P-process to produce Samarium 144 by Photo-disintegration

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Introduction

Heavy elements are formed in various astrophysical processes where various nuclear properties play important roles. The aim of the present work is to study these various nuclear properties and investigate how they affect the formation of heavy elements. It is well known that the majority of naturally occurring nuclide beyond the element iron can be made in two kinds of neutron capture processes, the s and r process [3]. However, there are some naturally occurring proton rich nuclide known as p-nuclei. The present work predicts an idea for producing Sm^{144} which is a p-nuclei by photo disintegration. This type of nuclear reaction may be occurred in astrophysical environment at relatively high temperature.

Theoretical approach:

In order to perform theoretical prediction and measurement of relevant nuclear cross section a model to calculate particle-induced reaction cross-section using statistical Hauser-Feshbach theory including any fluctuation may be employed. In our work we have used nuclear optical model [4]. We have here employed semi-microscopic nucleon-nucleus spherical optical model potential commonly known as JLM microscopic optical model. In these computation we have manually inserted relevant input parameters according to situations demanded. The normalization factors used here for both the imaginary spin-orbit potential and real spin orbit potential for JLM calculation are taken as 1.5. In this work we have mainly attempted to find the probable formation of p-nuclei Sm^{144} through nucleosynthesis. In order to do so we have studied few possible gamma neutron nuclear reactions (g,n) that might be occurred in the vicinity of Sm^{144}, Sm^{147}, Sm^{148}, Sm^{149}, Sm^{150}, Sm^{152} and Sm^{154} . We have computed reaction cross section of photo disintegration reactions (gamma-neutron) of these isotopes of Sm using TALYS software based on optical microscopic (JLM) model. It also could be expected that Sm^{144} be synthesized by possible reaction channels Sm^{146} (g,2n) Sm^{144} & Sm^{145} (g,n) Sm^{144}. For possible channels we have estimated neutron production cross section of Sm^{146} (g,n) Sm^{145} & Sm^{145} (g,n) Sm^{144} . At the same time production cross section of Sm^{144}, Sm^{145} from Sm^{146} and Sm^{144} from Sm^{145} are also measured using JLM nuclear model and local optical model by changing level density and other relevant parameters as required. Now we shall analyze the results related with our computation work to find the probable reaction channel for producing Sm^{144} .

Result and discussions:

The reaction cross section based on the statistical model was measured as lying between 1.50 barn to 2.80 barn [5] at 30 Kev energy. We have computed this cross section as 2.305 barn at 30 Kev which agrees well with the experimental result. It is evident from computation that the maximum production cross section of Sm^{145} is well above than that of Sm^{144} from Sm^{146}. At high energy beyond17 Mev production cross section of Sm^{144} is found to be greater than that of Sm^{145}. At 20Mev cross section for Sm^{145} and Sm^{144} are 14mb and 67mb respectively. So, at high energy greater than 17MeV production of Sm^{144} might be occurred through (g,2n) channel from seed nucleus Sm^{146} (Table 1)

Table 1

Parent nucleus	channel	Product nucleus	Energy (MeV)	Cross section mb
Sm^{146}	(g,n)	Sm^{145}	14.99	355.03
Sm^{146}	(g,2n)	Sm^{144}	17.1	97.37
Sm^{146}	(g,n)	Sm^{145}	20	14
Sm^{146}	(g,2n)	Sm^{144}	20	67
Sm^{145}	(g,n)	Sm^{144}	15.04	359.93
Sm^{145}	(g,n)	Sm^{144}	20	54.14

The above table also indicates that maximum production cross section of Sm^{144} from $Sm^{145}$is 359.93mb at 15.04MeV and it is 54.14mb at

20 Mev. So, probability of producing Sm^{144} from Sm^{145} is expected to be more likely.

Table 2

Reaction	Energy in MeV	Neutron cross section in mb
Sm^{145} (g,n) Sm^{144}	12.48	143.39
	15	355.16
	19.99	99.76
Sm^{146} (g,n) Sm^{145}	12.54	153.96
	15.5	355.04
	19.94	147.76

One more point may be noted that neutron production cross section for Sm^{146} (g,n) Sm^{145} and Sm^{145} (g,n) Sm^{144} are found to be 355.04mb and 355.16mb respectively at about 15.5MeV and 15MeV (Table 2). These are in well agreement with relevant production cross section. Hence the channels predicted for formation of Sm^{144} might be occurred in stellar environment at high energy. Reaction rates of different relevant reactions are also studied at different temperatures. It is found that the rate of reaction Sm^{145}(g,n) Sm^{144} is higher than the reaction Sm^{146} (g,2n) Sm^{144} up to temperature 7.63 T_9. After that the rate of (g,2n) reaction exceeds that of (g,n) (Fig 1). Thus it could be predicted that at high temperature Sm^{144} might be produced from (g,2n) reaction of seed nuclei Sm^{146}.

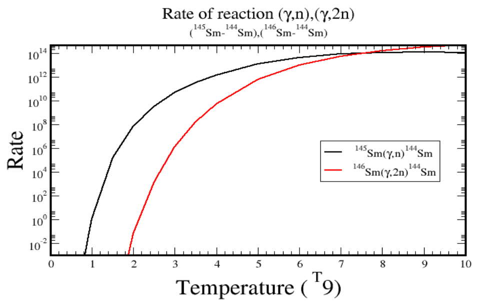

Fig 1

In order to perform these experiments in the laboratory high energy gamma ray source may be employed. High energy and high brightness laser Compton backscattering gamma-ray source are already employed at IHEP. At IHEP LCS gamma-ray source can produce energy from 0.1 MeV to 112 MeV. Recently study of the (g, n), (g, a), (g, p) reactions of La^{139}, Pr^{141}, $Sn^{116-118,120,122,124}$ and many others have proved the advantages of the LCS gamma-ray sources[2]. As these isotopes belong to the neighbor of our isotope of interest, this LCS source may be well applied to analyze the probable nucleosynthesis for formation of heavy nuclei in astrophysical environment including Sm^{144} also.

Conclusion:

The comparative studies of gamma neutron reactions to be occurred in Samarium isotopes with mass numbers 144, 147, 148, 149, 150, 152 and 154 in connection with relevant production cross section available from experimental source [1] are in agreement with our optical model oriented theoretical data mentioned earlier using TALYS software. So, this model can be well used in other astrophysical environment to study nuclear reaction. In this work we have used this model to find a route for formation of p nuclide Sm^{144} through nucleosynthesis. In this regard we have predicted channels as gamma neutron chain reaction from seed Sm^{146} . The measured cross section are in agreement with corresponding neutron and alpha separation energy levels. So, it can be concluded that Sm^{144} could be produced from Sm^{146} through gamma neutron chain at high energy and at high temperature.

References:

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