FIZIKA, 2 (1970) 113-119

^{6}Li (^{3}He, d) ^{7}Be REACTION AT LOW ENERGIES

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Received 18 December 1969; revised manuscript received 3 March 1970

Abstract: The reactions ^{6}Li (^{3}He, d_0) $^{7}Be_{g.s}$ and ^{6}Li (^{3}He, d_1) $^{7}Be_{431}$ have been investigated for ^{3}He energy interval from 0.5 — 1.3 MeV by measuring the ^{7}Be 431 keV and ^{7}Li 478 keV gamma-rays resulting from the decay of ^{7}Be. The excitation curves for both reactions were obtained. Their analysis shows presence of a $\frac{1^+}{2}$ or $\frac{3^+}{2}$ state ($T = \frac{1}{2}$) in ^{9}B at 17.20 $\pm$ 0.02 MeV, with $\Gamma = 110 \pm 30$ keV, and of a direct mechanism contribution indicating that wave function extranuclear contribution is dominant in the region just above the reaction threshold.

1. *Introduction*

The ^{6}Li (^{3}He, d) ^{7}Be reaction has not yet been measured at low ^{3}He energies. It was investigated in the energy region from 8—18 MeV$^{1)}$ where a direct mechanism was demonstrated. Therefore it was of interest to measure the excitation curves for d_0 and d_1 groups from 0.5 — 1.3 MeV ^{3}He energy in order to:

a) check the presence of highly excited ^{9}B levels, which in the corresponding energy interval, until now were demonstrated only by the ^{7}B (d, p) ^{8}Be reaction$^{2)}$, and

b) investigate the mechanism of this reaction at lower energies.

2. *Experimental procedure and results*

The 1.5 MeV Cockcroft — Walton accelerator of the »Boris Kidrič« Institute was used for production of the ^{3}He beam. The beam analysis was made by an electrostatic analyser defining the ^{3}He energy to $\pm$ 3 keV. The beam was collimated and focussed at the centre of target chamber; the current corresponding to ^{3}He beam was, after its collection, measured by a current integrator. The targets were made of 96 % enriched ^{6}Li evaporated on nickel foil. After the absorption of oxygen they were typically about 50 μg/cm^2 thick. Since the deuteron energy is small because of $Q = 0.115$ MeV for ^{6}Li (^{3}He, d_0) $^7\mathrm{Be}_{g.s.}$ and $Q = -0.316$ MeV for ^{6}Li (^{3}He, d_1) $^7\mathrm{Be}_{431}$, the detection of gamma-rays following these reactions was made by using a 40 cm^3 Ge (Li) detector with 1.1 % (5 keV) resolution and a 5" × 6" NaJ (Tl) detector with 8 % resolution. Both detectors were calibrated for energy and intensity measurements using a set IAEA calibrated gamma sources.

The typical 431 keV gamma spectrum in the vicinity of photo peak taken with Ge (Li) and NaJ (Tl) detectors, respectively, are shown in Fig. 1.

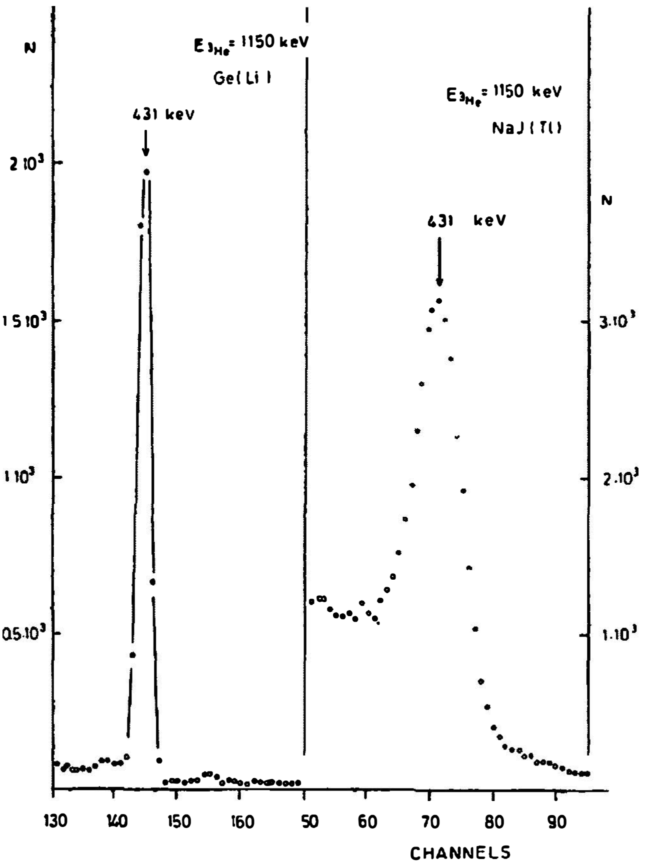

Fig. 1. Typical 431 keV gamma spectrum in the vicinity of the photo peak for Ge (Li) and NaJ (Tl) detectors.

