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POLARIZATION TRANSFER IN ELASTIC p-d SCATTERING AT E_p=22.7 MeV

W. GRÜEBLER, M. CLAJUS, P.M. EGUN, P. HAUTLE, A. WEBER,
P.A. SCHMELZBACH*, I. SLAUS**, B. VUARIDEL***, F. SPERISEN****,
W. KRETSCHMER*****, A. RAUSCHER*****, R. WEIDMANN*****,
R.O. KARSCHNICK*****, Th. WALTER*****, M. BRUNO******,
F. CANNATA****** and M. d'AGOSTINO******

Institut für Mittelenergiephysik, ETH, Zürich, Switzerland
* *PSI Villigen*
** *Institut Ruder Boskovic, Zagreb, Switzerland*
*** *University of Michigan, U.S.A.*
**** *IUCF, U.S.A.*
***** *Physikalisches Institut, Univ., Erlangen, F.R.G.*
****** *INFN, Bologna, Italy*

Résumé

La diffusion élastique proton-deuton a été étudiée à E_p = 22.7 MeV, où l'on a comparé calculs du type Faddeev et résultats expérimentaux. Les calculs prédisent que les coefficients de transfert de polarisation sont plus sensibles aux détails du potentiel nucléon-nucléon que les pouvoirs d'analyse. Par conséquent nous avons mesuré les coefficients de transfert proton-proton $K_y^{y'}$ et $K_z^{x'}$. L'observable la plus sensible à la force tensorielle est $K_y^{y'}$. La distribution angulaire de $K_y^{y'}$ et, dans une moindre mesure, celle de $K_z^{x'}$ favorisent le choix du potentiel Bonn A.

Abstract

The proton-deuteron elastic scattering has been investigated at E_p=22.7 MeV by comparison of rigorous Faddeev calculations with experimental results. From the calculations it was found that polarization transfer coefficients are more sensitive to details of the nucleon-nucleon potentials than the analyzing powers. Therefore we measured the proton to proton transfer coefficients $K_y^{y'}$ and $K_z^{x'}$. The observable most sensitive to the tensor force is $K_y^{y'}$. The angular distributions of $K_y^{y'}$ and, to a smaller extent, $K_z^{x'}$ clearly favour the Bonn A potential.

One of the most interesting and fundamental problems in nuclear physics is the description of the nucleon-nucleon (N-N) interaction by a general potential, which not only includes the central forces but also the non-central spin interactions. For the determination of the spin-dependent contributions to such a potential accurate measurements of polarization observables are required. Apparently, the most direct access to the information required would be offered by N-N experiments, where a large amount of data is available. However, at energies below 30 MeV the ^3P_J phase-shifts are quite small and consequently the analyzing powers in N-N elastic scattering are tiny, requiring extremely high precision measurements. In addition, important features of the potential, like the mixing parameter ϵ_1, are only accessible through n-p scattering, where the experimental results bear large uncertainties and are still incomplete. Consequently the corresponding phase shift analyses give also large uncertainties for ϵ_1, as seen in Fig. 1. On the other hand, ϵ_1 is among others a critical parameter for the calculation of the binding energies of ^3H and ^3He. Therefore, N-d scattering can deliver quantitative information on ϵ_1 at low energy provided one performs high precision measurements of polarization observables, which are sensitive to ϵ_1. Rigorous three body Faddeev calculations based on realistic potentials can provide information about the sensitivity of the relevant observables and give guidelines to the experiments to be carried out. It has been shown that the polarization-transfer coefficients $K_y^{y'}$ and $K_z^{x'}$ (Wolfenstein's notation D and A) are particularly sensitive to details of the N-N potentials, e.g. the strength of the $^3S_1$-$^3D_1$ tensor force /2/.

For these reasons we performed measurements of $K_y^{y'}(\theta)$ and $K_z^{x'}(\theta)$ at an incident proton energy of 22.7 MeV. These second order polarization observables are determined by double scattering experiments. After the first scattering by an angle θ, with an analyzing power $A_y(\theta)$, the polarization components $p_{x'}$ and $p_{y'}$, respectively, are given by

$$p_{x'}(\theta) = \frac{K_x^{x'}(\theta)\cdot p_x + K_z^{x'}(\theta)\cdot p_z}{1 + A_y(\theta)\cdot p_y} \quad (1)$$

$$p_{y'}(\theta) = \frac{A_y(\theta) + K_y^{y'}(\theta)\cdot p_y}{1 + A_y(\theta)\cdot p_y} \quad (2)$$

