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$Li^7(p, \alpha)He^4$ *REACTION INDUCED BY POLARIZED 0.5–2 MeV PROTONS*

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The sensitivity of the $Li^7(p, \alpha)He^4$ reaction to proton polarization is measured in the 0.5–2 MeV range. Polarized protons were obtained from $C^{12}(p,p)C^{12}$ elastic scattering. At low energies and at an angle of 45° the sensitivity of the $Li^7(p, \alpha)He^4$ reaction does not exceed 10%, but increases smoothly with proton energy and reaches 60% at 2 MeV.

1. INTRODUCTION

WOLFENSTEIN[1] has shown that the reaction $Li^7(p, \alpha)He^4$ should be sensitive to proton polarization. The cross section for this reaction in the case of protons that are completely polarized perpendicular to the direction of their motion is

$$\sigma(\theta, \varphi) = \sigma_0(\theta) + \sigma_p(\theta)\cos\varphi.$$

The ratio

$$r = \sigma_p(\theta)/\sigma_0(\theta)$$

characterizes the sensitivity of the reaction to polarization of the proton beam.

After analyzing the experimental angular distributions from $Li^7(p, \alpha)He^4$, Wolfenstein calculated r, assuming a contribution only from p waves and using two different hypotheses regarding the effective levels of the compound nucleus Be^8:

1) Contributions to the reaction come from two levels having spin and parity 0^+ and 2^+, respectively.

2) Contributions to the reaction come from two levels both having spin and parity 2^+.

The experimental angular distributions are equally consistent with both hypotheses.[2,3] In both instances the sign and magnitude of r depend on the phase shifts γ between the wave functions for different spin channels. The angular distribution is independent of γ. The measured sign and magnitude of r enable us to decide between the two considered sets of compound-nucleus spin states and to determine the phase shift γ.

The magnitude of r was measured in [4,5] for 1–3 MeV protons. Using a beam of polarized protons obtained from $C^{12}(p,p)C^{12}$ elastic scattering, Bearpark et al. derived $r \approx 43\%$, whereas Weddingen, obtaining polarized protons from the $C^{12}(d,p)$ reaction, arrived at $r \approx 0$ in the entire energy range.

In the present work we have again measured r for the reaction $Li^7(p, \alpha)He^4$ using 0.5–2 MeV polarized protons obtained from $C^{12}(p,p)C^{12}$ elastic scattering at 60°.

2. APPARATUS

Figure 1 shows the experimental arrangement for measuring the sensitivity of $Li^7(p, \alpha)He^4$ to proton polarization. The proton beam, accelerated by the ÉG-2.5 electrostatic accelerator of the Egyptian Atomic Commission, passed through diaphragms 3 and 4 of 5-mm diameter before impinging on the carbon target 1. Protons scattered at $\theta_1 = 60°$ struck target 2 containing Li^7 nuclei. Alpha particles from $Li^7(p, \alpha)He^4$ were registered at $\theta_2 = 45°$ with the two detectors 7 and 8. The number of protons traversing target 1 was measured with a Faraday cylinder and current integrator. The detectors were semiconductor counters 100 mm² in area and thin (0.2 mm) CsI(Tl) crystals with FÉU-35 photomultipliers (having 25-mm photocathode diameter). The target separation was 195 mm; the target diameters were 2 and 25 mm. Collimator 5 defined a beam of protons scattered at angles $\theta_1 \pm 4$. The solid

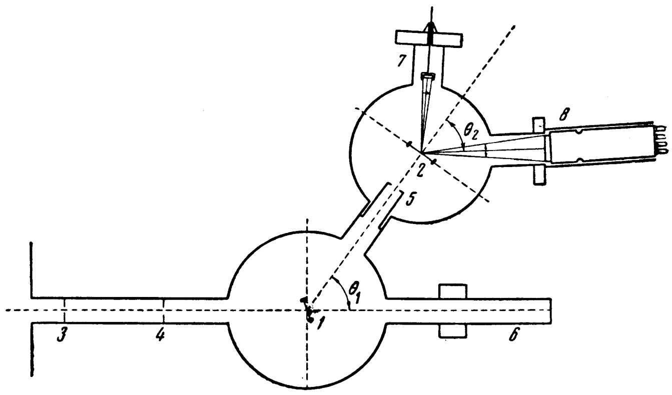

FIG. 1. Diagram of apparatus for measuring the sensitivity of the $Li^7(p,\alpha)He^4$ reaction to proton polarization.

angle of the first scattering was 0.01 sr. The distance from the second target to the detectors was such that α particles were registered with maximum angular spread $\pm 12°$. The solid angle for the second reaction was 0.06 sr.

