LINE-REVERSAL SYMMETRY BREAKING AND THE QUARK MODEL

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The recently observed violation of exchange degeneracy rules for charge- and strangeness-exchange meson-baryon scattering is discussed in the framework of the quark model. It is shown that one can qualitatively describe the effect using the model in which $q-q$ and $q-\bar{q}$ amplitudes have Regge form with exact exchange degeneracy and all observed deviations are caused by three-quark ($q-qq$) scattering.

1. *Introduction*

In this paper we continue the discussion of the quark model of scattering for high energy and small momentum transfer.

We are interested, in particular, in the breaking of the line-reversal symmetry, which was systematically observed in several two-body reactions at intermediate energy [1]. Line-reversal symmetry connects two processes

and states that these processes have to have equal cross-sections. It is a consequence of the assumption of exchange degeneracy for the leading Regge trajectories exchanged in these processes.

In the framework of the quark model there are two possibilities of understanding this effect

a) assume that the breaking occurs already on the level of quark-quark and antiquark-quark amplitudes,

b) assume that the qq and $q\bar{q}$ amplitudes are symmetric under line-reversal and introduce non-additive corrections which breake the symmetry.

In this paper we explore the possibility *b*) by observing that by introducing three-quark amplitudes in addition to qq and $q\bar{q}$ amplitudes one can understand the main qualitative features of the experimental results. We consider this observation as a further support

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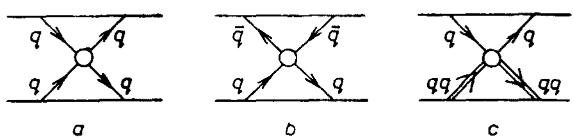
of the idea that the three-quark interactions, which were already shown to be helpful in understanding of the behaviour of total cross-sections [2] play an important role in the scattering at high energies.

In Section 2 we present and discuss the main assumptions of our model. In the Section 3 we show on the example of the strangeness-exchange reactions $K^-p \to \pi^- \Sigma^+$ and $\pi^+p \to K^+\Sigma^+$ the predictions of the model. In Section 4 we formulate the predictions more generally, listing the reactions for which the model can be used and discussing the comparison with the Regge pole model with broken exchange degeneracy [3]. We conclude with Section 5.

2. *Assumptions*

In order to describe the meson-baryon, baryon-baryon and antibaryon-baryon scattering we introduce in our model the three following kinds of diagrams:



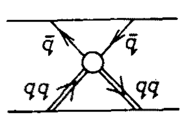
More precisely we assume that:

1) the main part of near forward scattering is described by the single q–q and $\bar{q}$–q scattering (diagrams a and b)

2) for the amplitudes of single scattering the Regge form with exact exchange degeneracy can be used

3) the existence of three-quark bound states (baryons) is reflected in the existence of the additional non-negligible mainly imaginary term in the amplitude (diagram c)

4) the possible contributions from diagrams of the type



(which can be obtained from diagrams c by s-u crossing) are negligible

5) all multiple scattering corrections (in the sense of Glauber [4] series) are also negligible.

Assumptions *1)* and *5)* are always accepted in the additive quark model. Assumption *2)* corresponds to the duality principle for the q–q and $\bar{q}$–q scattering [5]. Assumptions *3)* and *4)* are introduced in order to explain the experimentally observed systematic exchange degeneracy breaking, and in particular the failure of the equality between cross-sections for the line-reserved reactions.

In the usual additive quark model of scattering one takes only graphs of the a and b. In the particular version of the quark model given by Oakes [6] only graphs of the type b and c were used. So we combine the arguments of both models.

3. *Example*

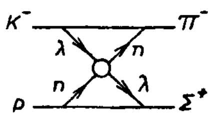
We neglect for simplicity the spin dependence of amplitudes; the obtained predictions will be, however, valid also in the non-zero spin case. Let us consider the pair of strangeness-exchange processes:

$$\text{a)}\ K^- + p \to \pi^- + \Sigma^+$$

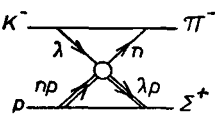
$$\text{b)}\ \pi^+ + p \to K^+ + \Sigma^+.$$

They are connected by the line reversal symmetry. If both reactions are dominated by the exchange of degenerate $K^* - K^{**}$ trajectory, their cross-sections should be equal. Experimentally [15, 16] the cross-section for the reaction a) is significantly bigger.

