SPIN OBSERVABLES IN PROTON-NEUTRON SCATTERING
AT INTERMEDIATE ENERGIES

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ABSTRACT

A summary of np elastic scattering spin measurements at intermediate energy is given. Preliminary results from a LAMPF experiment to measure free neutron-proton elastic scattering spin-spin correlation parameters are presented. A longitudinally polarized proton target was used. These measurements are part of a program to determine the neutron-proton amplitudes in a model independent fashion at 500, 650, and 800 MeV. Some new proton-proton total cross sections in pure helicity states ($\Delta\sigma_L(pp)$) near 3 GeV/c are also given.

INTRODUCTION

Although there have been a large number of new measurements of spin parameters for pp elastic and inelastic reactions below $T_{lab} = 1100$ MeV in the last few years, the np data base remains sparse above about 500 MeV.¹ There are a significant number of np differential cross section and polarization data, especially at backward angles. These include recent results from the polarized neutron beam at Saclay.^{2,3} However, there are only a few measurements of other spin parameters. This article describes recent np elastic scattering measurements from LAMPF, as well as the outlook for a complete determination of the five complex isospin-0 ($I=0$) amplitudes in the near future. Finally some intriguing new information has become available from a final analysis of past ZGS data on $\Delta\sigma_L(pp)$ (the total cross section difference between antiparallel and parallel longitudinally polarized beam and target), which are also included.

For this paper, the notation (beam, target; forward scattered, recoil) will be used to express the elastic scattering spin observables. The spin directions are $\hat{N}$ (up and normal to the horizontal scattering plane), $\hat{L}$ (longitudinal, along the incident beam direction or the outgoing particle directions), and $\hat{S} = \hat{N} \times \hat{L}$. An "0" denotes that the spin direction is not measured.

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np ELASTIC SCATTERING MEASUREMENTS

The free np elastic scattering data base presently contains many different spin parameters and energies below about 500 MeV, with a large body of data from TRIUMF a few years ago.⁴⁻⁶ Above 500 MeV, there are numerous differential cross section and polarization results. In addition, there is a set of older measurements from DUBNA near 600 MeV (see Ref. 1), a few spin transfer parameter data in the charge exchange peak at 800 MeV,⁷ and some preliminary polarized beam - polarized target results up to 665 MeV ($C_{NN} = (N,N;0,0)$, see Ref. 8).

Several groups have attempted to extract np spin parameters from pd quasielastic scattering measurements. For example, a number of $D_{ij} = (i,0;j,0)$ parameters, as well as differential cross sections and polarizations, were obtained at $\theta_{c.m.} \lesssim 70^\circ$ and 800 MeV using the LAMPF High Resolution Spectrometer (HRS - Refs. 9, 10). The pp spin parameter data extracted from these experiments agree reasonably well with free pp measurements from other experiments. This strongly suggests that the np spin parameters extracted similarly agree with free np results. Recently, these measurements were extended to larger $\theta_{c.m.}$ values in another beamline by the same group¹¹, but preliminary results are not yet available. Data are also being analyzed for D_{NN} from free np scattering at 800 MeV and large $\theta_{c.m.}$ values.¹²

In addition to the pd experiments above, the $\bar{p} + d \rightarrow \bar{n} + p + p$ reaction with the outgoing neutron along the incident proton direction is used to generate the LAMPF polarized neutron beam. The spin transfer parameters $K_{LL} = (L,0;0,L)$ and $K_{NN} = (N,0;0,N)$ have been measured at three beam energies.^{13,14}

Finally, total cross section differences for pd interactions

$$\Delta\sigma_L(pd) = \sigma^{\text{Tot}}(\uparrow) - \sigma^{\text{Tot}}(\downarrow)$$

were measured some time ago at the Argonne ZGS.¹⁵ Using Glauber theory relations,^{16,17} Fermi motion and deuteron D-state corrections, and results from dispersion relations,^{18,19} the values of $\Delta\sigma_L(np)$ were extracted; the results were reasonably featureless. Then the (Fermi-smeared) $\Delta\sigma_L(pp)$ data were subtracted to yield $\Delta\sigma_L(I=0)$. These derived results showed considerable structure because of the $\Delta\sigma_L(pp)$ subtraction. Free np measurements are being planned for SIN, Saclay and LAMPF to check the true value of $\Delta\sigma_L(I=0)$. The observed structure, if confirmed, might suggest the presence of dibaryon resonances.^{19,20}

A three year program at LAMPF to measure free np spin-spin correlation parameters for $\theta_{c.m.} \sim 50^\circ$ to 160° and $T_{lab} = 500, 650$ and 800 MeV recently completed data taking. The spins of both the polarized neutron beam and the polarized proton target were in the horizontal scattering plane. The spin parameters measured were $C_{SS} = (S,S;0,0)$,

$C_{LS} = C_{SL} = (L,S;0,0)$ and $C_{LL} = (L,L;0,0)$. Interference with the polarized target magnet coils prevented detection of both outgoing particles in coincidence. Consequently, only the recoil proton was measured in a magnetic spectrometer.