The first equation is considerably simplified, if the primary beam polarization p_1 (p_x, p_y, p_z) is purely longitudinal, i.e. $p_x = p_y = 0$. We then have

$$p_{x'}(\theta) = p_z \cdot K_z^{x'}$$

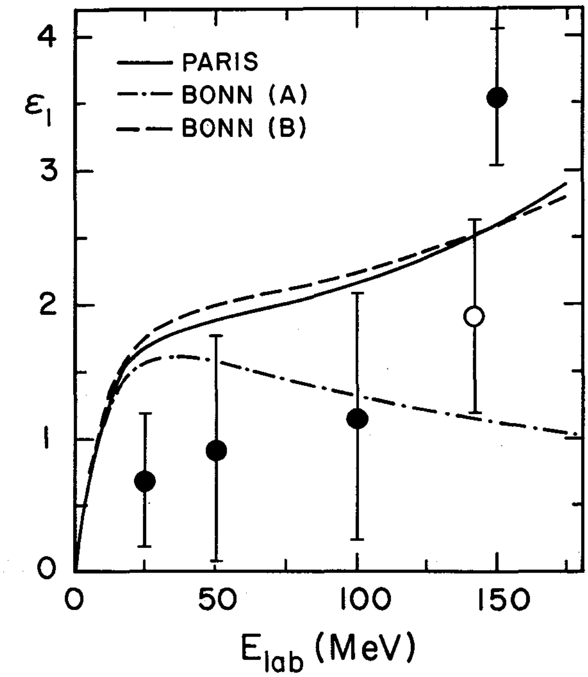

Figure 1: The N-N $^3S_1-^3D_1$ mixing parameter ε_1 as given by Arndt's phase-shift analysis (dots) /1/ and by the Paris, Bonn A and Bonn B potentials. The open circle is from Dubois et al., Ref. /1/.

The 22.7 MeV polarized proton beam from the PSI cyclotron was scattered from a deuterium target, which was pressurized to 12 bars and cooled to 77 K. The scattered protons were focussed by a magnetic quadrupole triplet lens into the polarimeters 2 m from the first scattering chamber. The beam polarization p_1 was continuously monitored by a ^{12}C polarimeter located upstream of the deuterium target. The incident beam polarization was also calibrated by replacing the D_2 target with a ^4He target and comparing our measurement with the calibration from ref. /3/. The sign of the beam polarization was inverted every few seconds. This method allows to determine $K_y^{y'}$ and $K_z^{x'}$ from the ratios of the detector counting rates independently of solid angles. The general formalism used is described in ref. /4/. For the analyzing power A_y needed to determine $K_y^{y'}$ interpolated values from ref. /5/ were used.

One of the main experimental problems is the measurement of the polarization of the scattered protons over a large angular range, since their energy decreases rapidly with scattering angle. Two different polarimeters based on p-α and p-^{12}C scattering were used to cover the energies of the protons scattered from θ_{cm} = 45° to 125°. Details of these polarimeters, their calibrations and their use in polarization transfer experiments for the same energy of protons incident into the polarimeters are given in refs. /4/ and /6/. The background observed in the present experiment was reduced by using an additional ΔE-detector in front of the polarimeter in coincidence with the side detectors. As a stringent consistency test the polarization transfer coefficient $K_y^{y'}$ in the sensitive region has been measured using both the ^4He polarimeter and the ^{12}C polarimeter. The two values agree very well within the error of the individual results of ± 0.02.

The measured and calculated $K_y^{y'}$ are shown in Fig. 2. The present data clearly favour the Bonn A potential with the weaker tensor force. Bonn B and Paris potential predictions are close together in accordance with their ϵ_1 parameter shown in Fig. 1.

One important question is what influence small uncertainties in our study may have on the results, particularly on the conclusions concerning the different N-N potentials. Since the systematic uncertainties in the present measurement (background subtraction, polarization of the incident beam, A_y values of

