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HIGH-ENERGY PHOTONUCLEAR DEUTERONS AND TRITONS

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The ratios of (γ, d) to (γ, p) cross sections for 15.5 — 30 Mev protons and deuterons produced by bremsstrahlung of $E_{\gamma\,max} \approx 90$ Mev are given as function of atomic number A for 14 elements from Li^6 to Au. For medium and heavy nuclei $\sigma(\gamma, d)/\sigma(\gamma, p) \sim A^{5/3} Z$, corresponding to the picture of production of photodeuterons in the capture process. The energy dependence of $\sigma(\gamma, d)/\sigma(\gamma, p)$ is given for Li^6 and Li^7, together with the energy distribution of photodeuterons from Li^6 and Li^7 and of phototritons from Li^7. A relatively large yield of high-energy phototritons from Li^6, Li^7 and B was observed. The angular distributions of photoprotons and photodeuterons from Li^6, Li^7, Be, and C are compared. The shape of the experimental photodeuteron angular distributions is found to agree with those computed on the assumption that the photodeuterons are produced in the capture process. Angular distributions of high-energy phototritons from Li^6, Li^7 and Be are also given.

1. INTRODUCTION

In the study of deuterons and protons of energy > 15 Mev produced in photodisintegration of the nucleus by bremsstrahlung of $E_{\gamma\,max} \approx 90$ Mev, ratios $\sigma(\gamma, d)/\sigma(\gamma, p)$ were obtained previously[1] for Be and C as functions of particle energy E_d and E_p, as well as the energy dependence of $\sigma(\gamma, d)$ In this work, a rough, semi-empirical analysis was carried out, assuming that the photodeuterons are produced in the so-called capture process. This gave results in good agreement with the experimental data. It was noted that analogous experimental data on photodeuterons of energy > 40 Mev produced[2] in photodisintegration of the nucleus by bremsstrahlung of $E_{\gamma\,max} \approx 300$ Mev could also be interpreted as following from this capture mechanism. Further light would be shed on the mechanism of the (γ, d) reaction by establishing such important characteristics as the dependence of photodeuteron yield on atomic number A and by obtaining angular distributions, and comparing these with the same characteristics for photoprotons.

In work carried out with the Pennsylvania betatron[3-5] with $E_{\gamma\,max} = 24$ Mev, using the method of counting grains in photoemulsion tracks, the following data on the yields $Y(\gamma, d)/Y(\gamma, p)$ of photodeuterons relative to photoprotons for energies up to 10 Mev were found: Cu[3], 0.31; In[4], < 0.01, Ce, 0.04; Bi, 0.01; Co[5], < 0.02. The large fluctuations in the ratio $Y(\gamma, d)/Y(\gamma, p)$ from element to element would seem to establish the basic influence of the specific structure of the nucleus on the yield of photodeuterons, whereas a similar effect on the yield of photoprotons, at least for Cu and Co, was not observed. However, Forkman[6] showed later, using bremsstrahlung of $E_{\gamma\,max} = 30$ Mev and the same method of detecting protons and deuterons, that it was impossible to identify protons and deuterons for each individual track by the method of grain counting in the energy region studied, and that some possibility of separating deuterons from protons could be realized only by a statistical processing of the data for a large number of tracks. Forkman found the following ratios $Y(\gamma, d)/Y(\gamma, p)$ for Co and Cu: Co, 0.22; Cu, 0.16, which are not very different. Using the same method, Makhnovskiĭ obtained $Y(\gamma, d)/Y(\gamma, p) = 0.14$ for Au.

