-x)^4/x^2$ and the K^- cross section behaves like $(1-x)^5/x^3$. All these cross sections behave like $(1-x)^4/x^3$ for diquark deuteron. It is clear that the actual magnitude of the cross sections near $x=1$ depends on the various parameters. With reasonable choice of these parameters (which we describe below), the kaon cross sections for the diquark deuteron turn out to be larger than those for the $2q+2(qq)$ system in the high-x region. These effects are depicted in Figs. 2 and 3.

The dearth of data on deuteron fragmentation makes precise determination of the various parameters in our theory extremely difficult. We have tried to make a tentative choice of these by analyzing the K^0 production data[12] in a limited range of x. A range of values of the single-quark-cascade (SQC) parameters has been suggested by Fukuda and Iso[10] who have used their quark-cascade model to fit the proton fragmentation data. Since they considered only the single-quark cascade in proton fragmentation, they equated the b/a ratio to the experimental K^+/π^+ ratio. This identification would not, however, be

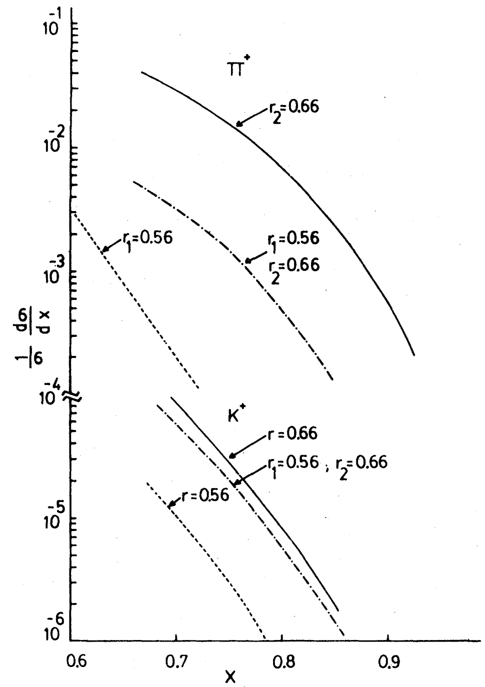

FIG. 2. $\pi^{\pm}$ and K^+ inclusive cross section in the high-x region. The dashed curve corresponds to the single-quark cascade in fragmentation of $3u+3d$ system; the dash and dot curve corresponds to fragmentation of $u+d+2(ud)$ system; the solid curve corresponds to the diquark cascade in fragmentation of $3(ud)$ system.

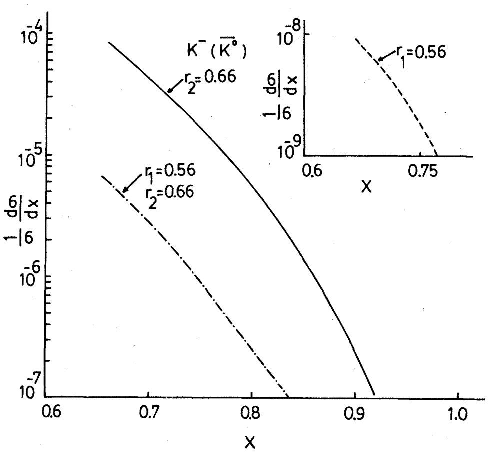

FIG. 3. K^- ($\bar{K}^0$) inclusive cross section in the higher-x region. Explanation of the different curves is the same as in Fig. 2.

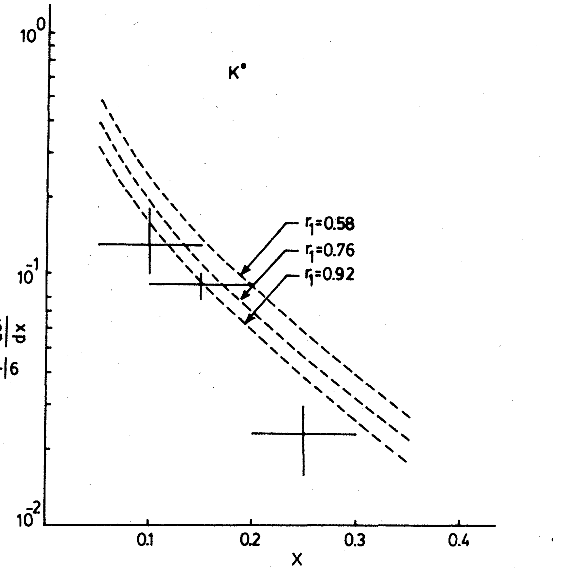

FIG. 4. K^0 inclusive cross section calculated from the single-quark cascade in fragmentation of $3u+3d$ system for three different values of r_1 $(=\lambda_1'/\lambda_1)$ compared with observed deuteron data from Ref. 12.