The second chamber could be rotated around the axis of the scattered proton beam without affecting the vacuum.

Unbacked carbon targets 1–2 mg/cm^2 in thickness were prepared through the thermal dissociation of CH_3I. The carbon was deposited on the surface of a nickel foil heated in CH_3I vapor at 5 cm Hg. The carbon film was easily separated from the nickel surface and was mounted on a metal ring 20 mm in diameter. The lithium targets were prepared by vacuum deposition of LiF on a 2-mg/cm^2 foil. The LiF thickness was 1 mg/cm^2.

3. ELECTRONIC EQUIPMENT

Figure 2 is a block diagram of the electronic apparatus. Amplified pulses from both detectors were fed to a mixing amplifier, which enabled the simultaneous registration by a 400-channel pulse-height analyzer of both spectra (200 channels for each detector).

A typical spectrum is shown in Fig. 3, where the peak on the right represents α particles from $Li^7(p, \alpha)He^4$, while the peak on the left represents α particles from $Fe^{19}(p, \alpha_0)O^{16}$. Since the two peaks were well resolved in the entire energy range, the presence of F^{19} in the target did not affect the accuracy of the measurements.

The experimental currents to the carbon target were in the range 5–7 μA. Each counter registered 150–200 α particles per hour from $Li^7(p, \alpha)He^4$.

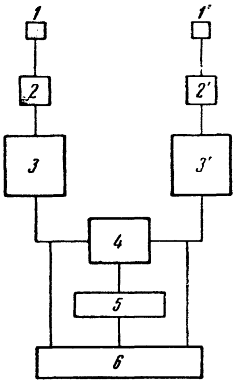

FIG. 2

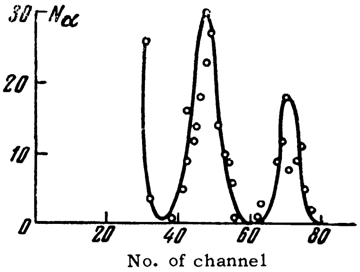

FIG. 3

FIG. 2. Block diagram of electronic circuit. 1,1'–detectors; 2,2'–preamplifiers; 3,3'–amplifiers; 4–mixing amplifier; 5–cutoff; 6–multichannel pulse-height amplifier.

FIG. 3. Typical pulse-height spectrum from one detector.

4. EXPERIMENTAL RESULTS

In order to determine the polarization sensitivity r we measured the left-right asymmetry R, which is the ratio of the number of counts in position 7 to the number of counts in position 8 (Fig. 1). The apparatus was adjusted to have both reactions occur in the same plane. The asymmetry R is related to the degree of polarization P_1 of elastically scattered protons and to r by

$$R = (1 + P_1 r)/(1 - P_1 r).$$

The positions of the planes of both reactions are given by the normal*

$$\mathbf{n} = [\mathbf{k}_{in}\mathbf{k}_{out}]/\,|\,[\mathbf{k}_{in}\mathbf{k}_{out}]\,|.$$

In the measurements of the asymmetry R the positions of the counters were changed several times. The second counter was rotated 180° around the axis of the scattered proton beam. The asymmetry was calculated for each counter separately; the final value was the geometric mean of the two values of R. In this way we eliminated asymmetry due to different counter efficiencies and variation of the experimental conditions.

In order to determine the asymmetry which might result from incorrect adjustment or finite solid angles, we measured the asymmetry R for protons scattered at 40° by Ni nuclei. A nickel foil 1 μ thick was substituted for the carbon target. The elastic p-Ni scattering at 40° below 2 MeV is practically entirely Coulomb scattering, which, as we know, does not result in proton polarization. In this case we can therefore expect R = 1 in the absence of spurious asymmetry. The accompanying table and Fig. 4 show that for 1.41 and 1.64 MeV protons R equals unity within 4% for the nickel target.

In [4] 2–3% spurious asymmetry was observed in the entire proton energy range. The experimental geometry was considerably improved in our work. We therefore assumed the absence of spurious asymmetry in the entire energy range (not only for 1.4–1.65 MeV).

