# Measurement of formation cross-section of $^{140}$Pr in $^{141}$Pr(n,2n) reaction at 14.8 MeV

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## Introduction

Thermal and fast neutron induced nuclear reactions are very important tool to obtaining information of the excited states and ground states of nuclei and nuclear reaction mechanisms. However, the low energy neutron can induce (n,γ) and (n,n') type reactions using 14 MeV neutron generator and a number of nuclear reactions have been studied[1]. Praseodymium is a rare earth element and has only one stable isotope that is $^{141}$Pr with 100% abundance. The rare elements are always present as minority in structural material of nuclear reactor.

Praseodymium can be used as an alloying element with magnesium to create high strength metals that are used in aircraft engines. Praseodymium-cobalt alloys have applications in the satellite, missiles and radar technologies [2]. The praseodymium exits in the structural material of nuclear reactor and therefore gets irradiated by neutrons during the nuclear fission and fusion process. It is therefore of great interest to study fast neutron induced reactions for rare elements. Accurate data for the measured cross sections of the nuclear reaction cross sections can be validated by theoretical cross sections obtained by different nuclear models. It also gives the information about the nuclear structure.

In present study cross section for formation of $^{140}$Pr through $^{141}$Pr(n,2n) nuclear reaction is studied using neutron produced in D-T reaction. The (n, 2n) reaction is important to obtain information on the relation between spins and parities of the initial and final states of the nuclei that take part in the nuclear reaction. The cross sections are measured with the activation technique relative to a monitor reaction.

The cross section were also theoretically estimated at 14.7±0.3 MeV and compared with the data available in the EXFOR (Exchange Format) data base[3].The theoretical calculations have been performed using the nuclear codes TALYS-1.8.

## Experimental Method

The neutron irradiation work was carried out at the 14 MeV Neutron generators Laboratory, Department of Physics, Savitribai Phule Pune University, Pune India. The 14 MeV neutrons were produced by bombarding deuterium ions of energy 175 KeV on a 8 Curie tritium target. On the tritium target, the deuterium beam was of diameter ~4mm and current 100 µA. The samples of praseodymium were made from natural $Pr_6O_{11}$(99.99%) powder, and aluminum as monitoring element. The monitor $^{27}$Al(n,p)$^{27}$Mg reaction was carried out using pure aluminum foil. Each sample praseodymium of known weight along with known weight of aluminum foil were packed in the a polyethylene bag. The sample size was close to 10 mm x 10 mm of rectangular shape. In each sample the weight of praseodymium and aluminum foil together was ~1.5 gm measured by a microbalance. Three such samples were prepared for the study of $^{141}$Pr(n,2n)$^{140}$Pr reaction with $^{27}$Al(n,p)$^{27}$Mg as the monitor reaction.

The decay data of the radioisotopes $^{140}$Pr produced through the $^{141}$Pr(n,2n)$^{140}$Pr reaction and $^{27}$Mg produced through the $^{27}$Al(n,p)$^{27}$Mg reaction are given in Table 1. At a time one sample was mounted on the sample holder very close to the tritium target. Deuterons of 175 keV energy were bombarded on the tritium target and current was adjusted at 100µA. The sample was irradiated for 10 minutes.

A HPGe detector coupled to MCA was calibrated by using standard γ-ray sources namely as $^{22}$Na, $^{54}$Mn, $^{60}$Co, $^{133}$Ba, $^{137}$Cs having energies 0.511 & 1.275 MeV, 0.835 MeV, 1.17 & 1.33 MeV, 0.356 MeV and 0.662 MeV respectively. After neutron irradiation, the sample was brought to the counting room with the help of radiation shielding box. The induced γ-ray activity of radioisotopes produced in the sample was measured for a period ten minutes.