In our version of the quark model the reaction a) is described by the graphs

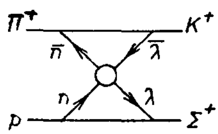


a



b

when for the reaction b) we have



c

The graphs *a* and *c* give the same cross-sections when Regge form and exchange degeneracy for the q–q and $\bar{q}$–q amplitudes is assumed. There remains, however, for the reaction a) the graph *b*. We have assumed that it corresponds to the additional imaginary term in the amplitude. Since exchange degeneracy in the q–q scattering is exact, the term from the graph *a* is real. So they add incoherently. Denoting the differential cross-section corresponding to the graph *a* by $\sigma(\lambda n \to n\lambda)$, that from the graph *b* by $\sigma(\lambda np \to n\lambda p)$ and that from graph *c* by $\sigma(n\bar{n} \to \lambda\bar{\lambda})$ we have

$$\sigma(K^- p \to \pi^- \Sigma^+) = \sigma(\lambda n \to n\lambda) + \sigma(\lambda np \to n\lambda p). \tag{1}$$

$$\sigma(\pi^+ p \to K^+ \Sigma^+) = \sigma(n\bar{n} \to \lambda\bar{\lambda}) \tag{2}$$

Since exchange degeneracy for the quark amplitudes gives

$$\sigma(\lambda n \to n\lambda) = \sigma(n\bar{n} \to \lambda\bar{\lambda}) \tag{3}$$

we can conclude that

$$\sigma(K^- p \to \pi^- \Sigma^+) > \sigma(\pi^+ p \to K^+ \Sigma^+). \tag{4}$$

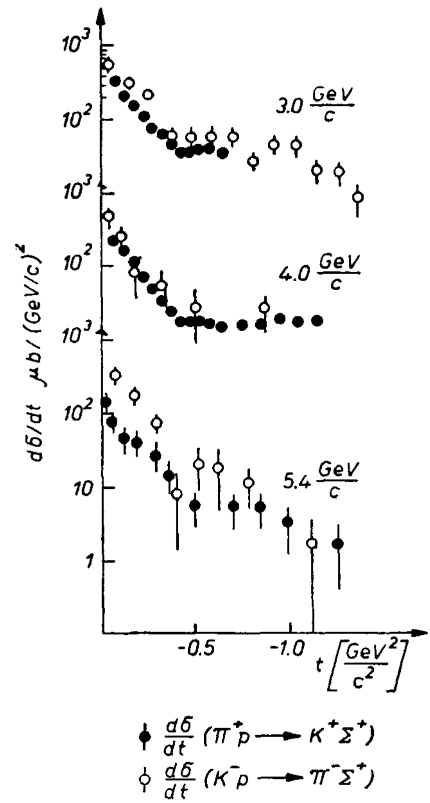


Fig 1. Comparison of $\frac{d\sigma}{dt}$ $(K^-p \to \pi^-\Sigma^+)$ and $\frac{d\sigma}{dt}$ $(\pi^+p \to K^+\Sigma^+)$ at 3.0, 4.0, and 5.5 GeV/c. Data taken from Ref. [12], [15], [16]

The experimental data from Ref. [12, 15, 16] shown at Fig. 1 are consistent with this prediction. The inequality seems to be strongest near $t = -0.6\ \mathrm{GeV}^2/c^2$, since the differential cross-section for the reaction b) seems to have here a dip according to model [7].

4. *General predictions; comparison with other models*

Since the graphs similar to *a*, *b* and *c*, can be drawn for many other line-reversed pairs of strangeness- and charge-exchange reactions, we list in Table I the amplitudes with moduli equal in the exact exchange degeneracy limit and connected by the inequality in our model. In the first column we write down the independent amplitudes for processes in which $\bar{q}$ is spectator, in the second the amplitudes for line-reversed reactions. In the third column we write down the measurable amplitude, equal to that from the second column by isospin invariance (with assumption of non-exotic exchange). In our model the additional term in the cross-section should be introduced for the reactions from the first column, so the cross-sections for them are expected to be systematically larger than for the reactions from the third column.

TABLE I

Reaction	Line-reversed reaction	Well-measured reaction
$A(K^-p \to \pi^-\Sigma^+)$	$A(\pi^+p \to K^+\Sigma^+)$	$A(\pi^+p \to K^+\Sigma^+)$
$A(K^-p \to \pi^0\Lambda)$	$A(\pi^0p \to K^+\Lambda)$	$\frac{1}{\sqrt{2}} A(\pi^-p \to K^0\Lambda)$
$A(K^-p \to \pi^-\Sigma^{*+})$	$A(\pi^+p \to K^+\Sigma^{*+})$	$A(\pi^+p \to K^+\Sigma^{*+})$
$A(K^+n \to K^0p)$	$A(\bar{K}^0n \to K^-p)$	$A(K^-p \to \bar{K}^0n)$
$A(K^+p \to K^0\Delta^{++})$	$A(\bar{K}^0p \to K^-\Delta^{++})$	$\sqrt{3}A(K^-p \to \bar{K}^0\Delta^0)$

