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Measurement of the polarization transfer parameter D_{NN} for $^{12,13}\mathrm{C}(\vec{p},\vec{p})$ at 500 MeV

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We report precision measurements of the polarization transfer parameter D_{NN} for 500 MeV polarized proton elastic scattering from ^{12,13}C at the first diffractive minima in the differential cross sections. The ratio $D_{NN}(^{13}\mathrm{C})/D_{NN}(^{12}\mathrm{C})$ (1.000 ± 0.028) is consistent with zero spin-flip probability (S) for ^{13}C, where $S \equiv \frac{1}{2}(1-D_{NN})$. Comparisons are made with results of theoretical calculations reported in the literature.

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Intermediate energy proton-nucleus scattering experiments provide data which allow the study of effective nucleon-nucleon (*NN*) interactions, investigation of nuclear structure, reaction mechanism studies, and testing of relativistic and nonrelativistic scattering theories [1]. Much work has been done for proton elastic and inelastic scattering from even-even target nuclei for isoscalar, non-spin-flip transitions [1,2].

Less work has been reported for proton-nucleus scattering and reactions involving spin and/or isospin transfer. These reactions are sensitive to the spin-transfer and isovector components of the *NN* effective interaction and single particle aspects of nuclear structure. Theoretical analyses of such reaction data provide independent tests of relativistic and nonrelativistic reaction models.

An interesting observable is the polarization transfer parameter D_{NN}, which is related to the spin-flip probability S through $S\equiv\frac{1}{2}(1-D_{NN})$. For proton elastic scattering from even-even ($J^{\pi}=0^{+}$) targets D_{NN} is unity, corresponding to $S=0$. However, for non-spin-zero targets, such as ^{13}C ($J^{\pi}=\frac{1}{2}^{-}$), transition amplitudes corresponding to total angular momentum transfer (ΔJ) 0 and 1 are both allowed. The presence of a nonzero $\Delta J=1$ amplitude can lead to $D_{NN}\neq 1$.

Here we report new measurements of the polarization transfer parameter D_{NN} for 500 MeV $^{12,13}\mathrm{C}(\vec{p},\vec{p})$ elastic scattering for scattering angles near the first diffractive minima (16° lab) in the differential cross sections [3], where various theoretical models [3,4] predict the spin-flip probability to be maximum for ^{13}C.

The measurements were made at the Los Alamos Clinton P. Anderson Meson Physics Facility (LAMPF) using the high-resolution spectrometer (HRS) and its focal plane polarimeter (FPP). Experimental details are described in Refs. [3] and [5]. In order to eliminate systematic errors, data were taken simultaneously for both ^{12}C and ^{13}C using individual 50 mg/cm^2 ^{12}C and ^{13}C targets sandwiched together. Significant systematic errors, if any, become readily apparent since D_{NN} must be unity for elastic scattering from ^{12}C.

The target foils were isotopically enriched ($\geqslant$99.9% for ^{12}C and $\geqslant$98% for ^{13}C). Beam energy was 497.5 ± 1 MeV. The beam polarization was typically 80% and was monitored continuously with a beam line polarimeter. An overall HRS resolution of about 120–180 keV (full width at half maximum) provided good separation of the ^{12}C and ^{13}C elastic peaks which were free of underlying background. Figure 1 shows the ^{13}C raw angular distribution data (2.0° angular acceptance) taken with the HRS positioned at 16° central laboratory scattering angle.

Table I gives the D_{NN} values for ^{12}C and ^{13}C with 10 mrad and 40 mrad angle binning. The errors given are statistical only. Systematic errors are believed to be $\pm$0.02–0.04 based on previous experiments [3,5] that used the HRS-FPP system. However, the ratio $D_{NN}(^{13}\mathrm{C})/D_{NN}(^{12}\mathrm{C})=1.000\pm0.028$ eliminates systematic errors anyway, and because $D_{NN}=1$ for ^{12}C, this ratio represents our final result for $D_{NN}(^{13}\mathrm{C})$.

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TABLE I. Measured values of D_{NN} for $^{13}\mathrm{C}(\vec{p},\vec{p})$ and $^{12}\mathrm{C}(\vec{p},\vec{p})$ at 497.5 MeV.

Nucleus	Binning (mrad)	$\theta_{\mathrm{c.m.}}$ (deg)	D_{NN}	ΔD_{NN}
^{13}C	10	17.02	1.045	0.032
^{13}C	10	17.65	0.985	0.054
^{13}C	10	18.29	1.023	0.055
^{13}C	10	18.92	0.969	0.056
^{13}C	40	17.97	1.018	0.021
^{12}C	10	17.16	1.039	0.025
^{12}C	10	17.80	1.045	0.043
^{12}C	10	18.44	0.979	0.059
^{12}C	10	19.08	0.909	0.053
^{12}C	40	18.12	1.018	0.019

The data indicate that D_{NN} is consistent with unity (zero spin-flip probability) for both target nuclei. The new D_{NN} are consistent with the previous data [3] in the overlapping angular range, but the statistical errors of the new data are much smaller.

