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ANNIHILATION AND CHARGE EXCHANGE IN $p\bar{p}$ SCATTERING

AT HIGH ENERGIES

A. Białas

Institute of Physics, Jagellonian University, Cracow

and

K. Zalewski^{*)}

CERN - Geneva

A B S T R A C T

The overlap matrix formalism is applied to $p\bar{p}$ charge-exchange scattering. The small slope of the forward peak is explained as resulting from the contribution of annihilation channels to non-diagonal elements of the overlap matrix.

^{*)} On leave of absence from the Institute of Physical Chemistry, Polish Academy of Sciences, Cracow, Poland.

In high-energy scattering the transition amplitude into each channel is affected by the presence of all the other open channels. This effect can be described, rigorously in principle, using the overlap matrix formalism. In this note we follow the method of Bia~~x~~as and Van Hove ¹⁾ (further quoted I), but we reject the simplifying assumption that the overlap matrix is diagonal. With this assumption, a description similar to that of the absorption model was obtained. Without it, a very different picture emerges. Our discussion can be made completely general, but for simplicity and definiteness we refer to the $\bar{p}p$ scattering, with charge-exchange singled out from the inelastic channels. The effect of the strong annihilation channels on the $\bar{p}p$ charge exchange is investigated. It seems that this can provide a qualitative explanation of the small slope of the forward $\bar{p}p \rightarrow n\bar{n}$ peak.

Our notation follows closely that of I. Thus index 1 denotes the $\bar{p}p$ channel and index 2 the $n\bar{n}$ channel. S denotes the 2×2 matrix with, e.g., S_{12} equal to the 1^{th} partial wave amplitude for the process $\bar{p}p \rightarrow n\bar{n}$. The index 1 is not written explicitly. The overlap matrix $\mathcal{F}$ is a 2×2 matrix defined by

$$2 \mathcal{F}_{ik} = \sum_j S_{ji}^* S_{jk} \quad \begin{matrix} i, k = 1, 2 \\ j \neq 1, 2 \end{matrix} \quad (1)$$

As shown in I, the unitarity of the total S matrix implies that

$$S^+ S = 1 - 2 \mathcal{F} \quad (2)$$

For vanishing coupling with other channels, i.e., for $\mathcal{F} \rightarrow 0$, the S matrix goes over into some unitary matrix Ω :

$$\Omega^+ \Omega = 1 \quad (3)$$

2.

In I, the $\mathcal{F}$ matrix was assumed diagonal. Then the S matrix is equal to the Ω matrix up to a numerical factor. Here we write down the general solution

$$S = \Omega \mathcal{G} \quad (4)$$

where

$$\mathcal{G} = \sqrt{1 - 2\mathcal{F}} \quad (5)$$

The isospin and time reversal invariance imply that the matrices S and Ω take the form

$$\mathcal{F} = \begin{pmatrix} F & -f \\ -f & F \end{pmatrix}; \quad S = \begin{pmatrix} S_{el} & S_{inel} \\ S_{inel} & S_{el} \end{pmatrix}; \quad \Omega = \begin{pmatrix} \Omega_{11} & \Omega_{12} \\ \Omega_{12} & \Omega_{11} \end{pmatrix} \quad (6)$$

where both F and f are real. It follows from a simple calculation assuming $\mathcal{G}_{11} > \mathcal{G}_{12}$ that

$$\mathcal{G}_{11} = \mathcal{G}_{22} = \frac{1}{2} \left\{ \sqrt{1 - 2F - 2f} + \sqrt{1 - 2F + 2f} \right\} \equiv G \quad (7)$$

$$\mathcal{G}_{12} = \mathcal{G}_{21} = \frac{f}{G} \quad (8)$$

Substituting (7) and (8) into (4), we obtain

$$S_{el} = \Omega_{11} G + \Omega_{12} f / G \quad (9)$$

$$S_{inel} = \Omega_{11} f / G + \Omega_{12} G \quad (10)$$

Experimentally the cross-section for $p\bar{p}$ charge exchange is known to be very small as compared to the cross-section for elastic scattering ²⁾. This suggests that the off diagonal elements Ω_{12} and f/G are small. Consequently the second term in (9) is very small. Assuming moreover that $\Omega_{11} = 1 + \text{small terms}$ we get approximately

$$S_{inel} = \frac{f}{S_{el}} + \Omega_{12} S_{el} \quad (11)$$

with an error quadratic in the small terms.

The interesting feature of formula (11) is that it exhibits two effects of the other channels on the selected two-body channel :

- a) the first term (f/S_{el}) represents the contribution from the indirect transitions from the initial to the final state through other intermediate states. It is analogous to elastic shadow scattering.
- b) the second term $(\Omega_{12} S_{el})$ represents the damping of the direct two-body reaction, as represented by the Ω matrix, by absorption. This is a well-known process ³⁾.

The assumption $\mathcal{F}_{12} = \mathcal{F}_{21} = 0$ and therefore $\mathcal{G}_{12} = \mathcal{G}_{21} = 0$, which yields the standard absorption models, has been discussed in some detail in I. Here we would like to investigate a "complementary" assumption.

$$\Omega_{12} = \Omega_{21} = 0 \quad (12)$$

We intend only a qualitative discussion, since we think that in nature neither $\mathcal{F}$ nor Ω is exactly diagonal. Which of the two limiting cases is a better approximation to reality should depend on the process considered.

