Entrance channel effect for CN ^{200}Pb

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Abstract. The spin distribution of Evaporation Residues (ER) was measured for the reaction ^{30}Si + ^{170}Er. ER spin distributions were compared for the systems ^{16}O + ^{184}W, ^{19}F + ^{181}Ta and ^{30}Si + ^{170}Er forming the Compound Nucleus ^{200}Pb. Mean gamma multiplicity vs. excitation energy curve shows saturation at a lower value in case of ^{30}Si + ^{170}Er. This was attributed to non compound nuclear processes.

1 Introduction

Entrance channel effect is a well-known phenomenon in heavy ion fusion reaction. For heavy nucleus, quasi fission becomes a hurdle in the formation of Compound Nucleus (CN). Recently few evidence of this phenomenon were reported even in CN ^{202}Po [1]. Quasi fission was observed for ^{34}S + ^{168}Er and heavier projectiles. ^{16}O + ^{184}W and ^{19}F + ^{181}Ta both forming CN ^{200}Pb, were studied [2] and suppression in ER cross section for the projectile ^{19}F was reported at higher excitation energies. It was explained that ^{19}F + ^{181}Ta has quasi fission and fast fission in its exit channel [3]. Still it is not well understood when and how quasi fission starts playing a role and more experimental studies are required to have better understanding of fusion-fission dynamics. Tools to study fusion-fission dynamics are mainly fission and ER cross sections, fission fragment distributions (mass and angular distribution), GDR gamma rays, pre-scission particle multiplicity and ER spin distribution. Study of ER can reveal the fusion dynamics in pre-scission stage, in a better way as, ER detection implies that CN has survived fission. On the other hand, in some cases fusion fission and quasi fission may overlap causing difficulties in their separation. ER spin distribution can throw light on partial wave contribution of ER cross section. We have compared spin distributions of three different entrance channels namely ^{16}O + ^{184}W, ^{19}F + ^{181}Ta and ^{30}Si + ^{170}Er forming CN ^{200}Pb. The ^{16}O and ^{19}F systems are very close in mass asymmetry and hence entrance channel spin are very close to each other. On the other hand ^{30}Si is a much heavier projectile and brings much higher angular momentum in entrance channel so, it can give a better

information about the way a CN deals with its higher angular momentum. Reduced ER cross section or partial ER cross section can throw more light on non compound nuclear effects by taking care of geometrical effects in the entrance channel. ^{16}O + ^{184}W and ^{19}F + ^{181}Ta were studied by P. Shidling et al. [2,4] and the authors mentioned about presence of entrance channel effect in terms of ER cross section and spin distribution of ER. We have measured the spin distribution of ER for ^{30}Si + ^{170}Er. ER and fission cross sections for this system are available in literature [5].

2 Experimental details

The experiment was performed at IUAC with the recoil mass spectrometer HYRA [6]. Pulsed beam of ^{30}Si with a repetition rate of 2 μs was provided by Pelletron + LINAC accelerators at energies of 132, 136,141,146,151,156,161 and 166 MeV. A thin target of ^{170}Er (97% enriched) with thickness 130 μg/cm^2, on a Carbon backing of 45μg/cm^2 and Carbon capping of 23 μg/cm^2 was used [7] in the experiment. 4π spin spectrometer [8,9] was coupled with HYRA [10] (also presented in this conference by N. Madhavan et al.) in such a way that the target was at the geometrical centre of the spin spectrometer. The spin spectrometer consists of 32 NaI detectors, 20 hexagonal detectors and 12 pentagonal, covering a solid angle of almost 4π Sr. Out of these 32, 28 detectors were used during the experiment. Two detectors were removed for beam pipe, one was removed for target ladder and the fourth one did not work satisfactorily. Total solid angle covered was 88% of 4π Sr with absolute efficiency 74%.