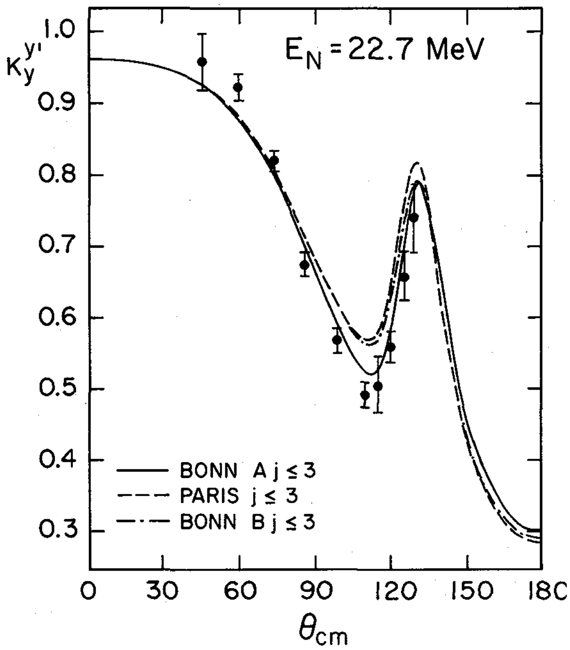

Figure 2: $K_y^{y'}$ as a function of angle.

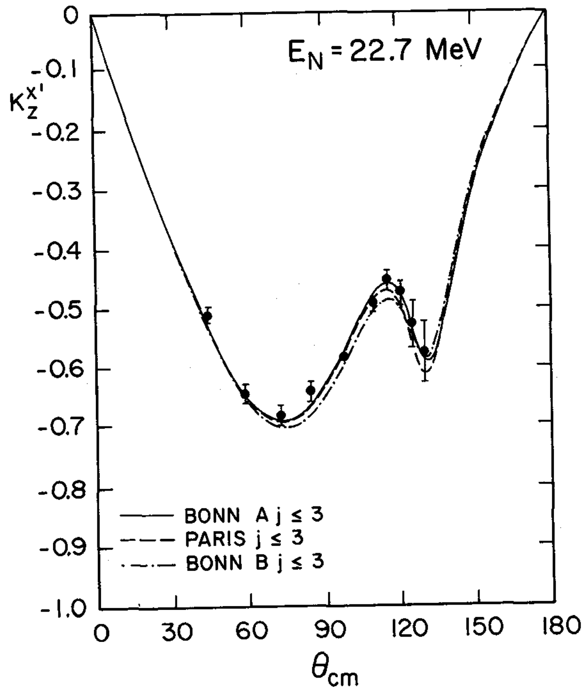

Figure 3: $K_z^{x'}$ as a function of angle.

p-d scattering and the calibration of the polarimeter) are smaller than 0.02, the data in the angular region $90^\circ \leq \theta_{cm} \leq 125^\circ$ still unambiguously favour the Bonn A potential. The calculations neglect the Coulomb force and there are no rigorous estimates about its effects. A model calculation /7/ (strong forces of rank 1 only) including the Coulomb force in the approximation that the two-body off-shell Coulomb t-matrix is replaced by the Coulomb potential, which was performed at the very low energy of $E_{p\ lab} = 2.5$ MeV, leads to small Coulomb effects in the differential cross section and analyzing powers in the interesting angular region. First order approximations to include Coulomb force effects at 10 MeV /6/ lead to only insignificant changes in $K_y^{y'}$. The fact that the calculations reproduce well the single scattering data at 22.7 MeV and also the data at 10 MeV /2/ makes it very unlikely that Coulomb effects are important and moreover would have conspired just to lower the minimum in $K_y^{y'}$ around 90° - 120°.

The preliminary results for the angular distribution of $K_z^{x'}$ are shown in Fig. 3. In comparing the theoretical curves with one another as well as with the experimental data the preferences in this case are not as clear as in the case of $K_y^{y'}$. However, also here the agreement between the result from the Bonn A potential and the experiment is excellent.

Our theoretical analysis is based on pure N-N forces. The present data clearly favour the predictions of the rigorous three body calculation using the Bonn A potential. Though three nucleon data sometimes provide a better insight into the N-N interaction than the two nucleon data, because they turn out to be more sensitive, our data considered alone cannnot yet decisively prove in favour of a weaker tensor force. Namely, whereas all on-shell N-N interactions relevant for the investigated observables are fully under control, our calculation does not include the Coulomb force and the three nucleon force. The inclusion of both of them might take quite some time, and the 3NF effects in the three nucleon system are not adequately understood, even not for the bound state problem. Comparison between our calculations using Bonn A, Bonn B and Paris potentials indicates that the off-shell effects and consequently the three nucleon force effects, i.e. the differences between Paris and Bonn B predictions, are considerably smaller than the effects due to the tensor force difference, which is the difference between Bonn A and Bonn B potentials. Therefore, taken together with information on the three nucleon bound state and on nuclear matter, our results argue in favour of the weaker tensor force. However, to settle this and other questions concerning the N-N interaction more data are needed, which could come from the proton-to deuteron polarization transfer.

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