The procedure for measuring the ^{6}Li (^{3}He, d_1) ^{7}Be reaction was the following:

1) one of the gamma-detectors set at 120° with respect to ^{3}He beam measured the yield of 431 keV gamma-ray resulting from the decay of ^{7}Be from the first excited to its ground state;

2) the calibration of the gamma-detector was previously made by placing the IAEA sources in the target position inside the target chamber; and

3) simultaneously the yield of protons from the ^{6}Li (^{3}He, p) ^{8}Be reaction, for which the cross section is known[3], was measured with a silicon detector, whose geometry was carefully determined.

In this way the relation between ^{6}Li (^{3}He, d_1) $^7Be_{431}$ and ^{6}Li (^{3}He, p) ^{7}Be cross-sections was established.

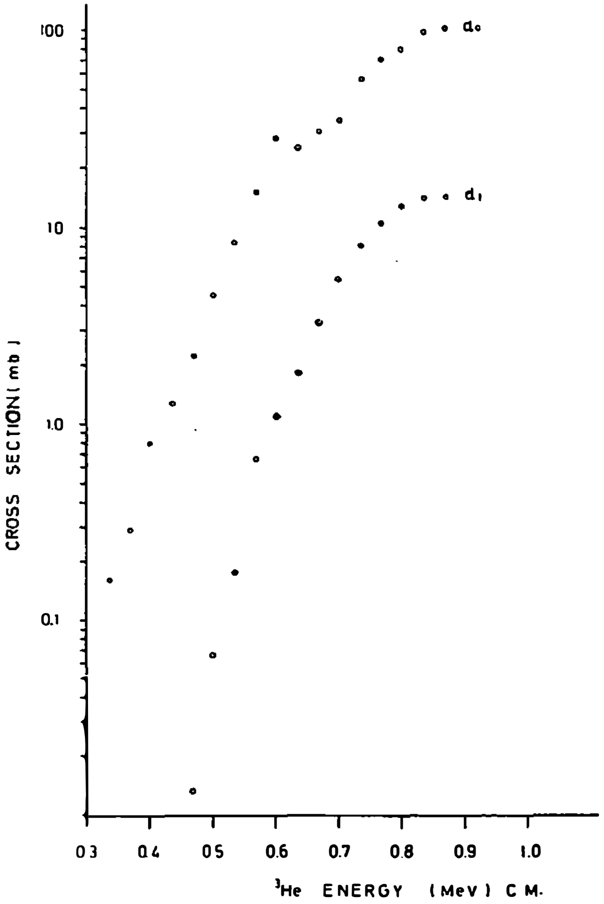

Fig. 2. Experimental excitation function for ^{6}Li (^{3}He, d_0) ^{7}Be and ^{6}Li (^{3}He, d_1) $^7Be_{431}$ reactions.

The procedure for measuring the ^{6}Li (^{3}He, d_0) ^{7}Be$_{g.s.}$ reaction was different from the previous one:

1) for each energy a separate target was irradiated with ^{3}He beam and the yield of the 478 keV gamma-ray has been determined in a low-background room;

2) during the irradiations of targets with ^{3}He beam, the beam current and the yield of protons from ^{6}Li (^{3}He, p) ^{8}Be, were measured in order to be able to normalise the 478 keV gamma-yield from the corresponding targets; and

3) each of the irradiated targets were measured a day or two after irradiation and a month later.

The time factors of ^{7}Be decay and the percentage of the decay to 478 keV ^{7}Li level were taken into account, as well as the fact that ^{7}Be activity is formed by the ^{6}Li (He, d_0) ^{7}Be$_{g.s.}$ and the ^{6}Li (^{3}He, d_1) ^{7}Be$_{431}$ reactions.

The energy of the ^{3}He beam was varied in steps of 50 keV from 0.7 — 1.3 MeV for d_1 reaction, and from 0.5 — 1.3 MeV for d_0 reaction. The excitation curves for d_0 and d_1 reactions are given on Fig. 2. The points below 0.7 MeV (lab) were measured only by the NaJ (T_1) detector, while all other points are an average of several measurements by both detectors.

