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# Strangeness Exchange in Proton-Antiproton Reactions*

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## Abstract

Results are presented of a coupled channels $P$-matrix model describing the reactions $\overline{p}p \rightarrow \overline{Y}Y$. An antibaryon-baryon potential is constructed with the use of *SU(3)* symmetry. Special attention is given to the influence of the different strange mesons and their coupling constants. The existing experimental data on the reactions $\overline{p}p \rightarrow \overline{\Lambda}\Lambda$ and $\overline{p}p \rightarrow \overline{\Lambda}\Sigma^0 + \overline{\Sigma^0}\Lambda$ are very well reproduced.

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## I. INTRODUCTION

Currently there is much interest in the production of antihyperon-hyperon pairs in antiproton-proton interactions. Stimulated by recent and future experimental work at the LEAR facility of CERN, this theoretical interest has concentrated on several points. The first question one might ask could be: to what extent in this intermediate energy region is the one-boson-exchange picture, so successful at low energies, still valid? In this approach, what can be said about the coupling constants of the strange mesons? Second, what is the importance of quark-gluon based exchange mechanisms?

Concerning the first point different results have been obtained in studies of the reaction $\overline{p}p \rightarrow \overline{\Lambda}\Lambda$. The model of Tabakin and Eisenstein [1] required $K^{**}(1430)$ exchange even close to threshold. Niskanen [2] included only the lighter $K(495)$ and $K^{*}(892)$ mesons. In Nijmegen this reaction was studied by P. Timmers [3], who also used $K(495)$ and $K^{*}(892)$ exchange. In the distorted-wave approach of Kohno and Weise [4] $K(495)$ exchange alone was needed. Moreover the coupling constants used by these authors differ considerably. The second question has been dealt with by Kohno and Weise [5] whose gluon exchange model describes the $\overline{p}p \rightarrow \overline{\Lambda}\Lambda$ and $\overline{p}p \rightarrow \overline{\Lambda}\Sigma^0 + \overline{\Sigma^0}\Lambda$ data reasonably well. However they claim that the inclusion of $K^*$ exchange can explain the data on the latter reaction as well.

In this paper we present a model in which we insist on the following two points. At least for larger distances (say, outside 1 fm) the one-boson-exchange mechanism should provide the correct treatment of the elastic and strangeness exchange interactions. Moreover since there are many competing baryonic channels in this energy region a coupled channels formalism should be used. In order to treat the short distance interaction which includes annihilation as well as possible multiparticle exchanges we use an energy-dependent $P$-matrix specified at 1 fm. In this formalism the potential tail can be studied most effectively. We can obtain in this way a unified treatment of all the $\overline{p}p \rightarrow \overline{Y}Y$ channels, although at this moment the only usable data are on the reactions $\overline{p}p \rightarrow \overline{\Lambda}\Lambda$ and $\overline{p}p \rightarrow \overline{\Lambda}\Sigma^0 + \overline{\Sigma^0}\Lambda$.

The plan of this paper is as follows. In section II we review briefly the $P$-matrix formalism [6] and its application to our model. In section III we construct the antibaryon-baryon potential. Finally in section IV we state and discuss the results.

## II. THE $P$-MATRIX FORMALISM

Consider the relativistic radial Schrödinger equation in channel space for a partial wave with angular momentum $j$:

$$\left(\tfrac{d^2}{dr^2} \; - \; \tfrac{\ell(\ell+1)}{r^2} \; - \; U \; + \; k^2\right) \; \Phi_j(r) \; = \; 0 \; . \tag{1}$$

Here $m$ and $k$ are the diagonal matrices containing the channel masses and momenta. $U = \sqrt{2m}\; V \sqrt{2m}$, where $V$ is the antibaryon-baryon potential. At distance $r = b$ we demand that the wavefunction satisfies the boundary condition

$$P \; = \; \left(\frac{d\Phi_j}{dr}\Phi_j^{-1}\right)_{r=b} \; . \tag{2}$$

| | $g_{\Lambda N}/\sqrt{4\pi}$ | $f_{\Lambda N}/\sqrt{4\pi}$ | $g_{\Sigma N}/\sqrt{4\pi}$ | $f_{\Sigma N}/\sqrt{4\pi}$ |
|---|---|---|---|---|
| $K(495)$ | -4.0243 | -0.2735 | 1.1657 | 0.0765 |
| $K^*(892)$ | -1.5441 | -3.5567 | -0.8915 | 1.3647 |
| $\kappa(1000)$ | -2.5296 | | -1.8268 | |
| $K^{**}(1430)$ | -0.8507 | | -0.5223 | |

TABLE I. Coupling constants of the strange mesons.

