Inelastic Scattering of Protons by Li^7†

F. MOZER, W. A. FOWLER, AND C. C. LAURITSEN
Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, California
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The absolute differential cross section for the inelastic scattering of protons by Li^7 has been measured at ten scattering angles for incident proton energies near the 1030-kev resonance. The differential cross section is nearly isotropic at the resonance whereas at higher energies the scattering shows marked fore-and-aft asymmetry, being predominantly in the backwards direction. The total cross section for inelastic scattering is 41.6±3.0 millibarns at an incident proton energy, $E_1=1050$ kev; 35.4±2.8 millibarns at $E_1=1140$ kev; and 32.0±2.7 millibarns at $E_1=1240$ kev.

THE 18.14-Mev excited state in Be^8_4 was studied in this laboratory in 1939 by Fowler and Lauritsen[1] who showed its existence by virtue of the resonance occurring in the production of gamma radiation from the reaction $Li^7(p,p'\gamma)$ near an incident proton energy of 1050 kev. In 1949, its energy was more exactly determined to correspond to an incident proton energy of 1030±5 kev.[2] From an analysis of angular distribution data[3] for $Li^7(p,p)$, it was concluded that the excited state in the compound nucleus may have a spin of one, odd parity, and be formed by *s*-wave protons.[4] However, the presence of a broad resonance at a higher energy precluded a detailed agreement, and thus the question of the spin and parity of the 18.14-Mev state in Be^8 remained open.

In an attempt to settle this question, investigations of the excitation curves and angular distributions for the processes $Li^7(p,p)$[5] and $Li^7(p,\gamma)$[6] near an incident proton energy of 1030 kev have recently been completed. With this knowledge, it became desirable to investigate the inelastically scattered protons from $Li^7(p,p')$ near 1030 kev in an attempt to correlate these three sets of data and thus attempt to assign a spin and parity to the 18.14-Mev state in Be^8.

This work was undertaken with a 2-Mev electrostatic generator as the source of the incident protons. These protons were analyzed into a monoenergetic beam to within 0.05 percent by an 80° electrostatic analyzer of one-meter radius and one-millimeter entrance and exit slits.[7] The inelastically scattered protons passed through a variable-angle, double-focusing, magnetic analyzer[8] and were then counted by a scintillation counter.

Targets were prepared by evaporation of natural lithium on thin beryllium foils.[9] Originally it was planned to carry out the experiment using thin targets of lithium. However, it was later found that this method did not yield reliably reproducible results because of contamination layers of oxygen, carbon, and hydrogen on the target and because of deterioration of the thin lithium layer under bombardment. The most consistent results were obtained by use of a thick target of lithium evaporated on a thin beryllium foil and by isolation of the products of reaction which arose in a thin lamina at any desired depth in the target by means of the high resolution of the magnetic analyzer. By this method the absolute cross sections for the reaction were determined.

Aluminum foils were placed before the scintillation counter to prevent the counting of alpha particles from $Li^6(p,\alpha)$, $Li^7(p,\alpha)$, and $Be^9(p,\alpha)$ with protons of the same energy. A correction was introduced for the small number of protons stopped by these aluminum foils. At the forward scattering angles, protons elastically scattered from hydrogen impurities on the target had nearly the same energy as the protons inelastically scattered from lithium. Since it was impossible to eliminate the hydrogen surface layer completely, experi-

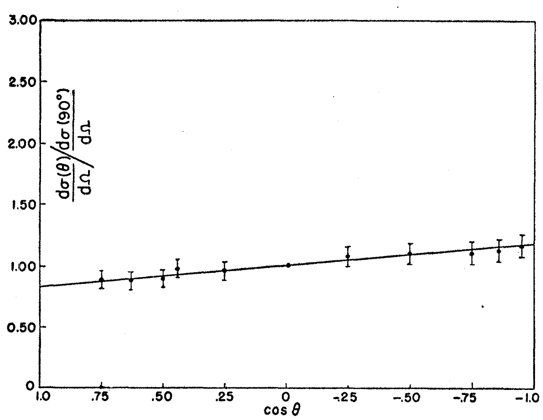

FIG. 1. Differential cross section of the inelastically scattered protons relative to that at 90° at an incident proton energy of 1050 kev.

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[1] W. A. Fowler and C. C. Lauritsen, Phys. Rev. **56**, 841 (1939). See also Hudson, Herb, and Plain, Phys. Rev. *57*, 587 (1940); Herb, Kerst, McKibben, Phys. Rev. **51**, 691 (1937).
[2] W. A. Fowler and C. C. Lauritsen, Phys. Rev. **76**, 314 (1949).
[3] Fowler, Lauritsen, and Rubin, Phys. Rev. **75**, 1463 (1949).
[4] E. R. Cohen, Phys. Rev. **75**, 1463 (1949).
[5] Warters, Fowler, and Lauritsen, Phys. Rev. **91**, 917 (1953).
[6] A. A. Kraus, Jr. (to be published).
[7] Fowler, Lauritsen, and Lauritsen, Rev. Sci. Instr. **18**, 818 (1947).
[8] Snyder, Rubin, Fowler, and Lauritsen, Rev. Sci. Instr. **21**, 852 (1950).