3. *Discussion*

Since the Coulomb barrier is dominating strongly the behaviour of excitation curves at low energy, we have computed the quantity

$$A = \frac{\sigma_{exp}}{4\pi \dfrac{k_{out}}{k_{in}} P_{l_{in}} P_{l_{out}}}, \qquad (1)$$

where σ_{exp} is the cross section taken from our excitation curves (Fig. 2), k_{in} refers to ^{3}He, and k_{out} to d_0 or d_1, while $P_{l_{in}}$ and $P_{l_{out}}$ are Coulomb barrier penetration factors for incoming and outgoing channels, respectively. Because the intrinsic parities of incoming and outgoing channels are opposite, the incoming and outgoing orbital momenta have also opposite parities. Therefore, we calculated two combinations: $l_{in} = 0$, $l_{out} = 1$ and $l_{in} = 1$, $l_{out} = 0$. The quantity A computed for d_0 in the exit channel is given in Fig. 3. The existence of 0.6 MeV (CM) resonance is seen clearly for both combinations of orbital momenta, which leaves as possible spin-parity assignements $\frac{1^+}{2}$, $\frac{3^+}{2}$ or $\frac{5^-}{2}$ with $T = \frac{1}{2}$. The fit to the Breit-Wigner one-level formula, taking into account that a 10 % error coming from our experimental data must be attributed to each point in Fig. 3, gives E_{ex} (^{9}B) = 17.20 + 0.02 MeV and Γ = 110 ± 30 keV. However, it is seen from Fig. 3 that this resonance »rides« on a flat curve indicating that the compound nucleus mechanism

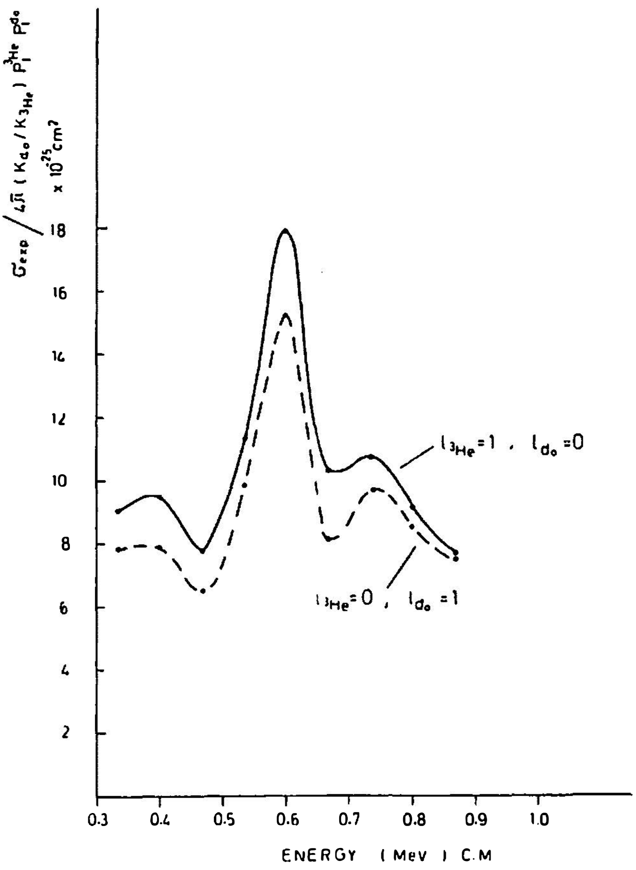

Fig. 3. Energy dependence of the quantity $A = \sigma_{exp}/4\pi \dfrac{k_{d_0}}{k_{^3He}} P_l^{^3He} P_l^{d_0}$ for ^{6}Li (^{3}He, d$_0$) ^{7}Be reaction.

probably is not the only existing one. This is still better seen from Fig. 4 where the quantity A is computed for d$_1$ in exit channel. The curve for $l_{^3He} = 0$, $l_{d_1} = 1$ may be fitted with Γ = 110 ± 30 keV resonance at 0.6 MeV contributing about one fifth of the whole yield, while the resonance-subtracted curve is monotonically decreasing with increasing energy. However, similar fit for $l_{^3He} = 1$, $l_{d_1} = 0$ curve after removal of the Γ = 110 ± 30 keV resonance gives a nonmonotonical resonance-subtracted curve. Therefore, we are inclined to the conclusion that $l_{^3He} = 0$, $l_{d_1} = 1$ combination is more acceptable. This would mean that the 17.20 ± 0.02 MeV level in ^9B has assignements $\frac{1^+}{2}$ or $\frac{3^+}{2}$ $(T = \frac{1}{2})$. It has been shown[4] that a $T = \frac{3}{2}$ state at similar energy in ^9Be appears with $\Gamma < 0.47$ keV — therefore $\Gamma = 110 \pm 30$ keV in our case could not be attributed to anything else but $T = \frac{1}{2}$. The absense of gamma-ray decays from 17.20 ± 0.02 MeV level in ^9B, which we checked in separate experiments, establishes also $T = \frac{1}{2}$ for this level. The fact that the major contribution to quantity A for d_1 data, monotonically increases with decreasing energy, could suggest, in our opinion, that for low-energy outgoing particles most of the reaction yield is due to a direct

