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Determination of the ΛpK coupling constant from LEAR data on $\overline{p}p \rightarrow \overline{\Lambda}\Lambda$*

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Abstract

From recent high quality data taken at LEAR on the strangeness-exchange reaction $\overline{p}p \rightarrow \overline{\Lambda}\Lambda$ we could determine the ΛpK coupling constant at the kaon pole. The value found is

$$f^2_{\Lambda pK} = 0.071 \pm 0.007 \qquad \text{or equivalently} \qquad g^2_{\Lambda pK} = 15.4 \pm 1.5.$$

Using SU(3) symmetry for the pseudovector coupling constants we find for the $\alpha = F/(F+D)$ ratio the value $\alpha_{\mathrm{PV}} = 0.34 \pm 0.04$, in excellent agreement with the value $\alpha = 0.355 \pm 0.006$ as obtained from weak semileptonic baryon decays.

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The $\overline{p}p \to \overline{Y}Y$ reactions, accessible at LEAR, constitute a unique window on strangeness-exchange because they require the exchange of at least one quantum of strangeness. The ongoing PS185 collaboration has recently published data [1–3] of high quality on the reaction $\overline{p}p \to \overline{\Lambda}\Lambda$, which has its threshold at 1435 MeV/c antiproton laboratory momentum. The experimentalists have meanwhile moved on to the reactions next in line, that is $\overline{p}p \to \overline{\Lambda}\Sigma^0$, $\overline{\Sigma^0}\Lambda$. Later the different $\overline{p}p \to \overline{\Sigma}\Sigma$ reactions will also be investigated. In this communication we want to demonstrate that these data can provide valuable information on the coupling of strange mesons to baryons. The coupling constants of the kaon can then be used to obtain information about the validity of SU(3) symmetry for the pseudoscalar-meson–baryon coupling constants. In this letter we extract the ΛpK coupling constant from the PS185 data taken so far on $\overline{p}p \to \overline{\Lambda}\Lambda$.

Our work is a continuation of the study of antibaryon-baryon scattering with the help of a coupled-channels OBE model [4], which had its application in a partial-wave analysis of the $\overline{p}p \to \overline{\Lambda}\Lambda$ scattering data from LEAR. The method of analysis used is essentially the same as the one used in the Nijmegen partial-wave analyses [5,6] of the very rich and accurate data on pp scattering below $T_{\rm lab} = 350$ MeV, where it allowed the determination of the $pp\pi^0$ coupling constant. Although a partial-wave analysis of the same degree of uniqueness is certainly not possible here, we think that using the same strategy one can determine the behavior of the dominant amplitudes rather well.

The scattering region is divided into two parts by using a boundary condition at $r = b = 1.2$ fm. For the theoretically well understood long-range interaction for $r > b$ a model based on meson-exchange is used. The coupled-channels Schrödinger equation is solved, taking into account all relevant baryonic channels and starting with the boundary condition at $r = b$. The poorly known short-range interaction is treated phenomenologically by parametrizing the boundary condition as a function of the energy. In antibaryon-baryon scattering the short-range interaction is especially complicated because it is dominated by the coupling to many mesonic annihilation channels. This additional complication can easily be handled by using a complex boundary condition. The imaginary part takes care of the disappearance of flux into the mesonic channels. For large values of the orbital angular momentum the inner region is screened by the centrifugal barrier, with the consequence that only a limited number of partial waves need to be parametrized. This separation between inner and outer region physics has proven to be very powerful in analyzing nucleon-nucleon scattering data.

For the intermediate- and long-range interaction with $r > b = 1.2$ fm a realistic meson-exchange potential is employed, in our case the Nijmegen soft-core baryon-baryon OBE potential, which gives an excellent description of the low-energy data on nucleon-nucleon [7] and hyperon-nucleon [8] scattering. This potential can also account very well for the low-energy data on elastic $\overline{p}p \to \overline{p}p$ and charge-exchange $\overline{p}p \to \overline{n}n$ scattering [9]. In Ref. [4] we have shown that the same potential describes also the data on $\overline{p}p \to \overline{\Lambda}\Lambda$ very well.