[9] For a discussion of some difficulties encountered in making targets as well as the methods used in calibrating the magnetic and electrostatic analyzers, see reference 5.

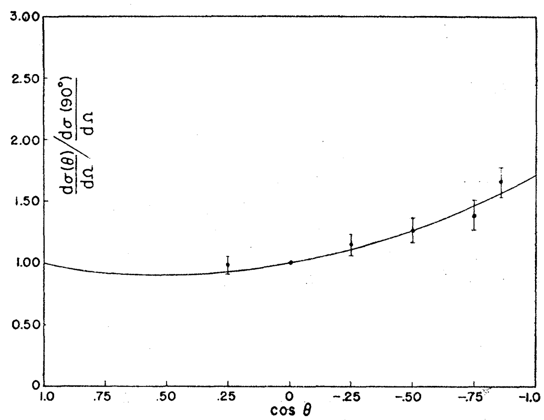

FIG. 2. Differential cross section of the inelastically scattered protons relative to that at 90° at an incident proton energy of 1140 kev.

mental data at the forward angles are somewhat uncertain.

The probable error in the absolute differential cross section due to statistical fluctuations averaged about 4 percent. Combining this with errors due to contamination layers on the target, uncertainties in the analyzer and spectrometer calibrations, angles of observation, and the absolute stopping cross section of protons in lithium, which enters into the reaction cross section formula, there arises a total probable error of about 7 percent. Thus the differential cross sections for $Li^7(p,p')$ at 90° were found to be 3.31 ± 0.24 millibarns per steradian at an incident proton energy E_1 of 1050 kev; 2.51 ± 0.18 millibarns per steradian at $E_1=1140$ kev; and 2.25 ± 0.16 millibarns per steradian at $E_1=1240$ kev.[10]

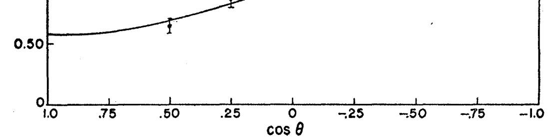

FIG. 3. Differential cross section of the inelastically scattered protons relative to that at 90° at an incident proton energy of 1240 kev.

[10] Differential cross sections were calculated from the inelastic proton yields using equations given in Brown, Snyder, Fowler, and Lauritsen, Phys. Rev. **82**, 159 (1951). The stopping cross section of protons in lithium was taken from reference 5.

The curves of reaction differential cross section relative to that at 90° are shown in Figs. 1, 2, and 3.

These experimental differential cross-section curves indicate the presence of interference effects near the 18.14-Mev resonance level in the compound nucleus, Be^8. This fact is shown by the presence of the $\cos\theta$ term and may possibly be attributed to an interference of the resonance level with a broad background level in the compound nucleus.

In Fig. 4, the coefficients in the equation

$$d\sigma(\theta,E_1)/d\Omega = a(E_1)+b(E_1)\cos\theta+c(E_1)\cos^2\theta$$

have been plotted against E_1, the incident proton energy. Near resonance, the coefficients $b(E_1)$ and $c(E_1)$

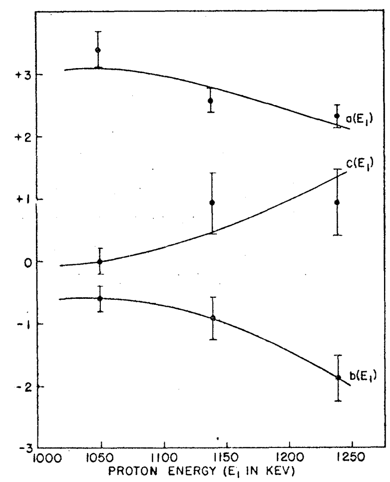

FIG. 4. Coefficients of

$$d\sigma(\theta,E_1)/d\Omega = a(E_1)+b(E_1)\cos\theta+c(E_1)\cos^2\theta,$$

plotted against the incident proton energy in kev. The curves are arbitrarily drawn so as to indicate symmetry about the resonance energy, 1030 kev.

become small, and the angular distribution becomes nearly isotropic. The fact that $b(E_1)$ is small at the resonance is consistent with the assumption of a nonresonant term of one parity interfering with the resonant term of opposite parity. The total cross sections for inelastic scattering $\sigma=4\pi[a(E_1)+\frac{1}{3}c(E_1)]$ are: 41.6 ± 3.0 millibarns at $E_1=1050$ kev; 35.4 ± 2.8 millibarns at $E_1=1140$ kev; and 32.0 ± 2.7 millibarns at $E_1=1240$ kev.

The observed angular distributions do not lead immediately to an assignment of spin and parity for the resonance at 18.14 Mev. The spherical symmetry at resonance and the deviations therefrom above resonance could be consistent with either an s- or a p-wave resonance.