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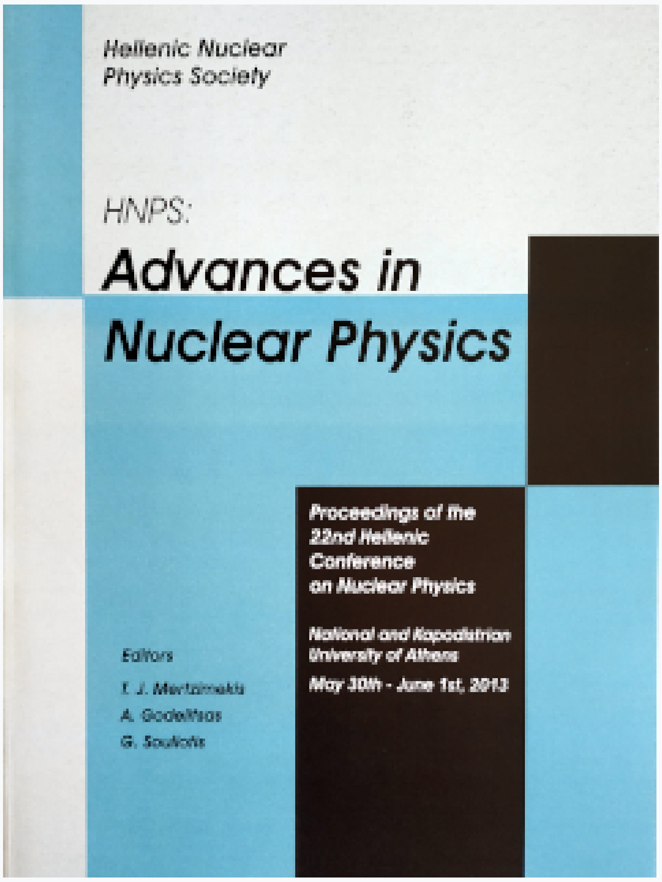

Experimental Study of the Astrophysically Interesting 112Cd(p,γ)113In Reaction

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Experimental Study of the Astrophysically Interesting ^{112}Cd(p,γ)^{113}In Reaction

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Abstract

An experimental study of the astrophysically interesting ^{112}Cd(p,γ)^{113}In reaction, conducted at INPP, NCSR "Demokritos", is presented. The purpose of the experiment was to study the total cross section and the angular distribution of the de-excited nuclei. The experiment aimed at both gaining knowledge of proton capture at low energies and serving as a validity test for the Hauser–Feshbach theory, a statistical model of compound reactions of high importance. Both in–beam and activation techniques were used during the experiment and the results are compared to TALYS calculations.

Keywords: Cross Section, Angular Distribution, (p,γ) Reaction

1. Introduction

One of the main subjects of Nuclear Astrophysics is understanding the mechanisms behind the nucleosynthesis processes of the heavier elements. The *p*-process, which is mainly responsible for the *p*-nuclei abundances that appear in the observed solar system [1], comprises an extended network of nuclear reactions (more than 20'000 reactions). Studying those *p*-nuclei, such as ^{113}In, requires knowledge of proton-capture cross sections at low energies. In addition, the vast number of nuclear reactions depends on cross-section predictions by the Hauser–Feshbach (H–F) theory, which models such a network [2, 3]. Therefore, it is of high importance to carry out experiments as a validity test for the H–F theory at low energies.

2. Experimental Details

Proton beams were accelerated at energies of 2.8, 3.0, 3.2 and 3.4 MeV by the 5.5 MV Tandem Accelerator at INPP, NCSR "Demokritos". The protons were collimated and impinged on a thin isotopic target of ^{112}Cd (1.2 mg/cm^2, 99.7% enriched) backed by three additional layers (Table 1). The target was mounted on a vacuum chamber tilted by 30° to avoid any shadowing effects by the aluminum frame. Air cooling was applied to avoid deterioration of the target due to overheating. In addition, a suppression voltage of -300 V was implemented to prevent false current readings due to scattered electrons.

