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Nuclear Physics **A111** (1968) 177—183; © *North-Holland Publishing Co., Amsterdam*

^{7}Li(p, α)^{4}He REACTION WITH POLARIZED PROTONS FROM 0.8 TO 3 MeV

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Received 28 December 1967

Abstract: A polarized beam was used to measure the asymmetry in the angular distribution of the alpha particles from the ^{7}Li(p, α)^{4}He reaction at 2.07 and 3 MeV. The polarization efficiency $P_a(\Theta)$ can be fitted to the form

$$P_a(\Theta) = \frac{1}{W_0(\Theta)} [A_2(E)P_2{}^1(\cos\Theta)+A_4(E)P_4{}^1(\cos\Theta)],$$

where $W_0(\Theta)$ is the normalized angular distribution for unpolarized protons. At these energies, the coefficient $A_2(E)$ is much larger than $A_4(E)$. A polarization excitation function at $\Theta = 135°$(c. m.) was measured from 0.8 to 3 MeV in 0.1 MeV steps from which $A_2(E)$ is calculated. The data consist of 40 points that were measured typically to an accuracy of 2.2 % with a target 110 keV thick at 2 MeV bombarding energy. A polarization contour map is given.

E | NUCLEAR REACTION ^{7}Li(polarized p, α), $E = 0.8$-3.0 MeV; measured $\sigma(E;\theta)$; deduced polarization analysing power. Natural target.

1. Introduction

The reaction ^{7}Li(p, α)^{4}He has been extensively studied experimentally and theoretically at low energies with unpolarized protons [1-3,4-6]) and with polarized protons [7-11,12]). Since the ^{7}Li ground state has negative parity and the outgoing channel is symmetric, only odd wave protons excite this reaction. The total cross section of the ^{7}Li(p, α)^{4}He reaction shows a broad resonance at 3 MeV proton energy, which is identified as a 2^+ level of the ^{8}Be intermediate nucleus [4]).

The differential cross section can be written [1-4])

$$\left(\frac{d\sigma}{d\omega}\right)_0 \approx 1+A(E)\cos^2\Theta+B(E)\cos^4\Theta+\ldots, \tag{1}$$

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†† Experiment performed at Carnegie Institution of Washington.

or in terms of Legendre polynomials [5])

$$\left(\frac{d\sigma}{d\omega}\right)_0 = \frac{\sigma_{tot}}{4\pi}\,[1+B_2(E)P_2(\cos\Theta)+B_4(E)P_4(\cos\Theta)\ldots] \tag{2}$$

$$= \frac{\sigma_{tot}}{4\pi}\,W_0(\Theta);$$

where Θ is the reaction angle, A, B, B_2 and B_4 energy dependent coefficients and $W_0(\Theta)$ the normalized angular distribution.

Wolfenstein [12]) predicted in 1949 that this reaction must be sensitive to proton polarization, because conservation of parity excludes s-wave protons. If the incident protons are polarized, the expressions for the angular distribution (1) and (2) have to be enlarged to [12])

$$\left(\frac{d\sigma}{d\omega}\right)_p = \left(\frac{d\sigma}{d\omega}\right)_0 + P_b[C(E)\sin\theta\cos\theta + D(E)\sin\theta\cos^3\theta + \ldots]\cos\Phi, \tag{3}$$

or

$$\left(\frac{d\sigma}{d\omega}\right)_p = \left(\frac{d\sigma}{d\omega}\right)_0 + P_b\frac{\sigma_{tot}}{4\pi}\,[A_2(E)P_2^1(\cos\theta)+A_4(E)P_4^1(\cos\theta)+\ldots]\cos\Phi, \tag{4}$$

where P_b is the incident proton polarization perpendicular to the beam and Φ the azimuthal angle between the normal to the reaction plane, defined according to the Basel sign convention, alphas and the axis of polarization, and C, D, A_2 and A_4 are energy dependent coefficients.

