Pre-equilibrium emissions in ^{6}Li+^{181}Ta reaction : A production route to ^{183}Os

Rishabh Kumar, Moumita Maiti,* and Rinku Prajapat
Department of Physics, Indian Institute of Technology Roorkee, Roorkee-247667, INDIA

Introduction

The collision of two heavy nuclei generates a wide variety of complex physical interactions that have been meticulously studied for more than half a century now, yet a universal understanding of these for different mass regions awaits. Nuclear reaction studies especially involving weakly bound stable projectiles have found enormous interest as they showcase multiple peculiar processes such as incomplete fusion (ICF), pre-equilibrium (PEQ) emissions, nucleon transfer, etc. Results obtained from the stable projectiles can be used along with those from weakly bound radioactive beams to understand the reaction mechanism better. PEQ emissions from reactions involving heavy-ion beam and intermediate to heavy mass targets also pose promising interest. PEQ emissions are characterized by light particles emitted fast in the forward direction before achieving the equilibration state. Its other feature is observing a high energy tail in the excitation function and it starts dominating over a compound nuclear mechanism at energies above 5–6 MeV/nucleon. Although PEQ emission studies for weakly bound projectiles have been reported for some cases [1, 2], yet more experimental data are required in the intermediate and low mass region to study PEQ processes over EQ comprehensively.

Further, precise optimization of production parameters is required because of the growing demand for neutron-deficient radionuclides of noble elements in applications. One such radionuclide is ^{183}Os, whose physicochemical properties make it suitable for medical application, and also it can be produced in a no-carrier-added state. The essential nuclear spectroscopic data of ^{183g,m}Os have been tabulated in Table I. Due to the moderate half-life and low energy γ peaks, ^{183g}Os is also a good choice for radiotracer studies [3]. In this abstract, we report the cross section measurement of ^{183g}Os and ^{183m}Os from the ^{6}Li induced reaction on ^{181}Ta up to 43 MeV.

*Electronic address: moumita.maiti@ph.iitr.ac.in

Experiment

The experiment was carried out at the BARC-TIFR Pelletron Facility, Mumbai, India. The ^{6}Li beam was made to impinge on the stacks of ^{181}Ta foils having thickness $\sim$ 1.4 – 2.4 mg/cm^2, and each foil was supported by an aluminum catcher foils of thickness $\sim$ 1.6 – 1.87 mg/cm^2 within 27 – 43 MeV range of energy. After the bombardment, the activity of the residual radionuclides produced in the Ta target matrix at various incident energies was measured with the help of γ-spectroscopy, and the cross sections were calculated from the background-subtracted peak area counts using the activation formula. The error associated with the cross sections is estimated considering all possible sources of uncertainty.

TABLE I: Spectroscopic data of ^{183g,m}Os

Nuclide ($T_{1/2}$)	Decay mode (%)	E_γ(keV)[I_γ%]	Reaction channel	E_{th} (MeV)
^{183g}Os (13.0 h)	EC (100)	114.43[21.1] 381.74 [91.6]	^{181}Ta(^{6}Li,4n)	23.74
^{183m}Os (9.9 h)	EC (85),IT(15)	1101.94 [49.0] 1107.92 [22.3]	^{181}Ta(^{6}Li,4n)	23.74

Results and discussion

From the offline γ–ray spectroscopy, seven radionuclides were identified in this experiment namely, ^{183g,183m,182}Os produced via xn evaporation channel, ^{183}Re from pxn channel, and ^{183,182m2,180}Ta from $3p/\alpha pxn$ channel. However, the focus of this abstract would be on ^{183g,m}Os. We have used the EMPIRE-3.2.2 code for the theoretical calculation of residue cross sections. It is based on the Hauser-Feshbach (HF) formalism for compound nuclear (CN) decay and Exciton model for PEQ emissions. CCFUS (coupled channel) provides the initial fusion cross sections. The Gilbert-Cameron (GC) and Generalized Super-fluid Model (GSM) level density have been used to check the sensitivity of cross section to different level densities. The pre-equilibrium cross sections have been calculated using PCROSS code with mean free path parameter set to 1.5. We have also estimated the pure CN cross section taking GSM in consideration.

Fig.1 displays the measured cross sections of ^{183g}Os (red filled circles) and ^{183m}Os (blue filled triangles) in comparison with theoretical model calculations performed using EMPIRE. It can be observed that the calculations with GSM (black dotted line) quite satisfactorily matches the experimental data for both the residues. However, the calculations with GC overestimate the cross section for both ^{183g}Os and ^{183m}Os. It was felt important out of curiosity to compare these results with full compound nuclear calculation. The solid blue curve in Fig. 1 represents the CN calculations with GSM. It can be well noted that both CN and CN+PEQ calculations agree with the experimental data at lower energies for both residues. Interestingly the experimental cross sections for ^{183m}Os (produced via the $4n$ channel) are well above the CN estimates at energies above 35 MeV marking the presence of pre-equilibrium emissions, which is also confirmed by the perfect matching of the data with CN+PEQ calculations (Fig. 1). It is also worth mentioning that the PEQ strength is increasing with energy (note the orange arrows). Since EMPIRE with GSM level density is adequately able to predict cross sections for ^{183g,m}Os, it can be used to optimize a suitable energy window for the production of these radionuclides. In the energy window 36 – 40 MeV, the cross sections for ^{183g}Os ranges from 350 – 400 mb, and that for ^{183m}Os ranges from 50 – 60 mb, which corresponds to a significant amount of production that can find applications in the medical and radio-tracer fields.

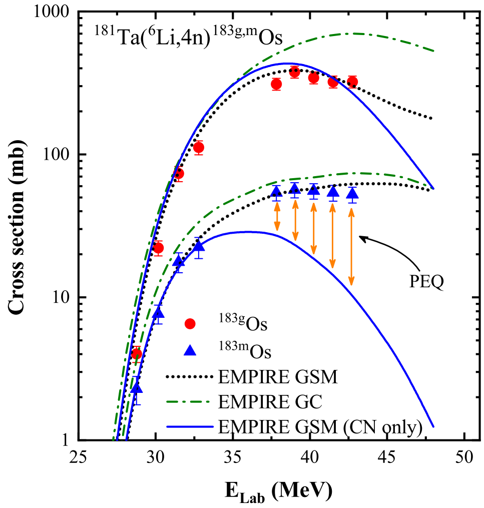

FIG. 1: Comparison of the measured cross sections of ^{183g}Os and ^{183m}Os with theoretical excitation functions from EMPIRE.

Conclusion

The production cross sections for ^{183g}Os and ^{183m}Os from the ^{6}Li+^{181}Ta reaction within 4.5 – 7.1 MeV/nucleon energy range have been reported. The CN+PEQ model calculation with GSM level density accurately predicts the experimental data within the studied energy range. Pre-equilibrium emissions were found contributing significantly to the production cross section of ^{183m}Os.

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