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Abstract

Full Text

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LOW-ENERGY DEUTERONS AND TRITONS IN THE PHOTODISINTEGRATION OF Li^6

Using thick-layer nuclear emulsions, the energy spectra and yields of charged particles arising upon irradiation of Li^6 with bremsstrahlung radiation with $E_{\gamma\,\max} = 35$ MeV were studied. To identify the charged particles, a specially designed vacuum chamber ([1]) was used, placed in a homogeneous magnetic field ($H = 13\,500$ Oe) approximately perpendicular to the direction of emission of the particles recorded by photographic plates. The target, containing 90% Li^6 and 10% Li^7, had dimensions 1.3×0.4 cm^2. The thickness of the target was 6.4 mg/cm^2. Particles were analyzed for which the emission angle with respect to the γ-beam was $50 \div 120°$. For particle identification, in addition to ranges, the orientations of their tracks in the emulsion were determined. Measurement inaccuracies in particle identification were taken into account by constructing the corresponding "error zones." Measurements were carried out at a microscope magnification of 1350×. Irradiation doses were measured with a quantometer ([2]). To estimate the background arising from scattered neutrons and γ-quanta, a separate irradiation was carried out with no target in the chamber. After the corresponding processing and reduction of the results of the background experiment to the irradiation dose of the main experiment, the background was subtracted. All background particles had a range in the emulsion $< 50\ \mu$. For $R < 50\ \mu$, the background in the proton zone was about 50%, in the triton zone about 15%, and in the deuteron zone $< 30\%$. The low-energy region of protons, owing to the high background level and large energy losses in the target, was not considered.

Figure 1a shows the distribution of charged photoparticles by the angles of magnetic deflection β and by ranges R in the emulsion in the case $R < 50\ \mu$. As can be seen, the largest number of particles is in the triton zone. The α-particle zone practically coincides with the triton zone. According to the estimate made, 20–25% of the particles present in the $(\alpha - t)$-zone are α-particles. The error zone for He^3 nuclei approximately coincides with the deuteron zone. He^3 nuclei could have made a noticeable contribution only for $R < 10\ \mu$. Particles in the $(d - He^3)$-zone with such ranges were not taken into account in the subsequent analysis. Particles falling into the region of overlap of the zones were identified as deuterons or as tritons, taking into account the weight of these particles in the nonoverlapping part of the zones for each range interval.

Fig. 1. Distribution of charged particles arising in photodisintegration of Li6, by angles of magnetic deflection and by ranges R in emulsion: a –R $\leq$ 50 μ; b –R $\geq$ 50 μ. 1 –proton zone, 2 –deuteron zone, 3 –triton zone

Figure 1: Fig. 1. Distribution of charged particles arising in photodisintegration of Li6, by angles of magnetic deflection and by ranges R in emulsion: a –R $\leq$ 50 μ; b –R $\geq$ 50 μ. 1 –proton zone, 2 –deuteron zone, 3 –triton zone

Figure 1b presents the distribution in β and R for photoparticles with range $\geq 50\ \mu$. Most of them are protons.

It is seen from Fig. 1 that the yield of tritons from Li^6 is comparable with the yield of protons. The yield of photodeuterons is also considerable. According to the estimate, the ratio of the deuteron yield to the triton yield for particle energies from 1.2 to 4.8 MeV is

$$Y_d/Y_t = 0.25^{+0.15}_{-0.06}.$$

The occurrence of a considerable number of low-energy deuterons in the present case can be explained only by three-particle decays of Li^6 into a neutron, deuteron, and He^3 nucleus, or into a proton, deuteron, and triton. In the absence of interaction of the particles formed in the final state, the energy distribution of any one of them has the form

$$W(E)\,dE \sim E^{1/2}(E_{\max} - E)^{1/2}\,dE,$$

where $E_{\max} = (E_\gamma - Q)\dfrac{M - m_i}{M}$ is the maximum possible energy in the spectrum of particles with mass m_i; Q is the threshold energy of the reaction; M is the mass of the initial nucleus. In this case the mean energy in the spectrum of particles with mass m_i is $\bar{E} = E_{\max}/2$. The accuracy of our data is insufficient for constructing a reliable experimental energy distribution of photodeuterons. However, the data

Fig. 1. Distribution of charged particles arising in the photodisintegration of Li^6, by angles of magnetic deflection and by ranges R in emulsion:
a –$R \leqslant 50\,\mu$; b –$R \geqslant 50\,\mu$.
1 –proton zone, 2 –deuteron zone, 3 –triton zone

allow one to assert that most deuterons have energies from 1.2 to 4.8 MeV, and the mean value of the energy in the spectrum is $\bar{E}_d = 2.7$ MeV. If one averages the threshold energies of the reactions $\mathrm{Li}^6 + \gamma \to \mathrm{p} + \mathrm{d} + \mathrm{t}$, $\mathrm{Li}^6 + \gamma \to \mathrm{n} + \mathrm{d} + \mathrm{He}^3$, then, according to the relations given, the obtained value $\bar{E}_d$ should correspond to a maximum in the summed excitation function of the reactions considered at $E_\gamma = 29.8$ MeV.

