# Analysis of the isomeric cross section ratios within the statistical model.

B. Satheesh[1,2,*] M. M. Musthafa[2], B. P. Singh[3], R. Prasad[3], and B. Lalremruata[1]
[1] *Department of Physics, Mizoram University, Tanhril - 796004, INDIA*
[2] *Department of Physics, University of Calicut, Calicut University P.O, Malappuram, Kerala - 673635, INDIA and*
[3] *Department of Physics, Aligarh Muslim University, Aligarh, U.P - 202002, INDIA*

## Introduction

The excitation of isomeric states in nuclear reactions may be considered as one of the efficient tools of statistical model testing. Qaim et al [1], Satheesh et al [2] have shown that the isomeric cross section ratio (ICR) is primarily governed by the spins of the two levels involved, rather than their separation and excitation energies. Keeping the above facts in mind, as a part of systematic study of nuclear reactions induced by light and heavy ions, we determined the isomeric population ratios for the production of isomeric pairs of $^{197g,m}$Hg, $^{195g,m}$Hg, $^{193g,m}$Hg, $^{198g,m}$Tl and $^{196g,m}$Tl nuclei formed in the $^{197}$Au(p,n), $^{197}$Au(p,3n), $^{197}$Au(p,5n), $^{197}$Au($\alpha$,3n) and $^{197}$Au($\alpha$,5n) reactions for energy ranges from threshold up to 40 MeV for proton induced reactions and 80 MeV for alpha induced reactions. Experimentally measured cross-sections for the reactions $^{197}$Au(p,n)$^{197g,m}$Hg over the energy range 8 to 20 MeV, have been used as the standard reference for evaluating cross-sections for other cases.

## Experiment and Analysis

Experiment has been performed at the variable energy cyclotron center (VECC), Kolkata, India, employing stacked foil activation technique. The Gold samples of thickness 3.32 mg/cm$^2$, were prepared by rolling method. A stack of nine such samples were irradiated using diffused beam of proton of energy 20 MeV, with a beam current of 100 nA, for 12 h. Suitable thickness of Aluminum degraders were introduced between the samples to have desired energy falling on each sample in the stack. The activity induced in each samples were followed using a precalibrated 100 cc HPGe detector coupled with a data acquisition system. Various standard sources of known strengths were used to determined the geometry dependent efficiency of the detector at various gamma energies. The isomeric cross-section ratios were calculated for the $^{197}$Au(p,n)$^{197g,m}$Hg, $^{197}$Au(p,3n)$^{195g,m}$Hg, $^{197}$Au(p,5n)$^{193g,m}$Hg, $^{197}$Au($\alpha$,3n)$^{198g,m}$Tl and $^{197}$Au($\alpha$,5n)$^{196g,m}$Tl reactions using the EMPIRE-II (version 3.1 Rivoli) code developed by Herman et al. [3]. This code makes use of the Hauser-Feshbach model (including the width fluctuation correction (HRTW)) for the statistical part and the exciton model for the pre-compound part of a nuclear reaction. For input parameters, the standard library was used. The particle transmission coefficients for both the exciton and Hauser-Feshbach formalisms were generated via the spherical optical model using the computer code SCAT 2 and a set of global parameters: for neutrons and protons of Koning and Delaroche, and for alpha particles of McFadden and Satchler. For calculations on the reactions $^{197}$Au(p,n)$^{197g,m}$Hg, $^{197}$Au(p,3n)$^{195g,m}$Hg, $^{197}$Au(p,5n)$^{193g,m}$Hg, $^{197}$Au($\alpha$,3n)$^{198g,m}$Tl and $^{197}$Au($\alpha$,5n)$^{196g,m}$Tl reactions the HF + MSC + MSD model as well as the HF + DEGAS exciton model with angular momentum conservation and gamma emission, were used. For the level densities, the dynamic approach of the EMPIRE-II was applied with the formalism of the super fluid model (BCS) below the critical excitation energies, and the Fermi gas model above the crit-