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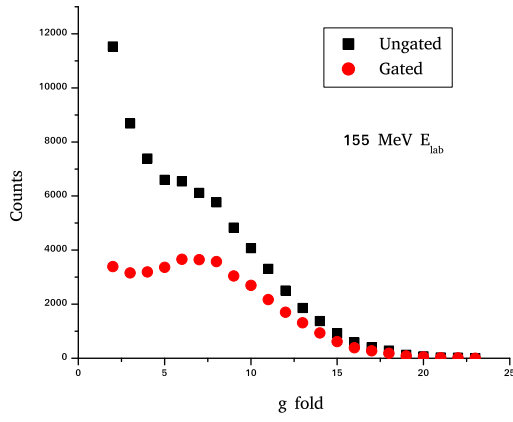
Fig. 1. Experimental gamma fold before and after gating.

HYRA was set to operate in gas filled mode, filled with Helium gas at a pressure of 0.15 Torr. A 2 μm thick foil of Carbon was used as window foil to separate the beamline vacuum from the gas filled region. Beam lost an average of 5 MeV energy in that window foil. A silicon surface barrier detector (SSBD) was placed at an angle of 25°, with respect to beam direction to detect the elastic recoils. A Multi Wire Proportional Counter (MWPC) of area 57 X 57 mm^2 was used to detect the recoils at the focal plane. The total flight path of the spectrometer is about 7.5 m and typical time taken by ERs was from 1.5 to 1.8 μs depending on the energy. To separate out the ERs from other events at focal plane, Time Of Flight (TOF) technique was used. Pulsed beam was used for this purpose with a repetition rate of 2 μs .Two Time to Amplitude Converters (TAC) were set. One TAC had start from MWPC anode signal and stop from TWD RF signal. Another TAC also had MWPC anode start and stop was taken from OR of all the NaI timing signals. Number of scattered beam particles at focal plane was found to be insignificant and well separated, in time, from ERs. The gamma rays detected at the target chamber gave the experimental gamma-fold which contained gamma rays from ER as well as from other events like inelastic scattering, fission etc. ER TOF gate was put to get the ER gamma-fold rejecting the other events. Significant contamination was there for lower folds whereas higher folds had less contamination. Figure 1. shows an experimental gamma fold distribution before and after TOF gating.

3 Result and analysis

Experimentally detected gamma-fold distribution was converted to corresponding gamma multiplicity distribution using the Van Der Warf prescription [11]. 0th and 1st folds were extrapolated as we could not get them experimentally. 1st fold merged with ADC pedestal and hence finding 0th and 1st folds were not possible. According to Van Der Warf prescription, if M numbers of uncorrelated gamma rays are
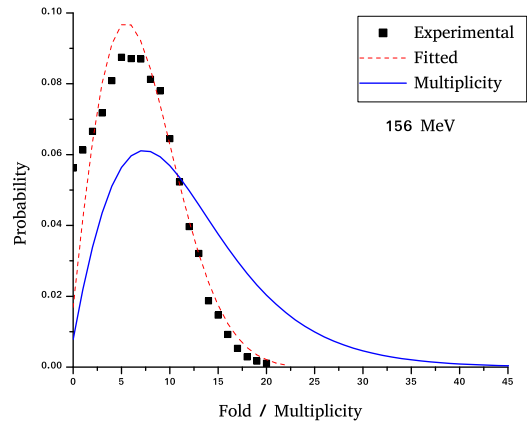
Fig. 2. Experimental and fitted folds. The solid line shows corresponding multiplicity distribution.

emitted and they are detected with the help of an array of N detectors such that i^{th} detector has efficiency Ω_i, then probability of firing p detectors i.e. probability of p-fold is given by

$$P_{NP}^M = \sum_{l=0}^{p}(-1)^{p-l}\binom{N-l}{N-p}[\sum_{P_a}[1-(\sum_{i=1}^{N}\Omega_i - \sum_{j=1}^{l}\Omega_{aj})]^M] \tag{1}$$

