SEARCH FOR A T_{20} ANALYZER FOR DEUTERONS

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In this experiment we surveyed the cross section and T_{20} analyzing power for several deuteron-induced reactions, looking for a case where the cross section and analyzing power are large and could be used to construct a polarimeter for intermediate-energy tensor-polarized deuterons. Such a polarimeter would find immediate use in double scattering experiments, measuring the recoil deuteron polarization from pion or electron elastic scattering. Such double scattering experiments are the only method available for examining tensor observables in these systems, since a tensor polarized deuterium target is not presently feasible.

A high-efficiency polarimeter for lower energy deuterons already exists.[1] Its analyzer is the $^3He(d,p)^4He$ reaction, which has a negative maximum in T_{20} near 6 MeV. This polarimeter consists of front scintillation counters to monitor the deuteron flux, a high pressure ^3He cell, and rear scintillation counters to identify protons emitted near 0°. Because of the energy loss in the front counters, its operating range is from 20 to 27 MeV. The operating efficiency, or ratio ε_0 of detected protons to incident deuterons, is 1.2×10^{-4} with a tensor analyzing power of about $T_{20} = -0.75$.

This polarimeter, and another like it, have been used in elastic pion-deuteron scattering experiments at LAMPF[2,3] and SIN[4,5]. These data have been used to study true pion absorption. Elastic electron scattering experiments are just beginning at MIT, and will provide the first separation of the charge and quadrupole form factors of the deuteron. In order to continue the electron scattering studies to higher momentum transfer, a polarimeter of greater efficiency is needed for deuterons in the range near 100 MeV.

To complement other experiments at IUCF, this survey examined five targets with 80-MeV polarized deuterons. The measured cross sections and T_{20} tensor analyzing powers were used to estimate the figure of merit of a polarimeter based on each observed reaction. The figure of merit, $Q = \sqrt{\varepsilon_0}\,|T_{20}|$, is inversely proportional to the statistical errors generated in an experiment using such a polarimeter. The present low energy design[5] has $Q = 8.6\times10^{-3}$.

To make a useful polarimeter, it is also important that the reaction products must be easily observable in a simple geometry, as well as possess a high figure of merit.

At 80-MeV, angular distributions of T_{20} exist only for elastic scattering[6] from ^{58}Ni. This angular distribution has T_{20} values near zero at forward angles, and values decreasing slowly to −0.2 at angles larger than 70°. At large angles the scattering cross section is small, and a polarimeter based on such scattering can provide only $Q = 2\times10^{-3}$. The values of T_{20} for elastic scattering from medium to heavy weight targets originates from the spin-orbit interaction, and so we expect the same analyzing power to apply to all reaction channels. Thus significantly different results can only be expected from the very lightest targets. Because there are fewer open reaction channels on light targets, each discrete final state has a larger cross section, and there may be reactions [such as $^6Li(d,\alpha)\alpha$] that, for structure reasons, have large values of T_{20}. Thus we chose to investigate ^3He, $^{6,7}Li$, ^9Be, and ^{12}C.

At lower energies, a large negative excursion in T_{20} has been reported for deuteron-proton scattering near $\theta = 120°$. This excursion gets larger as the bombarding energy increases. A rough calculation shows that a polarimeter based on this case would have $Q = 9\times10^{-3}$. Time did not permit us to extend these measurements to higher energy.

Measurements of T_{20} with the IUCF polarized deuteron beam require the measurement of the tensor analyzing power in both the horizontal (to get A_{yy}) and vertical (to get A_{xx}) planes. This was carried out with the new rotating scattering table mounted in the γ-cave. The solid carbon and beryllium targets were mounted in air, the lithium targets were mounted in an evacuated gas cell, and the helium gas was contained in the same gas cell. The detector telescopes consisted of 1 mm Si detectors backed by 15 mm Ge detectors. There was no active collimation, so we expected that the higher excitation regions of the spectra would contain ghost features. This scheme was considered satisfactory since any useful reaction must come from a strong, energetic group. A polarimeter based on reactions into the continuum was considered an unlikely prospect. The measurements were made with 78.9 MeV polarized deuterons, and concentrated at forward scattering angles. The measurements of A_{yy} and A_{xx} were combined to form T_{20} according to

$$T_{20} = -(A_{yy} + A_{xx})/\sqrt{2} \quad .$$

The cross section was measured in both orientations.

