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SPIN OBSERVABLES IN NUCLEON-NUCLEON SCATTERING NEAR 180 MeV


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Résumé - Nous avons mesuré des pouvoirs d'analyse et le coefficient de corrélation de spin C_{NN} de la diffusion élastique n-p et p-p près de l'énergie 180 MeV. En outre, nous avons fait un programme expérimental pour fixer avec précision la normalisation absolue des données. On décrit les expériences et on présente les résultats préliminaires en comparaison des calculs de déphasage et des prédictions des modèles.

Abstract - Measurements have been made of the analyzing power and spin correlation parameter C_{NN} for n-p and p-p elastic scattering near the energy of 180 MeV. In addition an experimental program to accurately determine the absolute normalization of the data has been carried out. The experiments are described and preliminary results are compared to phase shift fits and model predictions.

It is often assumed that the nucleon-nucleon interaction is well known at intermediate energies. In a qualitative sense this seems to be true. The various practitioners of phase shift analyses each find single solutions which, moreover, qualitatively agree with each other. However, when quantitative comparisons are made, it is clear that certain parameters have not been well determined and in some instances various analyses predict significantly different values for observables. Furthermore, new measurements often change the phases by much more than the claimed uncertainties. A recent example involved the realization that the $\epsilon_1$ mixing parameter for n-p scattering was poorly determined by the existing data/1/. It had been suggested that the fact that the Bonn potential predicted close to the correct $^3$H binding energy was related to the strength of the tensor force and the small values of the mixing parameter predicted by the potential./2/ The existing data could not confirm or reject the weak tensor force needed to get the $^3$H binding energy correct.

The existing data base for energies between 100 MeV and 200 MeV is in general quite old and sparse. It consists mainly of cross section and analyzing power data with some spin transfer parameters measured close to 140 MeV and 200 MeV. Given this situation, we realized that analyzing power and spin correlation parameter data, which had been obtained in conjunction with the IUCF experiment to measure charge symmetry violation in $^6$-5 scattering/3/, would be a valuable addition to the data base. The primary goal of that experiment has been to measure the difference between the analyzing power with the proton polarized and the analyzing power with the neutron polarized. The experiment was performed with the proton target and neutron beam polarized simultaneously. As a result measurements of the spin correlation with both spins normal to the scattering plane, C_{NN}, as well as the average analyzing power were obtained. These observables were measured to high statistical precision in both $\vec{n}$-p and $\vec{p}$-n scattering over center-of-mass angles of 60°-120° near 180 MeV. The $\vec{p}$-n data were taken as a null test of the charge symmetry breaking experiment. Experimental details of this work are described in ref. 3.

To provide an accurate normalization for these data we performed a series of separate measurements. An absolute polarization standard was derived from a precise determination of the $^4$He elastic scattering analyzing power near 20°. This determination makes use of the fact that in elastic scattering of a spin 1/2 particle on a spin 0 target the analyzing power and spin transfer parameters are related such that

$$A^2 + D_{LL}^2 + D_{LS}^2 \equiv 1.$$
One sees that if $|A|$ is nearly 1, the spin transfer parameters must be near 0. Because the equation is quadratic, relatively imprecise measurements of the spin transfer parameters allow a very precise absolute determination of the analyzing power. These measurements have been carried out at IUCF for both $^{12}$C and $^4$He. The results for $^{12}$C are presented elsewhere/4/. The $^4$He analysis is in progress and should provide a normalization precise to 0.1%.

In the second of the calibration experiments the above result is transferred to high precision $\vec{p}$-$p$ elastic scattering data taken over a c.m. angle range of $15^\circ$-$90^\circ$. This experiment was performed with a 180 MeV primary beam from the cyclotrons incident on a $^2$H$_2$ gas cell. Left-right symmetric arms, each with 2 slits to define the target region and NaI stopping detectors, were used to detect elastically scattered protons. The relative beam polarization was monitored continuously with transmission polarimeters based on $p$-$^{12}$C elastic scattering. The absolute cross-normalization was accomplished by setting the detectors to the calibration angles and filling the gas cell with $^4$He. Analysis of these data is in progress and the results will be used to determine the beam and target polarizations in the $\vec{p}$-$\vec{p}$ spin correlation measurements.

The normalization of the $n-\vec{p}$ data requires one more experiment. In this experiment a secondary beam consisting of both neutrons and protons was directed onto a polarized proton target. The measured $p-\vec{p}$ scattering asymmetries allow one to determine the target polarization by comparing to the normalized $\vec{p}$-$p$ analyzing power described above. The concurrently measured $n-\vec{p}$ analyzing power will then be determined with a well known target polarization, hence normalizing the analyzing power. The goal of normalizing the spin correlations and analyzing power measured in the charge symmetry experiment is thus accomplished by comparison to the data from the mixed beam experiment.

Some of our initial measurements of the analyzing power and $C_{NN}$ for $n-\vec{p}$ scattering were published several years ago/5/. These data now constrain the previously poorly determined $^3D_2$ phase. In addition, it was found that the Paris potential prediction differed considerably in shape with the data. Fig. 1 shows the full statistics for $C_{NN}$ compared to recent phase shift fits which include the published data/5/. Since the analysis of the normalization experiments has not yet been completed the analyzing power data have been fit to Arndt's SP89 prediction in order to determine the beam and target polarizations, and hence provide

![Figure 1](image.png)

**Figure 1.** The $n-p$ elastic scattering spin correlation with both spins normal to the scattering plane at 183 MeV. Statistical error bars are typically 0.0035. The four phase shift solutions all include our previously published data/5/ in their fits.
Figure 2. The n-p elastic scattering analyzing power at 183 MeV averaged over measurements with either the neutron and proton polarized. Statistical error bars are typically 0.0015. The SP89 phase shift solution and the Paris and Bonn potential curves are all generated from Arndt's program SAID/6.

Figure 3. The angle at which the n-p analyzing power crosses zero, averaged over measurements taken with either the neutron or proton polarized, plotted versus the neutron energy. The curves are generated as in Fig. 1. In addition to the statistical uncertainties indicated, there is an overall uncertainty of about ±2 MeV in the energy scale of the data.
The measurement of $C_{NN}$ for $p-p$ elastic scattering is shown in Fig. 4. At this time only about 1/3 of the accumulated data have been analyzed and presented here. Since the normalization, determined by fitting the $p-p$ analyzing powers measured at the same time to phase shift predictions, has a statistical uncertainty of ±4% the data have been fit to the SM88 curve shown. This is consistent with the normalization determined from the analyzing powers. Here we see that the phase shift solution and model predictions all agree quite well with the data within the normalization errors. Since the predictions differ by only a few percent, it will be very difficult to differentiate between them due to the final normalization uncertainties. In addition, we see that $C_{NN}$ is very close to 1 indicating that the scattering takes place almost exclusively in the triplet states at these angles.

In summary, we have made very precise measurements of spin observables near 180 MeV for both $p-p$ and $n-p$ scattering. These measurements will serve to constrain phase shift parameterizations of the data and have illuminated failings of N-N potential models to accurately predict certain observables in N-N scattering. We look forward to the inclusion of these measurements in the data base.

REFERENCES

/3/ See contributed talk by W.W. Jacobs et al. in this proceedings.
/8/ C. Leluc, private communication.