Experimental study of alpha-induced nuclear reactions on Tellurium isotopes for the astrophysical γ-process

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Abstract. Heavier p isotopes are believed to be produced through the γ-process. The path of γ-process can be modelled with network calculations. These calculations include about 20000 reactions on more than 2000, mostly unstable nuclei, many of these reactions involves alpha particles. Theoretical cross sections of reactions involving alpha particles are found to be very sensitive to the alpha-nucleus optical potential, which is not known well enough at low, astrophysical energies. This potential can be studied experimentally by measuring the cross section of (α,n) reactions close above the reaction threshold. The aim of the present work is thus to measure the cross section of the ^{122}Te(α,n)^{125}Xe, ^{124}Te(α,n)^{127}Xe and ^{130}Te(α,n)^{133}Xe reactions for which no data exist in literature. The half-life of the produced Xe isotopes allows us to use the activation technique. Tellurium targets with natural isotopic composition will be used in order to measure the three reactions in parallel. The experiments are in progress using the cyclotron accelerator of ATOMKI. In this paper details of the experimental technique and the preliminary results of the first test measurements are presented.

1. Introduction

The astrophysical γ-process [1] is the main part of the more general p-process, which is responsible for the production of the heavy, proton rich isotopes. These isotopes are inaccessible for the s- and r-processes. Modelling the path of the γ-process requires to take into account a complicated reaction network. These networks include more than 2000 nuclei, most of them being radioactive. The crucial nuclear reaction cross sections in these networks are mostly unknown at astrophysical relevant energies. In the networks the γ-induced reactions play the main role, but other reactions, such as α-captures, are also included. Moreover, among the γ-induced reactions the (γ,α) reactions become especially important in the region of the more and more proton rich isotopes.

Due to the lack of experimental data and their size, the networks utilize reaction rates based on theoretical cross sections. These reaction rates are very sensitive to various

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uncertainties. Therefore, the theoretical calculations have relatively poor predictive power, experimental data are thus needed to make the theoretical calculations more reliable.

Theoretical calculations describe the projectile-nucleus interaction with the so-called alpha-nucleus optical potential (α-OMP) [2]. The theory is very sensitive to the parameters of the α-OMP. The (α,n) reactions give a chance to study the α-OMP experimentally.

2. Preparation and characterization of the Te targets

The aim of the present work is to measure (α,n) cross sections on Te isotopes with the activation method which proved very powerful in cross section measurements for the γ-process [3]. In the case of the ^{120}Te(α,n) reaction there are data in the literature [4]. Therefore, in the present work three other Te isotopes are investigated (^{122}Te, ^{124}Te, ^{130}Te) where the activation technique is applicable for measuring the (α,n) cross section thanks to the lifetime of the created Xenon isotopes. The abundance of these isotopes is high enough to avoid isotopically enriched targets. Therefore, the targets were made from natural isotopic composition metallic Tellurium with vacuum evaporation on 10μm thick Aluminum foils.

The first information about the target thickness, which is an important quantity for the cross-section determination, was obtained by weighing. We measured the mass of the target backing foils before and after the evaporation to a precision of 1μg. The difference of the two masses gives the mass of the Te layer.

For the further measurement of the target thickness, we used Rutherford Backscattering Spectroscopy (RBS) with proton and alpha beams. Proton RBS is less suited for the target thickness measurement than alpha-RBS, but it was the only option before the first test experiments. Nevertheless, the result of the proton RBS provided enough target thickness information for the evaluation of the first cross section data. A typical proton-RBS spectrum can be seen in Fig.1, where the region of the Te peak and Al plateau are clearly visible and from the width of the Te peak the target thickness can be derived.

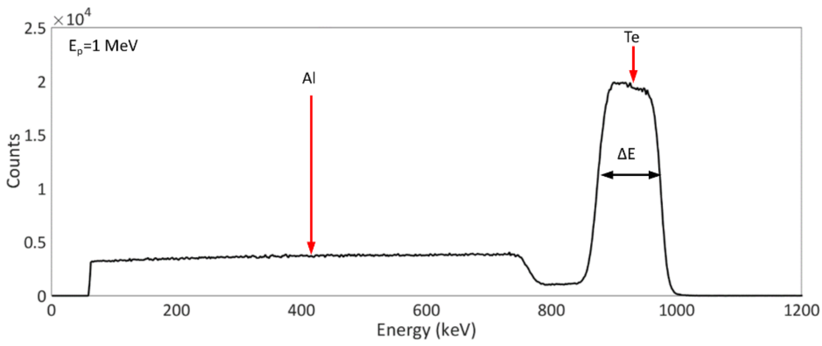

Fig.1. A typical spectrum of the proton RBS.