It is clear that these works suffer from the shortcoming of poor statistical accuracy. Values for the ratio $Y(\gamma, d)/Y(\gamma, p)$ of 0.76 and 0.15 were obtained for Cu[8] and S[9], respectively, with γ rays from a synchrotron with $E_{\gamma\,max} = 65$ Mev using a Wilson chamber in a magnetic field. Here, again, a surprisingly large number of photodeuterons were found in the case of Cu. In preliminary data of the Cornell group,[10] who used a synchrotron with $E_{\gamma\,max} \approx 300$ Mev and studied the high-energy protons and deuterons with a scintillation telescope of two crystals, the ratios $Y(\gamma, d)/Y(\gamma, p)$ increased gradually for a series of elements from 0.12 for C to 0.24 for Pb. The ratio $Y(\gamma, d)/Y(\gamma, p)$ of 0.21 for Be stood out. Comparison of relative yields of photodeuterons of a given energy produced by bremsstrahlung of $E_{\gamma\,max} \approx 90$ Mev[1] and $E_{\gamma\,max} \approx 300$ Mev[2] shows a substantial difference in the magnitudes of the yields. This fact shows that in comparing yields of photodeuterons from different nuclei, it is necessary to compare yields obtained for the same value of $E_{\gamma\,max}$.

In the data obtained on the Cornell synchrotron with $E_{\gamma\,max} = 300$ Mev, the photodeuterons from C, Cu, Ag and Pb of energies near 40 Mev have approximately the same angular distribution as photoprotons of the same energy.[10] It was found on the synchrotron of the Physico-Technical Institude with $E_{\gamma\,max} \approx 90$ Mev that photodeuterons from Be of energy greater than 18 Mev have an angular distribution analogous to that of photoprotons[1] in the interval 40 — 90°. These works exhaust the published information that we know of on the angular dependence of (γ, d) reactions. It can be seen that the questions noted above require further investigation.

In the present work the relative yields of (γ, d) and (γ, p) reactions were studied for a wide interval of mass numbers from Li to Au for protons and deuterons of energy 15 to 30 Mev, produced by bremsstrahlung with $E_{\gamma\,max} \approx 90$ Mev. In order to elucidate possible fluctuations in the yields of photodeuterons, nuclei of neighboring mass, but different occupation of upper nucleon shells, were chosen. The angular distributions of photodeuterons from the photodisintegration of the light nuclei Li^6, Li^7, Be, and C were also studied and compared with angular distributions of photoprotons of the same energy. In addition, some information about high-energy phototritons was obtained.

2. EXPERIMENTAL ARRANGEMENT AND DISCRIMINATION BETWEEN PARTICLES

Fast charged particles — products of the photodisintegration of the nucleus — were counted and identified by a telescope of scintillation counter-spectrometers. This was done by measuring $\Delta E \sim dE/dx$ of the particle, from the pulse of the first counter which had a thin crystal, and the energy E of the particle lost in the thick crystal of the rear counter. This method has been described in detail previously.[1] Measurements were carried out with four independent telescopes, each of which could be set at arbitrary angle to the direction of the γ-ray beam, at a definite distance from the target held strictly the same for all telescopes. The particle yields were studied mainly at 90°. Angular distributions were determined from measurements at 35, 57.5, 80, 102.5, 125, and 145° relative to the direction of the γ-ray beam in both left and right parts of the hemisphere, centered upon the target. Different telescopes gave the same results, within the limits of statistical errors, when placed at the same angles. Readings of the telescopes at each angle were lumped together. Targets for the angular distributions consisted of hollow cylinders with thick walls, corresponding to the range of protons of energy about 4 Mev, and for measurements of yields, of rectangular plates. The targets were placed in a vacuum chamber in order to exclude background due to nuclear reactions in air. The absolute intensity of γ rays was measured using a thick-walled ionization chamber, calibrated by the calorimetric method of Kruglov.[11]

Distributions of particles with ΔE and E for boron and cobalt are given in Figs. 1 and 2. In Fig. 1, which relates to boron, three distinct groups of particles registered by the telescope are seen. From measurements of ΔE and E, they are identified as protons, deuterons and tritons. In the case of cobalt, there are only two distinct groups of particles, lying in the regions of protons and deuterons, and only a few points fall in the triton region although the number in the deuteron region is about the same as for boron. The results for these and for all other nuclei were ob-

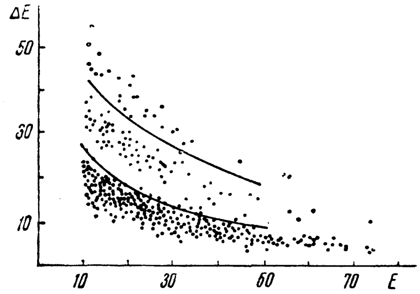

FIG. 1. Distribution of particles for B with energy ΔE lost in the first thin crystal of the scintillation telescope, and energy E absorbed in the rear thick crystal. ΔE and E are given in arbitrary units. The solid lines give the calculated upper limits of proton and deuteron regions.

