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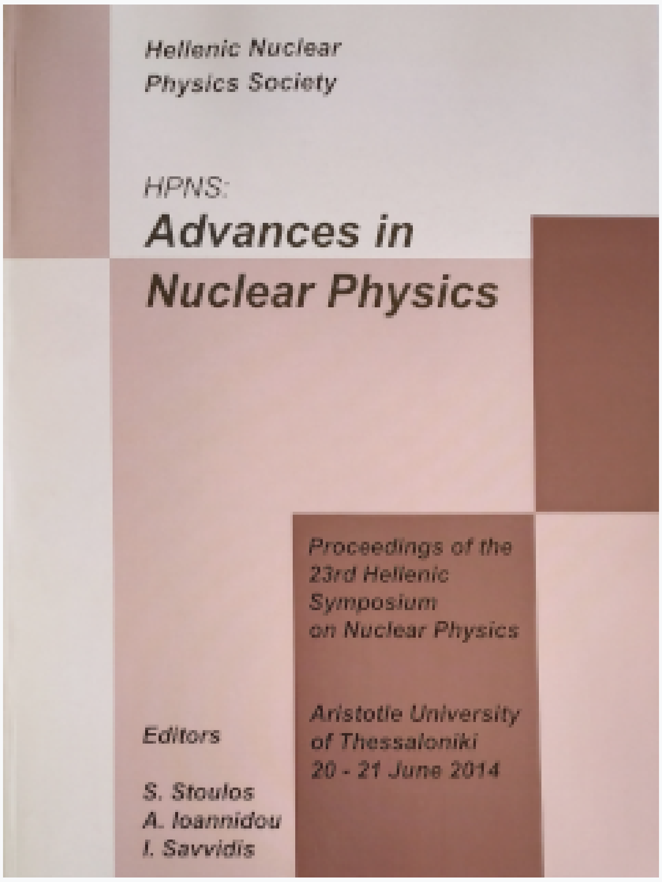

Neutron reaction studies in the rare earth region: First results for the 162Er(n,2n)161Er physics case

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Neutron reaction studies in the rare earth region:
First results for the ^{162}Er(n,2n)^{161}Er physics case

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Abstract
In the present work the first experimental results at near two threshold energies for the ^{162}Er(n,2n)^{161}Er reaction study are presented. The reaction cross section was determined at the energies of 11.0 and 11.3 MeV by means of the activation technique. The experimental method and setup is described.

1. Introduction

The study of neutron threshold reactions is of considerable importance for testing nuclear models as well as for providing new and updated nuclear data information for Nuclear Physics Applications. Erbium, as well as other rare earth elements, is extensively used in the Nuclear Reactor Technology as neutron absorbers. In view of the on-going research towards to the development of fast neutron nuclear reactors, accurate nuclear data are urgently needed. Erbium-162 is the lightest stable isotope of Erbium with abundance of just 0.139%. Thus, the experimental study of (n,x) reactions for this isotope is challenging. For this reason, the existing (n,2n) reaction cross section experimental information is limited to just a few data-points at energies around 14 MeV with discrepancies up to ~30% [1-7]. Unfortunately, there is no experimental information at energies close to the reaction threshold neither to higher energies where other competitive reaction channels (e.g. n,3n) become important. At both energy regions the determination of the (n,2n) reaction cross section is important for the investigation of the sensitivity of the input parameters in the statistical-model theoretical calculations. For ^{162}Er the study of the parameterisation in theoretical models becomes more interesting due to the fact that lies quite far from the main stream of the valley of stability as the more neutron deficient stable erbium isotope. Subsequently, within the present work the experimental study of the ^{162}Er(n,2n)^{161}Er reaction cross section was taken over. The reaction cross section was determined for the first time at two near threshold energies (11.0 MeV and 11.3 MeV) by using the neutron activation technique. In the following sections the experimental setup and technique is presented along with preliminary experimental results.

