LINE-REVERSAL SYMMETRY BREAKING AND THE ABSORPTION CORRECTIONS

By K. Fiałkowski

Institute of Physics, Jagellonian University, Cracow*

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The role of absorption corrections in the experimentally observed line-reversal symmetry breaking is discussed. The absorption parameters are estimated from experimental data and the quark model. It is shown that the absorption corrections cannot explain the experimentally observed effect.

1. Introduction

We discuss the pair of line-reversal symmetric processes

$$A+B\to C+D \tag{1}$$

$$\bar{C}+B\to\bar{A}+D \tag{2}$$

where A and C are 0^- mesons, and B is a nucleon.

In the Regge pole model with exact exchange degeneracy the cross-sections for reactions (1) and (2) are equal if amplitudes are dominated by an exchange of two degenerate trajectories. This is usually assumed for strangeness-exchange and KN charge-exchange scattering. Such equalities are known to be strongly violated by existing data [1].

It was pointed out in [2, 3] that the absorption corrections are not the same in reactions (1) and (2) and therefore may provide a way out of this difficulty. The differences between absorption corrections to the amplitudes of processes (1) and (2) are caused by two factors:

a) the t-dependent phase difference between uncorrected amplitudes, and

b) the difference between absorption parameters (total cross-sections).

In Refs [2, 3] only factor a) was discussed. The absorption parameters were assumed to be the same for reactions (1) and (2). The conclusion was that the absorption corrections do violate the line-reversal symmetry, but cannot explain the data because the corrections act in the wrong direction.

We discuss in detail the influence of both corrections a) and b). It appears that for the forward scattering the effect b) (neglected in Refs [2, 3]) is even stronger than a). In the

* Address: Instytut Fizyki, Uniwersytet Jagielloński, Kraków, Reymonta 4, Poland.

case of strangeness-exchange processes both corrections act in the same direction and we confirm the conclusions of Refs [2, 3]. In the case of charge-exchange KN scattering the effects a) and b) partially cancel each other; thus the breaking of line-reversal symmetry predicted by the absorption model is very weak.

The predicted difference in the shape of corrected differential cross-sections for reactions (1) and (2) is caused mainly by the effect a). The elastic scattering amplitude used in absorption calculations has a constant phase of $\pi/2$. Therefore, if the uncorrected amplitude also has a constant phase (*e. g.*, equal 0, as in the exact degeneracy limit for the exotic s-channel) a strong destructive interference with absorption correction (producing dip) is predicted. If the uncorrected amplitude has a t-dependent phase, only a smooth change of slope in this region is expected. These predictions are also in disagreement with experiment.

In Section 2 we present the absorption model used. In Section 3 we discuss the strangeness-exchange πN and $\bar{K}N$ scattering, and in Section 4 the charge-exchange KN and $\bar{K}N$ scattering. Conclusions are given in Section 5. The Appendix contains the details of the quark model used to obtain the values of unmeasurable cross-sections.

2. *The absorption model*

We use the formalism of Henyey *et al.* [4]. Let us consider first the forward scattering in the process (1). The absorptive correction to the amplitude of this process reads

$$\delta M = -\frac{i\Lambda}{32\pi^2 w}\int [kM_{\mathrm{el}}^{AB}M_{\mathrm{ex}}^{AB\to CD}+k'M_{\mathrm{ex}}^{AB\to CD}M_{\mathrm{el}}^{CD}]d\Omega. \tag{3}$$

Assuming that the elastic (M_{el}) and inelastic (M_{ex}) amplitudes depend exponentially on t we have

$$M_{\mathrm{el}}^{AB} = -2\sqrt{s}\,ki\sigma_t(AB)e^{a\frac{t}{2}} \tag{4}$$

$$M_{\mathrm{el}}^{CD} = -2\sqrt{s}\,k'i\sigma_t(CD)e^{a\frac{t}{2}} \tag{5}$$

$$M_{\mathrm{ex}}^{AB\to CD} = De^{\frac{b}{2}(t-t_0)} \tag{6}$$

where W, k and k' denote centre-of-mass energy, and initial and final momenta, respectively. t_0 is the t value for forward scattering.

After integration we obtain for the forward scattering [5]

$$\frac{\delta M}{M_{\mathrm{ex}}} = -\frac{\Lambda}{8\pi}\left[\frac{\sigma_t(AB)}{a+b\,k'/k}+\frac{\sigma_t(CD)}{a+b\,k/k'}\right]. \tag{7}$$

In what follows we put $\Lambda = 1$. This value is not crucial for further analysis provided we always choose the same value for processes (1) and (2).