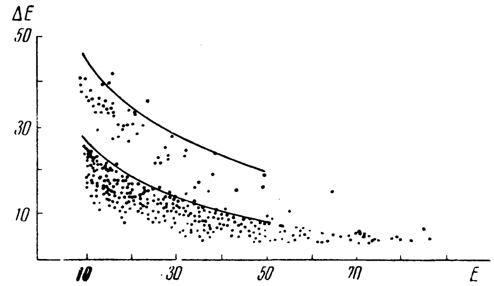

FIG. 2. Same as Fig. 1, but for Co.

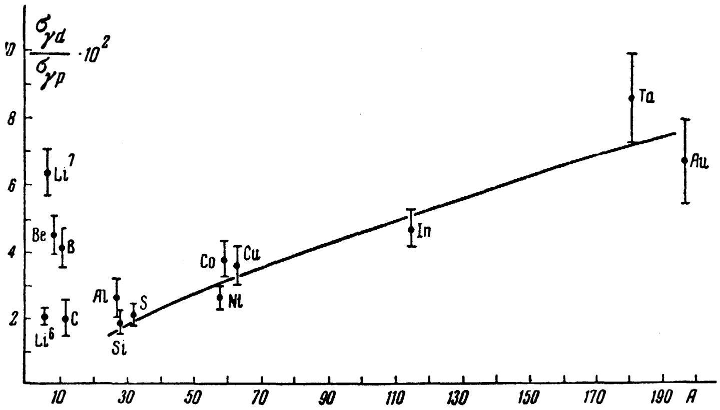

FIG. 3. Ratio of (γ, d) to (γ, p) cross sections for protons and deuterons of energies 15.5–30 Mev as function of atomic weight A. The solid curve shows the dependence given by Eq. (2), arbitrarily normalized.

tained by a frequent interchange of targets, so as to avoid errors from any uncontrollable fluctuations in the apparatus. The reproducibility of the results was very satisfactory.

The yields of phototritons were estimated in the following way. A calculated curve connecting E with ΔE for protons was normalized to the upper limit of the proton region which was very sharply defined so that above this curve lay only a negligible number of proton points. After such a normalization, the calculated upper limit to the deuteron region was determined. Points above the upper deuteron limit can relate only to tritons. In Figs. 1 and 2 these calculated curves are represented by solid lines. With this method, points relating to tritons, but falling in the region below the calculated upper limit for deuterons, are naturally not taken into account. However, from Fig. 1, where the whole triton region is displayed more or less distinctly, it can be seen that the loss of points from the lower tail of the triton distribution is insignificant. The measurements include protons and deuterons of energy 15.5 – 30 Mev and tritons of energies 17 – 30 Mev.

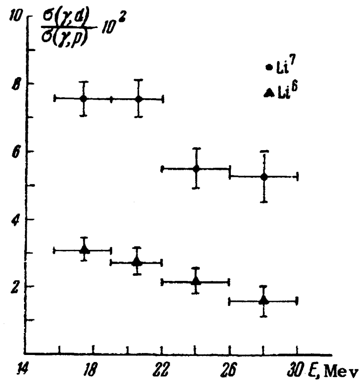

FIG. 4. Dependence of the ratio of (γ, d) to (γ, p) cross sections on the particle energy E for Li^6 and Li^7.

