Isomeric population ratio for some nuclei produced in ^{89}Y+p reactions at lower excitation energies

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Introduction

The study of the formation of nuclear isomeric pairs in nuclear reactions may be used as an aid in the investigation of the mechanism of nuclear reactions. It will provide important information on the angular momentum transfer and coupling in nuclear reactions and production of each nucleus. Qaim et al have shown [1] that the isomeric cross-section ratio is primarily governed by the spins of the two levels involved, rather than their separation and excitation energies. However the onset of preequilibrium emission at relatively higher incident energies may distort this smooth behavior

Keeping above facts in mind, as part of systematic study of nuclear reactions induced by light and heavy ions, we determined the isomeric population ratio of the nuclei ^{90g,m}Zr, ^{89g,m}Zr, ^{89g,m}Y, and ^{85g,m}Sr formed in reactions ^{89}Y(p,γ)^{90g,m}Zr, ^{89}Y(p,n)^{89g,m}Zr, ^{89}Y(p,p)^{89g,m}Y, and ^{89}Y(p,αn)^{85g,m}Sr respectively, for energy ranges from threshold to 20 MeV, ^{89}Y is an important material widely applied to increase the strength of alloys of important metals of nuclear technology (aluminum, magnesium and chromium). The proton-induced activation cross section on this element is important for dose estimation in accelerator technology, for Thin Layer Activation analysis of yttrium alloys and yttrium oxide ceramics. Yttrium is a mono isotopic element therefore ideal target material to test nuclear reaction theories. Experimentally measured cross sections for the reactions ^{89}Y(p,n)^{89}Zr^{m,g} over the energy range ~5-15 MeV, has been used as the standard reference for evaluating cross sections for other cases. Theoretical estimation of the cross sections for the above reactions have been done using the Nuclear reaction code EMPIRE-II[2]. Isomeric cross section ratio has been calculated as the ratio of production of isomeric state to the total production of the particular nucleus at the given energy.

Experiment and Analysis

Experiments have been performed at the Variable Energy Cyclotron Center (VECC), Kolkata, India employing stacked foil activation technique. The Yttrium samples, of thickness ≈ 3.32 mg/cm^2 , were prepared by centrifugal method) on Al- backing. A stack of nine such samples were irradiated using diffused beam of proton of energy ~ 15 MeV, with a beam current of ~ 100nA, for 12hrs. Suitable thickness of Al degraders were introduced between the samples to have desired energy falling on each sample in the stack. The average beam energy on each target was calculated using stopping power values for Y and Al at various energies. The activity induced in each sample were followed using a 100 cc HPGe detector coupled with a data acquisition system. Various standard sources of known strengths were used to determine the geometry dependent efficiency of the detector at various gamma energies. The experimental value of isomeric cross section ratio were measured for ^{89}Y(p,n)^{89g,m}Zr reactions using the measured cross sections for the production of ^{89g}Zr and ^{89m}Zr as mentioned above. Theoretical analysis of the data was performed using the code EMPIRE-II[2]. This code makes use of the Hauser- Feshbach model for the statistical part and the NVWY model[3] based on MSD-MSC approach[4] for the pre-equilibrium part. The HF model explicitly takes into account the conservation of spin and parity of each partial wave. For input parameters standard library was used; it included the nuclear masses, ground state deformations, discrete levels and level schemes, moment of inertia, and gamma ray strength functions. The particle transmission coefficients for both the exciton and Hauser- Feshbach formalism were generated via the spherical optical model[5] and a set of global parameters: for neutrons and protons. The cross sections for the production of each nucleus (for isomeric and ground population separately) are determined and the isomeric cross section ratio is deduced for each nucleus at various energies.

The experimentally measured cross sections for this reactions (isomeric, ground and total separately) along with the theoretically calculated values are plotted in Fig.1. Similarly, the experimentally measured isomeric cross section ratio at various incident energies for the nucleus ^{89g,m}Zr, is plotted in Fig.2., along with calculated values for this nucleus as well as for ^{90g,m}Zr, ^{89g,m}Y, and ^{85g,m}Sr. As can be seen from Fig. 1 the experimentally measured cross sections, for both isomeric and ground states, are well reproduced by code EMPIRE-II. Similarly in Fig. 2, the calculated isomeric cross section ratio matches very well with the experimentally measured values over the measured energy ranges. which justifies the selection of input parameters in the calculations.

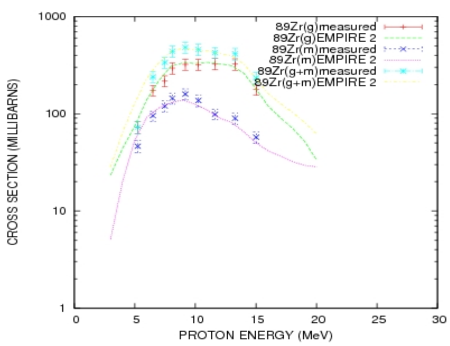

Fig.1 Measured and calculated excitation function for the reaction ^{89}Y(p,n)^{89g,m}Zr

Result and discussion

It can be seen from Fig. 2 that the isomeric cross section ratios for the nuclei ^{90g,m}Zr, ^{89g,m}Y, and ^{85g,m}Sr increases with increase in incident energy, and hence the excitation energy, with a tendency to form a saturation stage after a few MeV above threshold. However in the case of ^{89g,m}Zr nucleus the isomeric cross section ratio increases for the lower incident energies reaching a maximum at ~5 MeV and shows a regular decreasing trend over energy ranges from 5-14 MeV. The above nature can be interpreted in terms of relative spin states of the isomeric and ground state of the nuclei with spin states as follows. ^{90g,m}Zr(0^+,5^-), ^{89g,m}Zr($9/2^+$,$1/2^-$), ^{89g,m}Y($1/2^-$,$9/2^+$), and ^{85g,m}Sr($9/2^+$,$1/2^-$). Thus it is expected that at very low incident energies the ground state is initially populated followed by the higher levels. When sufficient energy is reached the population of higher spin stat increases with energy independent of relative energy states. However in the case of ^{89g,m}Y, the isomeric cross section ratio shows a further increasing trend for energies above ~14 MeV, regardless of spin state may attributed to the onset of preequilibrium emission whose contribution increases with increase in incident energy. Thus it may be interpreted that the isomeric population ratio reflects the relative spin states of the pairing isomers and the nature of reaction mechanism.

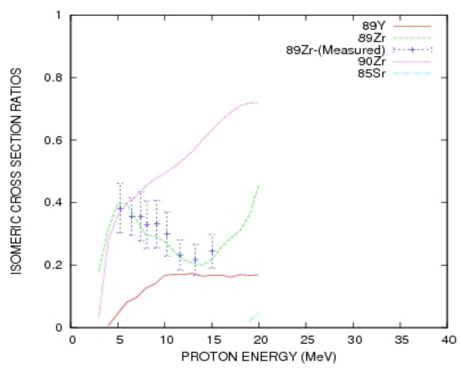

Fig.2.Isomer yield ratio for ^{90g,m}Zr, ^{89g,m}Zr, ^{89g,m}Y, and ^{85g,m}Sr nuclei produced in Y+p reactions

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