$P$ is a matrix that contains the parameters which describe the inner region $r < b$ of the interaction. For each partial wave the solution matrix $\Phi_j(r)$ is integrated numerically from $r = b$ up to $r = \infty$. There we construct the $S$-matrix from the wave functions. In antibaryon-baryon reactions we can take the many mesonic annihilation channels into account by using a complex $P$-matrix. In this way the total flux is not conserved and we can concentrate on the baryonic channels. Since we still have time-reversal invariance we get for $P = P(k, b)$:

$$\widetilde{P} = P \; ; \; P^\dagger \neq P \; , \tag{3}$$

where the tilde denotes transposition in channel space. This means for the $S$-matrix:

$$\widetilde{S} = S \; ; \; S^\dagger \neq S^{-1} \; . \tag{4}$$

In this way we make the assumption that the annihilation interaction has a range effectively shorter than the boundary $b$ which we take to be 1 fm. Moreover the annihilation background should vary slowly and smoothly over the energy range considered. Using standard methods we can from the $S$-matrix calculate the $M$-matrix $M(s, m, \alpha \rightarrow s', m', \alpha')$ where $\alpha$ refers to the channel and $m$ to the z-component of the spin $s$. With the $M$-matrix we can then calculate all the observables.

## III. THE ANTIBARYON-BARYON POTENTIAL

Our starting point is the Nijmegen soft-core nucleon-nucleon potential [7]. To calculate the coupling constants we use *SU(3)* symmetry, while keeping the parameters of the nucleon-nucleon part of the potential fixed at the values of ref. [7]. We emphasize that if one includes vector and scalar mesons in the initial and final state interactions, then in order to be consistent one should do the same in the strangeness exchange potentials. The momentum-dependent part of the potential is neglected which is a good approximation outside 1 fm. Charge-symmetry breaking which would result from the mixing of the $\Lambda$ and the $\Sigma^0$ is not included. For the pseudoscalar mesons we use *SU(3)* symmetry for the pseudovector coupling constant $f_{ps}$, while for the vector mesons this is done for the direct (or electric) and the derivative (or magnetic) couplings $g_v$ and $f_v$. The $F/F$+$D$ ratio for $f_v$ and for the scalar mesons is inferred from the couplings of ref. [7]. They are given by

FIG. 1. Cross-section and polarization for $\overline{p}p \to \overline{\Lambda}\Lambda$ at $p_{lab} = 1507.5$ MeV/c.

FIG. 2. Spin correlation coefficients $C_{ij}$ for $\overline{p}p \to \overline{\Lambda}\Lambda$ at $p_{lab} = 1507.5$ MeV/c. At backward angles from top to bottom: $C_{zz}$, $C_{yy}$, $C_{xz}$ and $C_{xx}$.

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$$\alpha_v^m = 0.318643$$
$$\alpha_s = 1.215067$$

We use a scalar mixing angle of: $\theta_s = 46°$. In the *SU(3)* formalism the $K^{**}$ is part of a nonet of tensormesons. The Pomeron $P$ is mixed with this nonet consisting of $A_2$, $f_2$ and $K^{**}$. For these so-called diffractive mesons we take the coupling constants from the new Nijmegen hyperon-nucleon soft-core potential [8]. These values are preliminary. Thus the coupling constants of the strange mesons are not searched, but given as input. They are summarized in Table I. The potentials are strongly attractive in the elastic channels.

*SU(3)* breaking is introduced by working in the isospin-hypercharge basis of *SU(2)* $\times$ *U(1)*. Since some of the channels have only isospin $I = 0$ or $I = 1$ this reduces the number of amplitudes. By taking into account the correct phase factors for the antiparticles we can calculate all the symmetry factors for the potentials. If we include the channels with charged sigma production we are forced to work on the particle basis because the Coulomb interaction is very important near threshold.

