EXCITATION FUNCTIONS FOR THE (γ, d) *AND* (γ, p) *REACTIONS IN* B^{10} *AND* Be^9

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The excitation functions for the (γ, d) and (γ, p) reactions of B^{10} and Be^9 are given. It is shown that the (γ, d) cross section has an appreciable magnitude only for photon energies that exceed the reaction thresholds by an amount approximately equal to the nucleon binding energy of the residual nucleus.

1. One of the authors [1] has previously obtained the dependence of the cross section of the reaction $Li^6(\gamma, d)$ as a function of the bremsstrahlung energy $E_{\gamma max}$ for deuterons in the energy interval 15.6—22 MeV. The cross section was given as a cross section per effective quantum. Figure 1 shows the excitation function of this reaction, i.e., the dependence of the cross section on the energy of the quanta per incoming γ quantum. The curve has been calculated with the assumption that the bremsstrahlung spectrum is of the form $n(E_\gamma)dE_\gamma = Q\,dE_\gamma/E_\gamma$. This approximation is sufficiently good in view of the statistical accuracy of the experiment. The arrow labelled d indicates the threshold of the reaction $Li^6(\gamma, d)He^4$ for the lowest kinetic energy of the detected deuterons. d_1 indicates the γ-ray energy sufficient to yield a measured deuteron and to break up the residual He^4 nucleus.

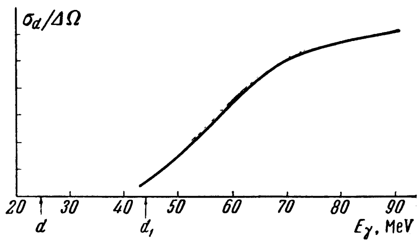

FIG. 1. Excitation cross section of the reaction $Li^6(\gamma, d)$ for deuterons of energies 15.6–22 MeV.

One sees from Fig. 1 that one of the peculiarities of the $Li^6(\gamma, d)$ reaction is that the cross section becomes appreciable only for γ-ray energies larger than d_1. As was remarked in [1] this could be explained by the selection rule which forbids E1 transitions in nuclei with equal proton and neutron number ($N = Z$) in which the isospin does not change ($\Delta T = 0$). However, this isospin selection rule holds only for γ-ray energies such that $kR \ll 1$ [2] (k is the wave number of the photon, R is the nuclear radius.) In the present experiment $kR \approx 1$. It is therefore possible that the indicated peculiarity of the $Li^6(\gamma, d)$ reaction is due not to an isospin selection rule but to some aspect of the structure of the Li^6 nucleus or of the production mechanism of photodeuterons. In order to clear up this question one has to perform analogous investigations for at least two isotopes of which in one case $N = Z$, in the other $N \neq Z$.

We have investigated the production of deuterons with energy above 15 MeV emitted at an angle $\theta = 90°$ in the photodisintegration of B^{10} and Be^9. The experimental method has been described earlier. [1]

2. In Fig. 2a are given the dependences on $E_{\gamma max}$ of the cross sections per effective quantum of the reactions $B^{10}(\gamma, p)$ and $B^{10}(\gamma, d)$. Figure 2b shows the excitation functions of these reactions. They were obtained from the smoothed experimental curves of Fig. 2a using the above approximation of the bremsstrahlung spectrum. The arrows labelled p and d indicate the thresholds for the reactions $B^{10}(\gamma, p)Be^9$ and $B^{10}(\gamma, d)Be^8$ respectively for the case where the kinetic energy of the outgoing particles is 15 MeV. The arrow d_1 indicates the sum of the threshold energy for the (γ, d) process and the binding energy of the "last" particle of the residual nucleus Be^8. The results, given in Fig. 2b show that, like the reaction $Li^6(\gamma, d)$, the reaction $B^{10}(\gamma, d)$ is also induced mainly by photons of energy larger than d_1. In both cases the cross section increases with increasing photon energy, up to 90 MeV, the top energy of the experiment.

The excitation function of the $B^{10}(\gamma, d)$ reaction for deuterons with energy larger than 22 MeV has a similar form; it will not be given in this paper.

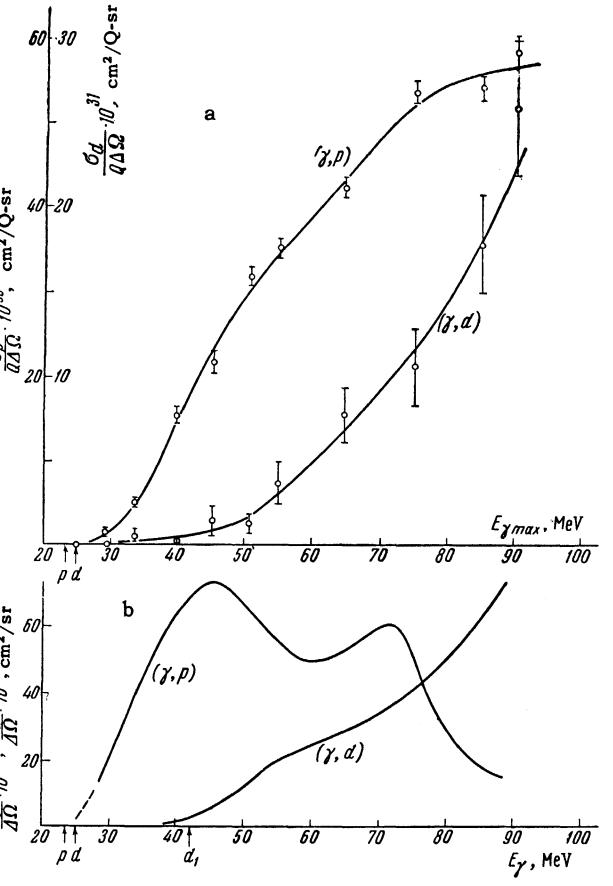

FIG. 2. a: cross section of the reactions B^{10} (γ, d) and B^{10} (γ, p) normalized per effective photon; b: excitation functions of the same reactions for particles of energies > 15 Mev.