Preliminary results over part of the angular range are shown in Fig. 1. Fairly good agreement with phase shift predictions can be seen at 500 MeV, where a variety of different spin parameters were previously measured at TRIUMF and elsewhere, and also at 650 MeV. Refinements to the values shown in Fig. 1 are expected soon for improved magnetic field integrals, background subtraction and cuts on the target projections and the particle mass.

Fig. 1 Preliminary results for C_{LL} and C_{SL} for free np elastic scattering at 500 and 650 MeV. The curves are phase shift predictions. The quoted errors are presently dominated by uncertainties in the background subtraction.

Basically the same apparatus used for measurements of C_{SS} , C_{SL} and C_{LL} was also employed in a short experiment to determine the polarization of free np scattering at 800 MeV and small $\theta_{c.m.}$. These data were collected late in 1985 and they are presently in the process of being analyzed.¹²

In the past few years, model independent amplitude analyses²¹ for pp elastic scattering have been achieved for data from SIN,²² LAMPF,²³ and the ZGS²⁴. Results from a single experimental group dominated the data base in each of these cases. Based on experience with the pp system at LAMPF, phase shift predictions generally did

not fit data for new spin observables very well until a model independent amplitude analysis could be performed. In the np case, this is likely to be true as well.

Using this experience as a guide, the number of additional np measurements needed to obtain unique phase shifts can be obtained. It has been shown²⁵ that measurements with polarized beam and/or polarized target ($d\sigma/d\Omega$, P , C_{NN} , C_{SS} , C_{SL} , C_{LL}) at $\theta_{c.m.}$ and $\pi - \theta_{c.m.}$, and knowledge of the pp amplitudes at $\theta_{c.m.}$, allows the model independent determination of the $I=0$ amplitudes up to discrete ambiguities. The absolute phase at each angle is anchored to the phase of the pp amplitudes. Therefore, the free np elastic data on C_{LL} , C_{SL} and C_{SS} from this experiment and existing data on the other three parameters, will allow an $I=0$ amplitude determination at 500 and 650 MeV at about 10 angles between $\theta_{c.m.} = 50^\circ$ and 90° . (The 800 MeV C_{NN} results will be measured this summer, permitting the reconstruction of the amplitudes at 800 MeV as well.) At each energy, there will be four discrete solutions as a function of angle. The existence of other spin parameter results, described above, may allow a unique solution at each energy.

Nevertheless, it is expected that additional measurements at 650 and especially 800 MeV may be required to clearly establish the $I=0$ amplitudes. Experimental difficulties with producing monoenergetic neutron beams and with the detection of neutrons probably leads to considerably larger systematic errors for np than for pp scattering. Differences in data sets from various experiments on polarization, total and backward differential cross sections outside quoted errors are probably caused by these experimental difficulties. Thus, it will be important to overdetermine the amplitudes, providing consistency checks on the data. For example, it is considered important to measure $K_{ij} = (i, 0; 0, j)$ for free np scattering at LAMPF for this purpose. The new high intensity polarized ion source planned for LAMPF should make such experiments feasible over the full angular range.

Additional experiments on free np scattering at SIN²⁶, Saclay²⁷, and TRIUMF²⁸ are expected to begin later this year. These include $\Delta\sigma_L(np)$, as well as $C_{ij}(np)$, etc. The neutron beam energies will be $T_{lab} = 400$ to 1150 MeV at Saclay and below 600 MeV at SIN and TRIUMF.

NEW $\Delta\sigma_L(pp)$ RESULTS

Final results for $\Delta\sigma_L(pp)$ from the ZGS at several new energies have revealed intriguing energy behavior. The experiment was similar to that reported previously.²⁹⁻³¹ The results are shown in Fig. 2 along with some of the earlier data. The errors plotted are purely statistical; systematic uncertainties are estimated to be 6% of $\Delta\sigma_L$. Coulomb-nuclear interference corrections are not included. It should

be noted that the Saclay measurement³² near 3.25 GeV/c is consistent with the new data.

Fig. 2

The $\Delta\sigma_L(pp)$ dependence on P_{lab} from 2.5 to 3.5 GeV/c from the new measurements reported and from Ref. 31. The errors shown are statistical only. The curve is to guide the eye.

Although the statistics are not compelling, a new peak structure is indicated near 2.75 GeV/c. If it is due to a resonance, the mass is around 2700 MeV with a width less than 80 MeV. Earlier indications of structure near this mass include pp spin-spin correlation parameter data at $\theta_{c.m.} = 90^\circ$ ($k^2 C_{LL} d\sigma/d\Omega$ ³³ and $k^2 C_{NN} d\sigma/d\Omega$ ³⁴, where k is the c.m. momentum) and polarization for the $pp \rightarrow d\pi$ reaction from Saclay.³⁵ Cloudy Bag model predictions^{36,37} include a narrow s-wave state near 2700 MeV, which may be consistent with the new structure. It is highly desirable to measure additional $\Delta\sigma_L(pp)$ data in finer steps near 2.75 GeV/c to clarify the energy dependence in this energy region.

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