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A POSSIBLE MECHANISM OF THE HEAVY QUARK FLAVOUR PRODUCTION

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Usually it is proposed that due to a large mass of $c-$, $b-$, $t-$ quarks their production can be calculated within perturbative theory (PT) of QCD[1]. However, recent experimental results have appeared that contradict the PT QCD. These are the BIS-2 data[2] on $\bar{D}^0 D^-$ production in neutron-carbon reactions, the charm production in a hyperon beam[3]. Later on, the results of the NA32 experiment on D-meson production in $K-$ and $\pi-$ meson beams have been published[4] as follows:

$$\begin{aligned} \sigma(K^- Si \rightarrow D/D^- X) &= 7.5 \pm 1.9 \mu b/Nucleon \\ \sigma(\pi^- Si \rightarrow D/D^- X) &= 5.2 \pm 0.8 \mu b/Nucleon \end{aligned} \qquad (1)$$

In the PT QCD the mechanism of charm pair production is based on the subprocesses $\bar{q}q \rightarrow \bar{c}c$, $gg \rightarrow \bar{c}c$. Therefore, an attempt was undertaken to explain (1) by the difference of the parton distribution functions in $\pi-$ and $K-$ mesons[5]. There was also shown that within the PT QCD one may reach an agreement with (1) only suggesting a large difference of gluon distribution functions in $\pi-$ and $K-$ mesons. However, then it is simulteneously impossible to explain equal $J/\Psi-$ meson production both in $\pi-$ and $K-$ beams[6].

Here we propose a nonperturbative mechanism of charm production which at least qualitatively explains these experimental data (a detailed calculation will be published elsewhere).

Some time ago it was discovered[7] that instantons[8] play a significant role in the vacuum structure of QCD. Researches carried out within the QCD sume rules[9] and quark model[10] have shown the dominance of effects related with 't Hooft's interquark interaction through instantons [11] on hadron spectroscopy. Thus, we have proved[10] that in fact all spin-spin splittings in hadron multiplets are not caused by one-gluon exchange diagrams as usually suggested[12] but just by interaction[11].

Within the QCD vacuum model as an instanton liquid[7] the Lagrangian of interaction of quarks through instantons is expressed as[10]:

$$\mathcal{L}^{(4)}_{inst} = \frac{2\pi^2\rho_c^2}{3} \mid \epsilon_{ij} \mid \{\bar{q}_{iR} q_{iL} \bar{q}_{jR} q_{jL}[1 + \frac{3}{32}(1 - \frac{3}{4}\sigma^i_{\mu\nu}\sigma^j_{\mu\nu})\lambda^a_i\lambda^a_j] + (R \leftrightarrow L)\}, \tag{2}$$

where $q_{R,L} = \frac{(1\pm\gamma_5)}{2}q$, $i, j-$ quark flavours, ρ_c is an effective size of an instanton in the QCD vacuum, $\epsilon_{i,j}$ is antisymmetric tensor.

Interaction (2) has a very interesting spin and flavour structure. Namely, it is only nonvanishing for a zero spin pair of quarks of different flavours.

Figure 1: Quark–antiquark pair production due to a) four–quark vertex, b) six–quark vertex (I—instanton).

Within the quark model[10] this fact results in the formation of a scalar diquark in baryons.

In addition to four-quark interaction (2), there is also six-quark interaction [11] (for $SU_f(3)-$ and $SU_f(4)-$ groups) of the form[13]:

$$\begin{aligned} \mathcal{L}^{(6)}_{inst} \;=\; & -\frac{4\pi^2\rho_c^2}{3 < 0 \mid \bar{q}q \mid 0 >} \mid \epsilon_{ijk} \mid \bar{q}_{iR} q_{iL} \bar{q}_{jR} q_{jL} \bar{q}_{kR} q_{kL} \\ & \{ \quad 1 + \frac{3}{32}[\lambda^a_i\lambda^a_j(1 + 3\vec{\sigma}_i\vec{\sigma}_j) \\ & + \quad \frac{3}{10}d^{abc}\lambda^a_i\lambda^b_j\lambda^c_k(1 - 3\vec{\sigma}_i\vec{\sigma}_j) + 2\ permut] \\ & + \quad \frac{9}{64}f^{abc}(\sigma^{\mu\nu}\lambda^a)_i(\sigma^{\nu\gamma}\lambda^b)_j(\sigma^{\gamma\mu}\lambda^c)_k\} + (R \leftrightarrow L)\,. \end{aligned} \tag{3}$$

The values of parameters in (2) and (3) are the following[7]:

$$\rho_c = 1.6\ Gev^{-1},\ < 0 \mid \bar{q}q \mid 0 >= (0.2\ Gev)^3 \approx 1/R^3_{conf}, \tag{4}$$

where $R_{conf} \approx 5\ Gev^{-1}$ is the radius of quark confinement. Lagrangian (3) has the same peculiarities as (2).