A variety of theoretical calculations for D_{NN} for this case are described in the literature (see Refs. [6–8]). These calculations use several reaction models, *NN* effective interactions, and nuclear structure models. The reaction models include nonrelativistic and relativistic distorted-wave Born approximation (NR-DWBA, Rel-DWBA) [4] and relativistic coupled channels (Rel-CC) [2,9]. The *NN* effective interaction models include nonrelativistic impulse approximation (NRIA), nonrelativistic density dependent (NRDD) [10], local relativistic impulse approximation (RIA) [4], and covariant meson exchange relativistic impulse approximation (IA2) [11]. The ^{13}C nuclear structure models include nonrelativistic $1p_{1/2}$ independent particle [7], relativistic (four-component) $1p_{1/2}$ independent particle [4], and nonrelativistic shell model [6,12].

Predicted values for $D_{NN}(^{13}\mathrm{C})$ (cross section weighted averages over the full 2° angular acceptance of the HRS) are given in Table II. The last column compares experimental and theoretical values of the ratio $D_{NN}(^{13}\mathrm{C})/D_{NN}(^{12}\mathrm{C})$.

The nonrelativistic DWBA results [6] that used the Cohen-Kurath shell-model wave functions [12] are in better agreement with the data ($\sim\sigma$) than are the NR results which use the $1p_{1/2}$ independent particle model. Density dependent corrections to the $\Delta J>0$ components of the nonrelativistic *NN* effective interaction have negligible effect on D_{NN}.

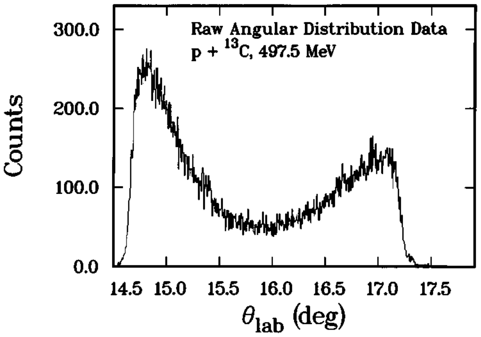

FIG. 1. Raw angular distribution data for 497.5 MeV $p+^{13}\mathrm{C}$ elastic scattering for HRS central angle of 16°.

The standard RIA-DWBA model [7] with the pseudoscalar (PS) amplitude predicts too much spin-flip probability; better ($\sim\sigma$) agreement is seen when pseudovector (PV) coupling is used. The calculations also show sensitivity to the relativistic enhancement of the lower component (Rel-λ) of the valence neutron wave function. The Dirac coupled channels solution for the standard RIA potential with the PS form gives a slightly smaller value for D_{NN} than does the corresponding RIA-DWBA PS model with relativistic $1p_{1/2}$ lower component. The D_{NN} values from the calculations which use the two-component, density-dependent effective interaction equivalent of the relativistic IA2 amplitudes (from Ref. [8]) agree best with experiment ($<\sigma$).

In the language of the Lorentz invariant form of the *NN* interaction, the spin-flip probability for this case is determined primarily by the PS invariant amplitude and to a lesser extent by the spacelike tensor component [4]. The D_{NN} prediction is particularly sensitive to the choice of PS or PV forms. Much of the success of the IA2 model for this case can be traced to its use of PV π-N coupling [11]. In contrast, for elastic scattering from polarized targets, the PS component is not important for the $\hat{n}$-type polarized ^{13}C observables [4,7]. Study of the PS component of the *NN* effective

TABLE II. Theoretical values of average D_{NN} for 500 MeV $^{13}\mathrm{C}(\vec{p},\vec{p})$ near 18° c.m. The last column compares experimental and theoretical values of the ratio $D_{NN}(^{13}\mathrm{C})/D_{NN}(^{12}\mathrm{C})$.

Reaction model type	*NN* effective interaction	Nuclear structure	Average D_{NN} over 2° HRS acceptance	Number standard deviations (σ) from experiment
NR-DWBA [6]	NRIA	Indep. particle	0.923	2.7
NR-DWBA [6]	NRDD	Indep. particle	0.925	2.7
NR-DWBA [6]	NRIA	CK shell model	0.977	0.8
NR-DWBA [6]	NRDD	CK shell model	0.977	0.8
Rel-DWBA [7]	RIA, PS	Indep. particle, Rel. λ	0.902	3.5
Rel-DWBA [7]	RIA, PS	Indep. particle, NR λ	0.967	1.2
Rel-DWBA [7]	RIA, PV	Indep. particle, Rel. λ	0.971	1.0
Rel-CC [2]	RIA, PS	Indep. particle, Rel. λ	0.883	4.2
Rel-DWBA [8]	IA2	Indep. particle, Rel. λ	0.982	0.6
Rel-DWBA [8]	IA2	CK shell model, Rel. λ	0.995	0.2

interaction using elastic scattering from polarized targets requires a difficult experiment involving an $\hat{s}$-type polarized target [4].

In conclusion we find that the measured value of D_{NN} for ^{13}C is statistically consistent with 1. We also find that the predictions of nonrelativistic models with shell model wave functions and relativistic models with PV coupling (RIA-PV, or IA2) best agree with experiment.

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