Quark model for high-energy $\bar{p}N \to PP$ reactions

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In our broken-SU(3) quark model, high-energy processes of the type $\bar{p}N \to PP$ are investigated in the crossed-t channel. It is assumed that the physical baryon octet contained in the direct product $\underline{3} \otimes \underline{3} \otimes \underline{3}$ is given by $\underline{8}$ (physical) $= \underline{8}' \cos\theta + \underline{8} \sin\theta$, where the baryon octets $\underline{8}$ and $\underline{8}'$ arise from $\underline{3} \otimes \underline{\bar{3}}$ and $\underline{3} \otimes \underline{6}$, respectively. We find that the available data on $R(\pi^+\pi^-) : R(K^+K^-) : R(K^0\bar{K}^0)$ are in reasonable agreement with our calculations for $\theta = 20°$ and $b = 0.2 \pm 0.04$; b is the strange-quark–to–nonstrange-quark coupling parameter.

I. INTRODUCTION

The high-energy reactions of interest to us in this paper are

$$\bar{p} + N \to P + P \,, \tag{1}$$

where N stands for the proton p or the neutron n, and P stands for the pseudoscalar meson. At present, some experimental data are available on these reactions and more data are being obtained.[1]

The earlier symmetry calculations on these reactions are for the capture of $\bar{p}$ from rest.[2] As is to be expected, these calculations do not explain the available data at high energies. Therefore, our main objective here will be to present our simple quark-model calculations and to compare them with the available data.

As in other quark models, the pseudoscalar meson octet is a composite of $Q\bar{Q}$. Our physical baryon octet contained in the direct product $\underline{3} \otimes \underline{3} \otimes \underline{3}$ is given by

$$\underline{8}\ (\text{physical}) = \underline{8}' \cos\theta + \underline{8} \sin\theta \,, \tag{2}$$

where the baryon octets $\underline{8}$ and $\underline{8}'$ arise from $\underline{3} \otimes \underline{\bar{3}}$ and $\underline{3} \otimes \underline{6}$ respectively. Our earlier quark-model calculations[3] on various particle reactions are consistent with the experimental data for $\theta = 20°$. Therefore, in this paper, we shall take $\theta = 20°$. Our quark model is discussed in considerable detail in Ref. 4.

In Sec. II, we calculate the matrix elements for the $\bar{p}N \to PP$ processes. Our results are discussed in Sec. III.

II. CALCULATIONS

In calculating the matrix elements for reactions (1), we shall assume the validity of (a) the impulse approximation, and (b) charge-conjugation invariance. Also, we shall assume that the basic interaction is dominated by the exchange of 1^- vector mesons. This implies antisymmetric coupling in the exchange of mesons.

At high energies of interest to us, the angular distributions for the $\bar{p}N \to PP$ processes are strongly peaked in the forward direction.[1] This implies the dominance of the crossed-t-channel effects. In our lowest order calculations, the interaction is represented by the diagrams (a) and (b) in Fig. 1. Corresponding to these diagrams, the t-channel effective Lagrangian can be written as

$$L_{\text{eff}}(t) = 6\hat{b}A[\bar{B}^{abc} P_d^c \bar{B}_{abe} P_e^d - \bar{B}^{abc} P_e^d \bar{B}_{abe} P_d^c] \,. \tag{3}$$

Here, $\bar{B}^{abc}$ refers to the incoming $\bar{p}$ state, $\bar{B}_{abe}$ refers to the incoming N state, and P refers to the pseudoscalar-meson octet. The numerical factor of 6 is introduced for convenience. The over-all complex amplitude A is the integral over the space-time variables and contains all the spin and kinematic dependences.

The SU(3)-symmetry-breaking effects are introduced into our calculations by treating the exchange of a strange quark λ_0 differently from the exchange of p_0 and n_0 quarks. This is accomplished by the inclusion of the symmetry-breaking operator $\hat{b}$, defined as

$$\begin{aligned} \hat{b} &= 1\,, \text{ for } p_0 \text{ and } n_0 \text{ exchanges}\,, \\ &= b\,, \text{ for } \lambda_0 \text{ exchange.} \end{aligned} \tag{4}$$

It may be mentioned that the parameter b is energy-dependent and its value is to be understood in the limit

$$\lim_{s \to \infty} b(s) = b \,,$$

where s is the square of the c.m. energy. It is, of course, expected that at high energies, b reaches a constant value.[3,5]

Earlier, we found[5]

$$b = 0.2 \pm 0.04 \,. \tag{5}$$

We shall use this value of b in calculating the branching ratios for processes (1).

