



Review

Nuclear physics experiments for the astrophysical p process

A. Sauerwein*, M. Elvers, J. Endres, J. Hasper, A. Hennig, L. Netterdon, A. Zilges

Institut für Kernphysik, Universität zu Köln, Germany

ARTICLE INFO

Keywords:

 p process

Explosive nucleosynthesis

Activation method

In-beam technique

ABSTRACT

We studied the two astrophysically interesting reactions $^{141}\text{Pr}(\alpha, n)^{144}\text{Pm}$ and $^{92}\text{Mo}(p, \gamma)^{93}\text{Tc}$ with the activation method and with the in-beam method, respectively. The $^{141}\text{Pr}(\alpha, n)^{144}\text{Pm}$ experiment was performed at the cyclotron of the 'Physikalisch Technische Bundesanstalt (PTB)' in Braunschweig, Germany, and the reaction was studied within and just above the so-called Gamow window. In this proceedings, we present the experimental details of this measurement. The proton-capture reaction on the neutron-magic nucleus ^{92}Mo was studied at energies relevant for the astrophysical p process. The reaction was investigated by the in-beam technique using the γ -ray detector array HORUS (High efficient Observatory for γ -Ray Unique Spectroscopy) at the TANDEM ion accelerator at the University of Cologne. The preliminary experimental results are compared to data stemming from other measurements.

© 2011 Elsevier B.V. All rights reserved.

1. Introduction

Most nuclei heavier than iron are synthesized by the s and r processes via neutron-capture reactions [1]. However, about 30–35 proton-rich nuclei, the so-called p nuclei, are bypassed by these processes [2,3]. It is not yet fully understood in how many processes the p nuclei are produced and in which astrophysical scenario these processes take place. Some of the p nuclei are believed to be produced in the explosive scenario of supernovae type II [4]. At this astrophysical site, the p nuclei can be produced by an extensive reaction network consisting of (γ, n) , (γ, p) , and (γ, α) reactions on more than one thousand nuclei. Due to the absence of experimental data, p -process network calculations are almost completely based on theoretically predicted reaction rates [5,6]. The accuracy of these predictions strongly depends on the adopted nuclear models for the optical-model potential, photon-strength functions and nuclear level densities. A comprehensive experimental data base for these reaction rates is strongly required to improve the accuracy of these models. It has been shown that proton and α -particle capture reactions are particularly well suited to constrain theoretical calculations [7,8].

Despite the increasing number of experiments on (p, γ) and (α, γ) reactions in the last decade, not all p -nuclei abundances can be reproduced satisfactorily in p -process network calculations. It is not clear whether these deficiencies are due to the astrophysical modeling or the employed nuclear physics. In Ref. [9], the sensitivity of the location of the p -process path and consequently of the final p -process abundance to the reaction rates is investigated. Therein the author shows that the reaction flow is mainly determined by only a limited number of reactions and suggestions for especially useful reactions to be studied experimentally are given.

* Corresponding author. Tel.: +49 221 470 5742; fax: +49 221 470 5168.

E-mail address: sauerwein@ikp.uni-koeln.de (A. Sauerwein).

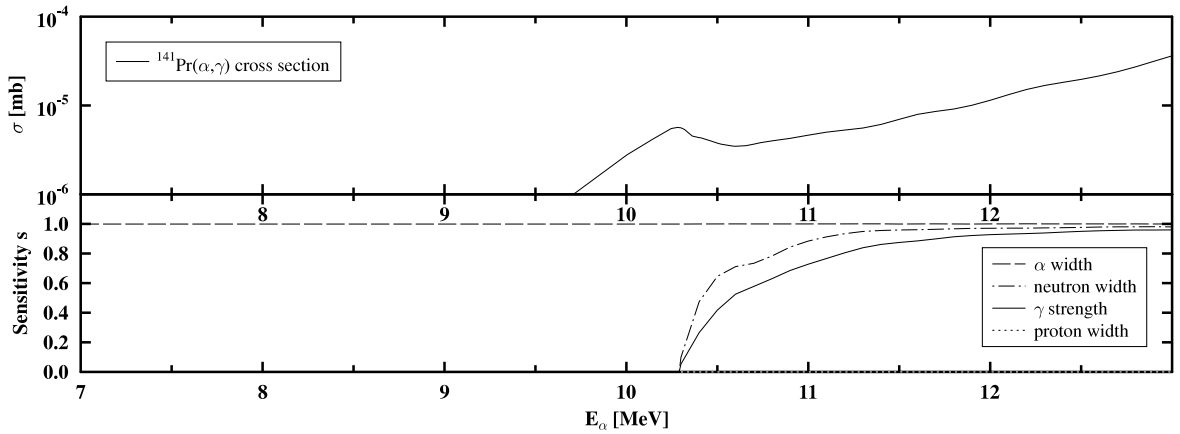


Fig. 1. In the upper row the (α, γ) cross section calculated by the NON-SMOKER^{WEB} code [6] is shown, whereas in the lower row the sensitivity factor s for a change in the widths of $f = 2$ is depicted. In the Gamow window, which is located between 7.2 and 10.3 MeV for $T = 3$ GK, the cross section of this reaction is dominated by the α -particle nucleus optical model potential, whereas at energies measurable with the activation method in a reasonable time (well above 10 MeV), the reaction rate is sensitive to additional nuclear parameters as well, e.g., the photon-strength function. See text for further details.