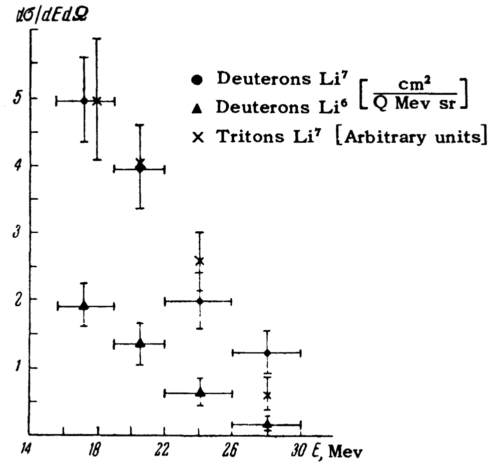

FIG. 5. Energy distributions of photodeuterons from Li^6 and Li^7 and phototritons from Li^7. The scale of the ordinate for phototritons is arbitrary.

3. EXPERIMENTAL RESULTS

The ratios of $\sigma(\gamma, d)/\sigma(\gamma, p)$ of cross sections for (γ, d) and (γ, p) reactions for protons and deuterons of energy 15.5 – 30 Mev are given in Fig. 3 as function of mass number A for 14 elements. The data are for angle $\theta = 90°$ relative to the direction of the γ rays. For the Li^6 and Li^7 targets, $\theta = 80°$. Only statistical root-mean-square errors are indicated. Figure 4 shows the energy dependence of $\sigma(\gamma, d)/\sigma(\gamma, p)$ for Li^7 and Li^6. This was obtained by summing data for angles 35 to 145°. The energy distributions of photodeuterons at $\theta = 80°$ for Li^7 and Li^6 are given in Fig. 5 in units of cm^2/Q Mev-sr. For comparison, the energy distribution of phototritons from Li^7, obtained by summing tritons at angles 35, 57.5, 80, 102.5, 125, and 145° is given in the same figure. The ordinate gives numbers of tritons in arbitrary units. In all cases, only statistical errors are indicated. The error in measurement of the absolute cross section was estimated to be ± 35%.

Relative yields of phototritons in numbers of phototritons per 100 deuterons are given in Table I. Here the data for Li^6, Li^7, and Be was obtained by summing results for angles 35, 57.5, 80, 102.5, 125, and 145° relative to the γ rays.

TABLE I

Element	$100N_t/N_d$	Element	$100N_t/N_d$	Element	$100N_t/N_d$	Element	$100N_t/N_d$
Li^6	30±3	B	39±8	Ni	10±4	In	5±2.5
Li^7	22.5±2.5	Si	10±4	Co	2.5±2	Ta	10±4
Be	13±2.6	S	8±4	Cu	2.2±2	Au	3±3

The data for the other elements relate to 90° and, because of large statistical errors, can serve as only preliminary estimates of the yields of fast phototritons.

It should be noted that the yield of photoprotons of the energy considered rises smoothly with Z for the elements plotted in Fig. 3, and that starting already with Al, no direct proportionality to Z is observed on account of the effect of the Coulomb barrier. For illustration, we give the yields of photoprotons $Y(\gamma, p)$ per proton in the nucleus for several elements in relative units (the error in these measurements was estimated to be ±10%):

	Li^6	Li^7	Be	C	Al	Cu
$Y(\gamma, p) =$	1.49	1.57	1.5	1.31	1.00	0.56

Angular distributions of photoprotons of energies 15.5 – 30 Mev are given in Fig. 6 for Li^6, Li^7,

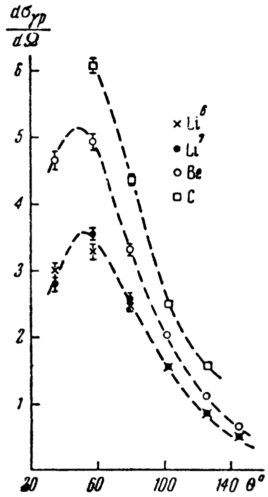

FIG. 6. Angular distributions of photoprotons of energies 15.5–30 Mev for Li^6, Li^7, Be, and C. The errors are statistical.

