Mechanism of the ^{7}Li(γ,N) Reactions

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Cross sections for the reactions ^{7}Li(γ, n_0+n_2) and ^{7}Li(γ, p_0) have been measured for photon energies in the range 60–120 MeV. Comparison is made between the data and simple calculations based on the modified quasideuteron and quasifree knockout models, which suggests that the former dominates.

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The dominant reaction mechanism in (γ, N) reactions at photon energies between the giant resonance region and the pion production threshold has long been a subject of discussion and debate in the literature. Recently Boffi, Giusti, and Pacati[1] have shown that all the available (γ, p_0) data could be explained within the framework of the single-particle quasifree knockout model. However, the similar magnitude of the (γ, n_0) cross sections,[2] which in the simple quasifree knockout model would be very small, has led other authors to invoke either short-range NN correlations[3-5] or longer-range correlations[6] to explain these data. An acceptable theoretical treatment of the (γ, N) reaction must, of course, produce the correct absolute magnitudes for both (γ, p) and (γ, n) cross sections. However, data which enable a comparison to be made between the two cross sections are sparse, mainly because of the difficulty of making (γ, n) measurements, and often consist of separate measurements of the (γ, p) and (γ, n) cross sections[2,4] or electron-induced reaction measurements.[7]

In this paper we present a measurement of the cross sections $d\sigma/d\Omega(\gamma, n_0+n_2)$ and $d\sigma/d\Omega(\gamma, p_0)$ for ^{7}Li, made with use of a recoil-ion detection technique. Self-supporting natural lithium foils, with thicknesses in the range 0.2 to 5 mg/cm^2, were irradiated with bremsstrahlung produced by 155-MeV electrons from the Kelvin Laboratory electron linac incident on a 0.033-radiation-length ^{181}Ta radiator located 10 cm upstream from the target. The contribution from electrodisintegration was obtained in separate runs with the radiator removed and has been subtracted. Surface-barrier detectors mounted in the focal plane of a magnetic spectrometer were used to detect recoiling ^{6}He and ^{6}Li nuclei from the (γ, p_0) and (γ, n_0+n_2) reactions. Other states, being particle unstable, were not observed. The two-body kinematics of the reactions enabled the photon energy corresponding to each event to be determined from the measured recoil energy. Differential cross-section data are shown in Fig. 1, and the ratio of the cross sections is presented in Figs. 2 and 3.

The magnitude of the ratio of the total cross sections is in the range 1.5–2.0 [indicating a ratio of the (γ, p_0) cross section to the individual (γ, n) channels of ~1] in qualitative agreement with the results from the less extensive electron-induced data of Asai, Murphy, and Skopik.[7] This suggests that processes in which two nucleons are involved in the photon absorption process are important. Unfortunately there have been no detailed calculations of this type for ^{7}Li. To estimate these cross sections we have therefore carried out a calculation using the formalism of Schoch[3] based on the quasideuteron model, modified to account for capture of one of the outgoing nucleons into a bound state. Schoch writes for the (γ, p) differential cross section [with a similar expression for (γ, n)]

$$\frac{d\sigma}{d\Omega}(\gamma, p) = L\,\frac{Z_s N^2}{A}\,\frac{d\sigma}{d\Omega_d}(k_\gamma, \theta_p)P_s\left|\int d^3k_p\;\varphi(k_p)F^{A-1}(q_p)\right|^2.$$

In this expression $d\sigma/d\Omega_d$ is the c.m. differential cross section for the photodisintegration of the deuteron, θ_p is the proton emission angle, $\varphi(k_p)$ is the bound-state proton momentum distribution, and $F^{A-1}(q_p)$ is the elastic form factor of the residual nucleus for $q_p = |\vec{k}_\gamma + \vec{k}_p - \vec{k}_p'|$ where k_p and k_p' are

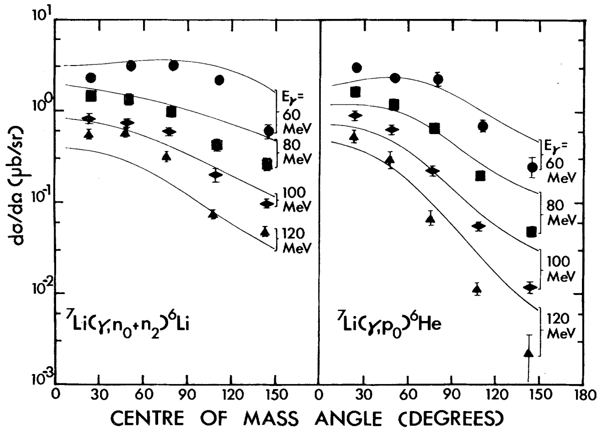

FIG. 1. Differential cross sections as a function of nucleon emission angle. Additional systematic errors not shown are estimated at ± 7%. The lines result from a modified quasideuteron model calculation as discussed in the text.

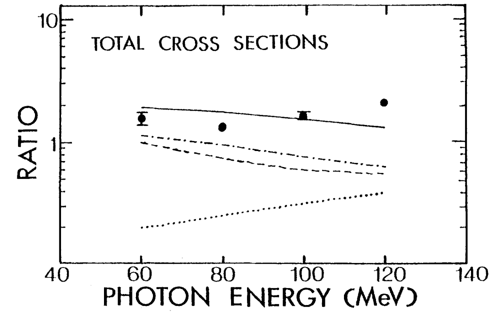

FIG. 2. Ratio of angle-integrated cross sections $\sigma(\gamma, n_0+n_2)/\sigma(\gamma, p_0)$ as a function of photon energy. The lines refer to calculations discussed in the text. Solid line, modified quasideuteron calculation. The other lines refer to a quasifree knockout calculation: dotted line, without recoil terms; dashed line, with recoil terms and harmonic-oscillator potential; dot-dashed line, with recoil terms and square-well potential.

the initial and final momenta of the ejected proton. The mass number and neutron number of the initial nucleus are A and N, Z_s is the number of protons in the active subshell, P_s is a phase-space factor, and L is the Levinger parameter.