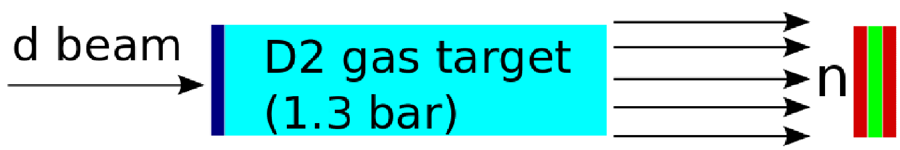

Figure 1: A simplified diagram of the irradiation setup. The neutron beam was produced by means of the D(d,n)^{3}He reaction. The sample sandwich was placed at 0º with respect the neutron beam.

2. Experimental method and setup

The $^{162}Er(n,2n)^{161}Er$ reaction cross section was measured at two near threshold energies of 11.0 and 11.3 MeV by means of the activation technique. The neutron flux was determined by using the reference reactions $^{27}Al(n,\alpha)^{24}Na$, $^{197}Au(n,2n)^{196}Au$ and $^{93}Nb(n,2n)^{92m}Nb$ [8]. The irradiations were carried out at the 5.5 MV Tandem Van de Graaff accelerator at NCSR "Demokritos".
The neutron beam was produced via the $^{2}H(d,n)^{3}He$ reaction (Q=3.27 MeV) by bombarding the D_2 gas target with deuteron beam currents typically kept between 0.3 – 2.0 μA. The samples sandwich was placed at 0º with respect to the neutron beam at a distance of 7 cm from the centre of the gas shell. At this distance the angular acceptance of the samples setup was less than ±5.5º. The Erbium sample was a pellet of 13mm in diameter and 2mm in thickness consisting of Er_2O_3 powder with 10% admixture of cellulose. At both sides of the Erbium oxide sample the monitor foils were placed as to record the integrated neutron at both sides of the Erbium sample. A simplified diagram of the irradiation setup can be seen in Fig.1.
During the irradiations the gas pressure was constantly operated with an electronically controlled micrometric valve at 1300 mbar as to keep the uncertainty of the neutron beam energy distribution as low as possible. For these irradiation conditions the neutron beam flux at the sample position was ranging between 0.3-2.0 x 10^6 n/(cm^2 s). The neutron flux was continuously recorded by a BF3 counter placed at 30º with respect the neutron beam and at a distance of 3 m from the deuteron gas target. Each irradiation lasted 10h, corresponding to the ~90% of the core activity of the ^{161}Er, given that the half life of the residual nucleus is $T_{1/2}(^{161}Er)$=3.2 h.
After the irradiations the activity of the Erbium samples was measured by means of two ORTEC High Purity Germanium (HPGe) detectors of 100% relative efficiency. As can be seen in Fig. 2 the two detectors were placed in close, face-to-face geometry, at a distance of 1 cm between the Erbium sample and the detector window. The adopted geometry combined with the high relative efficiency of the HPGe detectors provided the maximum possible detection efficiency. This was critical considering the minimal abundance (0.139%) of the ^{162}Er isotope in the natural composition Erbium sample. The adoption of such close detection geometry provides high detection efficiency. On the other hand such close detection geometry can cause issues attributed to the coincidence summing effects. For this reason the decay scheme of ^{161}Er was carefully investigated as to exclude such possibility. Indeed, as can be seen in Fig. 3, the strongest decay line comes from the ground state decay of the 827 keV level of the ^{161}Ho daughter nucleus. The feeding of this level from higher excited states is negligible. Furthermore, the 827 keV level, decays almost exclusively to the ground state. For these reasons we don't expect summing effects for this line. The efficiency calibration for this γ-ray energy region was determined by using a weak mono-energetic ^{54}Mn source that provides a single γ-ray line at 835 keV.
The induced activity of the Al, Au and Nb foils was measured after the irradiations by means of a 16% relative efficiency HPGe. For these measurements the sample to detector window distance was 7 cm.

