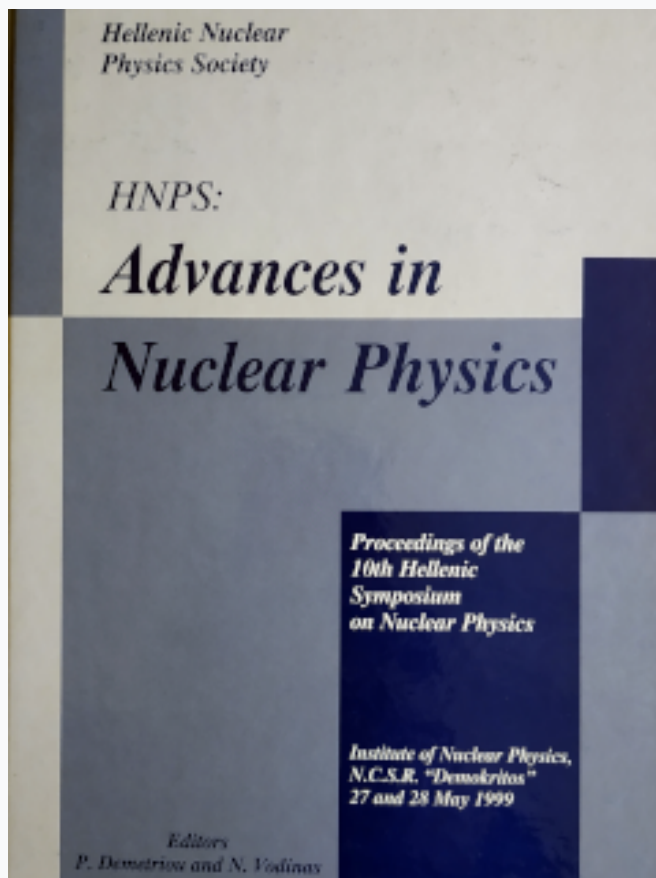


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# Cross section measurements of the ${}^6\text{Li}(p,\gamma){}^7\text{Be}$ reaction

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## Abstract

Measurements of the nuclear reaction  ${}^6\text{Li}(p,\gamma){}^7\text{Be}$  have been carried out at the Van de Graaf Tandem accelerator of NCSR "Demokritos". The total cross section of the nuclear reaction  ${}^6\text{Li}(p,\gamma){}^7\text{Be}$  has been measured over the proton energy range  $E_p=690-930$  keV.

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## 1 Introduction

The reaction  ${}^6\text{Li}(p,\gamma){}^7\text{Be}$  is a direct-capture reaction. In such reactions, the projectile interacts primarily at the surface of the target nucleus. The process is entirely electromagnetic: In our case, a photon is emitted and at the same time the proton is captured by the nucleus. The energy of the photon is  $E_\gamma=E_p^{cm}+Q-E_f$ , where  $E_p^{cm}$  is the projectile energy in the center-of-mass,  $Q$  is the  $Q$ -value of the reaction and  $E_f$  is the energy of the state of the compound nucleus the photon feeds. It is called a single-step process (alternatively, direct process) and is nonresonant because it can occur at all projectile energies with a cross section varying smoothly with energy [1]. The DC mechanism on  ${}^6\text{Li}$  and possible de-excitation is shown in Fig. 1. Of the two photons emitted during the reaction one proceeds directly to the ground state of  ${}^7\text{Be}$  while the other feeds the first excited state of  ${}^7\text{Be}$  with corresponding branching ratios of 60% and 40% respectively [2].

Data from previous measurements of the cross section of the  ${}^6\text{Li}(p,\gamma){}^7\text{Be}$  reaction are plotted in Fig. 2 as a function of energy. Cecil et al. [3] measured the cross section of the  $(p,\gamma)$  reaction indirectly, via the  $(p,\alpha)$  one, in the energy range from 40 keV to 180 keV. Switkowski et al. [4] measured the cross section of the reaction in the energy range from 200 keV to 1000 keV with a Ge(Li) detector placed at  $0^\circ$  to the beam direction. However, they analyzed the  $\gamma_0$  and  $\gamma_1$  photon emission, considering that their branching ratios are the same at all energies. Therefore,

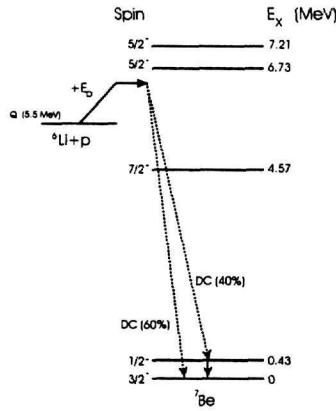


Fig. 1. The DC mechanism on  ${}^6\text{Li}$ .

new measurements should take place, using the same equipment, but without any restrictions concerning the branching ratios.

## 2 The detection system

The measurements have been carried out at the Van de Graaf Tandem accelerator of the Institute of Nuclear Physics of NCSR "Demokritos". The detection system called Ptolemeos, consists of two large NaI(Tl) crystals of cylindrical shape, each of them divided in 4 equal parts (segments) along the symmetry axis. Two additional NaI(Tl) detectors are placed vertically to the symmetry axis. A lead "box", 5cm thick, covers Ptolemeos, to shield it against natural radioactivity and cosmic rays. The energy signals of the 10 detectors are summed and this results to summation of the  $\gamma$ -rays of the reaction. The main advantages of this system is that a) it covers nearly  $4\pi$  geometry, so there is no need for measurements of angular distributions of the  $\gamma$ -rays of interest and b) it has a high absolute detection efficiency [5].

