Polarization of Neutrons from $Li^7(p,n)Be^7$ and from *n-d* Scattering*

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The polarization of neutrons produced in the reaction $Li^7(p,n)Be^7$ has been examined by using n-He^4 scattering as an analyzer and the pulsed-beam time-of-flight technique as a neutron spectrometer. Results are reported up to 4.95-Mev proton energy. The data include results on the neutron groups corresponding to beryllium-7 being left in its ground state and first excited state. Using neutrons of 2.1 Mev which are polarized 38%, the polarization for *n-d* scattering at several angles has been found to be less than 0.07, which is consistent with a prediction by Christian and Gammel of negligible polarization.

TO study the polarization of fast neutrons produced in nuclear reactions and the effects of the scattering of polarized neutrons by nuclei, the pulsed-beam time-of-flight technique is particularly advantageous because it affords a favorable combination of energy resolution, signal-background ratio, and counting rate. In particular this technique lends itself readily to the utilization of n-He^4 scattering as a means of determining the polarization of neutrons produced in target reactions. In this paper results are presented on the application of n-He^4 scattering to measurements of the polarization of neutrons produced in the reaction $Li^7(p,n)Be^7$. These neutrons are used in turn to study the polarization of *n-d* scattering at 2.1 Mev neutron energy.

The helium scatterer is contained in a spherical steel shell $1\frac{1}{2}$ inches in diameter with walls $\frac{1}{32}$ inch thick at 5000 psi. The apparatus is identical with that used previously for time-of-flight studies.[1]

Figure 1 illustrates the time spectra observed for scattering from a helium-filled sphere and from an identical evacuated sphere for a scattering angle of $+100°$, using neutrons from the $Li^7(p,n)Be^7$ reaction which are produced at 50° to the direction of the protons. (The plus sign means the scattering angle is measured in the same sense as the angle between the direction of the incident neutrons and the direction of the protons incident on the target.) The average proton energy was 3.50 Mev, target thickness 120 kev, flight path 46 inches, target-to-scatterer distance 5 inches, time per channel 2.2×10^{-9} sec, running time 1000 seconds per spectrum at an average target current of 1 μa. At this proton energy and angle two neutron groups are produced, corresponding to transitions to the ground state and first excited state in Be^7, whose mean energies are 1.5 and 1.0 Mev, respectively, the intensity of the latter group being approximately 10% of that of the ground state group.

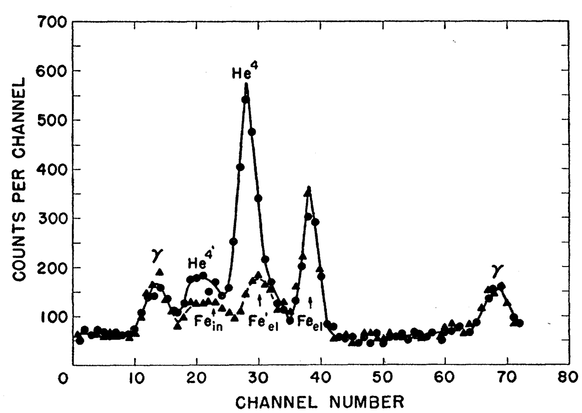

FIG. 1. Time spectra for neutrons from the reaction $Li^7(p,n)Be^7$ scattered from a thin-walled evacuated steel vessel (triangles), and from a similar vessel filled with He^4 (circles). The proton energy was 3.5 Mev. The primed and unprimed lines are due to neutrons from the target corresponding to excitation of the first excited state and the ground state in Be^7, respectively.

The peaks in Fig. 1, reading from right to left, are readily identified as follows for the evacuated sphere (triangles): a gamma ray due primarily to de-excitation of the 850-kev level excited by inelastic neutron scattering in iron, followed by neutron groups due to elastic scattering of 1.5-Mev neutrons by the steel sphere, elastic scattering of 1.0-Mev neutrons (designated Fe'_{el}) and inelastic scattering of 1.5-Mev neutrons corresponding to excitation of the 850-kev level in Fe. The gamma ray to the left belongs to the next cycle of data. The spectrum for the helium-filled sphere (circles) shows superimposed on the spectrum for the evacuated sphere two lines readily identified as those due to elastic scattering of 1.5- and 1.0-Mev neutrons by helium-4. The difference between these two curves is shown plotted in Fig. 2 together with the results obtained in a similar manner at $-100°$.

TABLE I. Polarization of neutrons from $Li^7(p,n)Be^7$.

E_p (Mev)	E_n (Mev)	θ (degrees)	P_1
3.48	1.494±0.057	50±5	0.44±0.03
3.48	1.062±0.057[a]	50±5	0.00±0.15
3.98	1.953±0.051	50±5	0.37±0.05
3.48	1.613±0.057	35±5	0.28±0.03
3.48	1.165±0.057[a]	35±5	−0.09±0.1
3.98	2.094±0.051	35±5	0.38±0.03
4.50	2.592±0.047[b]	35±5	0.31±0.07
4.95	3.032±0.043[b]	35±5	0.16±0.03

[a] Second neutron group.
[b] Ground-state neutron group not resolved from second neutron group. Polarization calculated assuming the second group is 10% of the main group and is unpolarized.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] L. Cranberg and J. S. Levin, Phys. Rev. 103, 343 (1956).