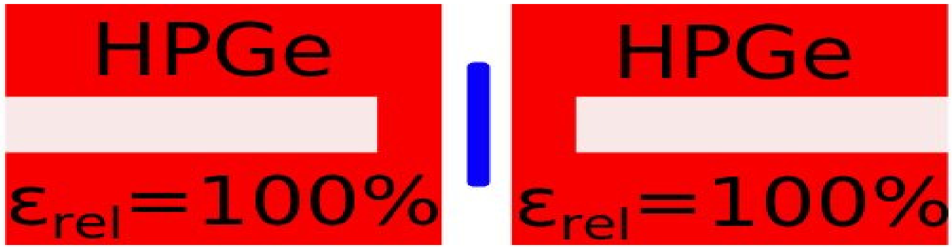

Figure 2: Erbium sample γ-ray measurements: Two HPGe detectors were used in close, face-to-face geometry. The sample (blue) to detector (red) distance was 1 cm. In this way, almost 4π detection angle was covered resulting in 11% total peak efficiency for both HPGe detectors at the region of 830 keV.

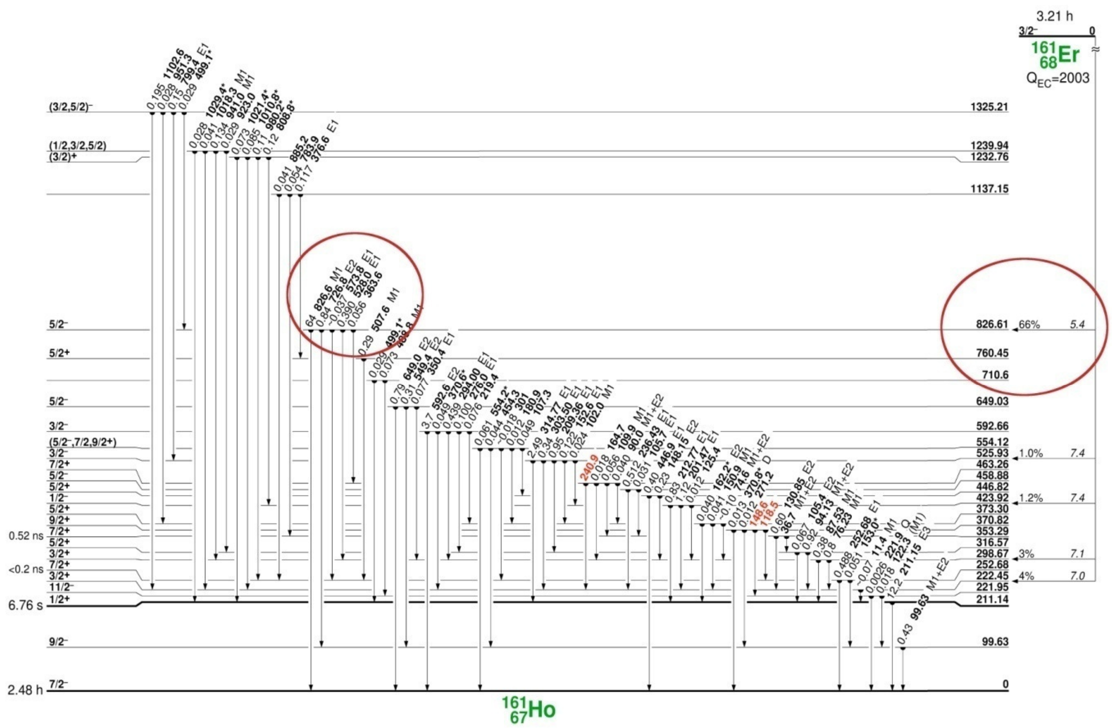

Figure 3: Part of the decay scheme of ^{161}Er [9]. The feeding, as well as, the stronger decay line at 827 keV are noted in the decay scheme with red circles.

