PHOTOTRITONS FROM Li^6 †

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Tritons from the disintegration of Li^6 by giant-resonance photons have not been observed[1,2] until recently.[3] This was puzzling since experiments[4,5] sensitive to all but two of the allowed reactions for $E1$ photons indicate that at least two-thirds of the dipole sum is unaccounted for up to 30 MeV, and at least one-third up to 60 MeV. The remaining two allowed reactions are $Li^6(\gamma,t)He^3$ and $Li^6(\gamma,pd)T$. We report here a measurement of the cross section for the reaction $Li^6(\gamma,t)$ for photon energies between 19 and 24 MeV. This work has been extended to higher energies.[6,2]

Lithium targets were irradiated with 40-MeV bremsstrahlung from the Yale electron linac. Charged disintegration products were momentum-analyzed by a quadrupole triplet magnet[7] and stopped in a silicon-barrier detector. The targets were made and maintained in vacuum by evaporating Li^6 of 99.3% isotopic purity onto Formvar backings loaded into the reaction chamber. Target thickness, typically 270 μg/cm^2, was measured by the shift of an Am^{241} alpha line. The magnet focuses according to charge divided by momentum, so that a triton peak has one-third the energy and width, and a deuteron peak one-half the energy and width, of the proton peak for a given magnet setting. The magnet transmission function[7] was measured by detecting photoprotons from solid and gaseous targets at different magnet settings.

In comparing the relative heights of triton and proton peaks, account must be taken of "kinematic compaction." If two-body breakup of Li^6 is assumed, for the reaction $Li^6(\gamma,t)$

$$k_t = 2T_t + Q_t, \tag{1}$$

and for the reaction $Li^6(\gamma,p)$

$$k_p = 6/5T_p + Q_p, \tag{2}$$

where k is photon energy, T is kinetic energy, and Q is the reaction Q value. Hence for an energy interval ΔT, the compaction ratio is $\Delta k_t/\Delta k_p = 5/3$. Figure 1 shows the photoproton spectrum from a deuterium gas target, the photoproton and phototriton spectrum of Li^6, and the photoproton spectrum of the Formvar target backing. The dotted wedge gives the position and width of the 5.48-MeV alpha line.[8] Clearly any yield of energetic deuterons from Li^6 is small compared with the triton yield.[9] Isospin selection rules forbid two-body deuteron production from Li^6 by $E1$ or $M1$ radiation, though $E2$ transitions (weaker than $E1$) are allowed. Deuterons can be produced by $E1$ photons through three-body breakup, which leaves $H^1 + H^2 + H^3$ or $n + H^2 + He^3$ in the final state. Insignificant deuteron yield indicates that tritons are produced mainly by two-body breakup in the energy region studied. The photon energy is therefore given by Eq. (1), with $Q_t = 15.791$ MeV. Absolute cross section was obtained by normalizing to the $H^2(\gamma,p)$ cross section[10] via photoprotons from the deuterium gas cell. The same angular distribution was assumed for $Li^6(\gamma,t)$ as for $H^2(\gamma,p)$. Normalization of beam intensity was achieved by continuous monitoring with an ionization chamber. The bremsstrahlung spectral shape was determined from the photoproton yield at 90° from deuterium, at several magnet settings.

Time gating eliminated tritons of 2.73-MeV energy due to the background reaction $Li^6(n,\alpha)T$. With the gate turned off, an (n,α) triton peak about 77 keV wide was observed as shown in

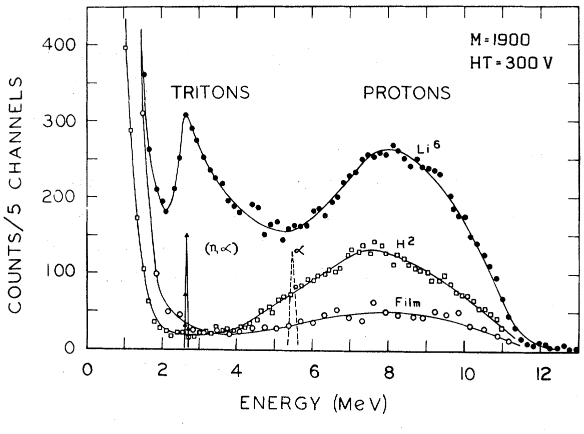

FIG. 1. Energy spectra of charged photoproducts taken with 14% momentum resolution at a magnet setting where the (n,α) background is greatest. For the Li^6 (film background included) and Formvar film the number of counts has been normalized to a standard integrated intensity. Deuterium scale arbitrary.

Fig. 1. The phototriton peak was much wider and had a shape imposed by the transmission function. It could be moved from about 1.5 MeV, where it merged with the background, to 7 MeV and beyond by varying the magnet current. The targets were less than 100 keV thick to (n,α) tritons, so background cannot explain tritons observed below 2.6 MeV. The high-energy tritons are not due to possible neutron contamination of the incident beam,[11] nor to secondary neutron reactions in the target.[12] Other workers[13] using nuclear emulsions as detectors have also reported (γ,t) measurements in the region of the giant resonance. Their results appear to be entirely due to slow-neutron background. Their triton energy spectrum is strongly peaked around 2.7 MeV, and their cross section is more than 10 times greater than ours.