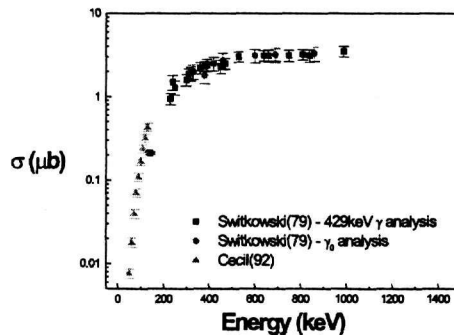


Fig. 2. Existing cross section measurements of the  ${}^6\text{Li}(p,\gamma){}^7\text{Be}$  reaction

Apart from the use of the NaI summing crystal, a high purity germanium detector shielded with lead and placed at 90° to the beam axis has been used. A sketch of the latter setup is shown in Fig. 3.

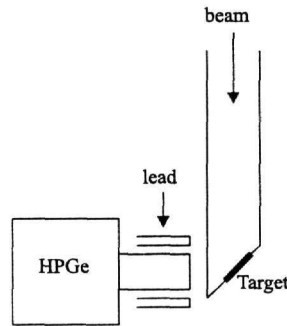


Fig. 3. The experimental setup of the measurements carried out via the HPGe detector.

### 3 Experimental Procedures

The use of the summing crystal of Ptolemeos requires targets and substrates free of impurities that could contribute to the sum peak. In our case the target must be free of fluorine since the reaction  $^{19}\text{F}(p,\alpha\gamma)^{16}\text{O}$  would produce  $\gamma$ -rays which overlap with the  $\gamma$ -rays of interest and also free of  $^7\text{Li}$  because the reaction  $^6\text{Li}(p,\gamma)^7\text{Be}$  would dominate the spectrum.

Considering the previous requirements, the target was made by means of evaporation of  $^6\text{Li}_2\text{CO}_3$  (stoichiometry: 16%  $^6\text{Li}$ , 16% C, 0.0085%  $^7\text{Li}$  and 67.9915% O) on W substrate and covered with  $115\mu\text{g}/\text{cm}^2$  Au (thin target). A second target was a pellet made by mixing  $^6\text{Li}_2\text{CO}_3$  with pure carbon (75%  $^6\text{Li}_2\text{CO}_3$  and 25% C) in order to provide stability under bombardment (thick target). Comparing the thin target with a standard one of LiF we determined that it contains 150ppm of fluorine in  $^6\text{Li}_2\text{CO}_3$  which contributes to the sum peak. Due to this fact, it was almost impossible to analyze the data obtained using the summing crystal. Hence, it was decided to continue measurements using the detection system with the germanium detector. The cross section was measured in the energy range from 690 keV to 930 keV in steps of 20 keV by analysis of the photon emission from the first excited state of  $^7\text{Be}$  to the ground state, using the  $^6\text{Li}_2\text{CO}_3$  pellet. The yield of the reaction was calculated with the following formula.

$$Y(E_0) = \int_0^{E_0} \frac{\sigma(E)}{T(E)} dE - \int_0^{E_0-20} \frac{\sigma(E)}{T(E)} dE$$

$$= \int_{E-20}^E \frac{\sigma(E)}{T(E)} dE = \frac{20 \cdot \sigma(E) \cdot N_A \cdot 6.25 \times 10^{15}}{T(E)A} \cdot P_1 \cdot P_2 \quad (1)$$

where  $Y(E) = \frac{\text{counts}}{mCb \cdot \epsilon}$ . Hereby,  $\epsilon$  is the absolute efficiency,  $T(E)$  is stopping power ( $\text{keV}/\mu\text{gr}/\text{cm}^2$ ),  $N_A$  is the Avogadro's number ( $N_A=6.022 \times 10^{23}$ ),  $P_1=0.16$  (the percentage of  ${}^6\text{Li}$  in the target),  $P_2=0.4$  (the branching ratio of the photon emission from the first excited state of  ${}^7\text{Be}$  to the ground state), and  $A$  is the molecular weight of the target ( $A=6.015121 \times 10^6$ ).

#### 4 Preliminary Results

Our results along with those of Ref. [4] are presented in Fig. 4. Both are based on the analysis of the photon emission from the first excited state of  ${}^7\text{Be}$  to the ground state. We observe deviations especially above 900 keV where the cross section of the present work increases with increasing energy contrary to Ref. [4]. This may be due to the fact that [4] was using a molecular beam which at high energies gives rise to the  $(d,n\gamma)$  reaction and to the same 429 keV  $\gamma$ -ray. Although in [4] the data have been corrected for this effect, the correction was apparently overestimated.

Additional measurements covering the same energy range and also the energy range above 930 keV will be performed in the near future with the same experimental setup using the thin target.

For the energy range below 690 keV the cross section will be measured via the reaction  ${}^1\text{H}({}^6\text{Li},\gamma){}^8\text{Be}$  which will allow us to obtain the cross section at energies lower than the limits of our accelerator (about 700 keV with proton beam): In the center-of-mass an energy of 2.2 MeV of a  ${}^6\text{Li}$  beam corresponds to an energy of 370 keV for protons. For this purpose a target will be made by deposition of hydrogen on a palladium substrate via electrolysis of a sulfuric acid solution.

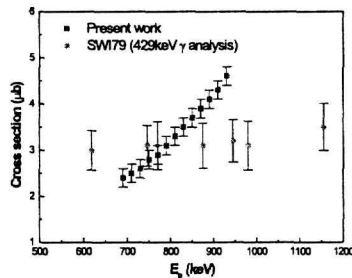


Fig. 4. Measured total cross section of the reaction  ${}^6\text{Li}(p,\gamma){}^7\text{Be}$  vs. proton energy.

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