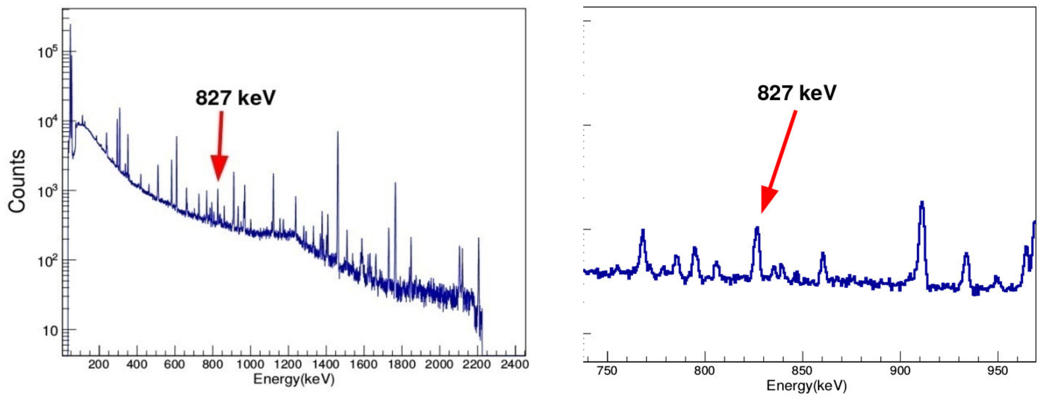

Figure 4: The γ-ray experimental spectrum of the Erbium sample after 10 h of irradiation 7h of activity measurement. The spectrum corresponds to the superposition of the spectra resulted from both HPGe that were previously gain matched. The right part is the enlargement of the region of interest around the strongest transition at 827 keV.

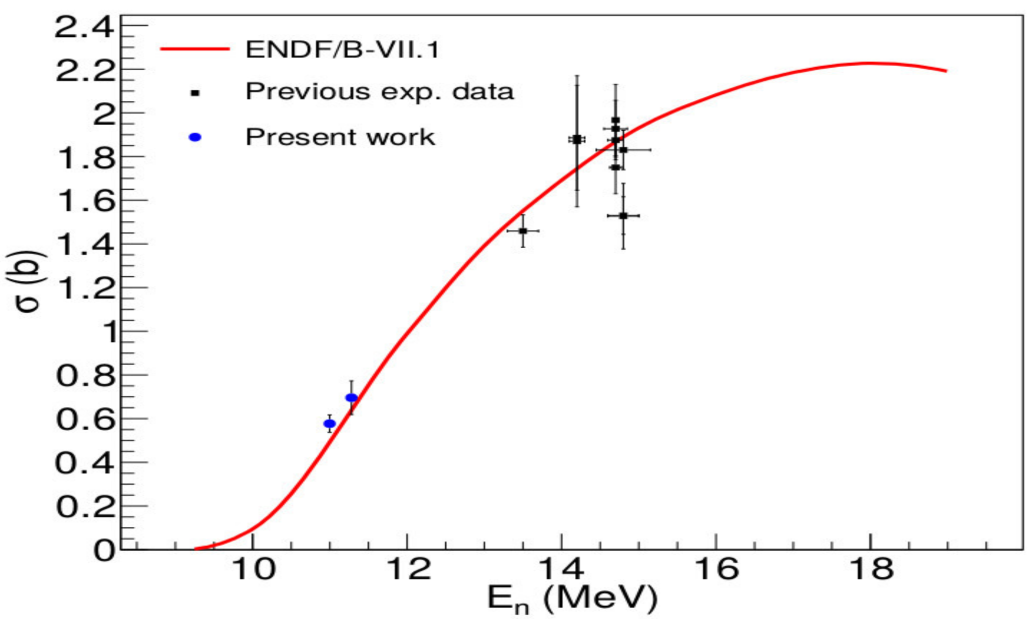

Figure 5: The net area counts of the 827 keV peak with respect the measurement time. The red curve corresponds to the expected number of counts according to decay and the half-life time of the residual nucleus (^{161}Er).