The data-set on $\overline{p}p \to \overline{\Lambda}\Lambda$ used in the analysis consists of 5 integrated cross sections, 99 differential cross sections, and 38 polarizations at six energies below $p_{\rm lab} = 1.55$ GeV/c. It thus comprises a total of 142 data-points. In this study we did not include in our data-set the spin-correlation data which were taken at one energy. The reason is that some of these spin-correlation data are outside their kinematically allowed region. (In our final fit these data are quite well described). We also rejected 4 data-points, 1 integrated cross section, 1 differential cross section, and 2 polarizations because of their abnormal high contribution to $\chi^2_{\rm min}$.

It is advantageous for the analysis that the data were taken so close to threshold because then only a limited number of partial waves make a significant contribution to the cross section. The value of the total kinetic energy in center-of-mass system of the hyperon pair is only 39.1 MeV at the highest momentum $p_{\rm lab} = 1546.2$ MeV/c where data were taken. The behavior of only a few dominant transitions must then be determined. An additional simplification occurs in $\overline{p}p \to \overline{\Lambda}\Lambda$ because this reaction is purely isospin 0.

The reaction $\overline{p}p \to \overline{\Lambda}\Lambda$ is mediated by the strange mesons. We include the pseudoscalar $K(494)$, the vector $K^*(892)$, the scalar $\kappa(1000)$, and the scalar-like 'diffractive' piece [7] of the tensor $K^{**}(1430)$. The κ and K^{**} potentials are quite weak outside $r = b$ and do not affect the results. The K^* potential on the other hand has a strong tail which extends well beyond the inner region. The tensor potentials of the K and K^* exchanges have equal sign, while their spin-spin potentials are of opposite sign. For low energies in the final state the tensor potential leads to a dominance of the off-diagonal tensor force transitions $\ell(\overline{\Lambda}\Lambda) = \ell(\overline{p}p) - 2$, in particular the ${}^3D_1 \to {}^3S_1$, ${}^3F_2 \to {}^3P_2$, and ${}^3G_3 \to {}^3D_3$ transitions [4]. In our model these transitions make up 90% of the cross section close to threshold and about 60% at the highest energy considered. This dominance of the tensor force explains the almost complete absence of scattering in spin-singlet states, even to such an extent that one can speak of a dynamical selection rule. We are confident that the behavior of these important amplitudes is described rather well in our model.

In our earlier work the tail of the meson-exchange potential was adapted from the Nijmegen potential and contained no free parameters. A total of eight short-range parameters were needed to achieve a good fit to the data. These were: one annihilation parameter for the initial $\overline{p}p$ state, one annihilation parameter for the final $\overline{\Lambda}\Lambda$ state, three additional parameters for the final state, and three for the off-diagonal $\overline{p}p \to \overline{\Lambda}\Lambda$ transitions. In this study the ΛpK coupling constant is added as a ninth parameter. In view of the strength of the K^* tensor force, this potential tail must be varied at the same time as that of the K. So a tenth parameter has to be introduced for the K^* potential, in order to avoid a possible systematic error.

The K^* exchange potential contains two independent coupling constants, namely the Dirac coupling g, and the Pauli coupling f. In Ref. [4] these were taken from the Nijmegen hyperon-nucleon potential, where SU(3)-flavor symmetry is assumed for the vector-meson coupling constants. Although there is no definite evidence that this assumption is correct, it certainly appears to be reasonable, in view of the success of the Nijmegen hyperon-nucleon potentials for example. It is at present not possible to determine both these coupling constants from the experimental data, in particular because only the linear combination $(g + f\sqrt{m_\Lambda/m_p})^2$ appears in front of the tensor part of the K^* potential. Several options remain for choosing the one parameter that is necessary. A convenient choise is to simply scale the K^* potential. The scale parameter that multiplies the potential is called γ. The two parameters for the intermediate- and long-range interaction, the kaon coupling constant and γ, are expected to be strongly correlated. The ten parameters are adjusted in a least-squares fit to the data-set consisting of 142 observables.