Be, and C. The cross section for (γ, p) reactions is plotted, in relative units, along the ordinate, and the angle between the axis of the telescope and the direction of the γ-ray beam, along the abscissa. Only statistical errors are indicated. The dashed lines show smoothed curves, characterizing the form of the experimental angular distribution of photoprotons.

Figure 7 shows the angular distributions of photodeuterons of energies 15.5 - 30 Mev from the same nuclei. The cross section for (γ, d) reactions is plotted along the ordinate in relative units, against the abscissa, the same angle as in Fig. 6.

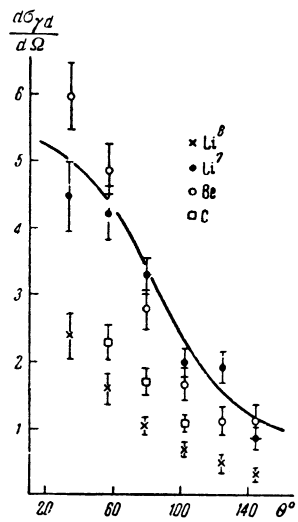

FIG. 7. Angular distributions of photodeuterons of energies 15.5–30 Mev for Li^6, Li^7, Be, and C. The errors are statistical. The solid curve gives the calculated results for photodeuterons from Be.

Figure 8 displays the differences in the shapes of the angular distributions of photoprotons and photodeuterons from Li^7, Li^6, and Be, the ordinate giving the ratios of (γ, d) to (γ, p) cross sections in percentages. The dashed line is a smoothed curve characterizing the shape of the ratio $\sigma(\gamma, d)/\sigma(\gamma, p)$ as a function of angle relative to the γ-ray beam. In Figs. 7 and 8, only statistical errors are shown.

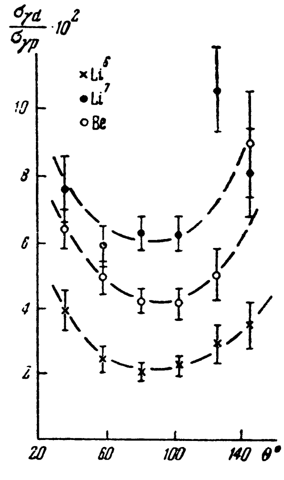

FIG. 8. Angular dependence of the ratio of (γ, d) to (γ, p) cross sections for Li^6, Li^7, and Be. The errors are statistical.

Figure 9 shows the angular distributions of phototritons of energy 17 – 30 Mev from Li^7, Li^6, and Be. In this case the indicated errors can be seen to be rather large; therefore, the results given in Fig. 9 should be considered preliminary. The cross section for (γ, t) reactions is given in

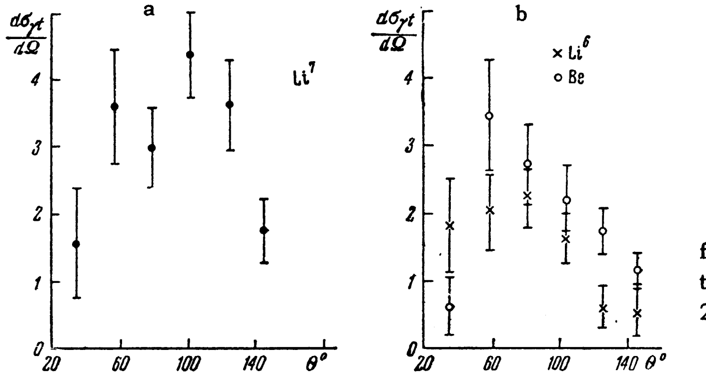

FIG. 9. Angular distributions of phototritons of energies 17–30 Mev for Li^7, Li^6, and Be. a – Li^7; b – Li^6 and Be. The scale is the same in a and b. The errors are statistical.

