Cross section measurements for γ-process studies using a LEPS detector

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Abstract. In this paper we present the ongoing experiments at ATOMKI related to our systematic γ-process studies. These studies are intended to enlarge the limited experimental database from α-induced reactions on nuclei in the heavier mass range of the γ-process. In all presented cases the activation method was used. The details of the cross section measurements and preliminary results on ^{115}In(α,n)^{118m}Sb, ^{115}In(α,γ)^{119}Sb; ^{162}Er(α,n)^{165}Yb, ^{162}Er(α,γ)^{166}Yb, ^{164}Er(α,n)^{167}Yb, ^{166}Er(α,n)^{169}Yb; ^{191}Ir(α,n)^{194}Au, ^{191}Ir(α,γ)^{195}Au, ^{193}Ir(α,n)^{196m}Au, ^{193}Ir(α,n)^{196}Au reactions are presented.

1. Introduction

The stable proton-rich nuclei with charge number $Z \geq 34$ are the so called p-nuclei [1]. It is generally accepted that the main stellar mechanism synthesizing these nuclei — the so called γ-process — is initiated by (γ,n) photodisintegration reactions on preexisting neutron-rich seed nuclei [2]. As the neutron separation energy increases along the (γ,n) path towards more neutron deficient isotopes, (γ,p) and (γ, α) reactions become stronger and process the material towards lower masses. In order to understand the path of the γ-process in the region of the heavy p-nuclei and to determine precisely the p-isotope abundances, experimental cross section data of the involved reactions are clearly needed. Stellar rates for (γ, α) photodisintegration reactions should always be derived from α-capture to maximize the experimental constraint on the rate [3, 4]. Above the $A \approx 100$ region very few (α, γ) cross sections relevant for the γ-process were measured [5, 6]. This way, the γ-process network calculations rely mostly on theoretical cross sections calculated using the Hauser-Feshbach statistical model. In order to test the cross section predictions of the statistical model in the region of the heavy p-nuclei, radiative alpha-capture and (α,n) cross sections were measured at ATOMKI using a Low Energy Photon Spectrometer (LEPS) [7, 8, 9]. This is a work in progress, we are extending the available database. In this article some details about the latest reactions that are being measured in ATOMKI are presented.

2. Method and equipment

2.1. Activation method

The activation method can be applied only when the reaction product is radioactive. In general the method is the following: the samples are irradiated by an accelerated ion beam resulting in radioactive nuclei. From the produced activity, with known irradiation and sample parameters, the cross section can be derived. The limitations are caused by the decay parameters. The reaction product must have suitable half-life (usually between few minutes and few weeks) and the emitted γ-rays must have suitable branching (i. e. typically more than 10 %). With our setup part of these limitations can be avoided by detecting low energy γ- and X-rays following the decay. The X-ray detection is not able to distinguish between the activity of different isotopes of the same element, however, this problem can be overcame by following the decay curve of the X-ray yield.

2.2. Counting setup

For the measurements a LEPS (Low Energy Photon Spectrometer) detector is used which consists of a thin (15.5 mm) HPGe crystal with relatively large active surface area (20 cm^2) and a 0.5 mm thick beryllium entrance window. The low energy efficiency of this detector is similar to that of a detector with a large HPGe crystal, but it is insensitive to the high energy photons of the background. The resolution is also better than that of a big crystal. The detector is surrounded with a layered shielding consisting of 4 mm copper, 2 mm cadmium and 8 cm lead to suppress the laboratory background. Owing to these facts, the minimum detectable activity of the LEPS detector is less than that of a 100 % relative efficiency HPGe detector, for γ- or X-rays with energy lower than 500 keV.

3. Investigated reactions

α-induced reaction studies are in progress on three γ-process related isotopes, ^{115}In, ^{162}Er and ^{191}Ir. The main goal is to measure the (α,γ) reactions on the given isotopes, but additionally the (α,n) reactions on the same elements can be investigated (see table 1.). Although the latter reactions do not enter directly into the network calculations, they can constrain the statistical models, both reactions have to be described with the same parameter set.