Forgetting for the time being the smallness of the photon wavelength compared to the nuclear radius, the smallness of the cross section of the reaction B^{10}(γ, d) for photon energies between d and d_1 can also be explained by the forbidden character of E1 transitions with ΔT = 0. From this point of view the reaction sets in at such energies where the residual Be^8 nucleus can be left in a state with T = 1. The known T = 1 levels of Be^{8*} have an excitation energy E^* of ~ 17 and ~ 19 MeV.[3] The minimum photon energy for such transitions approximately coincides with d_1 in Fig. 2. If the deuterons were produced mainly in the reaction B^{10}(γ, d)Be^{8*} with E^* ~ 17 and ~ 19 MeV then the excitation function of this process should have a maximum for photon energies below 90 MeV. This does not agree with the experimental results. The observed trend of the excitation function can be explained by the action of the selection rule only if one assumes the existence of many T = 1 levels in Be^8 with excitation energies larger than 20 MeV.

The experimental excitation function of the reaction B^{10}(γ, d) is similar to that of the reaction Li^6(γ, d). One can thus conclude that the observed features of the reaction Li^6(γ, d) are not due to some individual peculiarities of the structure of Li^6.

3. The deuterons from the photodisintegration of Be^9 were investigated in a similar manner. The results are given in Fig. 3. The notation is same as in Figs. 1 and 2.

One sees from Fig. 3 that the cross section of the reaction Be^9(γ, d) also becomes appreciable only for photon energies larger than the sum of the threshold energy d and the binding energy of the most loosely bound nucleon of the residual nucleus Li^7. This indicates that in the reaction Be^9(γ, d) the processes playing the most important role are those in which the deuteron emission is accompanied by the emission of one or more nucleons.

Thus the increase of the "threshold" of the (γ, d) reaction occurs also in that case where the reaction is not hindered by the isospin selection rule.

It should be noted that the processes in which the emission of a photodeuteron is accompanied by the emission of a complex particle evidently

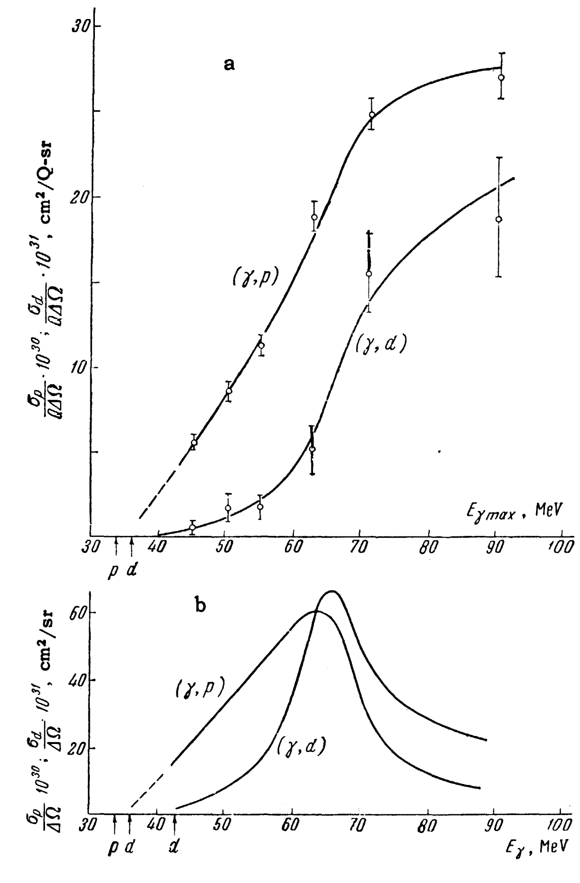

FIG. 3. The same as in Fig. 2, but for the reactions Be^9 (γ, d) and Be^9 (γ, p) (the nomenclature is the same).

have a low probability. Indeed, the residual nucleus Li^7 can emit a triton at an excitation energy ~ 2.5 MeV. However, according to experiment (see Fig. 3) the contribution of the reaction $Be^9(\gamma, d)Li^{7*}$, $Li^{7*} \rightarrow H^3 + He^4$ to the $Be^9(\gamma, d)$ reaction is small, in particular in the threshold region $E_{\gamma\,threshold}$ to $E_{\gamma\,threshold}$ + 5 to 6 MeV, above which begins the observed deuteron yield.

The above-described experiments reaffirm that the low cross section of the (γ, d) reaction, in an energy interval above threshold approximately equal to the nucleon binding energy in the residual nucleus, does not seem to be a peculiarity of nuclei with equal number of protons and neutrons but is observed also in different nuclei. Such an effect does not occur in the photoproduction of tritons.[4]

4. The probability of both reactions, $B^{10}(\gamma, p)$ and $Be^9(\gamma, p)$ increases monotonically with increasing photon energy (see Figs. 2 and 3) beginning at the threshold p, and reaches a maximum at a certain given energy. The position of this maximum is about 20 to 25 MeV above the threshold p. The natural explanation is that the protons are emitted in a broad energy spectrum. As the photon energy is increased the cross section for the reaction $Be^9(\gamma, p)$ begins to decrease. This shows that the protons are primarily associated with the reaction $Be^9(\gamma, p)Li^8$ where Li^8 is left in the ground state or a low excited state. On the other hand, the trend of the excitation function of the reaction $B^{10}(\gamma, p)$ indicates that in this process there exists a large contribution of transitions which lead to highly excited states of the residual nucleus Be^9, or of the quasideuteron mechanism of photon absorption.

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