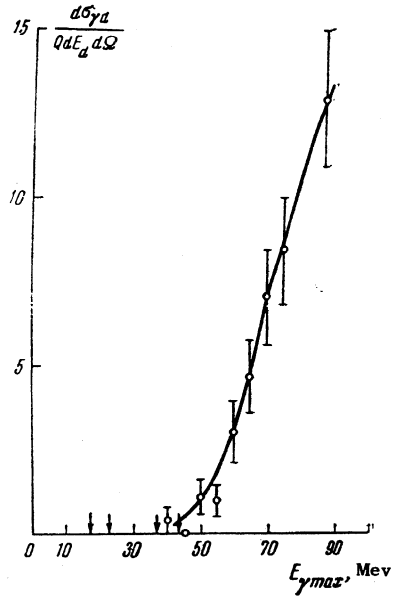

FIG. 10. Excitation function for photodeuterons of energies 15.6–22 Mev from Li^6.

relative units. Some quantitative comparisons of these cross sections with the cross sections for (γ, d) and (γ, p) reactions are given in Table II for 80° and the above intervals of particle energy.

TABLE II

	$\sigma_{\gamma p}\cdot 10^{30}$, $\frac{\text{cm}^2}{\text{Q-sr}}$	$\frac{\sigma_{\gamma d}}{\sigma_{\gamma p}}\cdot 10^2$	$\frac{\sigma_{\gamma t}}{\sigma_{\gamma p}}\cdot 10^2$
Li^7	66.0±1.3	6.3±0.55	1.0±0.25
Li^6	62.5±1.3	2.10±0.25	0.79±0.20

4. DISCUSSION OF EXPERIMENTAL RESULTS

a) Yields. The experimental results shown in Fig. 3 make it possible to show the main features of the dependence of the ratio $\sigma(\gamma, d)/\sigma(\gamma, p)$ on atomic number A. It can be seen that this ratio decreases in the region of light nuclei but, in the region of medium (beginning with $A \approx 30$) and heavy nuclei, gradually rises with increasing A. For neighboring nuclei, in particular, for Co and Cu, the ratios $\sigma(\gamma, d)/\sigma(\gamma, p)$ are very close to each other. An exception is Li^6 where the reaction $Li^6(\gamma, d)He^4$, which is energetically favorable for the absorption of electric dipole γ rays, is forbidden by isotopic-spin selection rules.[12] Such a reaction can proceed by magnetic-dipole and electric-quadrupole absorption of γ rays. In addition, the reactions $Li^6(\gamma, d)He^3 + n$ and $Li^6(\gamma, d)H^3 + p$ are not forbidden also in the case of electric-dipole absorption, but have a high energy threshold. The excitation function for photodeuterons of energy 15.6 – 22 Mev is given for Li^6 in Fig. 10. The maximum bremsstrahlung energy is plotted along the abscissa, and the cross section for (γ, d) reactions per effective quantum, in relative units, along the ordinate. The arrows in the region $E_{\gamma\,max} = 20$ Mev delimit the region of the energy threshold for the reaction $Li^6(\gamma, d)He^4$ for the given case. The arrows in the region of 40 Mev delimit the region of threshold for the reactions $Li^6(\gamma, d)He^3 + n$ and $Li^6(\gamma, d)H^3 + p$. It is seen that the (γ, d) reaction becomes large in Li^6 only for γ-ray energy above the second threshold region. Because of this, it is clear why the ratio $\sigma(\gamma, d)/\sigma(\gamma, p)$ is so much smaller for Li^6 than for Li^7.

When the capture mechanism is operative, the (γ, d) reaction can be considered to take place in two stages. In the first stage, the γ ray is absorbed by the proton or neutron in the nucleus, and in the second stage, the excited nucleon picks up a second nucleon, forming the emitted deuteron. If we assume such a process, then the ratio $\sigma(\gamma, d)/\sigma(\gamma, p)$ can be written in the following form:

$$\frac{\sigma(\gamma,\, d)}{\sigma(\gamma,\, p)} \sim \frac{[\sigma'(\gamma,\, p) + \sigma'(\gamma,\, n)]\, P_3 F_d}{\sigma'(\gamma,\, p)\, F_p}. \qquad (1)$$

