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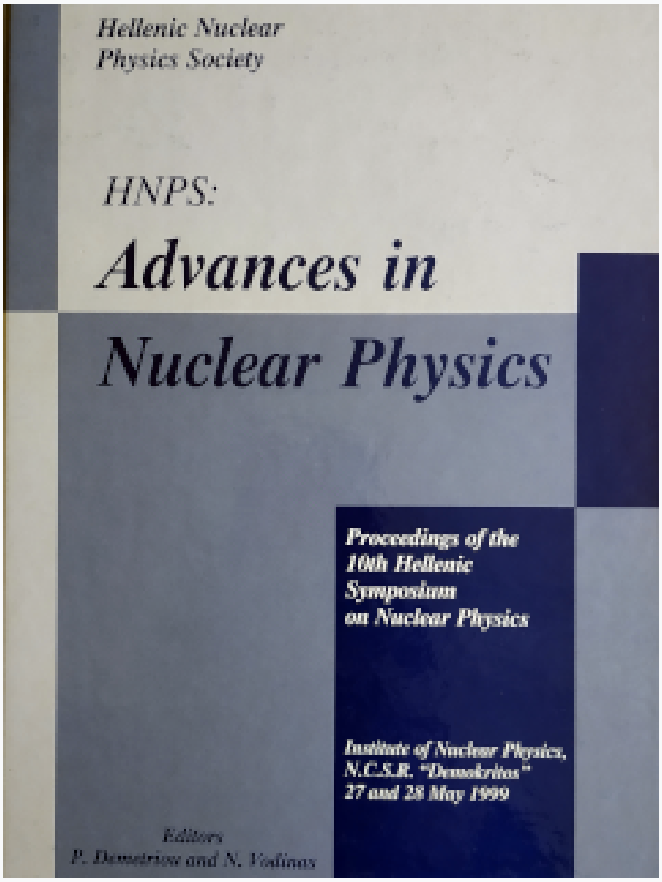

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Cross Section Measurements of the $^{89}Y(p,\gamma)^{90}Zr$ reaction in the energy range E_p=1.6-2.4 MeV.

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Abstract

The total cross section of the nuclear reaction $^{89}Y(p,\gamma)^{90}Zr$ has been measured over the proton energy range E_p=1.6-2.4 MeV. The results are compared with the predictions of statistical model calculations.

1 Introduction

A very important point in nuclear astrophysics models is the reproduction of the abundances of the so called p-nuclei, a class of nuclei heavier than iron, lying on the proton rich side of the chart of nuclides between ^{74}Se and ^{196}Hg. The p-process is a nucleosynthetic mechanism through which p-nuclei are produced. It therefore includes reactions such as (γ,n), (γ,p), (γ,α) and their inverse as well.

The predictions of the p-process models do not reproduce satisfactory the abundances in the A=90 mass region. This problem could be attributed either to the lack of experimental data or to the uncertainty in the theoretical estimates of the statistical models [1-3]. It is obvious that there is a need for precise measurements of (p,γ) cross sections and furthermore for tests of the validity of the Hauser-Feshbach model predictions in the A=90 mass region. These facts have motivated the present work which is concentrated in measuring the cross section of the nuclear reaction $^{89}Y(p,\gamma)^{90}Zr$ over the proton energy range E_p=1.6 -2.4 MeV.

2 Experimental details

The measurements have been carried out at the 4 MV single-ended Dynamitron accelerator of the University of Stuttgart, as well as at the 5.5 MV Van De Graaf Tandem accelerator of the Institute of Nuclear Physics of NCSR "Demokritos", Athens. Both machines have been calibrated during the experiments by means of the 992 keV resonance of the reaction ^{27}Al(p,γ)^{28}Si.