Where $\sum_{P_a}$ indicates sum over all permutations that can take away l out of N. If each emitted gamma has a probability distribution $P(M)$ then probability of fold p is given by

$$P(p) = \sum_{M=0}^{\infty} P_{NP}^M P(M) \tag{2}$$

For simplicity, the multiplicity distribution is assumed to be a modified Fermi function of the form

$$P(M) = \frac{(2M+1)}{(1 + exp(\frac{M-M_0}{\delta M}))} \tag{3}$$

The two free parameters M_0 and δM were varied to fit the experimental fold distribution and values of M_0 and δM were found by 'chi square' minimization of fold distribution. Obtaining the multiplicity distribution, moments of the distribution were calculated.

Another method for finding moments is from the equation

$$P(p) = \sum_{M=0}^{\infty}[\langle\binom{M}{m}m!\rangle]A_{pm}(\Omega_1, .., \Omega_N) \tag{4}$$

where A_{pm} is given by

$$A_{pm} = \frac{(-1)^m}{m!}\sum_{l=0}^{p}(-1)^{p-l}\binom{N-l}{N-p}[\sum_{P_a}[(\sum_{i=1}^{N}\Omega_i - \sum_{j=1}^{l}\Omega_{aj})]^m] \tag{5}$$
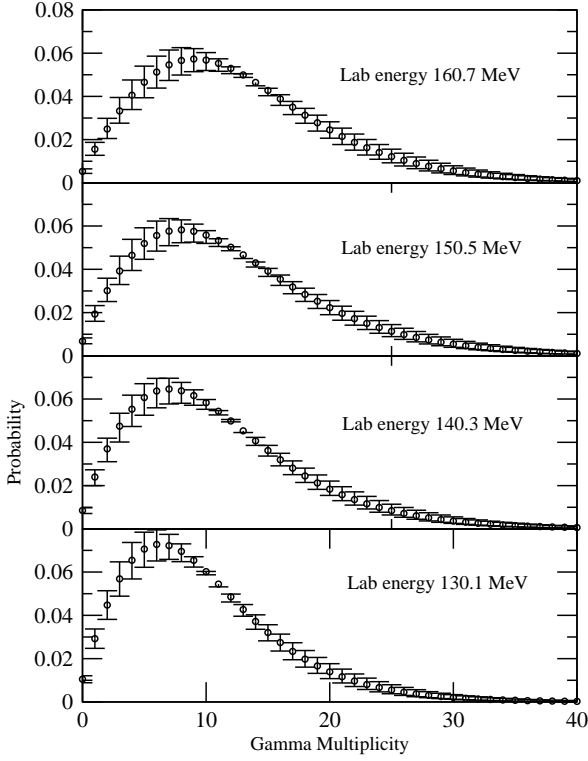
Fig. 3. Extracted gamma multiplicity for different beam energies.

and $\langle\binom{M}{m}m!\rangle$ is m^{th} factorial moment of emitted gamma multiplicity distribution.

Inverting Eq.4 we get

$$\langle\binom{M}{m}m!\rangle = \sum_{p=0}^{N} A_{mp}^{-1} P(p) \tag{6}$$

Using this equation one can extract factorial moments and convert them to corresponding raw moments. The first raw moment gives the mean of the distribution.

To cross check the multiplicity distribution that we obtained by fitting the experimental gamma-fold, we calculated raw moments in two different ways. First we calculated moments from the multiplicity distribution that we got from equation (3).

$$(moment)_i = \sum_{0}^{\infty} M^i * P(M) \tag{7}$$

Then we found the factorial moments using equation (6) and calculated corresponding raw moments. We compared the moments obtained by both the methods and they were found to be in agreement within 7%. Hence, we proceeded with the fitted multiplicity distribution.