A harmonic-oscillator momentum distribution was used for $\varphi(k_p)$ and modified oscillator forms were used for $F^{A-1}(q)$ with parameters taken from Suelzle, Yearian, and Cranell[8] for the ^{6}Li ground state. For the ^{6}Li excited state and the ^{6}He ground state the same s-shell oscillator parameter was used but the p-shell oscillator parameter was increased by 10% to simulate the increased radius of the p-shell nucleons.[9] An overall normalization of all the calculated cross sections was made by varying L until the (γ, p_0) result agreed with the $E_\gamma = 100$ MeV data point for $\theta_p = 78°$. The resulting curves for $L = 1.9$ are shown for $\theta_N = 50°$ in Fig. 1.[10] The cross-section ratio predicted by the model, which is independent of the normalization, is shown in Figs. 2 and 3.

The quasideuteron calculation successfully reproduces the magnitude of the total-cross-section ratio (see Fig. 2), as would be expected for a model in which the predicted (γ, n) and (γ, p) cross sections are necessarily of similar magnitude. This calculation also reproduces the angle and photon energy dependence of both differential cross sections to within a factor of 2 except for backward angles at the highest photon energies (see Fig. 1) and this reflected in the ratios plotted in Fig. 3. The success of this simple model would appear to demonstrate the dominance of two-nucleon photon absorption in these reactions. However, several reservations must be made. Firstly, there are other models of the (γ, N) reaction which predict $(\gamma, n)/(\gamma, p)$ ratios of the order of unity. In particular, Marangoni, Ottaviani, and Saruis[6] have successfully reproduced both the (γ, p_0) and (γ, n_0) cross sections for ^{16}O and ^{12}C using a random-phase-approximation calculation in which the reaction proceeds

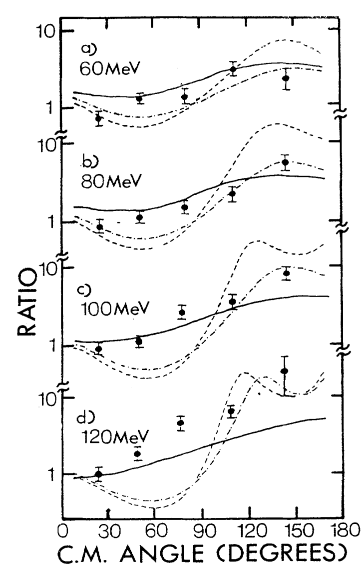

FIG. 3. Ratio of differential cross sections $[d\sigma/d\Omega(\gamma, n_0+n_2)]/[d\sigma/d\Omega(\gamma, p_0)]$ as a function of center-of-mass angle at the photon energies indicated. The calculations are labeled in the same way as in Fig. 2.

via intermediate excitation of resonance states. Secondly, there are several refinements to the simple quasifree knockout model which require further investigation. Cotanch[11] has suggested that charge exchange in the final-state interactions between the outgoing nucleon and the residual nucleus will increase the (γ, n) cross section. In addition, the effect of the recoil terms in the direct knockout model, which are usually neglected, may be significant. These arise from the interaction of the photon with the $A-1$ system.[12] A plane-wave calculation, including both electric and magnetic terms and a form factor to account for the finite extent of the $A-1$ system, was performed to estimate the importance of the recoil terms. The calculation, which will be described in more detail in a forthcoming paper, has been carried out for nucleon momentum distributions derived from harmonic-oscillator and square-well potentials; these contain respectively too few and too many high-momentum components compared to more realistic potentials and so should provide limits for the value of the ratio. The failure to include final-state interactions between the outgoing nucleon and the residual nucleus in such calculations is known to lead to large systematic errors. However, as the effects of these final-state interactions are expected to be similar in the two channels, the calculation should provide a reasonable estimate of the cross-section ratios which would result from a full quasifree knockout calculation. For these reasons only the calculated cross-section ratios are presented (Figs. 2 and 3). It is seen from Fig. 2 that the inclusion of the recoil terms has a significant effect on the total-cross-section ratio predicted by the quasifree knockout model; nevertheless the calculation still falls short of the experimental results. This is also the case for the differential-cross-section ratio (Fig. 3) except at backward angles, where the cross section is small, both in absolute magnitude and as a fraction of the total.

To conclude, the data presented here confirm the similarity of the (γ, p) and (γ, n) cross sections for ^{7}Li in this photon energy region and demonstrate that the quasifree knockout model of these reactions is inadequate. Comparison with a modified quasideuteron model calculation suggests that photon absorption on two nucleons is dominant. However, there is a clear need for more detailed theoretical work on these reactions, including a careful treatment of quasifree knockout contributions, which although unable to explain some gross features of these cross sections, may be significant especially at backward angles.

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[10]This rather small value of L results from the noninclusion of final-state interactions when comparing with individual cross sections. Inclusion of these effects as in Ref. 3 raises the value to $L = 5.9$ without significantly affecting the shape or magnitude of the cross-section ratios.

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