Figure 2 shows the cross section obtained from overlapping data taken at three magnet settings. The data from the different Li^6 runs agreed within the assigned errors. Since phototritons and photoprotons are detected simultaneously in this experiment, their yields can be compared. We find, for example, that the $\mathrm{Li}^6(\gamma,t)$ cross section at 21.5 MeV is about the same[14] as that for $\mathrm{Li}^6(\gamma,p)$ at 14.2 MeV, and equal to about 0.4 mb. One can infer from the Livermore data[5] that $\sigma(\gamma,p)\approx 0.6$ mb at 14 MeV, which confirms the order of magnitude of our cross sections. From Fig. 2 we conclude that $\sigma(\gamma,t)$ integrated to 24 MeV is less than 5 MeV mb. If the dipole sum[15] is exhausted in Li^6, there must be considerable dipole absorption above 24 MeV.

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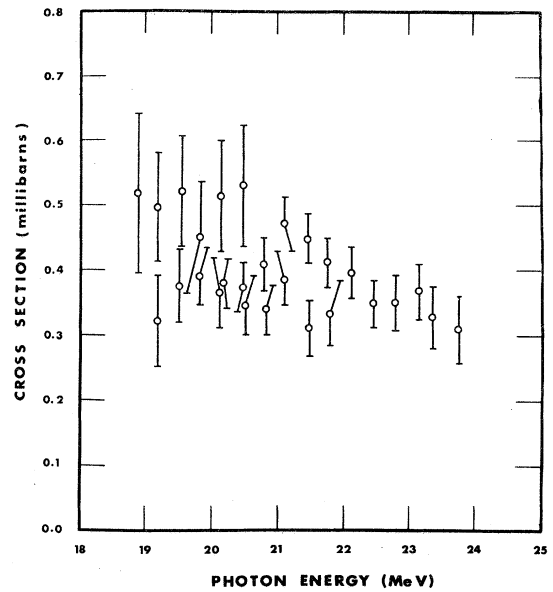

FIG. 2. Phototriton cross section obtained from data taken at three different magnet settings. The errors are greater than statistical, because of uncertainty in subtracting the proton transmission tail underlying the triton peak.

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[13] A. P. Komar and E. D. Makhnovsky, Dokl. Akad.

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PHYSICAL SIGNIFICANCE OF OPTICAL-MODEL PARAMETERS*

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A recent optical-model analysis of 30-MeV proton-scattering data[1] indicated that the radius parameter for the spin-orbit interaction was approximately 10% less than that for the real central interaction. A similar result has been noted at 10,[2] 14,[3] 18,[4] and 40 MeV.[5] At 30 MeV the averaged radius and diffuseness parameters for nuclei with A from 40 to 208 were 1.20 F, 0.7 F for the real central potential, and 1.10 F, 0.7 F for the spin-orbit potential, using a Saxon-Woods form and a Thomas form, respectively.

The difference between the radii for the real central potential and the spin-orbit potential of the optical model can be interpreted in terms of the interaction of the incident proton with the nuclear matter distribution via the two-body nucleon-nucleon force. To do this it is necessary to recognize the particular components of the two-body force giving rise to the two potentials and to adopt an appropriate folding procedure. In a first approximation neglecting target polarization and exchange effects, the folding procedure for the real central potential consists essentially of adding mean-square radii[6] with the dominant contribution coming from the "direct" (spin- and isospin-independent) part of the nucleon-nucleon potential. Phenomenological two-body potentials which are commonly accepted have mean-square radii for the attractive part of the "direct" component in the range 2.5-3.5 F^2. The precise value within this range is not critical for the present purpose and a value of 3 F^2 is taken which is the mean-square radius appropriate to a two-pion exchange mechanism.[7]

An indication that the approximations involved here are reasonable can be obtained from a consideration of alpha-alpha scattering where a great deal has been done using the resonating-group formalism.[8] In this case, using fully antisymmetrized wave functions, the effective interaction between the two alpha clusters is given by a direct term and an exchange term. The direct term represents a local potential which arises from the direct part of the nucleon-nucleon potential and has a mean-square radius equal to the sum of the mean-square radii of the two alpha particles and the mean-square radius of the two-body potential. The exchange term, on the other hand, represents a nonlocal potential with a kernel which is l dependent.

These results have been used by Ali and Bodmer[9] to construct phenomenological alpha-alpha potentials for $l = 0$, 2, and 4 which fit the relevant phase shifts for center-of-mass energies up to about 20 MeV. These potentials consist of an attractive and a repulsive part. The attractive part is l independent and of significantly longer range than the repulsive part which depends upon the l value. Furthermore, the tail of the attractive part of the alpha-alpha potential corresponds to a central spin- and isospin-independent part of the nucleon-nucleon force with a range close to that for a two-pion exchange mechanism.

The resonating-group formalism, upon which these results are based, neglects the effects of mutual distortion of the alpha particles. This is not a serious limitation as far as the mean-square radius of the alpha-alpha potential is concerned since Herzenberg and Roberts[10] have shown that the polarization potential resulting from this mutual distortion has a range similar to that of the exchange part (i.e., of shorter range than the direct term) and is relatively small in magnitude.

Thus for the alpha-alpha potentials the direct term has an appreciably longer range than the exchange and polarization terms. It seems reasonable to expect that a similar circumstance exists in the nucleon-nucleus case where, in addition, it has been estimated by Drell[11] that