*Electronic address: satheesh.b4@gmail.com

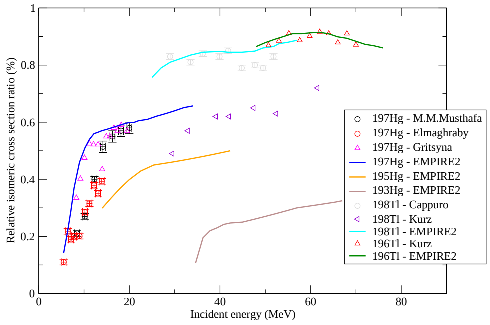


FIG. 1: The experimentally measured and theoretically calculated ICR for the isomeric pairs $^{197}$Hg, $^{195}$Hg, $^{193}$Hg, $^{198}$Tl and $^{196}$Tl for the reactions $^{197}$Au(p,n)$^{197}$Hg, $^{197}$Au(p,3n)$^{195}$Hg, $^{197}$Au(p,5n)$^{193}$Hg, $^{197}$Au($\alpha$,3n)$^{198}$Tl and $^{197}$Au($\alpha$,5n)$^{196}$Tl.

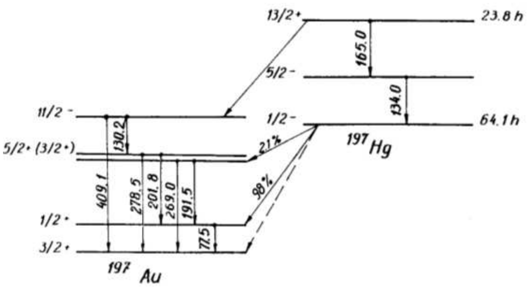


FIG. 2: Typical decay scheme of isomeric state and ground state of $^{197}$Hg.

ical energy.

## Results and discussion

The relative production probability is expressed as isomeric cross section ratio defined as the ratio of the formation cross section of the isomers of high isomeric state to the total production cross section $\sigma_m/(\sigma_m + \sigma_g)$. The ICR thus calculated for the production of $^{193}$Hg, $^{195}$Hg, $^{197}$Hg, $^{198}$Tl and $^{196}$Tl nuclei are determined at various incident energies and are plotted in Fig.1. along with the available experimental data. The typical decay scheme of isomeric state and ground state of $^{197}$Hg is shown in Fig.2. 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 presence of intermediate states and some dependence on decay modes. 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. In general it can be seen that the isomeric cross section ratio increases with incident energy in the cases were the isomeric spin is larger than the ground state spin. 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.

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

| Nuclide | Ground state | | Isomeric state | | | Intermediate state | | |
|---|---|---|---|---|---|---|---|---|
| | $J_\pi$ | $T_{1/2}$ | MeV | $J_\pi$ | $T_{1/2}$ | MeV | $J_\pi$ | $T_{1/2}$ |
| $^{193}$Hg | $3/2^-$ | 4 h | 0.1410 | $13/2^+$ | 11 h | 0.03949 | $5/2^-$ | 0.63 ns |
| $^{195}$Hg | $1/2^-$ | 10 h | 0.1760 | $13/2^+$ | 41 h | 0.03709 | $3/2^-$ | |
| | | | | | | 0.05330 | $5/2^-$ | 0.72 ns |
| $^{197}$Hg | $1/2^-$ | 64.1 h | 0.2989 | $13/2^+$ | 23.8 h | 0.1339 | $5/2^-$ | 7.0 ns |
| | | | | | | 0.1522 | $3/2^-$ | |
| $^{198}$Tl | $2^-$ | 5.3 h | 0.5437 | $7^+$ | 1.87 h | 0.1734 | $0^-$ | 4 ns |
| | | | | | | 0.2595 | $2^-$ | |
| | | | | | | 0.2828 | $3^-$ | |
| | | | | | | 0.2903 | $1^-$ | |
| | | | | | | 0.3820 | $1^-$ | |
| | | | | | | 0.3977 | $1^-$ | |
| $^{196}$Tl | $2^-$ | 1.84 h | 0.395 | $7^+$ | 1.41 h | 0.1918 | $0^-$ | |
| | | | | | | 0.2403 | $2^-$ | |
| | | | | | | 0.2532 | | |
| | | | | | | 0.275 | | |

## References


[1] S. M. Qaim, Sudar and A. Fessler, Radiochim. Acta. **93** 503 (2005).

[2] B. Satheesh et. al., Int. Jour. of Mod. Phys. E. **21** 6 (2012).

[3] M. Herman et. al., EMPIRE3.1 Rivoli, IAEA (2012).