So, there are two diagrams which describe the quark production due to nonperturbative effects (Fig. 1). Diagram 1a) defines the mixing of sea quarks in the hadron wave function.

Now, let us consider the heavy quark flavour production. Some of typical diagrams for $D-$, $\bar{D}-$ meson production in $\pi - n$ scattering due to (2) and (3) are pictured in Fig. 2. The contribution of diagram 2a) to the production cross section is obviously proportional to the fourth power of matrix element of (2):

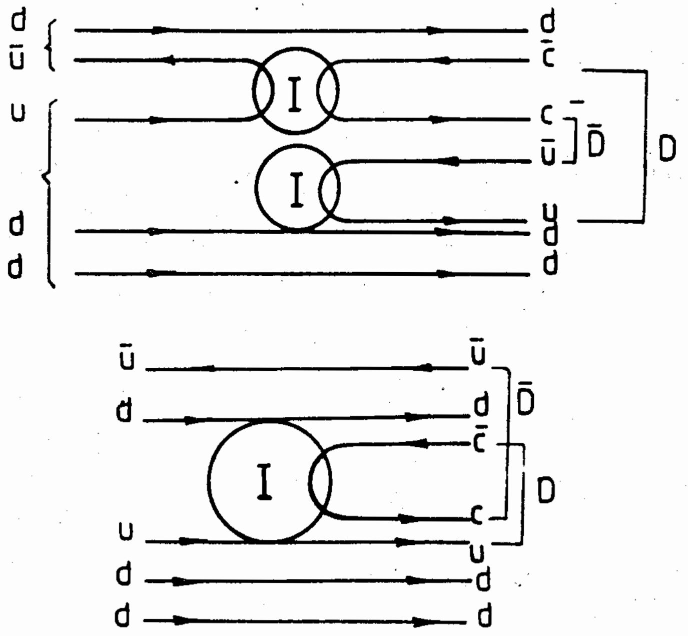

Figure 2: Example of diagrams that are responsible for nonperturbative charm production ($\pi^- n \to \bar{D}DX$)

$$\sigma^{(4)} \propto |< A \mid \mathcal{L}^{(4)} \mid B >|^4,$$

at the same time for 2b):

$$\sigma^{(6)} \propto |< A' \mid \mathcal{L}^{(6)} \mid B' >|^2,$$

where $\mid A >$, $\mid B >$ are initial and final states of quarks in subprocesses.

By using (2) and (3) we estimate:

$$\sigma^{(4)} = \left[\frac{\rho_c^2}{R_{conf}^2}\right]^4 \sigma_0,\ \sigma^{(6)} = \left[\frac{\rho_c^2}{R_{conf}^2}\right]^2 \sigma_0,$$

where σ_0 is some quantity related to initial hadrons wave functions and quark fragmentation ($\sigma_0 \propto R_{conf}^2$). So, we can write

$$\sigma^{(6)}/\sigma^{(4)} = (\rho_c/R_{conf})^4 \approx 10^2. \qquad (5)$$

Hence nonperturbative quark production in hadron collisions comes mostly from the diagram of Fig. 2b.

The given mechanism has to dominate over hard process described by the PT QCD only in the region of small transverse moment $p_\perp \leq 1\ Gev$, because here the PT QCD does not work and out of this region the nonperturbative effects are suppressed by the instanton formfactor[7]:

$$\frac{d\sigma}{dp_\perp^2} \approx \exp(-p_\perp \rho_c). \qquad (6)$$

In conditions of experiment[4] transverse momenta were certainly small, $p_\perp \leq 1\ \ Gev$. From the dominance of diagram, 2b), we get the estimation:

$$\frac{\sigma(KSi \to \bar{D}/DX)}{\sigma(\pi Si \to \bar{D}/DX)} \approx \frac{3}{2}, \qquad (7)$$

which follows from that $\mathcal{L}^{(6)}$ is nonzero only for a pair of different flavour quarks and the target does not contain strange quarks.

Note that the diagram, 2b), does not contribute to $J/\Psi-$ meson production because two quarks have to be in the state with zero total angular momentum [11].

Hence,

$$\frac{\sigma(KSi \to J/\Psi X)}{\sigma(\pi Si \to J/\Psi X)} \approx 1,$$

which is seen in experiment[6].

Thus, we have shown that in the region of small $p_\perp \leq 1\ Gev$ the nonperturbative mechanism of heavy quark flavour production apparently dominates.

This effect may be verified at the CERN hyperon beam where we predict the rise of D-meson production with respect to the proton beam.

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