Study of complete and incomplete fusion reactions at near and above the barrier energy

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Introduction

During the last few decades establishment of large particle accelerator enables the study of heavy ion ($Z \geq 2$) induced reactions in the energy range of near and above the Coulomb barrier. Classically, a nuclear reaction proceeds only when the incident energy of projectile is sufficient enough to over come the Coulomb barrier. Study of heavy ion induced reaction is important because it shows several characteristic features that makes them amenable to simple method of analysis and sensitive to particular aspect of nuclear structure. If the incident projectile, on over coming the Coulomb barrier, able to transfer the total incident momentum to the target nucleus then it is called complete fusion (CF). However in some cases, especially with weekly bound projectile, the incident projectile break-up near the periphery of the target nucleus prior to fusion leading to an incomplete transfer of momentum from projectile to target. Such type of reactions involving incomplete transfer of momentum are called incomplete fusion (ICF) reaction. ICF reaction was first observed by Britt and Quinton in year 1961 [1]. Since then several models were proposed to explain the dynamics of ICF reaction. The break-up fusion model of Udagawa and Tamura [2] proved to be most effective in explaining the ICF reaction dynamics. According to break-up fusion model of Udagawa and Tamura, ICF is usually understood as a two step process: break-up of the incident projectile in the vicinity of target, followed by fusion of one of the projectile fragment with the target nucleus, while the other escapes. In the present work CF and ICF reactions were studied for the ^{20}Ne + ^{165}Ho system at lab energy $E_{lab} \approx$ 90-145 MeV.

Experimental Details

The experiment was performed at VECC, Kolkata, India. The targets of thickness range 1.19-1.50 mg/cm^2 of spectroscopically pure ^{165}Ho (purity 99.99%) were prepared by depositing on aluminum backing of thickness range 2.06-3.78 gm/cm^2 by the vacuum evaporation technique at target lab of VECC. A stack of six ^{165}Ho targets was irradiated for $\approx$ 16 hrs by ^{20}Ne^{6+} beam at $\approx$ 145 MeV. The irradiation of the stack covered the desired energy range of $\approx$ 90-145 MeV. The beam current was kept $\approx$ 20-40 nA during the irradiation hours. The incident flux of ^{20}Ne was determined from the charge collected in Faraday cup. The energy of the ^{20}Ne ion beam incident on each target foil was calculated from the energy degradation of the initial beam energy using stopping power software SRIM[4]. The γ-ray activities produced in each target foil along with its catcher were recorded by using pre-calibrated 60 cc HPGe detector coupled to PC based data acquisition system. The γ-ray spectroscopy software package RADWARE was used for analyzing the spectrum. The activation cross section for a particular reaction was calculated from the intensities of the various identified γ-rays arising from the same product nuclei. Further details related to experimental arrangement, formulae used and error analysis are available

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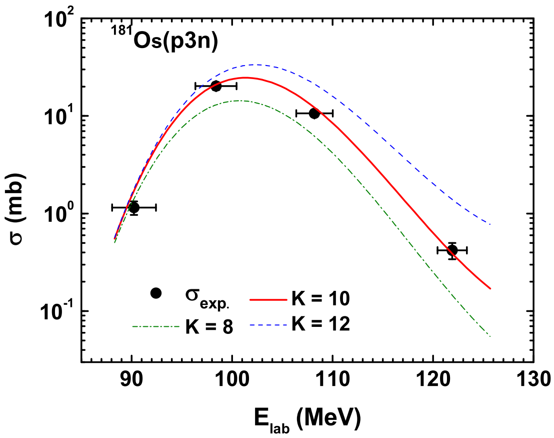

FIG. 1: Experimentally measured EFs of ^{181}Os($p3n$) is compared with the theoretical value calculated using PACE4 for different values of K.

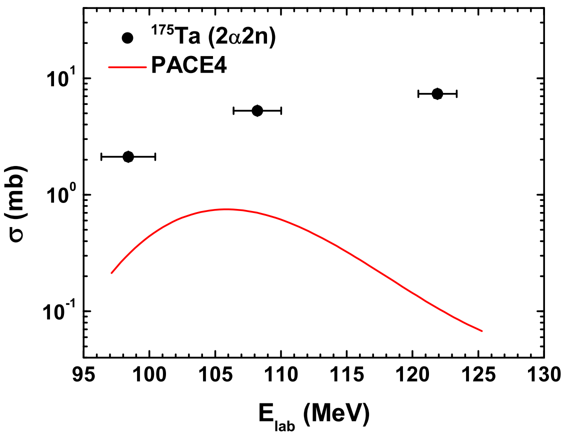

FIG. 2: Experimentally measured EFs of ^{175}Ta($2\alpha2n$) populated via CF and/or ICF processes are compared with the PACE4 calculation. .

in Ref. [3]. The overall error in the present work is estimated to be ≤20%.

Results and Discussion

In the ^{20}Ne + ^{165}Ho reaction at $E_{lab} \approx$ 90-145 MeV, total 12 residues were observed to be populated. Several radionuclides having half-lives either too short or long were not observed due to the constraint imposed by the available experimental facilities. The observed residues were likely to be populated via CF and/or ICF processes. In order to determine the extent of CF and ICF contributions in the population of observed residues, the excitation functions (EFs) of observed residues were compared with the theoretical values predicted by the code PACE4[5]. PACE4 is based on the Hauser-Feshbach theory of compound nucleus decay and gives the CF cross section of the populated residues in a given nuclear reaction. Fig. 1 and 2 shows the experimental and PACE4 calculated EFs of ^{181}Os($p3n$) and ^{175}Ta($2\alpha2n$) residues respectively. The theoretical and experimental EFs of xn and pxn channels were found to be agreed well with each other suggesting the population of these channels through the CF reaction only. On the other hand, the experimental EFs of α-channel show an enhancement over the PACE4 values. Since the PACE4 calculation does not take ICF reactions into account, so the residues populated through α-channels are expected to have contributions arising from ICF process in addition to CF.

Conclusion

In the present work the EFs of 12 radionuclides, populated in the ^{20}Ne + ^{165}Ho reaction at $E_{lab} \approx$ 90-145 MeV, have been studied. It has been observed through the study of EFs of xn and pxn channels that these residues were populated through the CF reaction only. On the other hand, the EFs of α-channels suggest the population of these residues through the combined effect of CF and ICF processes.

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