Fig. 2 and Fig. 3

Figure 2: Fig. 2 and Fig. 3

It should be noted that the value $\bar{E}_d$ given above does not contradict the possibility of three-particle decays of Li^6 also through intermediate highly excited nuclei Li^5 and He^5. If one averages the threshold energies of the reactions $\mathrm{Li}^6(\gamma,\mathrm{p})\mathrm{He}^{5*} \to \mathrm{d}+\mathrm{t}$, $\mathrm{Li}^6(\gamma,\mathrm{n})\mathrm{Li}^{5*} \to \mathrm{d}+\mathrm{He}^3$, then at $\bar{E}_\gamma \simeq 30$ MeV the indicated mean energy of deuterons, according to the kinematics of the process, corresponds to the level of $\mathrm{He}^5(\mathrm{Li}^5)$ at $E^* \simeq$ (20–21) MeV. In (3) there is an indication of the possible existence in He^5 of an excited state at $E^*_{\mathrm{He}^5} \sim 20$ MeV.

Fig. 2 shows the energy distribution of phototritons. The spectrum was constructed under the assumption that all particles lying in the $(\alpha - t)$-zone are tritons. The dashed line in the figure shows the energy spectrum of tritons arising in the reaction $\mathrm{Li}^6(\gamma,pd)\mathrm{H}^3$. The spectrum was calculated, in accordance with the formulas given in the text, from the data obtained on the deuteron spectrum. It was assumed here that the number of deuterons due to the reaction $\mathrm{Li}^6(\gamma,pd)\mathrm{H}^3$ is equal to the number of deuterons arising in the reaction $\mathrm{Li}^6(\gamma,nd)\mathrm{He}^3$. It is clear that three-particle decays of Li^6 into a proton, a deuteron, and a triton can explain only a certain fraction of the phototriton yield. The large yield of tritons is more likely

Fig. 2. Energy distribution of phototritons from Li^6. The dashed line shows the calculated energy distribution of tritons due to

$$\mathrm{Li}^6 + \gamma \to p + d + t$$

Fig. 3. Excitation function of the reaction

$$\mathrm{Li}^6(\gamma,t)\mathrm{He}^3$$

to be associated primarily with two-particle decays of Li^6, i.e., with the reaction $\mathrm{Li}^6(\gamma,t)\mathrm{He}^3$, which, according to theoretical calculations of the nuclear photoeffect ([4]) carried out on the basis of the shell model, should have a significant cross section.

The approximate excitation function of the reaction $\mathrm{Li}^6(\gamma,t)\mathrm{He}^3$, calculated in accordance with the triton spectrum obtained by us, is shown in Fig. 3. The calculations were carried out assuming an isotropic angular distribution of phototritons, with allowance for the possible contribution of the reaction $\mathrm{Li}^6 + \gamma \to p + d + t$. The statistical errors are indicated. As can be seen from the figure, the maximum of the excitation function of the (γ,t) reaction is located at $E_\gamma \simeq 21$ MeV. The integral cross section

$$\int_{18.3}^{24.3} \sigma_{\gamma t}(E_\gamma)\, dE_\gamma \simeq (29^{+9}_{-16}) \text{ mb} \cdot \text{MeV}.$$

From the estimate of the integral cross section it follows that the two-particle channel of photodisintegration of Li^6 under discussion is one of the most substantial.

The energy spectrum of the selected protons with $E_p > 4$ MeV is similar in shape to the spectrum obtained in (^{5}).

The presence of a comparatively high yield of phototritons and photodeuterons of low energies from Li^6 is in qualitative agreement with the results of calculations carried out in (^{4}) on the basis of the shell model. However, it follows from the experiment that the decay of Li^6 into H^3 and He^3 occurs mainly not at 17–18 MeV, but at excitation energies of 19–23 MeV. The integral cross section of the (γ, t) reaction is apparently somewhat larger than the calculated one. The maximum of the sum-

of the total excitation function of the reactions $Li^6(\gamma, pd)H^3$, $Li^6(\gamma, nd)He^3$ is located at $E_\gamma = 29 \div 30$ MeV. In [4] it is assumed to be at $E_\gamma = 25 \div 26$ MeV. The ratio of the total integral cross section of the reactions (γ, pd) and (γ, nd) to the integral cross section of the reaction $Li^6(\gamma, t)He^3$, according to the calculations, is $0.6 \cdot 53/16 \simeq 2$. In accordance with the experimental results, the above-mentioned ratio is approximately 0.5. The indicated discrepancies can hardly be explained by the fact that deuterons and tritons with energies below 1 MeV were not studied in the experiment.

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Note: Figure translations are in progress. See original paper for figures.