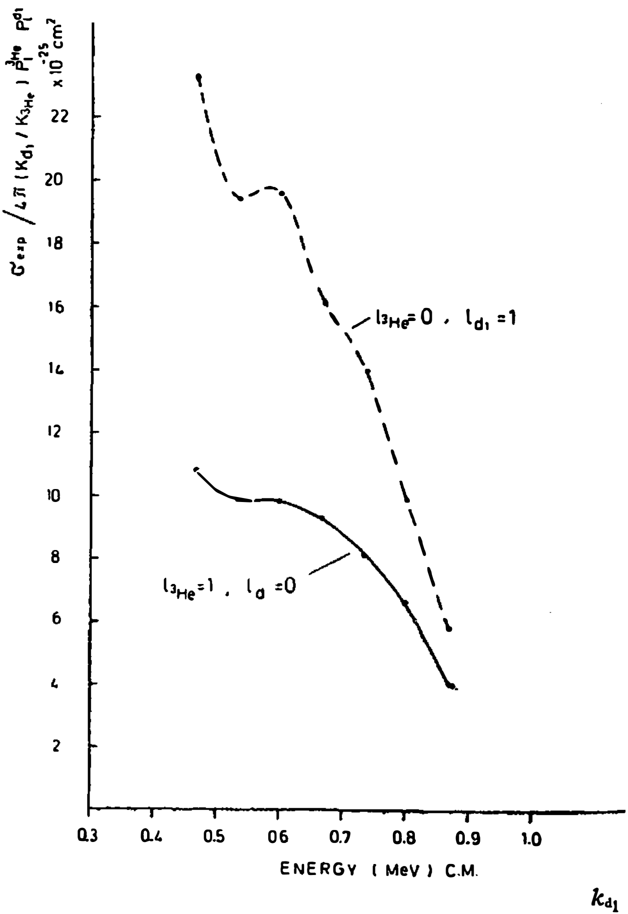

Fig. 4. Energy dependence of the quantity $A = \sigma_{exp}/4\pi \, \frac{k_{d_1}}{k_{^3He}} \, P_l^{^3He} P_l^{d_1}$ for $^6Li\,(^3He, d_1)\,^7Be$ reaction.

reaction mechanism. It is evident from Fig. 2 that the low-energy cross section from d_1 group falls down to 10 μb. Therefore, one can suppose that a model, similar to the one proposed by R. G. Thomas⁵⁾ for direct capture reactions is applicable in the energy region just above the threshold. Beyond the threshold, the wave function extranuclear contributions seem to be playing the most important role in the region of very low Coulomb barrier penetration.

Reference

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^{6}Li (^{3}He, d) ^{7}Be REAKCIJA NA NISKIM ENERGIJAMA

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Sadržaj

Radi ispitivanja nivoa sa visokom energijom ekscitacije u ^{9}B kao i ispitivanje mehanizma reakcija na niskim energijama, izmerene su ekscitacione funkcije za ^{6}Li (^{3}He, d_0) ^{7}Be i ^{6}Li (^{3}He, d_1) ^{7}Be$_{431}$ reakcije na $\Theta = 120°$ za energije ^{3}He od 0.5 — 1.3 MeV. Koristeći aktivacionu metodu izvršena su merenja gama zraka od 478 keV iz ^{7}Li za d_0 grupu, odnosno gama zraka od 431 keV iz ^{7}Be za d_1 grupu, pomoću Ge (Li) i NaJ (Tl) detektora. Eksperimentalni rezultati merenja ekscitacionih funkcija dati su na sl. 2. Da odstranimo efekte Coulomb-ove barijere reducirali smo eksperimentalne reakcione preseke računajući prema formuli (1) funkciju A koja je za d_0 i d_1 grupe data na sl. 3 i 4. Analizom krivih sa sl. 3 i 4 ustanovili smo:

a) da pri ekscitaciji od 17.20 ± 0.02 MeV postojeći nivo u ^{9}B ima širinu

$$\Gamma = 110 \pm 30 \text{ keV, spin i parnost } I^{\pi} = \frac{1^+}{2} \text{ ili } \frac{3^+}{2} \text{ i izospin } T = \frac{1}{2};$$

b) da se blizu energetskog praga reakcija ^{6}Li (^{3}He, d_1) ^{7}Be$_{431}$ najvećim delom odigrava preko direktnog mehanizma, što nagoveštava da ekstranuklearni deo talasne funkcije, slično mehanizmu predloženom od R. G. Thomasa za reakcije zahvata, igra bitnu ulogu u ovoj reakciji blizu praga.