3.1. Indium

Although the ^{115}In is not a p-isotope, the measured reactions can help to construct a global alpha-nucleus optical model potential [11], which enters into the γ-process network calculations. To test the potential was the main reason of this cross section measurement. The element indium has two stable isotopes with natural isotopic ratio of 4.29 % and 95.71 % for ^{113}In and ^{115}In, respectively. For the measurements thin targets produced by vacuum evaporation from natural indium onto thin pure aluminium foils were used. The relatively low abundant ^{113}In did not disturb the X-ray measurement, because of the low cross section of the alpha induced reactions on it, and the relatively short half-lives of the resulting reaction products.

3.2. Erbium

^{162}Er is one of the heavy p-isotopes. The lack of experimental alpha capture cross section data in this mass region calls for experimental investigations. Cross section measurement on this element in or close to the astrophysically relevant energy region is one of the next steps of our systematic studies. The natural isotopic abundance of the measured isotopes on which alpha induced reactions can be investigated with the activation method are 0.139 %, 1.601 %, 33.503 % for ^{162}Er, ^{164}Er, ^{166}Er, respectively. For the measurements thin targets were produced by vacuum evaporation onto thin pure aluminium foils both from natural erbium and from erbium enriched in ^{162}Er up to 25.8 %. From the irradiated natural targets cross sections of the (α,n) reactions on ^{164}Er, ^{166}Er have been determined. The cross section of (α,n) and (α,γ) reactions on the p-isotope have been derived from irradiation of enriched samples.