TABLE II. Neutron polarization in *n-d* scattering.

Scatt. angle (degrees c.m.)	P_2
44.5	0.02 ± 0.02
72.5	0.03 ± 0.02
98.0	0.00 ± 0.03
120.0	0.04 ± 0.02
138.0	0.02 ± 0.03

The difference in shape between the He^4 lines for the plus and minus sides is due to the dependence of neutron energy on angle of emission from the source. When the detector is in the positive position, it is nearer that part of the scatterer which is illuminated by less energetic neutrons and farther from that part which is illuminated by more energetic ones. Thus, there is a time-focusing effect on the plus side, and the inverse situation prevails on the minus side, but this does not affect the yield obtained by integrating over a line.

From the left-right asymmetry in yield, and the polarization calculated for n-He^4 scattering by Levintov *et al.*,[2] the polarization of the neutrons produced in the $Li^7(p,n)Be^7$ reaction is given in Table I for angles of neutron production, θ, of 35° and 50°. The values of polarization obtained are of the same magnitude as have been reported previously[3] for the ground-state neutron group at lower proton energies, that is, between 30 and 50%. An estimate of the polarization has also been obtained at one proton energy for the second group, and a much smaller value is indicated for it. (Note that the convention used here for the sign of the polarization is opposite to that of Striebel *et al.*[3])

The full spread in neutron energy for which these data were taken is given in Table I. The spread in the angle θ of 5° is essentially the spread in scattering angle because of the small target-scatterer distance. The value of 5° encompasses 90% of the scattering mass. Correction for the anisotropy of the source is negligible because of the large scatterer-to-detector distance and because the variation of the differential scattering cross section with angle is relatively slow. All data were taken at scattering angles larger than 90°, where the polarization for n-He^4 scattering is in excess of 60%. Multiple-scattering corrections, which amounted to about 10% of the observed counting rates, were made on the basis of the observed excess of foreground over background on the low-energy side of the lines due to single scattering. Errors in the polarization values given are primarily statistical, with some contributions from the uncertainty in the multiple-scattering correction. At 2.5 Mev and above the second group was not resolved from the main group, and the polarization values given are based on the assumption that the second group exhibits negligible polarization.

These results on the reaction $Li^7(p,n)Be^7$ confirm the results of Striebel *et al.*[3] that strong polarization of the neutrons from the reaction $Li^7(p,n)Be^7$ is not confined to the region of the prominent resonance in this reaction at a proton energy of 2.25 Mev, but extends well beyond it. However, there is a marked drop in polarization at 4.95 Mev proton energy corresponding to a known resonance[4] in Be^8 at 21.5 Mev.

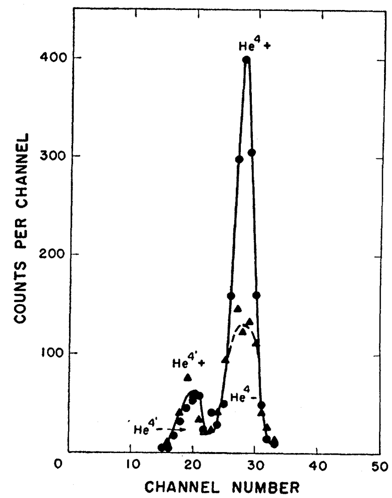

FIG. 2. The net yield obtained due to scattering of neutrons from the $Li^7(p,n)Be^7$ reaction by helium-4, for scattering angles of plus and minus 100°. The two lines observed in each case are due to the two neutron groups produced in the lithium target. The pair of lines corresponding to the weaker neutron group are primed.

An important consequence of these results is that they establish the feasibility of using the neutrons from this reaction to investigate polarization effects in other nuclei at higher energies than have been covered in previous work.[5] Using neutrons of 2.10 Mev mean energy at an angle of 35° to the proton direction, an investigation has been undertaken of *n-d* scattering using a scatterer of solid CD_2. For five center-of-mass angles from 45° to 138° (Table II) the polarization observed is less than 0.07. This is in disagreement with the result of 0.48 ± 0.05 reported[6] for $E_n=2.26$ Mev and a center-of-mass scattering angle of 90°, but in agreement with a theoretical prediction by Christian and Gammel.[7] Recent work at 3.27 Mev[8] has given values for *n-d* polarization similar to those reported here.

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[3] Striebel, Darden, and Haeberli, Nuclear Phys. **6**, 188 (1958).
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[7] R. S. Christian and J. L. Gammel, Phys. Rev. **91**, 100 (1953).
[8] Brüllmann, Gerber, and Meier, Helv. Phys. Acta **31**, 318 (1958).