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Shell Effects in the High Energy Photoproton Spectra from Li^6

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ABSTRACT

Measurements have been made of the energy spectra and angular distributions of protons from the $\text{Li}^6(\gamma, p)$ reaction. The experiment was performed at the Saskatchewan Accelerator Laboratory using a bremsstrahlung beam of maximum energy ~ 100 Mev. Structure observed in the photoproton spectra can be interpreted on the basis of a single-particle direct-interaction model.

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A study of the high energy protons emitted in the nuclear photoeffect in the $E_\gamma \sim 100$ Mev region can yield information about the photonuclear reaction mechanism, about the structure of the nucleus, and about the high-momentum components of nuclear wave functions. Experiments with $E_\gamma \gtrsim 200$ Mev are consistent in some detail with the quasi-deuteron model, in which the photon interacts with a neutron-proton pair.¹ At lower energies, the situation is not so clear. The most complete experiment is that of Whitehead et al.², who measured differential cross-sections for photoprotons at five energies from carbon, lithium, and beryllium with 40-100 Mev bremsstrahlung. Most of the data could be accounted for with the quasi-deuteron model. However, for the "threshold protons," i.e., those with the maximum energy kinematically allowed for a given photon energy, the size of the cross-section and the angular distribution deviated substantially from the predictions of a quasi-deuteron calculation. Moreover, the cross-section for the production of 37 Mev photoprotons from lithium as a function of E_γ exhibited two peaks, at $E_\gamma \sim 45$ Mev and $E_\gamma \sim 62$ Mev. A subsequent calculation by Fujii³, using a direct-interaction mechanism and the shell model, showed that this phenomenon, as well as the observed angular distribution, could be represented as the ejection of protons from the p-shell and the s-shell of Li^7 , and that in this respect the nuclear photoeffect was thus very similar to the (p,2p) reaction. A significant difference between the two processes lies in the initial particle momentum range investigated -- the majority of the (p,2p) data sample proton momenta up to ~ 200 Mev/c, whereas for a 100 Mev photon

ejecting a proton from the p-shell of Li^6 , the initial proton momentum goes from 310 Mev/c at $\theta_p = 0^\circ$ to 475 Mev/c at $\theta_p = 180^\circ$.

If these single-particle effects are indeed occurring, a measurement of the photoproton energy spectrum with sufficient resolution at a single bremsstrahlung energy should show two features displaced in energy by the difference in proton separation energies for the s- and p-shell.

An experiment to investigate with good resolution the proton spectra and angular distributions in the nuclear photoeffect at 100 Mev has been performed at the Saskatchewan Accelerator Laboratory. Bremsstrahlung produced by the electron beam striking a .004" aluminum radiator was collimated to a 2" spot at the target position. The electron beam was removed by a sweeping magnet. Protons were detected at eight angles -- 45° to 139° -- simultaneously by an array of two-counter telescopes. A 1/4" plastic scintillator ΔE counter was backed up by a 5" plastic scintillator E counter, the two parameter pulse-height distribution thus obtained yielding a clean separation of protons from particles of other masses. The energy resolution of the E counter was measured with monoenergetic protons to be about 4%; the angular resolution of each telescope was $\pm 3^\circ$. The reactions $\text{Li}^6(\gamma, p)$, $\text{Li}^7(\gamma, p)$, and $\text{C}^{12}(\gamma, p)$ were examined; the majority of the data were taken on Li^6 at bremsstrahlung endpoint energies of 95 and 102 Mev.

A typical spectrum, for Li^6 photoprotons at $E_{\gamma \text{ max}} = 102 \text{ Mev}$ and $\theta_p = 82^\circ$, is shown in Fig. 1. The proton energy scale was calibrated by observing the

position of the 1 Mev Na^{22} Compton edge with the signals passed through a gain-of-10 amplifier, and using the proton vs. electron response data for plastic scintillator of Gooding and Pugh.⁴ The arrows indicate "threshold proton" energies computed from the $\text{Li}^6(\gamma, p)\text{He}^5$ reaction kinematics, using $E_\gamma = 102$ Mev, and proton separation energies of $E_s = 4.9$ Mev for the p-shell and $E_s = 22.7$ Mev for the s-shell, values derived from the (p,2p) measurements.⁵ What the data suggest is two "bremsstrahlung endpoints," a group of protons at each of the maximum energies allowed by the kinematics.

To simulate the proton spectrum that would be observed with monochromatic incident photons, a spectrum measured with 95 Mev bremsstrahlung was subtracted, properly normalized, from the data of Fig. 1. This "difference spectrum" is displayed in Fig. 2. The threshold proton energies for $E_\gamma = 102$ Mev are again indicated by arrows.

Comparable data, exhibiting similar structure, are available at the other seven angles investigated in this experiment. These results are in qualitative agreement with predictions based on a single-particle direct-interaction model and are not to be expected from a simple quasi-deuteron model.

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FIGURE CAPTIONS

Figure 1 Spectrum of photoprotons from Li^6 at $\theta_p = 82^\circ$, with bremsstrahlung of maximum energy 102 Mev. The arrows indicate proton energies calculated from $\text{Li}^6(\gamma, p)\text{He}^5$ kinematics for $E_\gamma = 102$ Mev, and $E_s = 4.9$ Mev and 22.7 Mev.

Figure 2 "Difference spectrum": the photoproton spectrum measured with 95 Mev bremsstrahlung subtracted from that measured with 102 Mev bremsstrahlung, for Li^6 at $\theta_p = 82^\circ$. The arrows indicate proton energies calculated from $\text{Li}^6(\gamma, p)\text{He}^5$ kinematics for $E_\gamma = 102$ Mev, and $E_s = 4.9$ Mev and 22.7 Mev.

$\text{Li}^6(\gamma, p)$

$\theta_p = 82^\circ$

$E_{\gamma \text{ max.}} = 102 \text{ MeV}$

dN/dE_p (NUMBER OF PROTONS PER MeV)

PROTON ENERGY E_p (MeV)