## IV. RESULTS AND DISCUSSION

We first concentrate on the $\overline{p}p \to \overline{\Lambda}\Lambda$ channel for which recently high quality LEAR data have become available [9]. In order to limit the number of parameters we use the same $P$-matrix in all partial waves. Below the $\overline{\Lambda}\Sigma$ threshold we have one open $I = 1$ channel ($\overline{N}N$) and two open $I = 0$ channels ($\overline{N}N$ and $\overline{\Lambda}\Lambda$). The $P$-matrix elements describing the initial state interaction are fixed in such a way that they produce the experimental total, elastic and charge-exchange cross-sections as well as the forward slope of the elastic differential cross-section. The final state interaction $P$-matrix element is allowed to differ only slightly from the $\overline{N}N(I = 0)$ element. It turns out that this element is important to get the strangeness exchange cross-section at the right order of magnitude. The $P$-matrix element for $\overline{N}N \to \overline{\Lambda}\Lambda$ is then fitted to the differential cross-section. Only this element is allowed to vary slowly with the energy. The results of the fits are shown in Figure 1 for $p_{lab} = 1507.5$ MeV/c. We find that the inclusion of the $\kappa$ and $K^{**}$ mesons has only very little influence on the $P$-matrix parameters and on the quality of the fit, contrary to the addition of the $K^*$ meson. The 52 LEAR data at the two energies have total $\chi^2 = 55.47$. It is interesting to look at the contributions from the different partial waves to the cross-sections. These are given in Table II, where we have also included our results at $p_{lab} = 1546.2$ MeV/c. The reaction is clearly dominated by the tensor force transitions $\ell_{\overline{\Lambda}\Lambda} = \ell_{\overline{p}p} - 2$. The tensor forces of the $K$ and $K^*$ mesons have the same sign. The interference between these large tensor contributions and the other partial waves produces the sign change in the polarization data around $\cos\theta = 0.25$. Heavy meson exchange will not decrease the

| $\overline{p}p \to \overline{\Lambda}\Lambda$ partial wave | 1476.5 | 1507.5 | 1546.2 |
|---|---|---|---|
| $^1S_0$ | 0.5 | 0.7 | 0.2 |
| $^1P_1$ | 0.6 | 1.3 | 0.5 |
| $^1D_2$ | 0.1 | 0.3 | 0.3 |
| $^3P_1$ | 1.6 | 3.3 | 7.0 |
| $^3D_2$ | 0.2 | 0.8 | 2.9 |
| $^3F_3$ | | 0.1 | 0.3 |
| $^3P_0$ | 0.3 | 0.8 | 0.4 |
| $^3S_1$ | 1.3 | 1.3 | 1.3 |
| $^3P_2$ | 1.2 | 1.7 | 3.3 |
| $^3D_3$ | 0.2 | 0.5 | 1.4 |
| $^3S_1 \to ^3D_1$ | | 0.2 | 0.6 |
| $^3D_1 \to ^3S_1$ | 3.3 | 4.8 | 5.1 |
| $^3F_2 \to ^3P_2$ | 3.6 | 7.4 | 10.2 |
| $^3G_3 \to ^3D_3$ | 0.5 | 2.0 | 5.1 |
| Rest | | 0.1 | 0.6 |
| singlet $s = 0$ | 1.2 | 2.3 | 1.1 |
| triplet $s = 1$ | 12.3 | 23.2 | 38.3 |
| total | 13.5 | 25.5 | 39.4 |
| experimental | 13.8 ± 0.5 | 26.6 ± 0.7 | |

TABLE II. Partial cross-sections in $\mu$barn for $\overline{p}p \to \overline{\Lambda}\Lambda$ at different values of $p_{lab}$ in MeV/c. The data at 1476.5 and 1507.5 MeV/c are from ref. 9.

tensor force. Although we use only the scalar-like '$j = 0$ part' of the $K^{**}$ potential [7], the tensor piece of the full potential has the same sign as in $K$ and $K^*$ exchange. We have also calculated the spin-correlation coefficients $C_{ij}$. The results at one energy are shown in Figure 2. However these are rather sensitive to the behaviour of the different partial waves, especially the $^3F_2 \rightarrow {}^3P_2$ wave. The singlet fraction $S$ is very small, indicating that the $\overline{\Lambda}\Lambda$ pair is mostly in a triplet state. Next we considered the channel $\overline{p}p \rightarrow \overline{\Lambda}\Sigma^0 + \overline{\Sigma^0}\Lambda$, which is purely $I = 1$. The nice result for the differential cross-section at $p_{lab} = 2434.0$ MeV/c is not shown. Although the fit is quite good, new data are required to test the model better. Especially the $K^*$ contribution is expected to be more important in this reaction.

To summarize we find that the use of *SU(3)* coupling constants gives an excellent description of the available data on the reactions $\overline{p}p \rightarrow \overline{Y}Y$. In the reaction $\overline{p}p \rightarrow \overline{\Lambda}\Lambda$ the final state interaction is very important to obtain a good fit. To fix the relative importance of the strange mesons new data on channels other than $\overline{p}p \rightarrow \overline{\Lambda}\Lambda$ are neccesary. Also these channels may give more information on exchange mechanisms different from the *OBE*-picture.


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