2. Activation experiment of the reaction $^{141}\text{Pr}(\alpha, n)^{144}\text{Pm}$

2.1. Astrophysical motivation

As described in the introduction, photodisintegration reactions play a major role in the p process. A disadvantage common to all direct photodisintegration experiments is the fact that these measurements, in general, can only account for transitions stemming from the ground state of the target nucleus. The hot temperatures in an explosive astrophysical environment lead to a significant thermal population of excited levels. The enhancement of the reaction rates due to the thermal population is accounted for by the so-called stellar enhancement factor (SEF) which needs to be derived from theory [10]. Since the SEF for photodisintegration rates measured in the laboratory is typically up to a few orders of magnitude, it is very difficult to draw any reliable conclusions about the stellar reaction rates from photodisintegration experiments only.

On the contrary, the stellar enhancement plays a marginal role for reactions with large positive Q values. This condition is fulfilled for most of the (n, γ) , (p, γ) and (α, γ) reactions of relevance for the p process. Therefore, a common experimental strategy is to measure the inverse reaction rates of photon-induced reactions and then to calculate the stellar photodisintegration rates from the detailed balance theorem [11]. In this manner, the stellar reaction rates can be determined from experimental measurements without introducing significant uncertainties from theory.

One of the reactions suggested in Ref. [9] is the α -capture reaction $^{141}\text{Pr}(\alpha, \gamma)^{145}\text{Pm}$. For this purpose, we analyzed successively the sensitivity of this cross section to a change of one of the different input parameters, e.g., the α width. This is demonstrated in Fig. 1. In the upper row the (α, γ) cross section calculated by the NON-SMOKER^{WEB} code [6] is shown, whereas in the lower row the sensitivity factor s is depicted. The sensitivity factor s describes the change in the cross section when one of the nuclear physics input parameters is changed by a factor of $f = \Gamma'/\Gamma$. In Fig. 1 all widths have been varied by a factor $f = 2$, respectively.

A sensitivity $s = 1$ means that the cross section is changed by the same factor as the input parameter and a sensitivity $s = 0$ means that the cross section is not changed at all. Thus, if a width is changed by a factor $f = \Gamma'/\Gamma$, the cross section may change by

$$\frac{\sigma'}{\sigma} = s(f - 1) + 1 \quad \text{for } \sigma' > \sigma \quad \text{and} \quad \Gamma' > \Gamma \quad \text{or} \quad \sigma' < \sigma \quad \text{and} \quad \Gamma' < \Gamma,$$

$$\frac{\sigma'}{\sigma} = \frac{1}{s(f - 1) + 1} \quad \text{for } \sigma' < \sigma \quad \text{and} \quad \Gamma' > \Gamma \quad \text{or} \quad \sigma' > \sigma \quad \text{and} \quad \Gamma' < \Gamma.$$

In the Gamow window, i.e. the energy window of astrophysical relevance for charged-particle capture reactions under stellar conditions, which is located between 7.2 and 10.3 MeV for $T = 3$ GK [12], the cross section of the $^{141}\text{Pr}(\alpha, \gamma)^{145}\text{Pm}$ reaction is dominated by the α -particle nucleus optical model potential, whereas at energies measurable with the activation method in a reasonable time (well above 10 MeV), the reaction rate is sensitive to additional nuclear parameters as well, e.g., the photon-strength function. Thus, it is not easily possible to extrapolate the experimental data towards the Gamow window without further assumptions.

For this reason, we chose to perform an experiment on the reaction $^{141}\text{Pr}(\alpha, n)^{144}\text{Pm}$ instead. Within the Gamow window, which is located between 10.7 and 13.2 MeV for $T = 3$ GK [12], and up to $E_\alpha = 15$ MeV, the corresponding reaction rate is almost exclusively sensitive to the α -particle nucleus optical model potential so that this reaction is particularly well

Download English Version:

<https://daneshyari.com/en/article/1854527>

Download Persian Version:

<https://daneshyari.com/article/1854527>

[Daneshyari.com](https://daneshyari.com)