TABLE II

Relation	L.H.S.	R.H.S.	Difference	Momentum GeV/c	Ref.
$\frac{d\sigma}{dt}(K^-p \to \pi^-\Sigma^+) >$	236±17	148±24	88±29	3.0	[11, 14]
	107±27	74±16	33±31	4.07; 3.89	[15, 14]
$> \frac{d\sigma}{dt}(\pi^+p \to K^+\Sigma^+)$	84±14	29.7±3.5	54±14	5.47; 5.4	[15, 16]
$\frac{d\sigma}{dt}(K^-p \to \pi^0\Lambda) >$	138±15	42±6	96±16	3.0	[11, 14]
$> \frac{1}{2}\frac{d\sigma}{dt}(\pi^-p \to K^0\Lambda)$	115±40	38±8	77±41	3.5; 3.6	[17, 14]
$\frac{d\sigma}{dt}(K^-p \to \pi^-\Sigma^{*+}) >$	67±7	58±14	9±16	3.0	[13, 14]
$> \frac{d\sigma}{dt}(\pi^+p \to K^+\Sigma^{*+})$	90±15	26±10	64±18	3.5; 4.0	[17, 14]
$\frac{d\sigma}{dt}(K^+n \to K^0p) >$	750±80	430±35	320±86	3.0	[18, 11]
$> \frac{d\sigma}{dt}(K^-p \to \bar{K}^0n)$	175±20	125±10	50±22	5.5; 5.7	[20, 19]
$\frac{d\sigma}{dt}(K^+p \to K^0\Delta^{++}) >$	800±100	900±180	−100±210	3.0	[21, 13]
$> 3\frac{d\sigma}{dt}(K^-p \to \bar{K}^0\Delta^0)$	360±40	108±108	242±115	4.6; 4.1	[9, 10]

The comparison with experiment is shown in Table II. In nine cases inequalities are well fulfilled, in the remaining two cases difference between compared cross-sections is less then experimental errors.

The general criterion can be stated as follows: For the line-reversal symmetric pairs of strangeness- or charge-exchange reactions, which have equal cross-sections in the exact exchange degeneracy limit we expect the inequality. The process in which antiquark is spectator should have larger cross-section than that, in which antiquark interacts.

We would like now to discuss shortly some other prediction of our model. First we notice that our model provides an alternative explanation of the observation that the structure in the differential cross-sections for two-body reactions occur only in the processes in which $q\bar{q}$ amplitudes play an important role [7]. In our model the apparent absence of dips in qq amplitudes is caused by the contributions from qqq interactions which has no reason to have any particular structure in this region. This mechanism implies, in particular, that in the dip region the discussed effect of line-reversal symmetry breaking is expected to be rather strong. The last conclusion is in contradiction with that from the model of Auvil

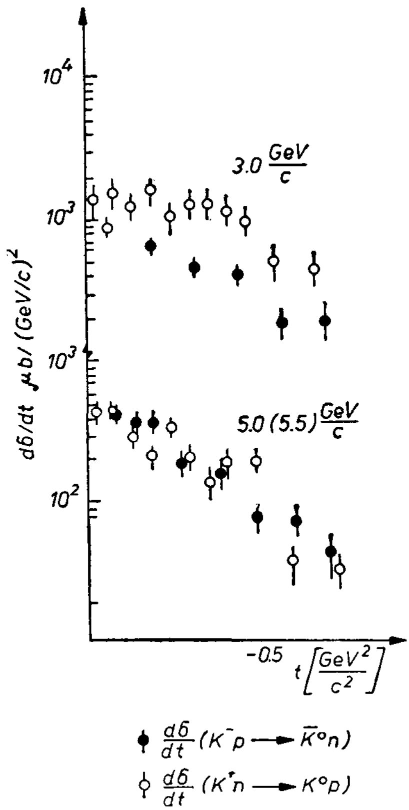


Fig. 2. Comparison of $\frac{d\sigma}{dt}(K^+n \to K^0p)$ and $\frac{d\sigma}{dt}(K^-p \to \bar{K}^0n)$ at 3.0 and 5.0 (5.5) GeV/c. Data taken from Ref. [1]

et al. [3] which predict that in the dip region the line-reversal symmetry should be almost exactly satisfied at high energies.

The second conclusion one can draw from the model concerns the behaviour of the ratio of real to imaginary part of the amplitude. Let us consider as an example a pair of reactions

$$K^+n \to K^0p \text{ and } K^-p \to \bar{K}^0n.$$

Auvil *et al.* [3] predict for forward amplitudes of both processes at high energy real and imaginary part of roughly equal magnitude. In our model this seems rather improbable. *E. g.* if at high energy the three-quark contributions vanish faster than qq and $q\bar{q}$ contributions we expect that the forward amplitude for reaction $K^+n \to K^0p$ will be real, and for reaction $K^-p \to \bar{K}^0n$ mainly imaginary. Data [8] suggest that this is true at low energy. So for the forward scattering line-reversal symmetry in this case should be well fulfilled. It is in accordance with experimental data for cross-sections, shown at Fig. 2.

5. *Conclusions*

We have investigated the systematic breaking of equalities between cross-sections. for line-reversed pairs of charge- and strangeness-exchange reactions in the framework of the quark model. It appears that the experimentally observed breaking of line-reversal symmetry can be explained by introducing three-quark interactions in addition to the qq and $q\bar{q}$ interactions which appear in the standard additive quark model. All qualitative consequences of the proposed mechanism are discussed and compared with the predictions of model of line-reversal symmetry breaking proposed by Auvil *et al.* [3].

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