The first moment of gamma multiplicity distribution for the three reactions $^{16}O + ^{184}W$, $^{19}F + ^{181}Ta$ and $^{30}Si + ^{170}Er$ were compared. Entrance channel mass asymmetries for ^{16}O, ^{19}F and ^{30}Si induced systems are 0.84, 0.81 and 0.70, respectively. Data for $^{16}O + ^{184}W$ and $^{19}F + ^{181}Ta$ were taken from [2]. Fig 4. shows first moment of gamma
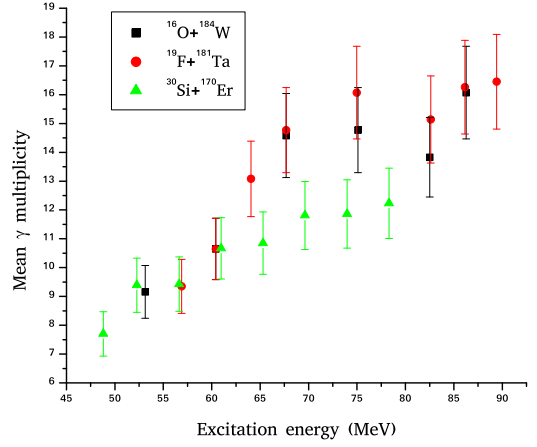
Fig. 4. Mean gamma multiplicty for three systems.

multiplicity as a function of excitation energy for all the three systems. It is clear from this figure that for ^{16}O and ^{19}F induced fusion reactions leading to the CN ^{200}Pb, the mean gamma multiplicity is not very different, as reported earlier. For ^{30}Si induced fusion reaction, mean multiplicity matches with the other two systems at lower excitation energies but at higher energies it has a lower value. This indicates that in $^{30}Si + ^{170}Er$ system, fission starts at much lower angular momentum compared to the other two entrance channels resulting in a lower mean gamma multiplicity at higher excitation energies. For CN events this is unlikely and hence this lowering of mean gamma multiplicity is interpreted as the occurrence of non compound nuclear processes in the case of $^{30}Si + ^{170}Er$.
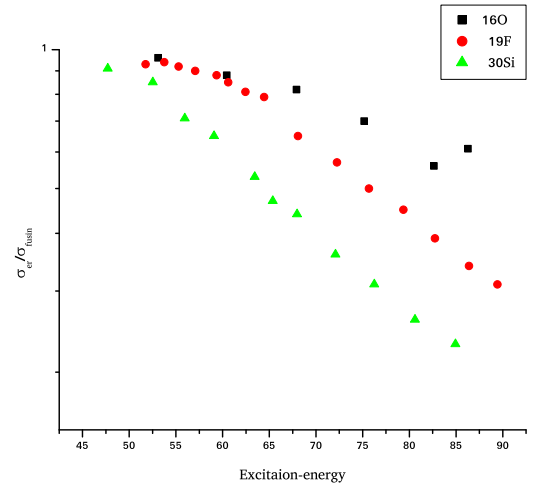
Fig. 5. $\sigma_{ER}/\sigma_{Fusion}$ cross sections for three systems.

If we look at fig. 5 which shows ratio of ER cross section to fusion cross section, $\sigma_{ER}/\sigma_{Fusion}$, it is evident that

in ^{30}Si + ^{170}Er system, fission plays an important role at higher excitation energies.

4 Conclusion

The comparison of mean gamma multiplicity of three systems, producing same CN at similar excitation energies, clearly indicates possibilities of enhanced non compound nuclear processes for the more symmetric system. Though all the three entrance channels populated the CN at same excitation enregies, ^{30}Si brought much higher angular momentum in its entrance channel yet produced ER at much lower angular momenta than other two entrance channels. Also, presence of quasi fission and fast fission was indicated for the system ^{19}F + ^{181}Ta [3]. Therefore chances of ^{30}Si+^{170}Er exhibiting non compound nuclear processes is more as it is a more symmetric system than ^{19}F + ^{181}Ta. The lowering of mean gamma multiplicities for ^{30}Si induced system can thus be attributed due to presence of non compound nuclear processes which may be verified by measuring the fission fragment mass distribution.

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