To present the effect of absorption corrections we use the parameter

$$C = \frac{d\sigma^{\mathrm{corr}}}{dt}\Big/\left.\frac{d\sigma^{\mathrm{ex}}}{dt}\right|_{t=t_0} = \left|1+\frac{\delta M}{M_{\mathrm{ex}}}\right|^2. \tag{8}$$

It is seen from formula (7) that the absorption corrections depend on praameters of elastic scattering (σ_t and a) which determine the absorption, and on the value of the slope b of the inelastic amplitude. If σ_t and a are the same for reactions (1) and (2), the difference between cross-sections is caused only by different b, reflecting the t-dependent phase difference between amplitudes for reactions (1) ans (2) [2, 3].

For the non-forward scattering we use the first approximation obtained by expanding the corrections into polynomial series [5]. The correction to the non-spin-flip amplitude of the form (6) reads:

$$\delta M = \frac{-D}{16\pi^2}\left[k^2\sigma_t(AB)\cdot I + k'^2\sigma_t(CD)\cdot I'\right] \tag{9}$$

where

$$I = \frac{2\pi}{c}\, e^{ak^2(z-1)+\varepsilon}\ ;$$

$$z = 1+\frac{t}{2kk'}\ ; \qquad c = ak^2z+bkk'; \qquad \varepsilon = \frac{(1-z^2)\,a^2k^4}{2c}\ ;$$

$$I'(k', k) = I(k, k'). \tag{10}$$

The correction to the spin-flip amplitude of the form

$$M^t = D\sqrt{-t}\, e^{\frac{b}{2}(t-t_0)} \tag{11}$$

reads

$$\delta M^t = -\frac{D}{16\pi^2}\left[k^2\sigma_t(AB)\cdot A + k'^2\sigma_t(CD)\cdot A'\right] \tag{12}$$

where

$$A = \sqrt{\frac{\varepsilon}{c}}\, I; \qquad A'(k', k) = A(k, k'). \tag{13}$$

3. Strangeness-exchange reactions

We discuss the reactions

$$K^-p \to \pi^-\Sigma^+ \tag{14}$$

and

$$\pi^+p \to K^+\Sigma^+ \tag{15}$$

The conclusions obtained for these reactions can be obviously extended to similar reactions such as

$$K^-p \to \pi^0\Lambda \quad \text{and} \quad \pi^-p \to K^0\Lambda \tag{16}$$

$$K^-p \to \pi^-\Sigma^{*+} \quad \text{and} \quad \pi^+p \to K^+\Sigma^{*+} \tag{17}$$

and other ones related by isospin invariance with assumption of $I = 1/2$ exchange. The total cross-sections computed from the quark model will be in the same ratios for Λ and Y^* as for Σ. Other parameters will also have similar values.

We use the parameters measured in πN and KN scattering [6]. They are listed in Table I.

TABLE I

p_{lab} [GeV/c]	$\sigma_t(K^-p)$ [mb]	$\sigma_t(\pi^-\Sigma^+)$ [mb]	a [GeV/c]$^{-2}$	b [GeV/c]$^{-2}$	k/k'
3.0	27.4±0.1	27.8±0.2	7.7±0.3	5.4±0.4	1.05
8.0	23.6±0.2	24.4±0.2	7.0±0.6	8.5±0.5	1.02
16.0	21.3±0.4	21.9±0.3	6.0±0.4	8.0±0.5	1.01
p_{lab}	$\sigma_t(\pi^+p)$	$\sigma_t(K^+\Sigma^+)$	a	b	k/k'
3.0	29.2±0.1	15.6±0.5	6.7±0.2	$7.2\pm1+i2\pi$	1.21
8.0	25.6±0.1	15.1±0.5	7.6±0.2	$10\pm1+i2\pi$	1.05
16.0	24.0±0.1	15.3±0.5	8.0±0.2	$10\pm1+i2\pi$	1.03

In order to compute total cross-sections which have not been measured we employ the quark model sum rules

$$\sigma_t(\pi^-\Sigma^+) = \sigma_t(\pi^-p) + \tfrac{1}{3}\sigma_t(K^-p) + \tfrac{1}{3}\sigma_t(K^+p) - \tfrac{2}{3}\sigma_t(\pi^-p) \tag{18}$$

$$\sigma_t(K^-\Sigma^+) = \frac{5}{6}\,\sigma_t(K^+p) + \frac{1}{6}\,\sigma_t(K^-p) - \frac{1}{6}\,\sigma_t(\pi^-p) + \frac{1}{6}\,\frac{[\sigma_t(K^+p) + \sigma_t(K^-p) - \sigma_t(\pi^-p)]^2}{\sigma_t(K^+p) - \sigma_t(K^-p) + \sigma_t(\pi^-p)}. \tag{19}$$

The derivation of these rules and discussion of necessary assumptions is given in the Appendix.