The differential cross section for polarized protons is given by the well-known formula

$$\left(\frac{d\sigma}{d\omega}\right)_p = \left(\frac{d\sigma}{d\omega}\right)_0 [1+P_bP_a(\Theta)\cos\Phi]. \tag{5}$$

Thus the polarization efficiency $P_a(\Theta)$ of the reaction can be written

$$P_a(\Theta) = \frac{A_2(E)P_2^1(\cos\Theta)+A_4(E)P_4^1(\cos\Theta)}{W_0(\Theta)} + \ldots; \tag{6}$$

$P_a(\Theta)$ contains no odd numbered polynomials, because the outgoing particles are identical. The coefficients $A_4(E)$ and $B_4(E)$ can only be significant, if f-wave protons are also involved.

Wolfenstein also performed some calculations about the behavior of the polarization excitation function at $\Theta = 45°$ assuming a 2^+ level corresponding to the 3 MeV resonance in interference with a 0^+ or 2^+ level at a lower energy. From these calculations, several investigators [7-11]) tried unsuccessfully to determine the spin of the lower energy level of ^{8}Be by polarization measurements. This experimental work has used protons polarized by reactions generally by elastic scattering on carbon. The measured polarizations have relatively large errors, and no satisfactory agreement has been achieved [11]).

2. Experimental technique

The experiment was performed with the pressurized Van de Graaff generator of the Carnegie Institution of Washington. A polarized ion source of the University of Basel [13]) installed in the terminal [14]) produces a 3 nA beam of 48 % polarized protons together with a background beam of unpolarized protons, which is of comparable

TABLE 1

Measured polarization efficiencies of the $^7Li(p, \alpha)^4He$ reaction, their statistical errors and calculated A_2 and A_4 coefficients

Energy (MeV)	c.m. angle (deg)	Polarization	Error	$A_2(E)$calc.	$A_4(E)$
0.80	135	−0.074	0.022	0.059	
0.90	135	−0.109	0.018	0.088	
1.02	135	−0.172	0.023	0.141	
1.12	135	−0.112	0.025	0.093	
1.23	135	−0.183	0.021	0.150	
1.34	135	−0.200	0.023	0.161	
1.45	135	−0.210	0.026	0.166	
1.56	135	−0.287	0.018	0.222	
1.67	135	−0.343	0.026	0.263	
1.77	135	−0.340	0.020	0.260	
1.87	135	−0.371	0.022	0.283	
1.97	135	−0.393	0.021	0.298	
	44.2	0.393	0.024		
	55.1	0.402	0.024		
	65.7	0.430	0.017		
	76.2	0.225	0.029		
2.07	90	0.038	0.038	0.301	−0.012
	101.6	−0.240	0.023	±0.005	±0.005
	116.2	−0.398	0.041		
	125.7	−0.404	0.022		
	135.1	−0.415	0.019		
	144.2	−0.342	0.025		
2.17	135	−0.382	0.020	0.284	
2.26	135	−0.398	0.025	0.288	
2.34	135	−0.367	0.019	0.264	
2.44	135	−0.425	0.023	0.298	
2.50	135	−0.353	0.017	0.244	
2.60	135	−0.384	0.025	0.257	
2.70	135	−0.357	0.018	0.235	
2.80	135	−0.368	0.025	0.232	
2.90	135	−0.351	0.014	0.213	
	45.1	0.384	0.027		
	56.1	0.318	0.021		
	66.8	0.260	0.021	0.222	−0.025
	77.4	0.179	0.019	±0.005	±0.005
3.00	107.8	−0.182	0.021		
	117.4	−0.325	0.020		
	126.8	−0.356	0.020		
	136.1	−0.381	0.020		
	145.1	−0.354	0.021		

size. The proton beam is focused onto a ^{7}Li target. Lithium is evaporated onto a 0.5 μm nickel foil in a separate vacuum chamber and then transferred in a helium