The experimental setup shown in Fig. 1 of the former measurements consisted of 4 HPGe detectors (three of them with 100% relative efficiency and one with 80%), all shielded with BGO detectors for Compton suppression, which were placed on a turnable table. Hence, the γ-angular distributions of all the γ-transitions of interest have been measured at each beam energy. In order to check properly the level

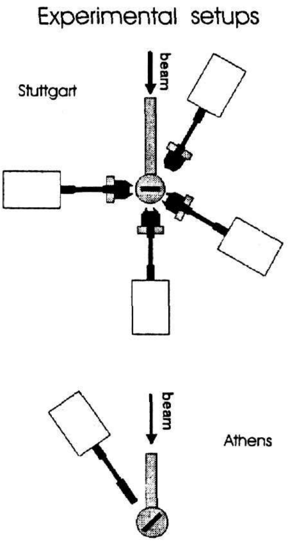

Fig. 1. The experimental setups.

scheme of the produced ^{90}Zr nucleus it was necessary to improve the statistics at certain beam energies. For this purpose γ-spectra have been additionally measured at the Tandem accelerator of the NCSR "Demokritos". In this experiment, one Ge detector with 80% relative efficiency was placed at 55^0 to the beam axis (see Fig. 1). Spectra have been measured at E_p=2.4, 2.3 and 2.2 MeV. In both experiments the same target has been used: metallic ^{89}Y with thickness 103.4 μgr/cm^2 evaporated on Ta-foil and covered with 31 μgr/cm^2 Au.

3 Data analysis and results

As it is shown in Fig. 2, the ^{89}Y(p,γ) ^{90}Zr nuclear reaction leads to the excitation of states of the ^{90}Zr nucleus with excitation energy $E=Q+E_p+\delta E$ where Q is Qvalue, E_p is the proton energy and δE is the target thickness. As the nuclear level density in the excitation energy region relevant to our experiment is very large, the individual resonances cannot be distinguished with the target thickness we used [4].

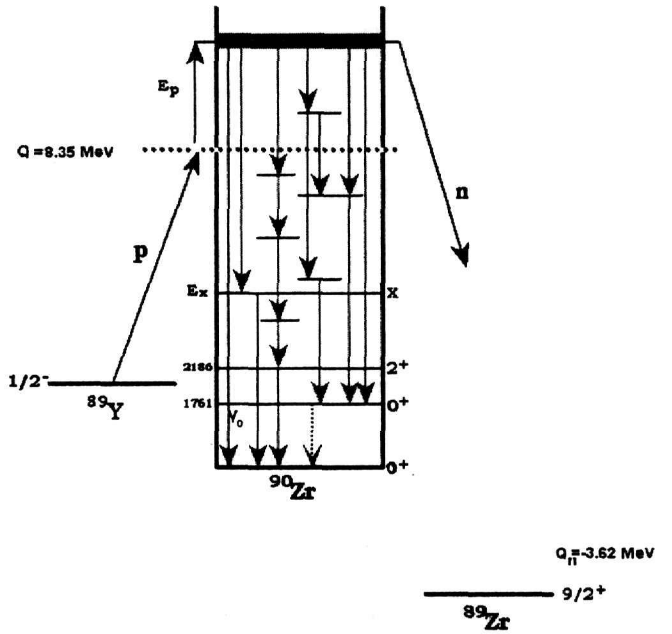

Fig. 2. The $^{89}Y(p,\gamma)^{90}Zr$ reaction.

The compound nucleus ^{90}Zr decays either directly into the ground state or into the state x which will subsequently decay. In order to obtain the total cross section of the reaction $^{89}Y(p,\gamma)^{90}Zr$ the absolute number of all the photons emitted by the reaction has to be determined. Hence one has to sum up the absolute yield of all γ-transitions feeding the ground state of ^{90}Zr. These γ-transitions are shown in Fig. 3 with solid black arrows. Especially for the forbidden transition (E0) from the first excited state to the ground state, (shown in Fig. 4 with a dashed arrow) one has to take into account all γ-rays feeding the first excited state (shown in Fig. 3 with grey arrows).

Typical γ-spectra taken in Stuttgart and in Athens are shown in Fig. 4 respectively. Hereby the γ_0-transition and γ_1-transition, i.e. the transitions from the entrance region to the ground state and to the first excited state are indicated by arrows.