Inserting proper cross-sections and slopes in formulae (7) and (8) we obtain the following values of the ratio of corrected to uncorrected cross-sections, C:

TABLE II

Reaction / P_{lab}	$K^-p \to \pi^-\Sigma^+$	$\pi^+p \to K^+\Sigma^+$
3.0 GeV/c	0.32±0.02	0.52±0.06
8.0 GeV/c	0.47±0.03	0.61±0.05
16.0 GeV/c	0.47±0.03	0.64±0.05

Since in the exact exchange degeneracy limit the uncorrected cross-sections for reactions (14) and (15) are equal, the ratio of parameters listed in Table II gives immediately the expected ratio of forward cross-sections for the discussed reactions. Let us compare this ratio with experimentally obtained values [7, 8]. We have

TABLE III

p_{lab}	$\frac{d\sigma}{dt}(K^-p \to \pi^-\Sigma^+) \Big/ \frac{d\sigma}{dt}(\pi^+p \to K^+\Sigma^+)\Big\|_{t=0}$	
	predicted	experimental
3.0	0.62±0.10	1.4±0.4
8.0	0.77±0.10	1.8±0.5
16.0	0.74±0.10	1.3±0.4

We see that there is complete disagreement between the model and experiment.

The differential cross-sections for reactions (14) and (15) do not exhibit any forward dip or slope breaking, so we assume the non-flip amplitude to be dominating in the forward peak region. So we compute the absorption corrections according to formula (9) and plot the corrected normalized cross-section

$$\frac{d\sigma}{dt} = \frac{1}{|D|^2}\,|M+\delta M|^2 \tag{20}$$

for both reactions (9) and (10). This is done in Fig. 1.

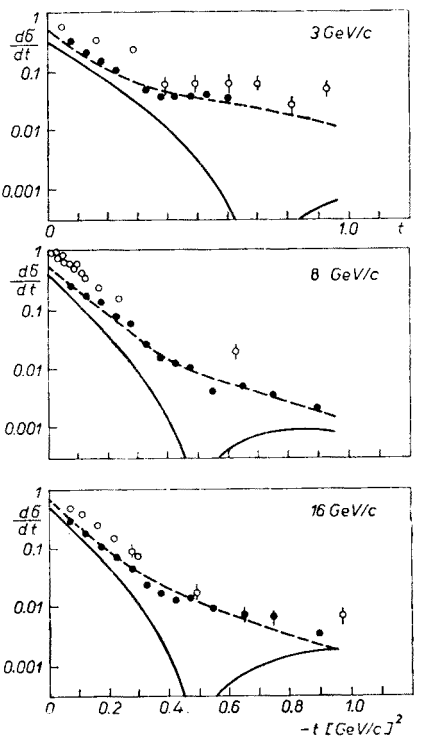

Fig. 1. The absorption model predictions compared at $p_L = 3.0$, 8.0 and 16.0 GeV/c with data from Ref. [7, 8]. Dashed lines and black dots are for reaction $\pi^+p \to K^+\Sigma^+$, full lines and open circles for reaction $K^-p \to \pi^-\Sigma^+$

We assume here exact degeneracy for exchange, *i.e.* the same $|D|$ for both reactions, real amplitude (14) and $e^{i\pi\alpha}$ phase of amplitude (15). Slope b is slightly different according to experimental values for very small $-t$; this bears no practical consequences for our results. We see that normalizing the curve to the reaction (15) we can roughly reproduce the shape of the differential cross-section (the slope breaking being too weak, however). For the reaction (14) data disagree completely with the curve because of

a) wrong normalization, and

b) absence of predicted strong dip.

The parameters used were not fitted. The only parameter not directly measured (slope b) cannot however affect in any drastic way the shape and normalization of the obtained curves.

4. *Charge exchange reactions*

We discuss here only K and $\bar{K}$ induced reactions since in the $\pi N \to \pi B$ charge-exchange processes (B being a non-strange baryon) pairs of reactions related by line-reversal symmetry have always equal cross-sections due to isospin invariance.