The target thickness obtained from weighing and from the proton-RBS have typically 7% difference. This may be caused by tellurium oxide formation during or after the irradiation. The target composition is therefore to be further investigated by e.g. alpha-RBS.

Xenon is a noble gas, so we need to be sure about the stability of the created Xenon in the backing foil. For this purpose, we are planning to do lifetime calculations based on our experiments and compare the results with the precise half-life data from literature. Earlier experiments showed that Xenon seems stable inside the target foil [5].

3. The irradiation and the γ-detection

The alpha beam was provided by the cyclotron accelerator of ATOMKI. The first two measurements were carried out at energies of 12 MeV (20-hour long irradiation) and 17 MeV (3-hour long irradiation) with 1μA intensity. After the irradiation, we used a HPGe detector to count the gamma rays coming from the produced Xe isotopes. A typical γ-spectrum can be seen in Figure 2. The detector was calibrated with three calibration sources in three different geometries. Measurements in far geometry and their comparison with close geometry ones allows to eliminate the summing-in effect typical in close geometries.

The ^{130}Te(α,n)^{133}Xe reaction leads to two distinct final states because of the isomeric state of ^{133}Xe. The calculations to determine the ground state cross section are still in progress.

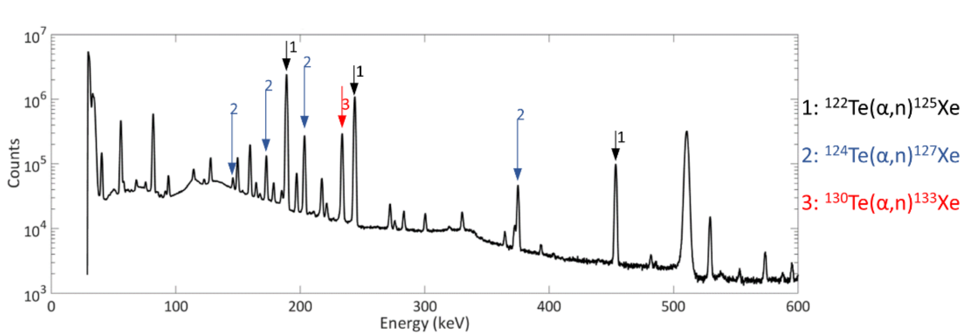

Fig. 2. The γ-spectrum after the 17MeV irradiation. The relevant γ-peaks are labelled. In the case of ^{130}Te(α,n)^{133}Xe only the isomeric state γ-peak is labelled.

We made a TALYS [6] calculation to compare our preliminary results. Figure 3 shows the preliminary results of our work in the case of the ^{124}Te(α,n)^{127}Xe reaction. The error bar of the measured points is smaller than the size of the symbols. In the case of 17 MeV data point, the ^{125}Te(α,2n)^{127}Xe reaction gives a contribution to the measured yield, explaining the rather high value compared to TALYS. This will have to be taken into account in the analysis. Due mainly to the not final target thickness determination, however, the results may still change and can be considered as preliminary.

4. Conclusion and outlook

The experimental procedure seems feasible. Further measurements are in progress. The cross section of the three reactions will be measured at different beam energies from the thresholds up to about 18 MeV. The results of the measurements will be compared with calculations using different alpha nucleus optical potentials to choose the best models and improve their parameters.

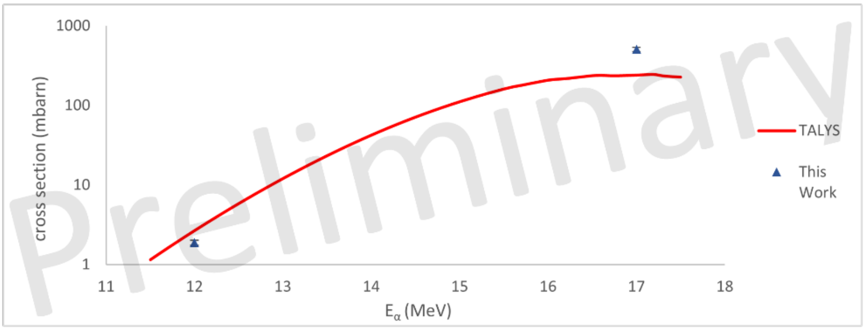

Fig. 3. The preliminary results of this work in the case of $^{124}Te(\alpha,n)^{127}Xe$.

5. Acknowledgments

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