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P-matrix Model for Antibaryon-Baryon Reactions*

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I. INTRODUCTION

The LEAR experiment PS185 has provided data (Barnes *et al.*, 1987) of unprecedented high quality on the strangeness exchange of proton-antiproton pairs into hyperon-antihyperon. Previous studies have pointed to some difficulties in describing the data. While the reactions are quite sensitive to both initial and final state interactions, it is possible to take into account only the first properly. More or less arbitrary assumptions have to be made about the latter. Also, since the energy in the initial state is high there are many partial waves that contribute to the scattering. In our model we have adopted the following attitude. Since there are many hyperonic channels opening up in this energy region and in order to take into account initial and final state effects well, all relevant baryonic channels should be treated in a coupled channels formalism. The long range part of the interaction is given by the conventional one-boson-exchange forces. All strange mesons should be included to which the data are sensitive. The short range part of the interaction is much more complicated and theoretically less known. It is probably dominated by quark-gluon based exchange mechanisms. Certainly in nucleon-antinucleon reactions it is not given purely by a G-parity transformation of the corresponding nucleon-nucleon potential. We decided to describe the inner region in our model with the help of the P-matrix formalism. This separation of short and long range interaction will prove to be extremely useful to study the tail of the nuclear interaction.

II. THE P-MATRIX

The P-matrix (Jaffe and Low, 1979) is a special kind of boundary condition used in scattering problems. The scattering of two particles is described by the relativistic version of the Schrödinger equation:

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

This is a matrix equation in channel space. $U = \sqrt{2m}\,V\sqrt{2m}$, where V is the *OBE* potential. For this we use the Nijmegen soft core nucleon-nucleon potential of Nagels, Rijken and de Swart (1978), properly *SU(3)* adapted. The P-matrix is the logarithmic derivative of the wave function matrix at a boundary $r = b$, which we take to be 1 fm:

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

We integrate eq. 1 numerically for each partial wave up to 15 fm where the solution matrix is matched to the free spherical Hankel functions. Using standard techniques we can then calculate all the observables.

If the asymptotic wave function and the interaction in the outer region are completely known one can determine the P-matrix. Alternatively, since this is not usually the case, the P-matrix can be parametrized as a function of energy. These parameters are then fitted to the data. It is very difficult to relate the parameters to the physics in the inner region. If we assume a square well in the inner region then the P-matrix for a one-channel problem is given by:

$$P \; = \; \frac{J'(k'b)}{J(k'b)} \tag{3}$$

with $k'^2 \; = \; k^2 - U$, where U is the square well potential. In order to provide for the annihilation the square wells are taken to be complex. Consider the reaction $\overline{p}p \to \overline{\Lambda}\Lambda$. In this three-channel problem we work on the isospin basis: $\{\overline{N}N(\mathrm{I{=}1}),\ \overline{N}N(\mathrm{I{=}0}),\ \overline{\Lambda}\Lambda\}$. The three diagonal elements in the P-matrix are of the form eq. 3. The transition element between $\overline{N}N(\mathrm{I{=}0})$ and $\overline{\Lambda}\Lambda$ can be taken a power series in $\varepsilon = \sqrt{s} - 2m_\Lambda$, where $\sqrt{s}$ is the total center-of-mass energy. For tensor coupled waves we take $1_2 \otimes P$, where P is the 3×3 P-matrix of the same form as for uncoupled waves.

III. RESULTS AND DISCUSSION

We concentrate on the $\overline{p}p \to \overline{\Lambda}\Lambda$ channel. The strange mesons included are the $K(495)$, the $K^*(892)$ as well as the scalar meson $\kappa(1000)$ and the tensor $K^{**}(1430)$. The data however are not sensitive to the inclusion of the last two mesons. To fix the initial state interaction we fit the high quality data of Eisenhandler *et al.* (1976) on $\overline{p}p \to \overline{p}p$ at lab-momentum of 1500 MeV/c. In order to do this properly we need eight parameters, namely two complex square wells for S- and P-waves, one for each isospin value, and two square wells more for D- and F-waves, again one for each isospin. We then get the nice result shown in Figure 1. At this energy the elastic scattering is dominated by P- and D-waves, but many partial waves contribute significantly. To fix the different isospin contributions better we would need a differential cross-section $\overline{p}p \to \overline{n}n$. Also an elastic polarization would be of great help. The largest unknown factor in these reactions, however, is the short range final state interaction. We decided to take only one square well here (two parameters), the same for each partial wave. This does not mean the same P-matrix, since in eq. 3 there is still the dependence on orbital angular momentum. With these parameters and the transition P-matrix element $\overline{p}p \to \overline{\Lambda}\Lambda$ set equal to zero we can get only a crude descripiton of the data: $\chi^2/N_{\mathrm{df}} = 3.0$. To achieve a better fit we need two more parameters for the strangeness exchange P-matrix element. The results for the polarization and cross-section at one energy are shown in Figure 2. For the 87 LEAR data at three energies (one preliminary) we get $\chi^2/N_{\mathrm{df}} = 1.25$. The reaction is dominated by the tensor force transitions $\ell_{\overline{\Lambda}\Lambda} = \ell_{\overline{p}p} - 2$, most notably the ${}^3F_2 \to {}^3P_2$ transition. Also the ${}^1P_1$ wave is important. The S-waves are suppressed. When data for more energies become available we can parametrize the P-matrix as a function of energy better. Then a partial wave analysis will be possible down to threshold. Other $\overline{p}p \to \overline{Y}Y$ channels can be included easily into the model.

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FIGURES

FIG. 1. Cross-section for $\overline{p}p \rightarrow \overline{p}p$ at $p_{\rm lab}$= 1500.0 MeV/c.

FIG. 2. Observables for $\overline{p}p \rightarrow \overline{\Lambda}\Lambda$ at $p_{\rm lab}$= 1507.5 MeV/c.