The simplest example is KN and $\bar{K}N$ charge-exchange scattering

$$K^+n \to K^0p \tag{21}$$

and

$$K^-p \to \bar{K}^0n. \tag{22}$$

The obtained results will be approximately valid also for the production of any baryon resonance if the equality

$$\frac{\sigma_t(K^-N)}{\sigma_t(K^+N)} = \frac{\sigma_t(K^-N^*)}{\sigma_t(K^+N^*)} \tag{23}$$

and similar equalities between other parameters are good approximations.

Let us now compute the absorption corrections for reactions (21) and (22). Formula (7) is simplified here, since initial and final state have the same parameters due to isospin invariance (also the mass difference is negligible). We have

$$\frac{\delta M}{M} = -\frac{1}{4\pi}\frac{\sigma_t}{a+b}. \tag{24}$$

Calculating correction factor A (Eq. (8)) from experimental parameters [6] for both reactions listed in Table IV, we can compare predictions for the ratio of the cross-sections with experimental values [9, 10]. This is presented in Table V.

TABLE IV

p_{lab}	$\sigma_t(K^-p)$	$\sigma_t(K^+p)$	$a(K^-p)$	$a(K^+p)$	$b(K^-p)$	$b(K^+n)$
3	27.4±0.2	17.2±0.4	7.7±0.3	4.2±0.3	6±1+$i2\pi$	4.6±1
5	24.0±0.7	17.9±0.8	7.5±0.5	5.2±0.5	7±1+$i2\pi$	5.7±1
12	21.6±0.2	17.3±0.1	6.9±0.3	6.2±0.2	10±1+$i2\pi$	6.10±0.5

TABLE V

p_{lab}	$\frac{d\sigma}{dt}(K^+n \to K^0p) \Big/ \frac{d\sigma}{dt}(K^-p \to \bar{K}^0n)\Big\|_{t=0}$	
	predicted	experimental
3.0	0.93±0.30	1.5±0.6
5.0	0.93±0.30	0.9±0.4
12.0	1.02±0.15	1.7±0.5

We see that the deviations from exact line-reversal symmetry are less definite than for the strangeness-exchange processes.

In the case of non-forward scattering we must take into account the spin-flip amplitude, since the forward dip observed for both reactions suggests the domination of this amplitude in the forward peak. This cannot be done unambiguously.

We have chosen the following procedure.

Taking the slope b (which is assumed to be the same for flip and non-flip amplitudes) and the ratio R of flip to non-flip amplitudes as free parameters, we have fitted the cross-section for reaction (22). Other parameters needed in the fit are taken as in the preceding discussion of forward scattering. Once b and R are determined in this way, we obtain the absolute predictions of our model (within errors of parameters) for the reaction (21). They disagree completely with experiment (Fig. 2). The reason for these discrepancies is the same as for reaction (14): the absorption model predicts a dip which is not observed experimentally. Changing b one can shift this dip outside the forward region ($-t < 1.0$ GeV/c^2), but the unobserved increase of slope for larger $-t$ remains. The overall normalization of the obtained curve is in this case roughly correct.

5. *Conclusions*

We have reanalysed the absorption corrections for line-reserved pairs of reactions dominated by the exchange of two exchange-degenerate Regge trajectories.

The breaking of line-reversal symmetry by absorption corrections may be caused by two effects:

a) difference in phase, and

b) different absorption parameters.

Assuming that the absorption parameters are determined by elastic scattering in the initial and final state, and estimating them on the basis of the quark model, we have shown that effect b) represents a very important factor in the discussion of breaking of line-reversal invariance. In particular, for forward strangeness-exchange scattering, it appears that this effect is stronger than the effect a) discussed earlier in Refs [2, 3]. The failure of the obtained predictions can be interpreted as an effect of violation of quark model rules for total cross-sections, perhaps due to three-quark interactions [11]. The qualitative conclusions in the case of strangeness-exchange reactions are the same as that of other authors, *i.e.* the absorption corrections do not explain the data, because both effects a) and b) go in the wrong direction. For charge-exchange processes the corrections tend to cancel each other. Con-

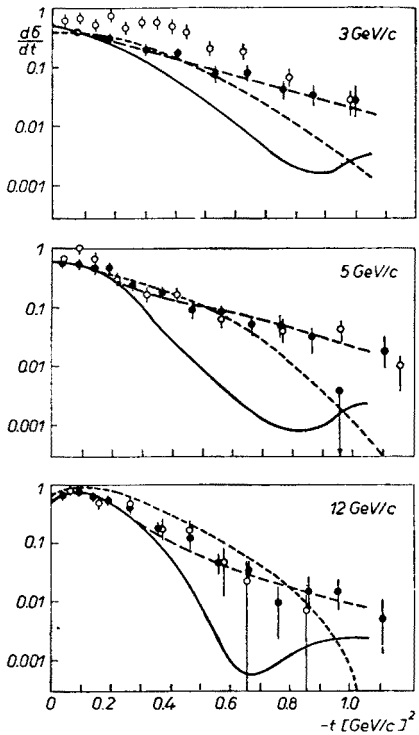

Fig. 2. The absorption model predictions compared at $p_L = 3.0$, 5.0 and 12.0 GeV/c with data from Ref. [9, 10]. Dashed lines and black dots are for reaction $K^-p \to \overline{K^0}n$, full lines and open circles are for reaction $K^+n \to K^0p$. Dotted lines are obtained for the same reaction assuming slope b different than for the first reaction