There is some arbitrariness in the kaon-baryon interaction. One can use the pseudoscalar PS or the pseudovector PV vertex with the respective interaction lagrangians

$$\mathcal{L}_{\rm PS} \;=\; g\sqrt{4\pi}\;(\overline{\psi}i\gamma_5\psi)\phi \quad \text{and} \quad \mathcal{L}_{\rm PV} \;=\; \frac{f}{m_S}\sqrt{4\pi}\;(\overline{\psi}i\gamma_\mu\gamma_5\psi)\partial^\mu\phi \;\;, \tag{1}$$

where m_S is a scaling mass to make the PV coupling constant f dimensionless. It is commonly chosen to be equal to the charged-pion mass $m_S = m_+$. The one-kaon-exchange (OKE) potentials following from these vertices are the same, provided

$$f_{\Lambda pK}/m_+ = g_{\Lambda pK}/(M_\Lambda + M_p) \;\; . \tag{2}$$

It is also possible to add a form factor to the potential, but this is a short-range effect. We have checked explicitly that including a form factor in the OKE potential has no influence on the final results. Thus we wil use for $r > b = 1.2$ fm the following OKE potential

$$V_{\rm OKE}(r) = f^2_{\Lambda pK}\left(\frac{m}{m_+}\right)^2 \frac{1}{3}\left[\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2 + S_{12}\left(1+\frac{3}{(mr)}+\frac{3}{(mr)^2}\right)\right]\frac{e^{-mr}}{r} \;\;, \tag{3}$$

where $m^2 = m_K^2 - (M_\Lambda - M_p)^2$, m_K being the charged-kaon mass. This form of the OKE potential follows from a standard non-relativistic reduction of the OKE Feynman diagram with the vertices prescribed by Eqn.(1).

Let us now come to the results of the analysis. Fitting the parameter-set to the observables, we reach $\chi^2_{\rm min} = 146.0$ for our data-set consisting of 142 data. The ΛpK coupling constant is found to be

$$f^2_{\Lambda pK} \;= 0.071 \pm 0.007 \quad \text{or} \quad g^2_{\Lambda pK} \;= 15.4 \pm 1.5 \;\; . \tag{4}$$

We determine the coupling constant at the kaon pole because we use only the tail of the OKE potential. The value found is in agreement with the value used in the recent soft-core Nijmegen hyperon-nucleon potential [8], where $\alpha = F/(F + D)$ for the pseudoscalar-meson nonet was determined in a fit to the data on hyperon-nucleon scattering. Other independent determinations of the ΛpK coupling constant come from single- or multi-channel analyses of kaon-nucleon scattering data using forward dispersion relation techniques [10,11], or from the analysis of data on the kaon photoproduction reaction $\gamma p \rightarrow K^+\Lambda$ [12]. The values for the coupling constant are summarized in Table [1]. Further references to other determinations can be found in the papers quoted. The value found for the scale parameter γ introduced in the K^* potential is $\gamma = 0.74 \pm 0.21$. The expected strong correlation between the two parameters was indeed found.

The method of analysis used here is probably as model-independent as one can hope for. The model-dependent short-range interaction is parametrized phenomenologically. The theoretical uncertainty in the long-range interaction is small. For instance in the Nijmegen partial-wave analyses of the low-energy *pp* data several realistic meson-exchange models were used as long-range potential tails and all gave quite similar results. In our case, the most important source of possible systematic errors is the remaining part, next to the OKE potential, of the long-range meson-exchange potential. We have taken care of this by introducing a scale parameter for the K^* potential. As stated above, the other heavier strange

	method	$10^3\, f^2_{\Lambda pK}$	$g^2_{\Lambda pK}$
Martin, Ref.[10]	KN forward dispersion	64 ± 12	13.9 ± 2.6
Antolin, Ref.[11]	KN forward dispersion	58 ± 5	12.5 ± 1.1
Adelseck and Saghai, Ref.[12]	K photoproduction	80.3	17.4
Maessen *et al.*, Ref.[8]	YN potential	73.4	15.9
This work	analysis of $\overline{p}p \to \overline{\Lambda}\Lambda$	71 ± 7	15.4 ± 1.5

TABLE I. Determinations of the ΛpK coupling constant. In Ref.[8] and Ref.[12] no errors were quoted.

mesons do not affect the final results. In view of this, we are confident that our calculation is free of large systematic errors.

