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Coupled Channels and P-matrix Approach to Baryon-Antibaryon Interactions*

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I. INTRODUCTION

Recent data [1, 2] taken at LEAR on the reaction $\overline{p}p \rightarrow \overline{\Lambda}\Lambda$ show some interesting features. The differential cross-section is highly anisotropic even close to threshold, suggesting the contribution of many partial waves to the reaction. Also the polarization changes sign down to the lowest energies which were measured. Future data on spin-correlation coefficients will give additional information on the spin-structure of this reaction.

We present results for two coupled channels potential models which take rather different approaches to the problem and to the treatment of the annihilation in particular. We test how well the data-features mentioned above are reproduced by the models and search for similar predictions.

II. THE MODELS

Our first approach is to describe the inner region of the interaction phenomenologically with the use of a boundary condition. This so-called P-matrix [3] has been specified at a distance of 1 fm. To avoid the use of many parameters the boundary condition has been taken the same for each partial wave. Outside the boundary an antibaryon-baryon potential constructed with the help of *SU(3)*-symmetry is used. Here the inner region is represented as a kind of 'grey sphere' with no spin-structure and is thus rather easy to handle. This model is well suited to study the nuclear potential tail of the interaction. Details can be found in [4]. The strange mesons included are the $K(495)$ and the $K^*(892)$. This model will in the following be referred to as model 1.

We also tried to fit the data with an antibaryon-baryon version [5] of the coupled channels Nijmegen potential model for $\overline{N}N$ scattering [6]. In this model we construct a $\overline{B}B$ nuclear potential $V_{\rm nuc}$ from the G-parity transformed Nijmegen model-D *OBE* potential [7]. The coupling constants are related by *SU(3)*-symmetry. The $\overline{B}B$ potential is cut off linearly in the inner region of the interaction. In the lower energy $\overline{N}N$ model an important further ingredient is given by an isospin-dependent phenomenological potential $V_{\rm ph}$ containing most of the parameters of the model. It was decided to take $V_{\rm ph}$ into account only in the $\overline{N}N$ channels (see below).

Each of the $\overline{B}B$ channels is coupled to two effective two-particle annihilation channels, one with low and one with high threshold. These thresholds are kept at the values of the $\overline{N}N$ model. The off-diagonal annihilation potential V_a is of a Woods-Saxon form:

$$V_a^{(i)}(r) = V_0(i)\ \frac{1}{1+\exp(m_a r)}$$

where $i = 1, 2$ denotes the annihilation channel. The mass m_a is taken the same for both annihilation channels.

Thus for our coupled channels model we have a potential matrix of the form:

$$V = \begin{pmatrix} V_{\overline{B}B} & V_a \\ \tilde{V}_a & 0 \end{pmatrix}$$

model	$\chi^2/N_{\rm df}$	parameters
1	1.06	4
2a	2.46	3
2b	2.19	3
2c	1.77	3

TABLE I. χ^2 of the 4 models for the 42 cross-sections and 10 polarizations at two energies.

where $V_{\overline{B}B} = V_{\rm nuc} + V_{\rm ph}$ and $V_{\rm ph}$ works only in the $\overline{N}N$ channels. The tilde denotes transposition in channel-space. This potential matrix is used in the Schrödinger equation. In the $\overline{N}N$ channels we use the parameters of [6], except that we neglect non-local effects present in the $\overline{N}N$ model.

The observables are rather sensitive to details of the initial and final state interactions. We feel that in this way for our treatment of the reaction $\overline{p}p \to \overline{Y}Y$ the initial $\overline{p}p$ state is described quite well. The uncertain part of the model is the description of the final $\overline{Y}Y$ state. Since the origin of $V_{\rm ph}$ is not clear and since there are no data to determine one analogous to the one in the $\overline{N}N$ channels, we only use the strengths $V_0(i)$ and the mass m_a of the $\overline{Y}Y$ annihilation potential as parameters of the final state.

In our detailed look at the reaction $\overline{p}p \to \overline{\Lambda}\Lambda$ we will consider two possibilities for the strangeness exchange potential. These potentials are not cut off in the inner region. Instead we use soft-core potentials for the strange mesons as in the Nijmegen soft-core *OBE* nucleon-nucleon potential [8].

- First we will include only $K(495)$ exchange, which gives a spin-spin and a tensor potential. This solution will be referred to as model 2a.

- Second we include also the vectormeson $K^*(892)$. This potential has the same sign for the tensor part as the K-potential, whereas the signs of the spin-spin parts are opposite. This is model 2b.