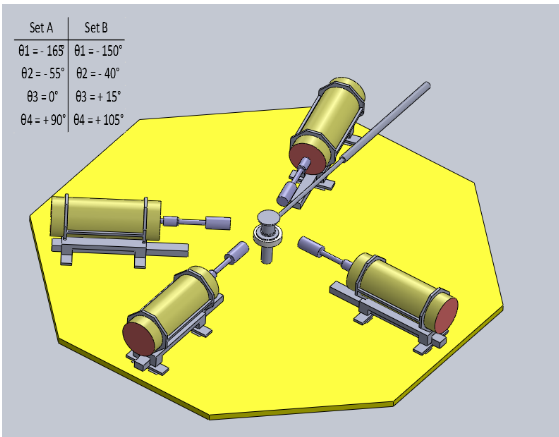


Figure 1: A sketch of the experimental setup

The γ rays from the de-exciting ^{113}In nuclei were detected by four high-efficiency HPGe detectors. The detectors were placed on a goniometric table at specific angles (Fig. 1) to obtain sufficient information on the angular distribution of the γ rays. A 15° rotation of the goniometric table, driven by a remotely-controlled motor, enabled collection of data at four additional angles. Data were recorded in singles mode.

E_{level} [keV]	$J\pi$	$t_{1/2}$	E_γ [keV]	γ mult	Final level E_{level}	$J\pi$
391.7	$1/2^-$	99.5 m	391.7	M4	0.0	$9/2^+$
1024.3	$5/2^+$	3.6 ps	1024.3	E2	0.0	$9/2^+$
1029.7	$1/2^+$,$3/2^+$	0.33 ns	638.0	E1	391.7	$1/2^-$

Layer No:	1	2	3	4
	^{112}Cd (99.7% enr.)	^{nat}Bi	^{nat}In	^{nat}Cu
thickness [mg/cm^2]	1.2	40	1	18

Table 1: Spectroscopic information and target composition

Due to the existence of a low-lying isomeric state at 391.7 keV ($t_{1/2} = 99.7$ m), it was considered necessary to use the activation technique to extract the cross section for that state. The target was irradiated during in–beam measurements for a time interval exceeding 10 halflives of the isomeric state, and was then left to de-excite. Decay radiation was recorded for a period of ≈3.5 lifetimes (6 h).

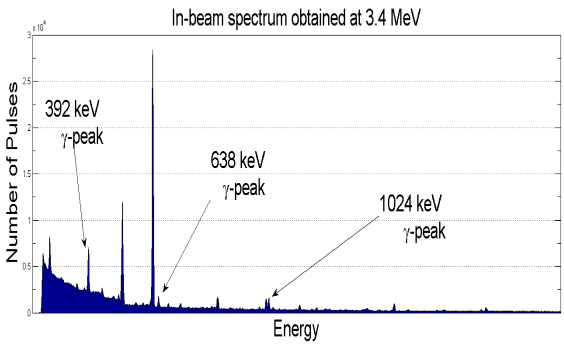


Figure 2: Typical spectrum of data collected using the in–beam technique. Energy scale is in keV.

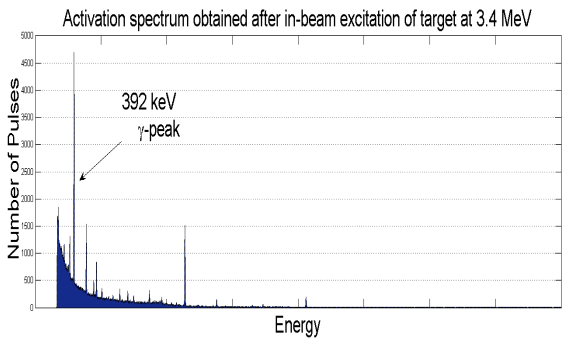


Figure 3: Typical spectrum of data collected using the activation technique. Energy scale is in keV.