sequently, the situation in forward scattering is much more complicated and no simple conclusion can be obtained.

The t-dependence of cross-sections predicted by the model is also in disagreement with experiment. It is affected mainly by the phase difference resulting in the strong dip for reactions (14) and (21) and the smooth break for (15) and (22). Experimentally, the opposite effect for reactions (14) and (15), and no significant difference between (21) and (22), is observed. The discrepancy may be regarded as an argument against the flat Pomeron [12], or the reflection of a new trajectory important for elastic scattering [13]. Indeed, it is obvious that the strong dip is due to the constant phase difference (equal π) between the exchange and absorption terms for reactions (14) and (21). The t-dependent phase in elastic scattering (and, consequently, in absorption terms) could fill this dip completely.

APPENDIX

We specify here the quark model assumptions used to obtain rules (18) and (19). Let us express KN and πN total cross-sections by the quark-quark and antiquark-quark cross-sections according to the known quark structure of hadrons and the additivity assumption

[14]. We denote quarks by p, n, λ and, to avoid confusion, nucleons by P and N. We have

$$\sigma_t(K^-P) = 2\sigma_t(\bar{p}p) + \sigma_t(\bar{p}n) + 3\sigma_t(\lambda p) \tag{A1}$$

$$\sigma_t(K^+P) = 3\sigma_t(pp) + 3\sigma_t(\lambda p) \tag{A2}$$

$$\sigma_t(\pi^+P) = 3\sigma_t(pp) + 2\sigma_t(\bar{n}p) + \sigma_t(\bar{n}n) = 3\sigma_t(pp) + 2\sigma_t(\bar{p}n) + \sigma_t(\bar{p}p) \tag{A3}$$

$$\sigma_t(\pi^-P) = 3\sigma_t(pp) + 2\sigma_t(\bar{p}p) + \sigma_t(\bar{p}n). \tag{A4}$$

In the formulae above we have assumed:

$$\sigma_t(np) = \sigma_t(pp); \ \sigma_t(\lambda p) = \sigma_t(\bar{\lambda}p). \tag{A5}$$

These assumptions are supported by the experimentally observed equalities

$$\sigma_t(KP) = \sigma_t(KN); \ \sigma_t(PP) = \sigma_t(PN) \tag{A6}$$

and by the fact that leading Regge trajectories are usually assumed to be decoupled from the $\lambda\bar{\lambda}$ vertex. The use of simplifying assumptions enables us to avoid in rules (18) and (19) baryon-baryon and antibaryon-baryon cross-sections, which are known to be greater than expected from the quark model.

In the quark model the cross-sections to be computed can be expressed as follows

$$\sigma_t(K^+\Sigma^+) = 2\sigma_t(pp) + 3\sigma_t(\lambda p) + \sigma_t(\bar{\lambda}\lambda) \tag{A7}$$

$$\sigma_t(\pi^-\Sigma^+) = 2\sigma_t(pp) + 2\sigma_t(\bar{p}p) + 2\sigma_t(\lambda p). \tag{A8}$$

Eliminating quark cross-sections we obtain the rule (18). In order to obtain rule (19) it is necessary to assume factorization of quark-quark cross-sections, *i.e.*

$$\sigma_t^2(\lambda p) = \sigma_t(\lambda\lambda) \cdot \sigma_t(pp) \tag{A9}$$

and the equality between $\lambda\lambda$ ans $\bar{\lambda}\lambda$ cross-sections

$$\sigma_t(\lambda\lambda) = \sigma_t(\bar{\lambda}\lambda). \tag{A10}$$

Now we can eliminate quark cross-sections and obtain rule (19). The last assumption (A10) which raises the most doubts, affects the rule (19) very weakly. Assuming

$$\sigma_t(\bar{\lambda}\lambda) = 2\sigma_t(\lambda\lambda) \tag{A11}$$

changes the right-hand side of rule (19) only by 5 per cent.

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