measurement. In order to assign a standard error to each momentum measurement an estimate of the measurement error was made for each event.

The resolution function $R_2(p,p')$ represents the probability per unit momentum interval of observing electrons with momentum p' if the actual momentum of all electrons is p. If $Q(\sigma)$ represents the probability distribution function of standard momentum errors for all events with momenta roughly equal to p, then an estimate of $R(p,p')$ is:

$$R_2(p,p')=\frac{1}{2\pi}\int_0^\infty Q(\sigma)\exp[-(p-p')^2/2\sigma^2]d\sigma.$$

$R_2(p,p')$ was found for $p=20$ and 50 Mev/c by using events with momenta between 15 and 25, 45 and 55 Mev/c respectively to find $Q(\sigma)$. The resolution functions for $p=20$ and 50 Mev/c are shown on Fig. 2 for all events and on Fig. 3 for the more restricted data.

For the two values of p, the shapes of $R(p,p')$ are very closely identical and the half-widths are nearly proportional to p. The uncertainty in the value of the resolution width is quite large (perhaps of the order of 35 percent) because of the arbitrary nature of the assignment of standard measurement errors to the individual events.

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Asymmetry in High-Energy p-n-p Double Charge-Exchange Scattering*

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Asymmetries have been observed in double charge-exchange p-n-p scattering from carbon and tantalum. High-energy protons striking a first target gave charge-exchange neutrons. These neutrons were collimated and allowed to strike a second target. The final proton fluxes to the right and left were then counted. The asymmetries are zero at small scattering angles, and increase with angle up to 45° in the laboratory system. The maximum asymmetry observed was 10.4±2.1% for carbon with the first and second scattering angles equal to 45° (lab). Evidence is given for a large n-p charge-exchange polarization from carbon bombarded with 170-Mev neutrons.

INTRODUCTION

POTENTIAL models using tensor forces or spin-orbit coupling have been found[1,2] to give better fit to the experimental n-p angular distribution[3] than those using only central forces. Wolfenstein[4] predicted that the presence of these noncentral forces should give rise to an asymmetry in a double-scattering experiment. The azimuthal asymmetry of a double charge-exchange (p-n-p) scattering has been investigated by Wouters[5] and others,[6–8] with results of the order of a few percent. These asymmetries are much smaller than those obtained by double-proton scattering.[9]

In the experiment presented here, small but experimentally significant asymmetries have been observed in (p-n-p) scattering from carbon and tantalum targets.

This experiment is an extension of Wouters's experiment, with some modification, to elements of higher atomic number. A target was bombarded by the circulating proton beam of the 184-inch cyclotron and the ejected neutrons were collimated and allowed to strike a second target. The right and left fluxes of protons from the second target were then counted.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

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APPARATUS

Experimental Arrangement

Figure 1 shows the experimental arrangement for the p-n-p scattering. The first scattering occurred inside the cyclotron vacuum tank. It was possible to place the first target at each of the following positions: (a) inside the dee in such a position that the observed neutrons came off at an angle of 45° to the right of the circulating proton beam, (b) on the "main probe" in such a position that the observed neutrons came off at 0° to the proton beam (this position provided an unpolarized neutron beam), and (c) on an adjustable probe in such a position that the observed neutrons came off at any desired angle between 0° and 45° to the left of the beam.

Table I. Asymmetries measured for carbon and tantalum targets for various angles and rejection energies. The errors are probable errors and include only counting statistics.

First and second target material	First scattering angle	Counter angle ±6°	Bombarding energy (Mev)	Energy of rejection (Mev)	$e=\frac{L-R}{L+R}$ (percent)
C	17°	25°	190	45	0.4±0.4
C	17	25	190	75	1.9±0.8
C	17	25	190	110	0.5±1.9
C	30	45	225	85	8.7±2.2
C	35	35	245	90	5.2±2.0
C	45	45	340	45	4.3±1.2
C	45	45	340	85	10.4±2.1
C	45	45	340	110	10.5±2.5
Ta	17	25	190	45	1.0±0.5
Ta	17	25	190	85	−1.0±0.3
Ta[a]	45	45	340	45	2.2±2.5
Ta[a]	45	45	340	85	6.0±2.2
Ta[a]	45°	45°	340	110	4.5±2.5

[a] These values are an average of a 45° left and 45° right first scatter.