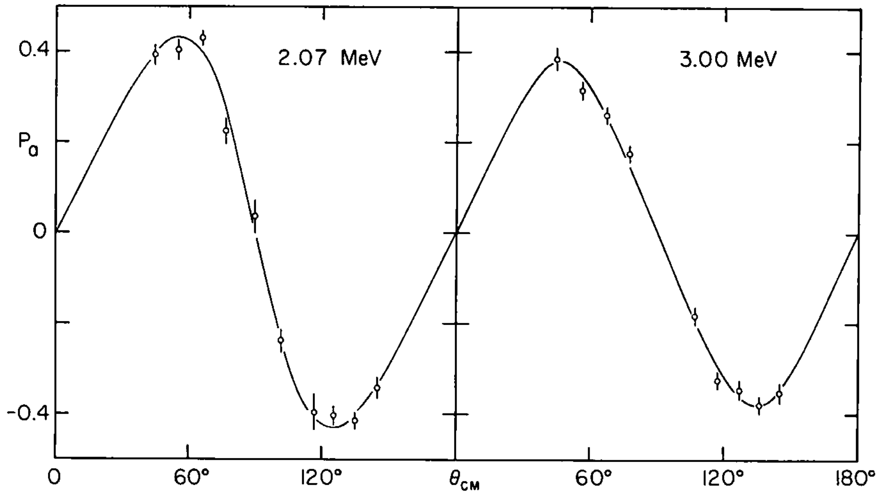

Fig. 1. Polarization efficiencies of the ^{7}Li(p, α)^{4}He reaction obtained at 2.07 and 3.00 MeV plotted against the center-of-mass angle. The curves are least-squares fits of formula (6).

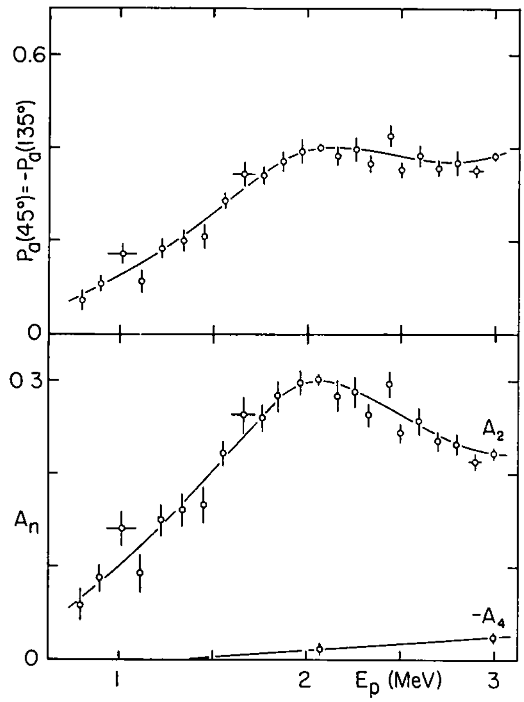

Fig. 2. Polarization excitation function of the ^{7}Li(p, α)^{4}He reaction at Θ = 135° (c.m.) and attributed values of the A_2 and A_4 coefficients.

atmosphere to the center of the scattering chamber [15]). The alpha particles of the ^{7}Li(p, α)^{4}He reaction are observed by two CsI crystals mounted on photomultipliers. Their pulses are counted with a 400-channel pulse-height analyser. The polarization efficiencies are calculated from left-right asymmetries at various angles Θ. The axis of polarization is perpendicular to the reaction plane, and the asymmetries can be reversed by reversing the magnetic field of the ionizer. A more complete description is given in ref. [15]).