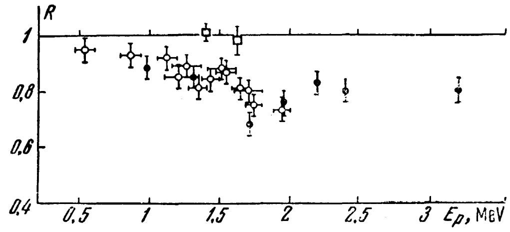

FIG. 4. Asymmetry R. Circles–present work; dots–results in [4]; squares–measurements with nickel target.

*$[\mathbf{k}_{in}\mathbf{k}_{out}] = \mathbf{k}_{in} \times \mathbf{k}_{out}$.

Results obtained from an investigation of $Li^7(p, \alpha)He^4$ with polarized protons

E_p, MeV	$R \pm \Delta R$	$P_1r \pm \Delta P_1r$	$(r \pm \Delta r)$ %	Type of detector*
0.55±0.07	0.95±0.04	—0.025±0.02	7±6	
0.87±0.07	0.93±0.04	—0.03±0.02	10±6	S
1.13±0.07	0.92±0.04	—0.04±0.02	11±6	C
1.35±0.07	0.81±0.04	—0.10±0.02	28±5	
1.44±0.06	0.84±0.04	—0.09±0.02	29±6	
1.55±0.07	0.87±0.04	—0.07±0.02	20±6	Both
1.65±0.06	0.81±0.04	—0.10±0.02	30±7	
1.75±0.06	0.75±0.04	—0.14±0.02	48±7	S
1.95±0.06	0.73±0.04	—0.16±0.02	64±8	
1.21±0.1	0.85±0.04	—0.08±0.02	23±6	Both
1.21±0.1	0.89±0.04	—0.05±0.02	21±6	
1.52±0.1	0.89±0.04	—0.06±0.02	22±7	C
1.71±0.1	0.80±0.04	—0.11±0.02	44±9	
With nickel target				
1.41±0.01	1.01±0.03			
1.64±0.01	0.98±0.05			

*Type of detector: S—semiconductor, C—CsI(Tl) crystal.

The table gives the measurements obtained with the carbon target. The first column gives the mean energy of polarized protons in the lithium target; at 1.2—2 MeV this energy was measured by varying the energy of protons impinging on the C^{12} target, while at 0.5—1.35 MeV it was measured by slowing down in aluminum foils positioned between the targets. The asymmetry is given in the second column. The values of P_1 required for calculating r were taken from [6]. The measured sensitivity r of $Li^7(p, \alpha)He^4$ is given in the fourth column. The indicated errors of r are statistical and do not include the inaccuracy of P_1 (15—20%). The fifth column states the type of detector. Measurements using semiconductor detectors and CsI(Tl) crystals are seen to coincide within statistical error limits.

5. DISCUSSION OF RESULTS

Our energy dependence r(E) of the sensitivity was compared with Wolfenstein's calculation.[1] The experiment agrees with the calculation if it is assumed that the $Li^7(p, \alpha)He^4$ reaction proceeds via two 2^+ levels of the compound Be^8 nucleus. Figure 5 shows the experimental values of r and the calculated curves for the 2^+, 2^+ case for different phase shifts γ. The experimental results are seen to agree with $\gamma \approx 225°$.

It should be noted that the choice of effective levels and the values of the phase shift γ were based on calculations neglecting the contribution of f waves to the reaction. Since the influence of f waves on r was not evaluated, there is a corresponding uncertainty in the interpretation of the measurements.

For protons below 1 MeV, r does not exceed 10%. Therefore the $Li^7(p, \alpha)He^4$ reaction apparently cannot be used to analyze low-energy polarized protons.

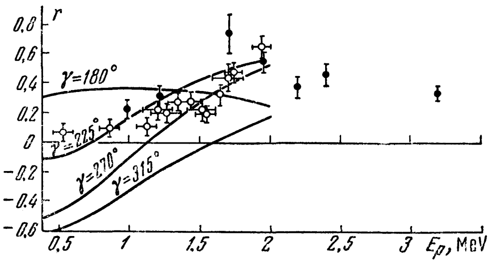

FIG. 5. Measured sensitivity of $Li^7(p,\alpha)He^4$ to proton polarization compared with calculations in [1]. Circles—present work; dots—[4].

Our present results confirm [4]; the values of R and r taken from [4] are shown in Figs. 4 and 5. Most points are seen to agree within experimental error limits. There is evidently some error in [5].

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