In general, the reaction cross section was dominated by deuteron elastic scattering and protons from deuteron breakup. Sample spectra are shown in Fig. 1. The T_{20} analyzing power for deuteron breakup was close to zero for all angles and targets. For deuteron elastic scattering and inelastic scattering to the first few discrete states, T_{20} was near zero at forward angles and fell to −0.4 at 60°. Because of the appearance of negative analyzing powers at angles more forward than previously observed for ^{58}Ni, a

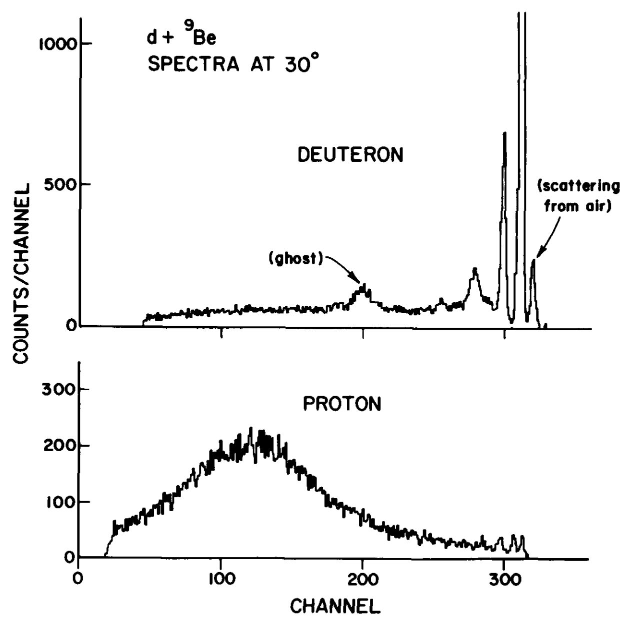

Figure 1. Sample spectra from deuteron-induced reactions on ^9Be, observed as inclusive spectra for deuterons and protons at 30°. A contaminant from air and a ghost of the elastic peak are visible in the deuteron spectrum.

polarimeter based on this effect would achieve $Q = 6\times10^{-3}$ using a ^{12}C target.

There were few reactions with large enough cross section and T_{20} analyzing power to be considered for a polarimeter. The T_{20} angular distribution for the $^3He(d,p)^4He$ reaction oscillates about zero at 80 MeV, and a simple polarimeter detection geometry did not seem possible. The $^6Li(d,\alpha)\alpha$ reaction carried the largest analyzing power, namely $T_{20} = -0.92$ at 10°. But a small cross section (< 100 μb/sr) limits this analyzer to $Q = 3\times10^{-3}$.

The tensor analyzing powers we measured all obeyed the empirical relation

$$|T_{20}| < 0.3/\sqrt{\sigma}$$

Assuming that most polarimeters would usefully span a solid angle of 1 sr and would have targets thick enough to stop 100 MeV deuterons (about 5 g/cm^2), then the figure of merit has a upper limit given by

$$Q < 0.016/\sqrt{A}$$

where A is the target mass. This relation is sketched in Fig. 2, along with the figures of merit for the polarimeters we considered possible.

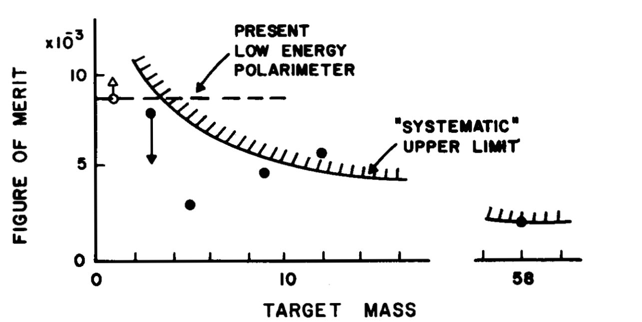

Figure 2. The systematic upper limit on the figure of merit (defined in the text) for any T_{20} polarimeter. The figure of merit for any polarimeters based on reactions observed in this experiment are indicated as dots or arrows. The design for a hydrogen target is based on the data of Ref. 7.

Unlike the experience with vector polarization, the potentials leading to significant tensor analyzing powers are not ℓ-dependent, and do not give larger effects with increasing bombarding energy. In fact, the origin of a significant fraction of the tensor analyzing powers near 100 MeV becomes the second-order spin-orbit potential. Thus we can find no case in the periodic table where there is a reaction that would yield a polarimeter with a significantly higher value of Q than the one presently in use. The best prospect for a target, especially at even higher bombarding energies, appears to be hydrogen.

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