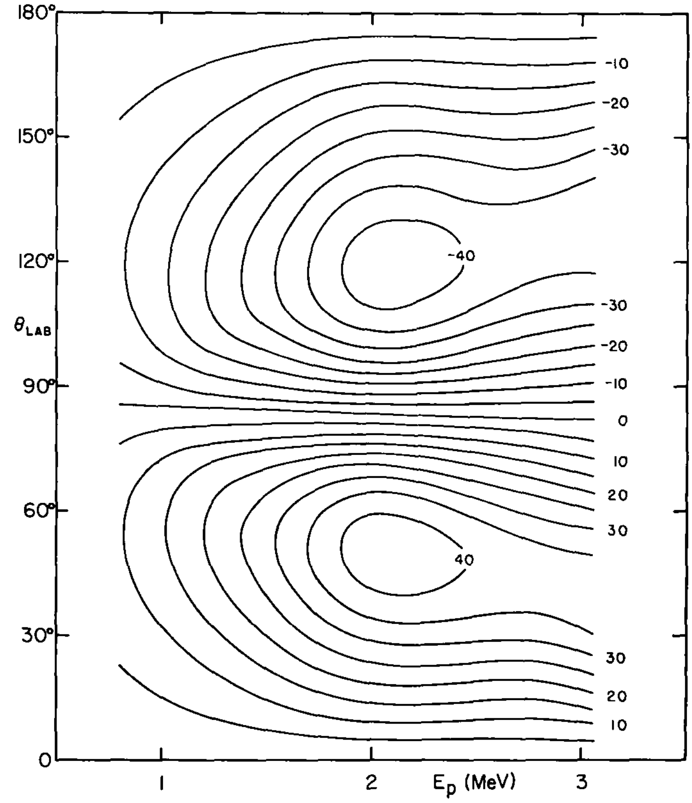

Fig. 3. Polarization contour map for the polarization efficiency of the ^{7}Li(p, α)^{4}He reaction. The polarization efficiency is given in units of 0.01, and the contour interval is 0.05.

The target thickness and the proton polarization were checked before and after this experiment. The target thickness was measured by observing the shift in energy needed to excite the 874 keV resonance of the ^{19}F(p, αγ)^{16}O reaction when the target was inserted in the beam. Two targets of 110 keV thickness at 2 MeV bombarding energy were used. The polarization of the beam was checked with the analysing reaction ^{4}He(p, p)^{4}He.

3. Results

The angular distribution of the alpha particles has been observed with polarized protons at 2.07 and 3.0 MeV. The measured polarization efficiencies and their statistical errors are given in table 1 and illustrated in fig. 1.

The data are fitted to formula (6); the values of the unpolarized angular distribution $W_0(\Theta)$ are taken from ref. [5]). At both energies A_2 is much larger than A_4, but the latter is five times the error limit at 3 MeV. Higher-order polynomials do not improve the fit of our data. A comparison with measurements of the ^{7}Li(p, α)^{4}He reaction at 3 MeV recently made at the University of Wisconsin [16]) shows good agreement.

In addition a polarization excitation function was measured from 0.8 to 3 MeV in 0.1 MeV steps at the center-of-mass angle 135°. These results shown in fig. 2 generally agree within 0.1 with earlier measurements [8-11]) except ref. [7]) and some high values [8,9]) near 1.8 MeV. The coefficient $A_2(E)$ was calculated from the polarization under the assumption of a linear variation of the A_4 coefficient, and the results are given in table 1.

4. Conclusions

The angular distributions measured at 2.07 and 3 MeV can be fitted by theory and indicate that the ^{7}Li(p, α)^{4}He reaction below 3 MeV is mostly induced by p-waves, because the coefficients A_4 and B_4 are both small.

The polarization can result from interference between the 2^+ state at 3 MeV and another state which has not yet been established. These data increase greatly the amount of experimental information available for analysis and may well allow the determination of the parameters of the other state (or states).

This reaction is a useful analyser for proton polarization, and for this reason we have included in fig. 3 a polarization contour map calculated from the smooth curves of A_2 and A_4 in fig. 2. The polarization efficiency varies smoothly, which allows the use of thick targets, and the reaction has a large Q-value, which aids the identification of the α-particles in the presence of background radiation.

Mr. Robert Cadmus worked with us in the preparation of the experiment and in taking the data. We wish to express our thanks here for his intelligent and cheerful help.

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