Here, $\sigma'(\gamma, p)$ and $\sigma'(\gamma, n)$ are the cross sections for (γ, p) and (γ, n) reactions neglecting the potential barrier, P_3 is some average probability of the proton or neutron capturing a second nucleon with emission of a deuteron, F_d and F_p are barrier penetrabilities for deuterons and protons, respectively. On the basis of work carried out to date,[13,14] one can take $[\sigma'(\gamma, p) + \sigma'(\gamma, n)] \sim A$ and $\sigma'(\gamma, p) \sim Z$. Further, it is natural to consider that such a weakly bound system as the deuteron can be formed and emitted from medium and heavy nuclei mainly from the surface region only; consequently, one can assume that $P_3 \sim A^{2/3}$. Finally, the ratio F_d/F_p for medium and heavy nuclei depends only weakly on A. Thus, one can expect that if the capture mechanism is operative, the dependence of $\sigma(\gamma, d)/\sigma(\gamma, p)$ on A will go roughly as

$$\sigma(\gamma,\ d)/\sigma(\gamma,\ p) \sim A \cdot A^{2/3}/Z. \qquad (2)$$

The solid curve in Fig. 3, normalized arbitrarily to experimental results, reproduces the dependence (2). It can be seen that the calculated curve reproduces the trend of experimental ratios $\sigma(\gamma, d)/\sigma(\gamma, p)$ rather well. Equation (2) is, of course, not applicable in the region of light nuclei, where the concept of nuclear surface loses meaning because of the small number of nucleons. The ratios $\sigma(\gamma, d)/\sigma(\gamma, p)$ for high-energy deuterons ($\approx$ 40 Mev) produced[10] by bremsstrahlung with $E_{\gamma \max}$ = 310 Mev, are 0.21 for Be, 0.12 for C, and 0.24 for Pb. Noting that $\sigma(\gamma, d)/\sigma(\gamma, p)$ here increases gradually with increasing A between C and Pb,[10] we come to the conclusion that the dependence of $\sigma(\gamma, d)/\sigma(\gamma, p)$ on A has the same character at high energies as that shown in Fig. 3 of this article. There is a difference, in that the ratios $\sigma(\gamma, d)/\sigma(\gamma, p)$ obtained in reference 10 are substantially larger. This fact was explained by the semi-empirical calculations based on the capture mechanism.[1] The energy dependence of the ratios $\sigma(\gamma, d)/\sigma(\gamma, p)$ for Li^6 and Li^7 and the energy distributions of photodeuterons given in Figs. 4 and 5 are, in the main, similar to those for Be and C given in reference 1.

In Table I, where the relative yield N_t of fast phototritons is given, it can be seen that for all nuclei given, with the exception of Li^6, Li^7, and B, the magnitude of the ratio $\sigma(\gamma, t)/\sigma(\gamma, d)$ is about the same, within the limits of statistical error, as the magnitudes of the ratio $\sigma(\gamma, d)/\sigma(\gamma, p)$ for the same nucleus. It is possible that these phototritons are produced by a mechanism of double capture. The noticeable larger yield of phototritons from Li^6, Li^7 and B is striking. From Fig. 5 it is seen that the shape of the energy distribution of phototritons from Li^7 is similar to the energy distribution of photodeuterons.

b) Angular distributions. It can be seen from Figs. 6 and 7 that the angular distributions of photoprotons and photodeuterons in the same energy interval are rather similar in shape. However, it is striking that the shapes of the angular distributions of photodeuterons are completely different in one definite characteristic. This is especially clear in Fig. 8 for Li^6, Li^7, and Be. The characteristic difference consists in the fact that the cross section for (γ, d) reactions drops much less quickly with increasing angle in the large angle region, and in the small angle region does not have such a sharp drop as that observed in the (γ, p) cross section. The fact that the form of the angular distribution of the (γ, d) cross section resembles that of the analogous (γ, p) distribution, does not qualitatively contradict the earlier assumption,[1] justification for which was given in reference 1, that the deuterons are formed in the process of capture. We can try, on the basis of this assumption, to estimate the shape of the angular dependence of the (γ, d) reactions. Under this assumption, the γ ray is absorbed by a single nucleon in the nucleus and the excited nucleon either goes right out of the nucleus at angles θ', φ' to the γ-ray beam, or, with a definite probability, picks up another nucleon to form a deuteron emitted at angles θ, φ. Then, in a rough approximation, the angular distribution for (γ, d) reactions looks like