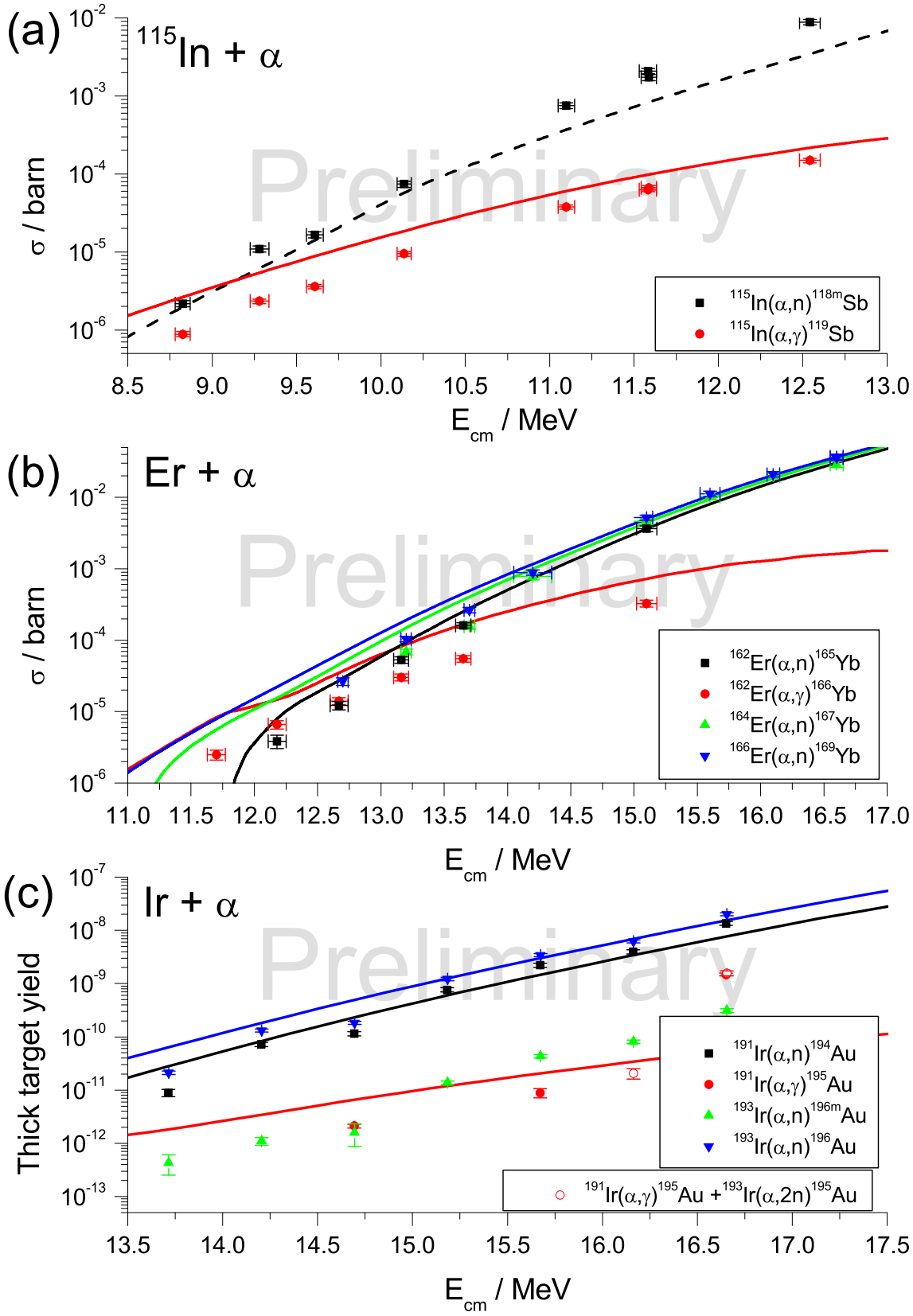

Figure 1. Preliminary results of the investigated reactions. The symbols shows the measured quantities, the curves with the same color are the respective theoretical predictions (see text).

3.3. Iridium

The element has two stable isotopes ^{191}Ir and ^{193}Ir with natural abundance of 37.3 % and 62.7 %, respectively. This measurement is a bit different from the others, because in case of the iridium, thick targets were used in which the alpha particles stops completely. The reactions take place all along the path of the alpha particles with reaction energies between zero and the initial incident energy of the projectiles. In this case from the accumulated activity the so called thick target yield can be directly determined instead of the cross section. There is an integral relation between the cross section and the thick target yield. With precise thick target measurements carried out with small enough energy steps, the two quantities can be derived from each other, but in this paper we present only the preliminary thick target yields.

Table 1. Parameters of the investigated reactions

	Indium		Erbium				Iridium			
Target isotope	^{115}In		^{162}Er		^{164}Er	^{166}Er	^{191}Ir		^{193}Ir	
Studied reaction	(α,n)	(α,γ)	(α,n)	(α,γ)	(α,n)	(α,n)	(α,n)	(α,γ)	(α,n)	
Reaction product	^{118m}Sb	^{119}Sb	^{165}Yb	^{166}Yb	^{167}Yb	^{169}Yb	^{194}Au	^{195}Au	^{196m2}Au	^{196}Au
Half-lives [10]	5.00 h	38.2 h	9.9 m	56.7 h	17.5 m	32 d	38.0 h	186 d	9.6 h	6.2 d
Detected radiation	γ, X	γ, X	γ	γ, X	γ	γ	γ	γ, X	γ	γ

4. Preliminary results

The measured quantities are shown in figure 1. for indium (a), erbium (b) and iridium (c) with the respective Hauser-Feshbach statistical model predictions (solid curves SMARAGD [12], dashed curve TALYS [13] with their default settings). The theoretical discussion of the reasons of the differences are beyond the scope of this paper.

The work is in progress. For each isotopes we are at different stage of the studies. The results will be presented in separate papers devoted to the different elements.

Acknowledgment

This work was supported by the EUROGENESIS research program, by the HUNGARIAN PORTUGUESE INTERGOVERNMENTAL S&T COOPERATION PROGRAMME NO. TÉT_10-1-2011-0458, by the European Research Council grant agreement no. 203175, by OTKA (NN83261, K101328, PD104664, K108459). G. G. Kiss acknowledges support from the János Bolyai Research Scholarship of the Hungarian Academy of Sciences.

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