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Measurement of excitation functions and analysis of isomeric population in some reactions induced by proton on natural indium at low energy

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Abstract

The excitation functions for reaction residues populated via ^{115}In$(p,p)^{115m}$In, ^{115}In$(p,pn)^{114m}$In, ^{115}In$(p,p2n)^{113m}$In, ^{113}In$(p,p)^{113m}$In, ^{115}In$(p,n\alpha)^{111m}$Cd, ^{115}In$(p,3n)^{113}$Sn and ^{113}In$(p,n)^{113}$Sn channels were measured over the proton energy range of 8–22 MeV using stacked foil activation technique. Theoretical analysis of the data were performed within the framework of two statistical model codes EMPIRE-3.2 and TALYS-1.8. Isomeric cross section ratio for isomeric pairs ^{115}In^{m,g}, ^{114}In^{m,g}, ^{113}In^{m,g}, $^{113}Sn^{m,g}$ and ^{111}Cd^{m,g} were determined for the first time. The dependence of isomeric cross section ratio on various factors are analysed.

Keywords: Indium target; Proton irradiation; Excitation function; Isomeric cross section ratio

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1. Introduction

The nuclear isomers continue to make key contributions to the development and understanding of nuclear structure physics [1,2]. Isomers are widely distributed in neutron number, proton number, excitation energy and angular momentum with half-lives ranging from nanoseconds to years. They offer a variety of opportunities to explore unusual and extreme states of nuclei.

The isomeric cross section ratio (ICR), defined as the ratio of the cross section for the formation of isomeric state to the total production cross section $\frac{\sigma_m}{\sigma_m+\sigma_g}$, is known to depend strongly on the spins of the isomers concerned and the incident energy [3,4]. Experimental and theoretical studies on the ICR, as a function of incident particle energy, should, therefore, lead to useful information on the spin-cutoff parameter, angular momentum transfer, the level structure of the product nucleus as well as the progress of nuclear reaction mechanism. Hence it is important to have information about the various parameters that may affect the relative isomeric population.

Keeping the above facts in mind, as a part of the systematic study of nuclear reactions induced by light and heavy ions, the excitation function for the reaction $^{115}\mathrm{In}(p,p)^{115m}\mathrm{In}$, $^{115}\mathrm{In}(p,pn)^{114m}\mathrm{In}$, $^{115}\mathrm{In}(p,n\alpha)^{111m}\mathrm{Cd}$, $^{115}\mathrm{In}(p,p2n)^{113m}\mathrm{In}$, $^{113}\mathrm{In}(p,p)^{113m}\mathrm{In}$, $^{115}\mathrm{In}(p,3n)^{113}\mathrm{Sn}$ and $^{113}\mathrm{In}(p,n)^{113}$ Sn have been measured and analyzed. The isomeric cross section ratios for the production of isomeric pairs of ^{115m}In, ^{114m}In, ^{113m}In, ^{113m}Sn and ^{111m}Cd, over the energy ranges from threshold up to 21.8 MeV have been deduced. ^{115}In is an important material in making alloys and is widely used to make gold and platinum much harder. It is also used in multiple junction solar cell [5]. In addition, compounds of indium are used in making optical [6] devices. Two of the radioactive isotopes namely ^{113m}In and ^{114m}In, included in the present analysis, are widely used in therapeutics and diagnostic purposes [7]. Hence the analysis of proton induced reaction on indium is of much interest in industrial medical and space applications.

The predictive power of any nuclear reaction models depends upon the extent of reproduction of available experimental data. The prediction of some of the models differ, sometimes, significantly. Hence in the present study theoretical analysis of the data has been done using two nuclear reaction model codes EMPIRE [8] and TALYS [9]. The above two codes are widely used for analysis of nuclear reaction data, particularly for nucleon-induced reactions. Prediction of this model has been compared with reference to the experimental data.

2. Experiment and analysis

The experiment has been performed at the Tata Institute of Fundamental Research (TIFR), Mumbai, India, using the 14UD pelletron accelerator. Stacked foil activation technique has been employed. The Indium samples of thickness 13 mg/cm^2 were prepared by the rolling method. A stack of four samples of Indium, along with aluminium degraders were irradiated using proton beam, of energy 22 MeV and an average current of 23 nA, for 1.28 h. Mean energy incident on each sample was 21.82, 17.68, 12.68 and 8.61 MeV respectively. The beam current was monitored continuously through current integrator connected to the Faraday cup kept behind the target stack. The activities induced in each sample were followed using a low background 100 cc HPGe detector coupled to the ORTECs PC based multichannel analyzer at the TIFR. The typical gamma-ray spectrum of the activated sample irradiated with mean proton energy 21.8 MeV is shown in Fig. 1. The activities of the following isotopes (produced in respective channels) ^{115m}In $((p,p))$, ^{114m}In $((p,pn))$, ^{113m}In$((p,p),(p,3n))$, ^{113}Sn $((p,n),(p,3n))$ and

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