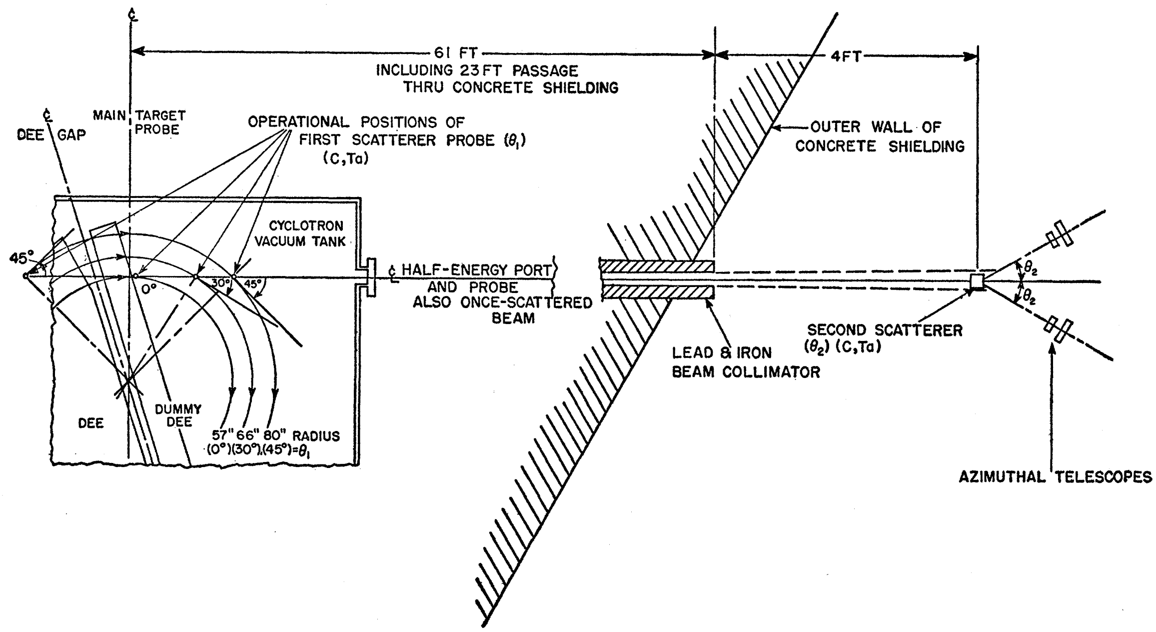

FIG. 1. Schematic layout of *p-n-p* polarization experiment (scale not uniform).

The maximum proton beam energy was 340 Mev. In the approximation of nonrelativistic nucleon-nucleon collisions between protons of the beam and target nucleons at rest, one sees from the geometry that the energy of the neutrons is a constant, independent of the scattering angle. There is, of course, a variation in energy of the ejected neutrons because of the internal momentum distribution inside the target nucleus. As the momentum of the bombarding protons changes with a change of scattering angle, this variation in energy is a function of the scattering angle.

The second target was placed in the collimated neutron beam. The fluxes of protons to the right and left of the axis of the neutron beam were measured simultaneously by means of two counter telescopes.

Targets, Counters, and Electronics

Targets of carbon and tantalum were used. The first and second tantalum targets were both of 10 g/cm^2 thickness. The first and second carbon targets were 4.1 g/cm^2 and 1.5 g/cm^2, respectively. The solid angle subtended by the second target from the first target was 2×10^{-6} steradian.

The right and left counter telescopes were made as nearly identical as possible. The counters were all liquid scintillators with dimensions of 2 by 2 by $\frac{5}{8}$ inches for the front and 3.5 by 3 by 0.75 inches for the rear counters. The solid angle subtended by the counter telescopes from the second target was 0.04 steradian. The counter photomultipliers were adequately shielded from stray fields by means of soft iron and μ metal.

Crystal diode double-coincidence circuits with diode clamps were used for both telescopes. Each circuit had a resolution time of 10^{-8} sec.

The plateaus of the coincidence counting rates with respect to the photomultiplier high voltages were located by raising the voltages until the coincidence counting rate for a pair of counters remained constant when the voltage of either counter was lowered by 100 volts. In addition, all counters were supplied by the same high-voltage source to help avoid false asymmetry due to high-voltage drifts.

PROCEDURE

With the first target in the 0° position, the second target and the collimators were aligned by means of a telescope situated about 75 feet from the first target. This defined the axis of the scattered neutron beam. The counter telescopes were then placed in the plane of the first scattering at approximately equal angles to the right and left of the axis of the neutron beam.

