Theoretical interpretation of the dynamics of ^{9}Be+^{181}Ta reaction at the low energy range

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Introduction

The renewed interest in the light-heavy ion (A ≤20) induced reactions on the medium and heavy targets is a great motivation to understand the mechanism involved in the low energy nuclear reactions. Efforts are always required to elaborate on the formation of the excited nucleus and its progression to the equilibrium state. Both experimental and theoretical aspects are needed to comprehend the interplay among the processes, such as complete fusion (CF), incomplete fusion (ICF), pre-equilibrium emissions (PEQ), etc. and to determine the competition between CF and ICF in lower energy region [1, 2]. Although several studies have been demonstrated to predict the CF/ICF in the heavy-ion induced reactions, the mechanism involved in the fusion is still being dreamt to understand the phenomena1. It is also important to explore various possibilities to produce neutron-deficient radionuclides using light-heavy ion induced reactions to meet the growing demand of medical isotopes in various fields.

In view of this, we have explored a theoretical analysis of the cross-section data from the ^{9}Be induced reaction on ^{181}Ta target reported by Zhang *et al.* [3] within ∼3.9–5.6 MeV/A energy range to understand the mechanism involved in producing the Ir and Re-isotopes through various reaction channels.

Model estimation

Theoretical model estimations have been executed using the nuclear reaction code EMPIRE3.2. It utilizes Hauser-Feshbach formalism (HF) to estimate the EQ process and the simplified coupled channel calculation for the heavy-ion fusion cross-section. The width fluctuation correction factor is adopted to explain the interaction between the entrance and exit channels. The exciton model (EM) with Iwamoto-Harada cluster emission model and 1.0 mean free path are used to predict PEQ processes. The enhanced generalized superfluid model (EGSM) level density is adopted to evaluate the nuclear data with Ignatyuk energy dependent level density parameter to study EQ emissions. Below the BCS critical energy, the superfluid model and above it Fermi gas model is selected for the model calculations. In EGSM, collective effect (rotational/vibrational) of nuclei is considered in the nuclear level density (NDL). The effect of superconducting pairing is taken into account in terms of the correlation function which strongly impact the phenomena of nuclear level density. In addition to this, the enhancement of the NLD has accounted shell effects, and nuclear deformation; nuclear masses, optical model parameters and γ-ray strength functions are selected by RIPL-3.

Analysis and results

The cross-sections of ^{187,186,185}Ir radionuclides [3] are compared with the theoretical model calculations obtained from EMPIRE3.2 and are shown in Fig.1. The production cross-section values for ^{187}Ir are overpredicted by the theoretical estimation throughout the energy range, yet they follow the trend of the EQ+PEQ calculations with EGSM level density. The production of ^{186,185}Ir well agreed with the EMPIRE over the range. However, the production cross-sections of ^{184,183}Re reported in the ^{9}Be+^{181}Ta system are well above the theoretical estimations, which essentially considers the production through αxn channel. The enhancement observed in

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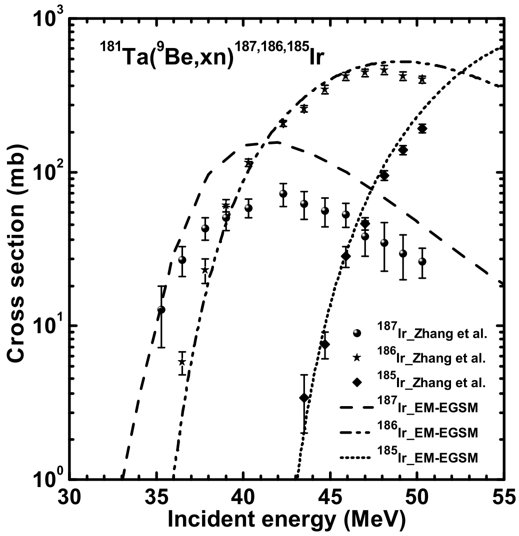

FIG. 1: Comparison of theoretical cross-sections with the Zhang *et al.* data for ^{187,186,185}Ir from ^{9}Be+^{181}Ta reaction.

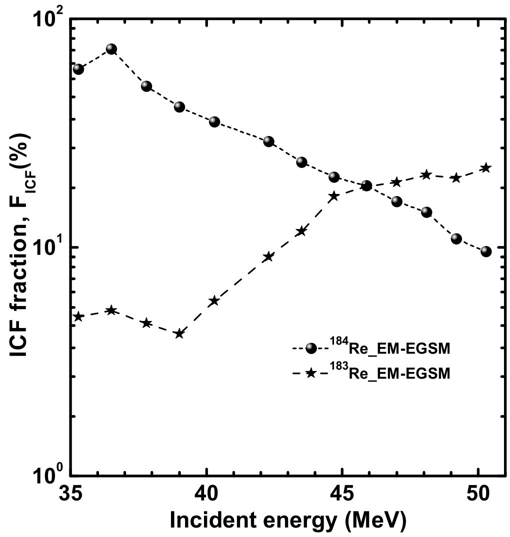

FIG. 2: ICF fraction for ^{184,183}Re.

the cross-sections of ^{184,183}Re is perhaps due to the contribution of ICF. Estimation of ICF fraction is the measure of the extent of incomplete fusion relative to the total reaction cross-section at a given projectile energy. It is defined as $F_{ICF}\%=[(\sigma^{r}_{ICF})/\ \sigma^{theor}_{total}]\times100$, where $\sigma^{r}_{ICF}= \sigma^{r}_{exp}$ - σ^{r}_{theor}; r stands for the radionuclides ^{184,183}Re and, σ^{r}_{theor}, σ^{r}_{exp}, σ^{theor}_{total} represent the cross-section of theoretical, experimental and the total reaction cross-section, respectively [1]. The estimated ICF fraction of ^{184,183}Re at different energies is shown in Fig.2. The theoretical cross-section values of the ^{184,183}Re radionuclides are obtained using HF with EGSM level density with all other parameters fixed as it was for the cross-section estimation of Ir-isotopes. There is an increasing trend in the ICF fraction of ^{183}Re with increasing bombarding energy, while it decreases for ^{184}Re, which display the aspect of ICF for the production of ^{184,183}Re.

Conclusion

The EMPIRE estimation of the cross-sections of the residues produced via xn-reaction channels (n=3,4,5) from the complete fusion of ^{9}Be and ^{181}Ta within $\sim$ 35-52 MeV energy shows a good agreement with the experimental data compared to the only HF estimations obtained from the PACE code. The trend of HF+EM with EGSM estimation for $3n$ is on the edge of the measured excitation function within the energy range. Hauser-Feshbach model with EGSM level density well reproduces the results for $4n$ and $5n$ channels. The compound nucleus formation is a major contributor to the xn channels (^{187,186,185}Ir). The variation of ICF fraction with the projectile energy shows the dominance role of ICF over CF in producing Re-isotopes (^{184,183}Re).

Acknowledgments

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References

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