4.

Under assumption (12) and putting $\Omega_{11} = 1$ we have from (9) and (10)

$$S_{el} = G \quad (13)$$

$$S_{inel} = \frac{f}{G} = \frac{f}{S_{el}} \quad (14)$$

Let us now apply this formalism to the $\bar{p}p$ data. From the fits given by Kokkedee ⁴⁾ one gets easily

$$S_{el}^t = 1 - C \exp[-\alpha k^{-2} (t + \frac{1}{2})^2] \quad (15)$$

where $\alpha \approx 0.04 \text{ (GeV/c)}^{+2}$, and C is a slowly varying function of the energy, not very different from unity.

Using the formulae (14) and (15), and the experimental data for the reaction $\bar{p}p \rightarrow n\bar{n}$ it is now easy to determine the approximate shape of the inelastic overlap function f . A precise formula for S_{inel} would be rather complicated, because in charge exchange $\bar{p}p$ scattering the forward peak is not quite exponential ²⁾. For our qualitative discussion, however, we may put

$$S_{inel}^t = \bar{C} \exp[-\beta k^{-2} (t + \frac{1}{2})^2] \quad (16)$$

$\beta \approx 3\alpha$, since the slope is about one third of the slope for elastic $\bar{p}p$ scattering ²⁾. Thus from (14) and (15)

$$f^t = \bar{C} \left[\exp(-\beta k^{-2} (t + \frac{1}{2})^2) - C \exp(-(\alpha + \beta) k^{-2} (t + \frac{1}{2})^2) \right] \quad (17)$$

This formula admits an interpretation similar to that given by Kokkedee for elastic $\bar{p}p$ scattering ⁴⁾. The first term corresponds to the intermediate annihilation channels. The second one is the correction to the first, which is necessary because of absorption by other channels where the baryon and the antibaryon survive the interaction. Further we call such channels non-annihilation channels. Our interpretation assumes that the direct contribution of the non-annihilation channels to the overlap function f is negligible. This is plausible, because the pn charge-exchange scattering, which might be expected to have a set of non-annihilation channels similar to that for $\bar{p}p$ charge exchange, has a small cross-section ⁵⁾. It is seen from (8) that this corresponds to small values for f . A quantitatively stronger argument is the following. The overlap function is related to the imaginary part of the scattering amplitude. Indeed from (2) and (6) $\text{Re}(S_{el}^* S_{inel}) = f$, and if following Kokkedee ⁴⁾ we assume that S_{el} is real we see that f is proportional to the real part of S_{inel} , i.e., to the imaginary part of the scattering matrix element. On the other hand there is evidence ⁵⁾ that the imaginary part of the pn charge-exchange amplitude is very small. Using the terminology proposed by Kokkedee ⁴⁾, our interpretation of formula (17) implies that $\mathcal{G}_{as}$, i.e., the part of the overlap which persists for $E \rightarrow \infty$, which dominates in $\bar{p}p$ elastic scattering, at least at high energies, is negligible for charge exchange.

We come now to the point which motivated our analysis. The rather central character of the contribution of the annihilation channels to the overlap matrix ($\beta \approx 3\alpha$) can be deduced from the fact that the angular distribution of particles in annihilation is in general much less peaked than the distribution in non-annihilation where leading particles are present. We find therefore a correlation between the following two experimental facts :

- i) the angular distribution of particles in annihilation is less peaked than in non-annihilation ;
- ii) the slope for $\bar{p}p$ charge exchange is smaller than for elastic scattering.

For $p\bar{p}$ elastic scattering the slope is large, because $S_{as}^{*})$ which dominates in the overlap, corresponds to non-annihilation channels⁶⁾. For the production of $N^*\bar{N}^*$, however, again the slope is small⁶⁾, which suggests that the case is analogous to charge exchange, and that the annihilation channels dominate. A similar argument can be applied to any two-body final state in $p\bar{p}$ scattering.

We would like to mention two possible theoretical objections against our work. Firstly the overlap matrix is related to the imaginary part of the amplitude. If the amplitude for $p\bar{p}$ charge exchange and other processes turned out to be mainly real, our discussion would be irrelevant. Secondly the angular distribution of particles in a final state depends only on the squared modulus of the amplitude integrated over all the particles except one, while the overlap function also depends on the phase factors and on interparticle correlations. Consequently the relation angular distribution - overlap function is not obvious. In spite of the above arguments we feel that in the absence of information to the contrary the assumptions as used in this note are plausible.

Our final remark concerns the applicability of the Regge pole model to NN and $N\bar{N}$ scattering. We think that the presence of the annihilation channels may be the source of the present difficulties of the model in these cases. Annihilation is not a peripheral process. Consequently one does not expect the contribution described above to factorize into a term corresponding to the nucleon vertex and a term

*) In this case the annihilation part of the overlap function, which is a comparatively small correction, interferes with the main term in such a way that it increases slightly the slope⁴⁾.

corresponding to the antinucleon vertex, and the usual analysis does not apply. Factorization is also implied by the quark model (see, e.g., Kokkedee and Van Hove ⁷⁾). Consequently also the quark model has difficulties with annihilation ⁸⁾.

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