$$\frac{d\sigma_{\gamma d}(\theta,\ \varphi)}{d\Omega} \sim \int_0^{\pi}\int_0^{2\pi}\left[\frac{d\sigma_{\gamma p}(\theta',\ \varphi')}{d\Omega'} + \frac{d\sigma_{\gamma n}(\theta',\ \varphi')}{d\Omega'}\right] P_3(\omega)\, d\Omega'. \qquad (3)$$

When applied to results given in Fig. 7, $d\sigma_{\gamma d}(\theta, \varphi)/d\Omega$ denotes the cross section for the (γ, d) reaction at angles θ, φ, integrated over photodeuteron energy from 15.5 to 30 Mev, while $d\sigma_{\gamma p}(\theta', \varphi')/d\Omega$ and $d\sigma_{\gamma n}(\theta', \varphi')\, d\Omega'$ are the cross sections for (γ, p) and (γ, n) reactions at angles θ', φ', integrated over energies from the minimum value for which the proton and neutron can form a deuteron of energy E_d = 15.5 Mev to the maximum observed in the experiment. The connection between the energy of the photodeuteron and the energy of the photoproton (photoneutron) which would be emitted without formation of a photodeuteron, is found from energy conservation for (γ, p) and (γ, d) reactions in which the residual nucleus is formed in its ground state. $P_3(\omega)$ is some capture probability, averaged over deuteron energy and depending on angle ω between the directions of emission of the proton (or neutron) and deuteron. In carrying out the calculations for Be, one can consider the angular dependence of the (γ, n) reaction[15] to be very near in form to that of the (γ, p) reaction. Consequently, we need only the dependence of $d\sigma_{\gamma p}(\theta', \varphi')\, d\Omega'$, given directly by experiment. This dependence is not shown separately, since it does not differ essentially from that given in Fig. 1. In analogy with the usual capture process,[16,17] the angular distribution of the probability of capture can be written, in a well-known approximation, as

$$P_3(\omega) \sim N(\mathbf{n}) \sim e^{-E'/E_0}, \qquad (4)$$

where $N(\mathbf{n})$ is the distribution function of nucleon momentum in the nucleus, E' is the energy of the captured nucleon in the nucleus, $E_0 \approx 20$ Mev for Be[18]. For the dependence of the averaged capture probability on angle ω in Eq. (3), we substituted $P_3(\omega)$ calculated for some mean deuteron energy in the interval 15.5 – 30 Mev studied.

Results of the calculations for photodeuterons from Be, using Eqs. (3) and (4), are given in Fig. 7 by the solid line, arbitrarily normalized to the experimental data. It is seen that agreement between the calculation and experiment is rather good. Everything said above applies also to photodeuterons from Li^7, and since the dependence of $d\sigma_{\gamma p}(\theta', \varphi')/d\Omega'$ and $P_3(\omega)$ for Li^7 and Be are very similar, the calculated results agree well with experiment also in the case of Li^7. Consequently, by application of the capture mechanism, one can explain not only the rough similarities of the characteristics of angular distributions of photoprotons and photodeuterons, but also the difference between them, as shown in Fig. 8.

The angular distributions of high-energy phototritons from Li^7, Li^6, and Be given in Fig. 9, differ markedly in form from the angular distributions of photodeuterons and, it would appear, could not be explained by a mechanism analogous to double capture in (p, t) and (n, t) reactions. The dependence of the (γ, t) cross section on angle is approximately as $A + B \sin^2\theta$. It is possible that here direct electric-dipole absorption of γ rays by quasitritons formed inside the nucleus takes place. The probability that these exist part of the time cannot be excluded.

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