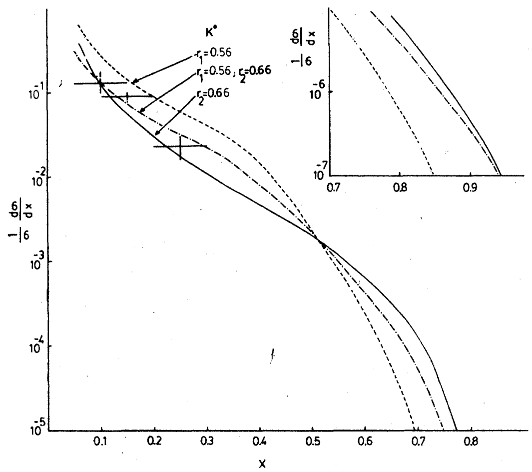

FIG. 5. K^0 inclusive cross section in the entire x region (the high-x region shown separately in the inset) for fragmentation of $3u+3d$ system (dashed curve); $u+d+2(u+d)$ system (dash and dot) and $3(ud)$ (solid curve). The values of the different parameters are given in the text.

quite true if one were to treat the proton as a $1q+1(qq)$ system and introduce the diquark cascade in the calculation following our method. One may therefore like to consider some variation of b/a around the value chosen by Fukuda and Iso.[10] Similar remarks apply to the other SQC parameters. Some of the results obtainable from Eq. (2.18) with such variations of the parameters can be seen in Fig. 4. The fit with experimental data is not good unless either the probabilities are made ridiculously small or r_1 is given some value much beyond the range (0.3—0.7) suggested by the work of Fukuda and Iso.[10]

On the other hand, it is not at all difficult to fit the experimental K^0 data with reasonable values of the SQC and DC parameters provided the normal deuteron is pictured as being made up of two single quarks and two diquarks (ud). We interpret this fact as evidence in favor of the currently popular diquark model of baryons according to which one would expect four of the valence quarks of the deuteron to exist in diquark clusters. At the same time, it also points to the necessity of introducing diquark cascade in our description of soft-hadron-production processes. The fit shown in Fig. 5 was obtained with the following choice:

$$b/a=0.06,\quad c'=c=0.6\ ,$$

$$b'=b=0.012,\quad r_1=0.56\ ,$$

$$\epsilon=\epsilon'=0,\quad \delta=\delta'=0.024\ ,$$

$$\gamma=\gamma'=0.4,\quad \alpha=0.08\ ,$$

$$\kappa=0.04,\quad r_2=0.68\ .$$

In the approximation to which we have calculated $M_2{}^{-1}$, the fit is independent of c''. It is also seen from Fig. 5 that the spectrum gets enhanced for the δ fragmentation only for $x\to 1$ and also just the opposite behavior for low x. The fit for the normal deuteron $[2q+2(qq)]$ is not very sensitive to the choice of r_2, which can be allowed to assume a large value without spoiling the fit. More deuteron data are obviously needed before one can get reliable values for the diquark-cascade parameters.

It is to be noted that we have worked with the assumption that only (ud) diquarks occur in the incident deuteron or diquark deuteron. Presence of (uu) and (dd) diquarks in the incident particles could in principle be incorporated in our calculation. But this would not affect the large-x behavior at all.

V. CONCLUSION

We have shown in this paper that the meson spectra, in particular the $\pi^{\pm}$ and K^- spectra, are expected to be enhanced in the large-x region in fragmentation of the diquark deuteron compared to that in fragmentation of the normal deuteron. The available data on K^0 production off the normal deuteron cannot be fitted with the single-quark cascade alone and point to the necessity of treating the deuteron as a system of two quarks plus two diquarks and to the necessity of introducing diquark cascade in the process where each diquark is to be regarded as a single unit as far as momentum sharing is concerned, although its composite nature allows it to often undergo flavor-changing transition by meson emission. The last feature agrees with the findings reported in Refs. 7 and 8. While the prospect of testing our results for diquark-deuteron fragmentation is not very encouraging at the moment, it should be possible to test some of our ideas by careful measurements of inclusive particle spectra in deuteron fragmentation. We think greater effort should go in this direction.

The question of model dependence of our result may naturally be raised. Regarding the low-x region, we do not claim much generality, but we believe that our higher-x result $(x>0.7)$ is much less model dependent than what one may suppose it to be. It may be recalled that our derivation of the result involves the following elements: (1) The idea of diquark cascade, (2) the evolution equation corresponding to it, (3) the kinematics of the initial average momentum of the fragmenting units and the consequent choice of the initial distribution, (4) the choice of the momentum-sharing function $f(x,x')$, and finally (5) the choice of the fragmentation-probability parameters. As mentioned above, the higher-x result is largely independent of (4) and (5). The evolution equation follows from (1) through perfectly general arguments. The idea of diquark cascade is well founded in view of the support it obtains from Refs. 7 and 8. The element (3) is purely momentum conservation that any model of low-p_T production must necessarily satisfy.

The lesson that we derive from our study is that even if the fragmentation probabilities of quarks and diquarks are of the same order of magnitude, the low-p_T inclusive distributions in the large-x region may show a striking difference between the contribution from quark cascade and that from diquark cascade, depending of course on the number of these fragmenting objects in the incident hadron. The effect should be more pronounced for incident hadrons with greater number of quarks or diquarks. In fact it is easy to see that the pion spectra for large x go as $(1-x)^n$ in the fragmentation region of an $I=0$ hadron made up of n diquarks, while they go as $(1-x)^{2n}$ in that of the corresponding system of $2n$ quarks. On the other hand, the difference should be less discernible for fragmentation of smaller incident hadrons such as proton. If colored quark clusters in reality behave as fragmenting units, these conclusions are inescapable.

ACKNOWLEDGMENT

The authors acknowledge the help of Mr. Amiya Biswas during the progress of this work.

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