A good consistency check is to determine in an analogous way the mass of the charged kaon. The mass also appears in the tail of the OKE potential. Varying both $f^2_{\Lambda pK}$ and the mass (which increases the number of parameters to 11) we find $f^2_{\Lambda pK} = 70 \pm 20$ and $m_K = 480 \pm 60$ MeV. The mass found in this way is in good agreement with the experimental value $m_K = 493.646 \pm 0.009$ MeV. This indicates that we are actually looking at a one-kaon-exchange mechanism in the reaction $\overline{p}p \to \overline{\Lambda}\Lambda$.

In case of exact SU(3)-flavor symmetry of the PV meson-baryon coupling constants the ΛpK coupling constant is related [13] to the pion-nucleon coupling constant by

$$f_{\Lambda NK} \;=\; -f_{NN\pi}(1+2\alpha)/\sqrt{3} \;, \tag{5}$$

where $\alpha = F/(F+D)$. When we assume SU(2)-isospin symmetry (charge-independence) for the pion-nucleon coupling constants, we can use for $f_{NN\pi}$ the value of the $pp\pi^0$ coupling constant $f^2_{pp\pi^0} = 0.0750 \pm 0.0007$ as obtained in the recent Nijmegen partial-wave analyses [5,6] of proton-proton scattering data. We then find for the $\alpha = F/(F+D)$ ratio

$$\alpha_{\rm PV} \;=\; 0.34 \pm 0.04 \;. \tag{6}$$

However, if we assume SU(3) symmetry for the PS coupling constants we get

$$\alpha_{\rm PS} \;=\; 0.42 \pm 0.04 \;. \tag{7}$$

The difference between $\alpha_{\rm PS}$ and $\alpha_{\rm PV}$ comes from SU(3) breaking of the baryon masses.

Using SU(3) symmetry in weak semileptonic baryon decays the value $\alpha = 0.355 \pm 0.006$ is obtained [14] for the hadronic axial-vector current. If we assume the validity of the SU(3) generalized Goldberger-Treiman relations this value for α can be related to $\alpha_{\rm PV}$ for the pseudoscalar-meson–baryon PV coupling constants. One then finds $\alpha_{\rm PV} = \alpha$. The agreement between the two different ways of determining α is seen to be good.

In anticipation of further experimental results from PS185 on the reactions $\overline{p}p \to \overline{\Lambda}\Lambda$, $\overline{p}p \to \overline{\Lambda}\Sigma^0, \overline{\Sigma^0}\Lambda$, and $\overline{p}p \to \overline{\Sigma}\Sigma$, it is interesting to speculate on the possibilities of determining in an analogous way the ΣpK coupling constant. From our experience with the reaction

$\overline{p}p \rightarrow \overline{\Lambda}\Lambda$ we feel that is needed a data-set of cross sections and polarizations at various energies close enough to threshold such that scattering occurs mainly into S, P, and D final states. Once the data have become available the method outlined above will be eminently suited to extract in a combined analysis the ΛpK and ΣpK coupling constants. One hopes that the statistical errors will be small enough to draw more definite conclusions on the validity of SU(3)-flavor symmetry for meson-baryon coupling constants.

The fact that in charge- or strangeness-changing $\overline{p}p$ scattering only a very limited number of mesons can be exchanged makes these reactions especially good candidates for determining the corresponding coupling constants. A good place to extract the charged-pion coupling constant is for example in $\overline{p}p \rightarrow \overline{n}n$ charge-exchange scattering. In $\overline{p}p \rightarrow \overline{n}n$ similar features are encountered as in $\overline{p}p \rightarrow \overline{\Lambda}\Lambda$. For instance the π and ρ tensor potentials add up. We have analysed the data on $\overline{p}p \rightarrow \overline{n}n$ along the same lines as followed here [15].

To summarize our findings, we have determined the ΛpK coupling constant from accurate scattering data on the strangeness-exchange reaction $\overline{p}p \rightarrow \overline{\Lambda}\Lambda$ taken at LEAR. Comparing the value found for the $F/(F+D)$ ratio with that obtained from weak semileptonic baryon decays, we conclude that PV coupling of pseudoscalar mesons to baryons is favored over PS coupling. We find that the SU(3) relation (5) for the PV coupling constants is valid with no indication for an appreciable breaking.

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