**Table 1:** The decay data of the radioisotopes produced in neutron induced reaction.

| Nuclear Reaction | Abundance (%) | Half life | Eγ (MeV) | Iγ (%) |
|---|---|---|---|---|
| $^{140}$Pr (n,2n)$^{140}$Pr | 100 | 3.39m | 0.511<br>1.596 | 100<br>0.3 |
| $^{27}$Al(n,p)$^{27}$Mg | 100 | 9.46± 0.04 m | 0.841<br>1.013 | 70<br>30 |

The area under each photopeak was estimated using computer program. The cross section of the (n,2n) reactions was calculated from the measured peak counts using the following activation equation,

$$\sigma = \sigma_M \frac{A\varepsilon_M I_{\gamma M}\lambda N_M}{A_M \varepsilon I_\gamma \lambda_M N} \frac{(1-e^{-\lambda_M t_1})}{(1-e^{-\lambda t_1})} \frac{e^{-\lambda_M t_2}}{e^{-\lambda t_2}} \frac{(1-e^{-\lambda_M t_3})}{(1-e^{-\lambda t_3})}$$

where, $\sigma$ is the reaction cross section, A is the number of counts under the photo peak, Iγ is photon disintegration probability, ε is the detector efficiency, $\sigma_M$ is the cross section for monitor reaction, λ is decay constant, N is the number of atoms of the isotope of the element, $t_1$ is the irradiation time, $t_2$ is the cooling time, and $t_3$ is the period for which the γ activity is measured. The subscript M stands for the monitor element and reaction.

## Theoretical Calculation Using Nuclear Code – TALYS

The excitation functions for the reactions were studied theoretically using the numerical nuclear model code TALYS-1.8[4]. The theoretical calculations were performed using the default parameter values and by changing the choice of the level density models. The level density parameters were calculated using the six different choices of the level density model available in TALYS-1.8.

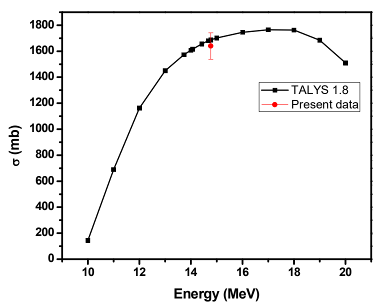


**Fig. 1** comparison of our measured cross section for $^{141}$Pr(n,2n)$^{140}$Pr with TALYS 1.8.

The results of the theoretical calculation and measured cross section are given in Table 2.

## Conclusion

In the present paper, cross section of $^{141}$Pr(n,2n)$^{140}$Pr is reported at 14.8 MeV neutron energy. Using TALYS 1.8 code theoretical values of the cross section was obtained with default level densities. Activation cross sections for $^{141}$Pr(n,2n)$^{140}$Pr reaction induced by 14.8 MeV neutrons has been plotted with other global values of cross section and shown in the Fig.1. The constant temperature and Fermi-gas model (ldmodel 1) is to be preferred for $^{141}$Pr(n,2n)$^{140}$Pr reaction. The result was compared with previously experimental results reported in the literature and given in the Table 2.

**Table 2:** Measured cross sections of the $^{141}$Pr(n,2n)$^{140}$Pr nuclear reaction

| Reaction/ Energy | Measured $\sigma$(mb) | EXFOR $\sigma$(mb) |
|---|---|---|
| $^{141}$Pr(n,2n)$^{140}$Pr/ 14.8 MeV | 1639±101 | 1879±113[5]<br>1378±206[6] |

The experimental results presented here may be used to more accurately describe the reaction processes and verify statistical model parameters used in their theoretical representation.

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## References

[1] B. Lalremruata, “Excitation function of the $^{93}$Nb(n,2n)$^{92}$Nb$^{m}$ reaction from threshold to 24 MeV” Physical Review C **80**, 014608 (2009).
[2] Zhu Zhonghan, “Rare-earth metals and their applications in aviation”,Foreign Technology Division, China (1985).
[3] EXFOR “Experimental Nuclear Reaction Data” https://www-nds.iaea.org/exfor/exfor.htm.
[4] A. Koning, “TALYS-1.8, A nuclear reaction program”, http://www.talys.eu/
[5] Lu Junhua,“Crosssection measurements for 141Pr isotopes at neutron energies from 13.5 to 14.8 MeV”, Radiation Physics and Chemistry, 1169-1177 (2010)
[6] C.S. Khurana, “cross sections for (n,2n) reactions at 14.8 MeV”, Journal of Nuclear Physics 560 (1961).