Study of isomeric cross section ratios in proton and alpha induced nuclear reactions on ^{141}Pr.

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Introduction

It is known that the isomeric cross section ratio (ICR) is governed primarily by the spins of the levels and intermediate states involved, rather than by their separation energies [1,2]. The study of ICR in the formation of isomeric pairs in nuclear reactions give important information about the nuclear reaction mechanism, particularly the energy and angular momentum transfer during the reaction process as well as the progress of nuclear reactions. Keeping this in view we have studied the ICR for the isomeric pairs ^{139g,m}Nd and ^{141g,m}Nd produced in (p,n), (p,3n) and (α,p3n) reactions respectively on ^{141}Pr target over the energies from threshold up to 70 MeV for proton induced reactions and 80 MeV for alpha induced reactions. Experimentally measured cross sections for the reactions ^{141}Pr(α,n)^{144}Pm and ^{141}Pr(α,2n)^{143}Pm over the energy range $\sim$ 14.2 - 40 MeV, have been used as the standard reference for evaluating cross sections for other cases.

1. Experiment and Analysis

Experiment has been performed at the Variable Energy Cyclotron Center (VECC), Kolkata, India, employing stacked foil activation technique. The Praseodymium samples of thickness $\sim$ 5 mg/cm^2, were prepared by vacuum evaporation technique. A stack of seven such samples were irradiated using diffused beam of alpha of energy 40 MeV. Suitable thickness of Aluminum degraders were introduced between the samples to have desired energy falling on each sample in the stack.

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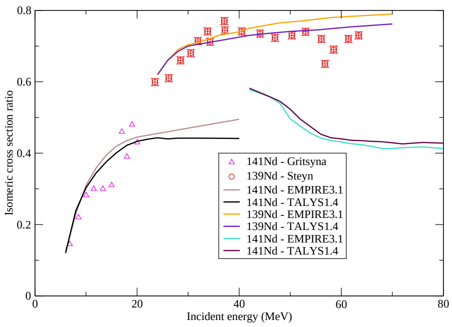

FIG. 1: The experimentally measured and theoretically calculated isomeric cross section ratios for the isomeric pairs ^{139}Nd and ^{141}Nd for the reactions ^{141}Pr(p,n)^{141}Nd, ^{141}Pr(p,3n)^{139}Nd and ^{141}Pr(α,p3n)^{141}Nd .

2. Theoretical analysis

Theoretical calculations of cross sections were carried out using two computer codes, namely EMPIRE 3.1 [3] and TALYS 1.4 [4]. Those codes are based on different nuclear models for the description of nuclear reactions. Depending on the incident particle and considered energy range, pre-equilibrium calculations are performed by the modules based on quantum mechanical (MSD/ MSC) and exciton (DEGAS/ PCROSS) models. In TALYS 1.4 statistical treatment of the compound nucleus is based on the HauserFeshbach model along with the width fluctuation correction model of Moldauer. The pre-equilibrium contribution is estimated by the exciton model.

TABLE I: Spins of the relevant states of the isomeric nuclides of interest

Nuclide	Ground state		Isomeric state			Intermediate state		
	J_π	$T_{1/2}$	MeV	J_π	$T_{1/2}$	MeV	J_π	$T_{1/2}$
^{139}Nd	$3/2^+$	29.7m	0.231	$11/2^-$	5.50h	0.0953		
^{141}Nd	$3/2^+$	2.49h	0.7571	$11/2^-$	61s	0.1940		1.2ns

3. Results and discussion

A. Isomeric cross section ratios

The ICR thus calculated for the production of ^{139}Nd and ^{141}Nd nuclei produced through proton and alpha induced reaction on ^{141}Pr and are determined at various incident energies and are plotted in Fig. 1 along with the available experimental data [5,6]. The analysis indicate that the ICR has reflection on the relative level difference between the isomeric state and ground state as well as the spin of the states. At relatively larger energies the system is seems to prefer higher spin states rather than the excitation energy available for the system as is indicated by relative population of the above nuclei. Relevant data on ground state, isomeric state and intermediate state, such as energy, spin and parity, half lives and decay modes for the above nuclei are tabulated in table. 1 and 2. It is found that ICR critically depends on the spins of ground state and isomeric state as well as the incident energy. In the case of nuclei with ground state spin is greater than the isomeric state spin the ICR increases steadily up to certain energy and thereafter it get saturated. This general behavior may be explained as follows. The energy of the incident particle increases the state with lower spin get populated initially and thereafter the population of higher spin state getting more and more populated and finally reaches an equilibration between the states. Close analysis of the data reveals that the ICR is affected by many other parameters like presence of intermediate states.

B. Effect of reaction channel

The ICR are plotted against the incident projectile energy and the results are shown in Fig. 1. For each reaction, initially the ratio increases, but becomes almost constant at high excitation energies. It is interesting to note that the (p,n) and (p,3n) reactions occur on the same target nucleus and the product studied is also the same. But in the case of (α,p3n) reaction, the magnitudes of the ICR, however, differ appreciably. From the observed trends it is concluded that the reaction channel affects the isomeric cross-section ratio considerably, particularly when the channels differ widely, e.g. (p,n), (p,3n) and(α,p3n) processes.

TABLE II: Decay mode of the isomeric nuclides of interest

Reaction	Nuclide	Decay mode
		Isomeric state
^{141}Pr(p,n)	^{141}Nd	IT, ε <0.05%
^{141}Pr(p,3n)	^{139}Nd	IT 11.8%, ε 88.2%
^{141}Pr(α,p3n)	^{141}Nd	IT, ε <0.05%

4. Conclusion.

The ICR is found to depend strongly on the relative spins of the isomeric and ground state, energy difference between the levels, presence of intermediate states and some dependence on decay modes as well as multiparticle emission. The ICR shows smooth behavior when decays through electron capture.

References

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