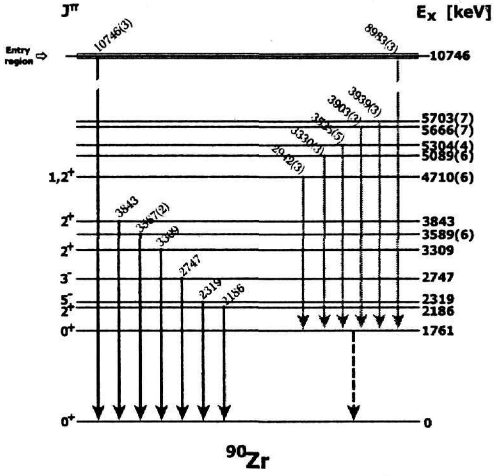

Fig. 3. Partial level scheme of ^{90}Zr.

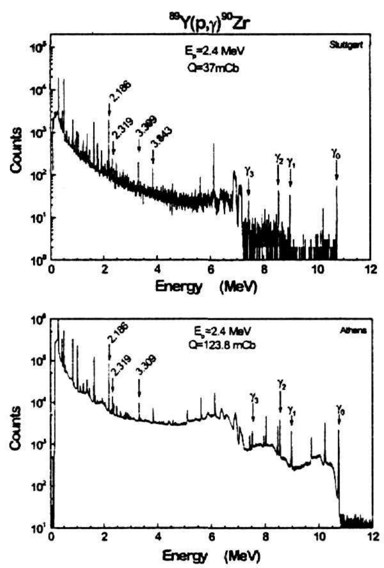

Fig. 4. Gamma-spectra of the ^{89}Y(p,γ)^{90}Zr reaction taken in Stuttgart (upper part) and in Athens (lower part).

For each γ-ray which contributes to the total cross section, we obtain the absolute yield Y_θ at several angles θ. In this way we produce the angular distribution of each γ-ray and after fitting with Legendre polynomials we obtain the term A_0 [5] A typical angular distribution measured is shown in Fig 5.

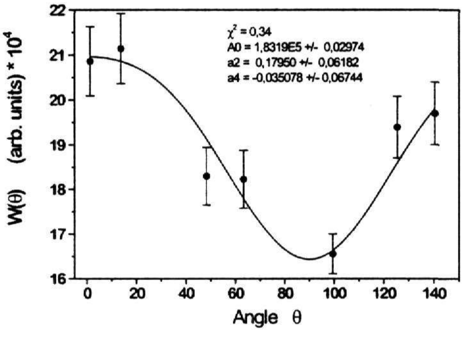

Fig. 5. Angular distribution of the E_γ=2186 keV γ-transition.

The total cross section is given then by the formula

$$\sigma_{tot} = \sum \sigma_i = 4\pi A_{0_i}$$

where i accounts for the γ-transitions feeding either the ground state or the 1st excited 0^+ state. Finally we repeat this procedure for every proton energy.

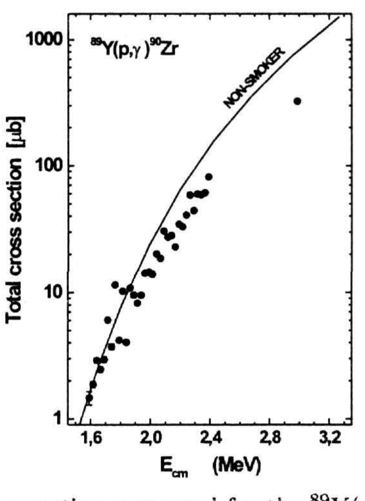

Fig. 6. Total cross section measured for the $^{89}Y(p,\gamma)^{90}Zr$ reaction.

The cross sections measured in the present work are plotted in Fig. 6 (solid circles), together with the results of the theoretical calculations (solid line) obtained with the NON-SMOKER code. In these calculations the nucleon-nucleus optical potential of [6] and the nuclear level density of [6] were used respectively. We can see that the predictions of the statistical model code deviate from the data about 20-40% at $E_p \geq 2$ MeV.

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