Analysis of spectra was performed using the SpectrW analysis software [4]. Typical γ-spectra from both in–beam and activation techniques are shown in Fig. 2 and Fig. 3.

3. Analysis and Results

3.1. Angular Distributions

In–beam data were collected at two angle sets accounting for a total of eight (8) angles of detection (Fig. 1). Data were normalized to total charge, in mC, delivered by the beam, and the solid angle of each detector. Fig. 4 illustrates the experimental angular distributions for the decay of $5/2^+ \rightarrow 9/2^+$ (E_γ =1024 keV) at 3.4 MeV proton beam energy. A function of the form $W(\theta) = A_0(1 + A_2P_2(\cos\theta) + A_4P_4(\cos\theta))$ was used to fit the experimental data for the line 1024 keV, corresponding to an E2 transition to the ground state. Here $A_k, (k = 0, 2, 4)$ are free parameters and P_k k-order Legendre polynomials. The experimental results and the corresponding fitted curve are illustrated in Fig. 4.

Angular distribution data were used subsequently to correct for the angular dependence in the total cross section data measured by all four detectors in the setup.

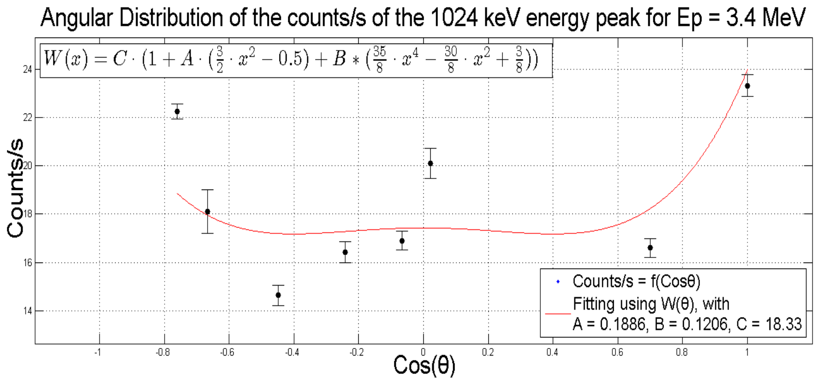


Figure 4: Angular distributions for the $5/2^+ \rightarrow 9/2^+$ decay

3.2. Total Reaction Cross Sections

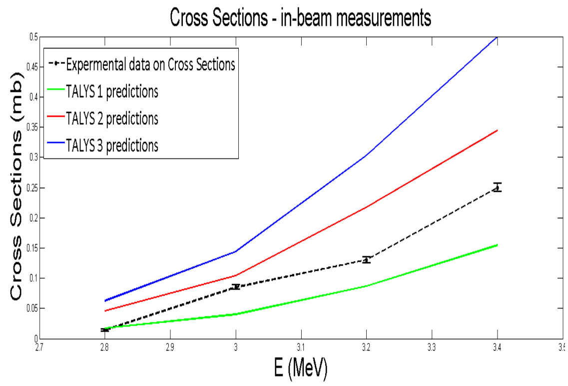
The total cross section σ_{tot} of the reaction was derived from the total reaction yield Y using

$$\sigma = \frac{A \cdot Y}{N_A \cdot \xi} \tag{1}$$

where A is the atomic weight of the target used in amu, N_A is the Avogadro number and ξ is the target thickness in mg/cm^2. The deduced experimental cross sections were compared to Hauser-Feshbach calculations using the TALYS code [5].

The H–F formula uses global models of optical model potentials (OMP), nuclear level densities (NLD) and γ strength factors (γSF). Three combinations of nuclear ingredients that are either phenomenological or microscopic correspond to three curves in Fig. 5, which are labeled as TALYS-1(KD-CTFG-KU), TALYS-2 (BDG-HFBCS-HFBCS) and TALYS-3 (BDG-HFB-HFB). The results from the comparison between theory and experiment are in a good agreement, both at absolute magnitude and trend.

Figure 5: Total cross-section measurements for data obtained with the in–beam technique at 3.4 MeV



Acknowledgments

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