For these two models the coupling constants of the strange mesons are taken from the Nijmegen soft-core hyperon-nucleon potential [9], while the cut-off mass is kept at the value of [8].

III. RESULTS

We have performed least χ^2-fits to the 52 data on $\overline{p}p \to \overline{\Lambda}\Lambda$ at two energies of [1] for each of the three models. See Table I for the results. In model 1 the initial state is fixed by fitting to the total, elastic and charge-exchange cross-sections as well as to the forward elastic differential cross-section. The parameters of this model are the final state and transition elements of the boundary condition matrix on the wave function while for the three variants of model 2 they are the strengths and mass of the $\overline{\Lambda}\Lambda$ annihilation potential.

Only for model 1 it turned out to be possible to get a simultaneous fit to the cross-sections and polarizations. In Figure 1 those fits are shown which give an optimal result for

$\overline{p}p \to \overline{\Lambda}\Lambda$ partial wave	1	2a	2b	2c
$^1S_0$	0.7	0.1	0.2	2.6
$^1P_1$	1.3	1.4	0.0	5.0
$^1D_2$	0.3	0.2	0.0	0.3
$^3P_1$	3.3	1.4	0.0	0.3
$^3D_2$	0.8	0.3	0.0	0.1
$^3P_0$	0.8	2.2	3.7	2.5
$^3S_1$	1.3	1.6	0.3	1.1
$^3P_2$	1.7	1.2	0.5	1.4
$^3D_1$	0.0	0.2	0.2	1.7
$^3D_1 \to ^3S_1$	4.8	8.5	4.2	4.1
$^3F_2 \to ^3P_2$	7.4	8.3	14.3	4.2
$^3G_3 \to ^3D_3$	2.0	1.0	1.8	1.1
rest	1.1	0.4	0.3	1.0
singlet $s = 0$	2.3	1.8	0.2	8.0
triplet $s = 1$	23.2	24.4	25.3	17.4
total	25.5	26.2	25.5	25.4

TABLE II. Partial cross-sections in μbarn for $\overline{p}p \to \overline{\Lambda}\Lambda$ at $p_{\rm lab} =$ 1507.5 MeV/c.

the differential cross-section. The results for the polarization suggest that the dynamics of the inner region is described well by neither of the models 2. This might be improved upon by allowing more freedom in the strangeness exchange potentials, but for this first report we have chosen to keep the parameters of the YN and NN models. We merely test how far we can get with a few parameters for the final state interaction. Thus the fits are preliminary in the sense that the influence of heavier strange mesons and of a better description of the final state interaction have to be investigated.

In model 2b we had to distort the wave-function in the inner region heavily by increasing the $\overline{\Lambda}\Lambda$ annihilation potentials by a factor 1.5–2.5 w.r.t. the $\overline{N}N$ annihilation potential in order to achieve reasonable results. Even then the polarization at backward angles is way off. The reason for this is the strong combined tensor-force of the K and K^* mesons at short distances.

This can also be seen in Table II where we show the partial wave cross-sections for the different models at one energy. At this particular energy the off-diagonal tensor-force transitions $\ell_{\overline{\Lambda}\Lambda} = \ell_{\overline{p}p} - 2$ provide for 68% of the cross-section in model 2a, for 80% of the cross-section in model 2b, while this percentage was 56% in model 1. It should be stressed that the tensor-force can not be decreased by the inclusion of heavy mesons like the $\kappa(1000)$ or the $K^{**}(1430)$, since either these exchanges do not give a tensor-force or if they do, it has the same sign as that of the K and the K^*.

We tried to modify the short distance K^* tensor-potential by using an alternative parametrization of the form factor. In this form factor we built in a zero for one value of momentum transfer. Thus we have as coupling in the potential:

$$g^2(1 - \frac{\vec{k}^2}{m_0^2})$$

multiplied by an exponential form factor. This is called model 2c in the tables and figures. In our model we take the mass $m_0 = 630$ MeV/c^2. Because of this zero the K^* potential changes sign at distances smaller than about 0.8 fm. The resulting cross-section is very good, but the model gives too little polarization.

The models differ widely in their predictions of the spin-correlation coefficients C_{ij}. All three variants of model 2 give very large values for all C_{ij} with much structure, whereas model 1 predicts values somewhat smaller. The singlet fraction is sizable only in model 2c. Data on C_{ij} may give decisive support to one or more of these models.

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