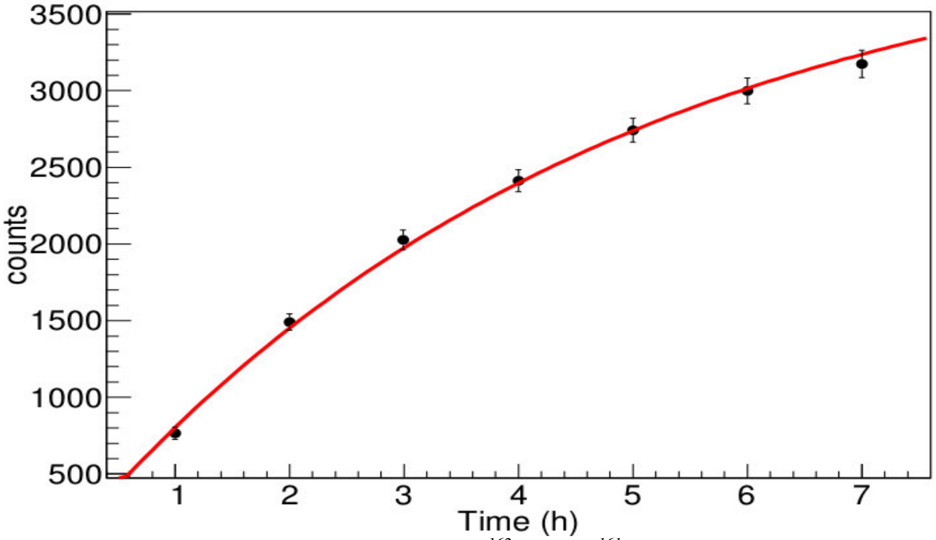

Figure 6: Preliminary experimental results of the $^{162}Er(n,2n)^{161}Er$ reaction cross section at two near threshold energies: 11.0 MeV and 11.3 MeV. The results of the present work are presented along with previous experimental results at energies around 14.5 MeV [2-7] and the ENDF/B-VII.1 theoretical excitation function [8].

3. First results

After 10 h of irradiation at each neutron beam energy the activity of the Erbium sample was recorded for 7 h. A typical experimental spectrum is presented in Fig. 4, corresponds to the addition of the two spectra of both HPGe detectors that were previously carefully gain matched. Despite the complexity of the resulted spectrum, as can be seen in the right part of Fig. 4 a well defined and isolated peak was observed at 827 keV energy regions. In order to verify the purity of the net area counts of the 827 keV transition the integrated peak area counts was recorded with respect the measurement time and compared with the theoretically expected growth for the given half-life time of the residual nucleus (^{161}Er). As can be seen in Fig. 5 the net area counts fully obey the expected theoretical curve, proving that the observed 827 keV peak originates exclusively from the ^{161}Er decay.
By taking into account the γ-ray activity measurements of the monitor foils combined with the activity measurement of the Erbium sample the ^{162}Er(n,2n)^{161}Er reaction cross section was deduced for the two irradiation energies at 11.0 MeV and 11.3 MeV. The preliminary results of the data analysis are presented in Fig. 6 along with the previous measurements [1-7]. As can be seen in Fig. 6 the results of the present work are the first experimental results at near threshold energies.

4. Conclusions

Within the present work the ^{162}Er(n,2n)^{161}Er reaction cross section was measured for the first time at two near threshold energies. The experimental determination of the reaction cross section in this energy region is very important for testing and improving the theoretical description of the reaction mechanism. Furthermore, considering that ^{162}Er is the most neutron deficient stable Erbium isotope the (n,2n) reaction study consist an interesting test ground of the input parameters of Hauser-Feshbach calculations.
Additionally, it should be highlighted the sensitivity of the activation technique as resulted from the present work given the minimal abundance (0.14%) of ^{162}Er in the natural composition Erbium oxide sample that was used. The existing neutron beam facility at NCSR “Demokritos” combined with the state-of-the-art γ-ray spectroscopy systems allows the deduction of accurate experimental data for a wide range of neutron induced reaction studies.

The data analysis of the presented experimental data is still in progress. In the future two more irradiations are going to be performed aiming to the reaction cross section determination at higher neutron beam energies (>17 MeV) where the contribution of the (n,3n) reaction cross section becomes important. As to understand better and map the parameterization of the theoretical calculations in this mass region of the chart of nuclides more experimental data are needed. Accordingly, the present work is going to be extended with more (n,2n) reaction studies in the rare earth region.

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