With the unpolarized (0°) neutron beam in use, the counting rates in the right and left telescopes, with background subtracted, were equalized by small adjustments in the detector angles. The backgrounds, which were of the order of 10%, were determined by counting with the second target removed. The above adjustments were always within the limits of the estimated error of about 0.3° in the original positioning. This procedure had the effect of eliminating false asymmetries due to small differences in solid angle and counter efficiencies between the right and left telescopes. The counters were then left fixed throughout the run, and all angle changes were made by moving the first scatterer (situated inside the cyclotron).

Counting rates were then obtained for both a 45° left and a 45° right first scatter. Asymmetries of the same magnitude but opposite sign, obtained for right and left first scatterings, provided a check on the alignment. With the second-scattering angles held constant, asymmetries were then measured for various first-scattering angles.

Some runs were made with copper absorbers placed between the first and second counters of each telescope. This absorber determined the minimum proton energy accepted. In this manner asymmetries were measured as a function of a "rejection energy."

RESULTS

The observed asymmetry e in a double scattering experiment can be defined by the equation $e=(L-R)/(L+R)$, where L and R are the counting rates observed at equal scattering angles to the left and right of the first scattered beam.

Table I shows the asymmetries observed from tantalum and carbon targets at various angles and rejection energies. The errors quoted are probable errors and include only counting statistics. To determine one source of error due to misalignment, the internal targets were displaced perpendicular to the beam by an amount equal to the estimated error of positioning, about $\frac{1}{16}$ in. This displacement gave a change of asymmetry of less than 1%.

CONCLUSIONS

The azimuthal asymmetries for a double charge-exchange scattering from carbon and tantalum are small and in general agreement with previous investigations.[5,6–8]

As might be expected from the Fermi gas model, no significant difference was found between carbon and tantalum. The asymmetries show an increase with angle up to 45° (lab).

The relatively high asymmetry at 45° (lab) is not consistent with the Serber potential (50% exchange). This potential gives no odd angular momentum states, and predicts an asymmetric distribution about 45°.[10]

The subsequent measurement of the p-n quasi-elastic polarization using a proton beam of known polarization[11,12] allows an estimate to be made of the n-p charge exchange polarization for carbon bombarded by 170-Mev neutrons. The p-n quasi-elastic polarization for 315-Mev incident protons is, from Chamberlain *et al.*,[13] $P_1=-16\%\pm2\%$. Ignoring the energy difference, we can apply this polarization to the p-n-p asymmetry for a 45°–45° (lab) scattering through the relation $e=P_1P_2$, where P_1 is the polarization in the first scattering and $P_2=P_2(E,\theta)$ is the polarization in the second scattering. A polarization is obtained for 170-Mev neutrons scattered at 45° equal to $P_2(170, 45)=-64\%\pm15\%$. The same procedure can be applied to the 30°–45° and the 35°–35° p-n-p asymmetries. Using the p-n polarization at 285 Mev given in the following paper, and again ignoring the energy difference between the p-n and p-n-p initial energies, we obtain the polarizations $P_2(170, 45)=-43\%\pm9\%$ and $P_2(170, 35)=-29\%\pm12\%$. The errors quoted are all probable errors and the angular resolution for the second scattering was 12°. The energy extrapolation used in these calculations is quite doubtful; there is some evidence, however, for a large n-p charge-exchange polarization at a neutron energy of 170 Mev and angles near 45° (lab).

It should be noted that because of the internal momentum distribution of the nucleons in the target, the angles at which the asymmetries are measured actually correspond to averages over a distribution of nucleon-nucleon collision angles.

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Asymmetry in p-n and p-p Scattering from Targets Bombarded with 285-Mev Polarized Protons*

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Asymmetries in neutron and proton production have been observed in the quasi-elastic scattering of 285-Mev, 65±4% polarized protons by carbon, lithium, and beryllium targets. The neutrons and protons were counted in coincidence with the associated scattered protons. The quasi-elastic neutron data are not antisymmetric about 90° cm. The proton asymmetries are much smaller than the asymmetries from a free hydrogen target.

INTRODUCTION

IN the preceding paper, results on double charge-exchange asymmetry were presented. This paper gives the results of a different approach to the n-p polarization problem and also the p-p polarization problem.

With certain restrictions,[1] the left-right asymmetry of the counting rate of neutrons in a p-n collision can be

* This work was done under the auspices of the U. S. Atomic Energy Commission.

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