In order to simplify our notation (also since we

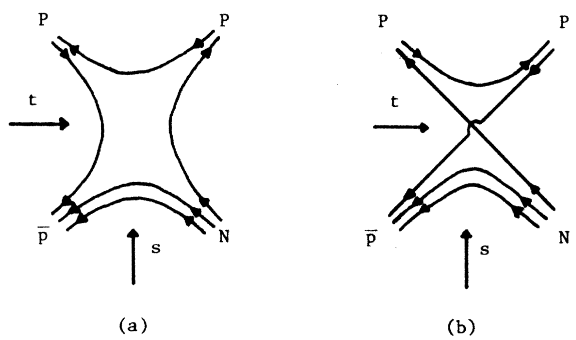

FIG. 1. Typical lowest-order quark-model diagrams for $\bar{p}N \to PP$ reactions.

are interested in calculating only the branching ratios), we define

$$
\begin{aligned}
&a=\cos 2\theta-\sqrt{3}\,\sin 2\theta\,,\\
&2\sqrt{2}\,(1+a)A=1\,,\\
&(4+a)/[2(1+a)]=c\,,\\
&(2-a)/[2(1+a)]=d\,.
\end{aligned}
\tag{6}
$$

Now, in order to calculate the $\bar{p}N\to PP$ matrix elements, we use Eqs. (4) and (6) in (3) together with the values of P_d^c and B^{abc} from Ref. 3. Then dropping the word "physical" from the $\bar{p}$ and N states, we obtain the following matrix elements:

$$\langle \pi^-\pi^+|\bar{p}p\rangle=-\langle \pi^+\pi^-|\bar{p}p\rangle=(\tfrac{1}{2})^{1/2}\,, \tag{7a}$$

$$\langle K^-K^+|\bar{p}p\rangle=-\langle K^+K^-|\bar{p}p\rangle=bc/\sqrt{2}\,, \tag{7b}$$

$$\langle \bar{K}^0K^0|\bar{p}p\rangle=-\langle K^0\bar{K}^0|\bar{p}p\rangle=bd/\sqrt{2}\,, \tag{7c}$$

$$\langle \pi^0\pi^0|\bar{p}p\rangle=\langle \eta\eta|\bar{p}p\rangle=0\,, \tag{7d}$$

$$\langle \pi^0\eta\,|\bar{p}p\rangle=\langle \eta\pi^0|\bar{p}p\rangle=0\,, \tag{7e}$$

$$\langle \pi^0\pi^-|\bar{p}n\rangle=-\langle \pi^-\pi^0|\bar{p}n\rangle=1\,, \tag{7f}$$

$$\langle K^-K^0\,|\bar{p}n\rangle=-\langle K^0K^-|\bar{p}n\rangle=b/\sqrt{2}\,, \tag{7g}$$

$$\langle \eta\pi^-\,|\bar{p}n\rangle=\langle \pi^-\eta\,|\bar{p}n\rangle=0\,. \tag{7h}$$

The zero values of the matrix elements in (7d), (7e), and (7h) are a consequence of assuming c invariance and of the interaction being governed by the exchange of 1^- vector mesons.

III. DISCUSSION AND CONCLUSIONS

In order to compare our calculations with the experimental data, we first note the relation between the measured rate R and the square of the matrix element[6]:

$$R(PP)=q_P\,|\langle PP|\bar{p}N\rangle|^2\,, \tag{8}$$

where q_P is the final c.m. momentum. In writing this expression, it is assumed that we compare the rates at the same value of $\bar{p}$ laboratory momentum p_L. It may be mentioned that in the expressions for the rates, we omit writing the initial states $\bar{p}p$ and $\bar{p}n$.

Using (8) in (7) gives

$$
\begin{aligned}
R(\pi^+\pi^-):R(K^+K^-):R(K^0\bar{K}^0):R(\pi^0\pi^-):R(K^0K^-)&=1:b^2c^2q:b^2d^2q:2:b^2q\\
&=1:(0.31\pm0.13)q:(0.13\pm0.05)q:2:(0.04\pm0.02)q\,,\\
&\qquad\text{for } \theta=20^\circ,\text{ and } b=0.2\pm0.04\,.
\end{aligned}
\tag{9}
$$

In Eq. (9), the phase-space correction factor q is defined as

$$q=q_K/q_\pi\,. \tag{10}$$

At high energies ($p_L \gtrsim 5$ GeV/c), the phase-space correction factor can be ignored by taking $q=1$. The error introduced in this approximation amounts to an effect of less than 4%. Unfortunately, there are no data available on $\bar{p}N\to PP$ reactions at high energies. However, some data are available at $p_L=1.89$ GeV/c. At this value of p_L, we obtain using expression (9)

$$
\begin{aligned}
&R(\pi^+\pi^-):R(K^+K^-):R(K^0\bar{K}^0)\\
&\quad=1:(0.40\pm0.15):(0.07\pm0.03)\ \ (\text{experiment}^1)\,,\\
&\quad=1:(0.29\pm0.12):(0.12\pm0.05)\ \ (\text{calculations})\,.
\end{aligned}
\tag{11}
$$

As is obvious, within one standard deviation, our calculations agree with the available data at $p_L=1.89$ GeV/c. However, it should be emphasized that our t-channel calculations are expected to be good at high energies. This is also essential because the value of the symmetry-breaking parameter b depends on the energy, assuming a constant value at high energies.[5]

Finally, it is our sincere hope that very soon, experimental data will become available on all the high-energy $\bar{p}N\to PP$ reactions to test our quark model.

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