Fusion of $^{16}O+^{165}Ho$ at Deep Sub-barrier Energies

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Introduction

Fusion at deep sub-barrier energies is important to understand the reaction dynamics inside the barrier and also have astrophysical interest for fusion with light nuclei. Fusion at deep sub-barrier energies has been observed to be hindered in some systems [1], compared to the coupled channel calculations using standard Woods-Saxon potential. Currently, it is presumed that fusion hindrance is a generic property for negative Q value systems. However, owing to the difficulty in measurement of extremely low fusion cross section at energies far below coulomb barrier, studies have been limited. However, such data are important to have a better understanding of the phenomenon of deep sub-barrier fusion hindrance.

In the light of the problem of fusion hindrance, very recently we measured the fusion cross sections of $^{16}O+^{165}Ho$ (V_b~74 MeV) at energies below and above Coulomb barrier. Although fusion studies of the system have been realized above the Coulomb barrier [2], it is yet to comprehend the nature of excitation function below the barrier.

Experimental Details

The experiment has been performed at BARC-TIFR Pelletron facility at TIFR, Mumbai, using the $^{16}O^{6+,7+}$ beam, having energies in range 63-85 MeV. The targets were self-supporting foils of ^{165}Ho targets (~ 1–2 mg/cm^2), followed by Al catcher foils (~1.5–2 mg/cm^2). The targets were mainly irradiated for ~ 1 hour, at each of the bombarding energies. After each bombardment, the irradiated target, along with the catcher foil, was placed in front of an efficiency calibrated HPGe detector, in a low background setup with graded shielding, to detect the γ-rays. The detector has been energy and efficiency calibrated using the radioactive sources, ^{152}Eu and ^{133}Ba. The compound nucleus $^{181}Re^*$ produced in the reaction decays to $^{178\text{-}176}Re$ by evaporating successive neutrons (3n-5n), over the energy range of measurement. The evaporation residues $^{178\text{-}176}Re$ undergo β-decay to produce excited states of $^{178\text{-}176}W$, which then to decay to their ground states by emitting γ-rays. The residues arising from fusion reaction were identified from the characteristic γ-rays emitted by the daughter nuclei and following the half-lives of the residues. The Faraday Cup installed behind the target-catcher foil assembly measured and recorded the beam current which is essential for calculation of fusion cross-section and to observe the stability of the current during irradiation. This was done by recording the charge on the target as a function of time. Table I shows the half-lives and other details for residues ^{178}Re and ^{177}Re.

Residue	$T_{1/2}$	J^{π}	E^{γ}(keV)	I^{γ} (%)
^{178}Re(3n)	13.2 min	3^+	237.0	44.5
			939.1	8.9
^{177}Re(4n)	14.0 min	$5/2^-$	197.0	8.4

***Table 1:** List of reactions measured so far with their residues and spectroscopic properties*

Analysis& Results

The time consumed between turning off the beam current and initiating the offline measurement has to be taken into account for cross-section calculation.

In this measurement, the length of the irradiation is longer than the half-lives of the evaporation residues and so the number of evaporation residues produced (N_{prod}) reached saturation during the period of irradiation. Hence N_{prod} is given by:

$$N_{prod} = \sigma_{reac} \cdot N_A \cdot \phi_b \frac{1-e^{-\lambda t_{irrad}}}{\lambda},$$

Where σ_{reac} is the cross section, t_{irrad} is the time of irradiation, λ is the disintegration constant. N_A and ϕ_b are the surface density of the target and current of beam particles respectively. The number of decay products, N_{decay} after a given counting time t_c for a given irradiated sample is related in the following way:

$$N_{decay} = N_{prod} e^{-\lambda t_w}(1 - e^{-\lambda t_c})$$

where t_w is the wait time elapsed between the end of the irradiation and the beginning of the counting.

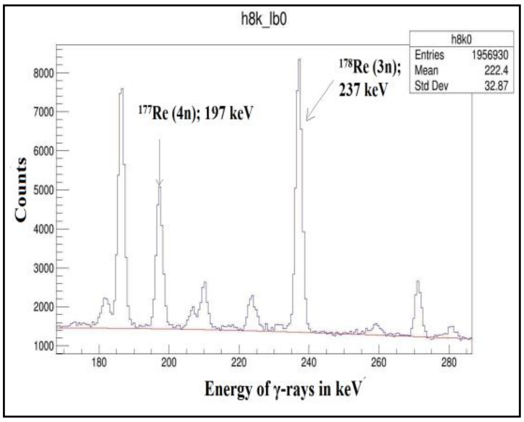

Fig.1. shows a part of a typical γ-ray spectrum at E_{lab}=70 MeV.

To ensure the γ-rays that have been considered for calculation of cross sections are occurring exclusively from the residues of $^{181}Re^*$, the half- lives of the residues have been measured from the list mode data accumulated and compared with the values given in literature [3]. The γ-rays with energies 237 keV and 939 keV correspond to ^{178}Re and 197 keV correspond to ^{177}Re. At two energy values above E_{lab}=83 MeV, ^{176}Re γ-rays have been observed.

So far, a preliminary analysis of the data has been done. The cross sections for 3n and 4n channels populated via complete fusion of $^{16}O+^{165}Ho$ have been determined.

Fig. 2 shows the sum of the cross sections arising from the 3n and 4n channels, which essentially makes up the fusion cross sections, at energies below the barrier.

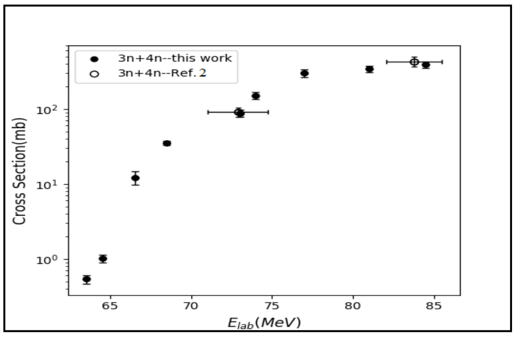

Fig.2. Sum of the cross section of 3n and 4n channels compared with earlier measurement at higher energy [3]

The analysis is at a very preliminary stage and contributions of other channels are yet to be investigated. Further analysis is in progress and will be presented at the conference.

References

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