Dependence of ER formation probability on entrance channel isospin asymmetry in the mass region A ∼ 200

Hajara. K[1],*
[1]*Department of Physics, Safi Institute of Advanced Study, Vazhayur, Kerala – 673633, INDIA*
. * *email: khajara3@gmail.com*

Introduction

Heavy ion induced reactions are a prominent tool to study the dynamics of a nuclear reaction. When two heavy ions interact with each other, depending on the incident energy of the projectile and impact parameter, different kinds of nuclear reactions are possible. Quasi-fission is a fission like process that precedes the formation of a compound nucleus and subsequently, the formation of an ER. Since quasi-fission occurs before the target and the projectile fuse completely to form a compound nucleus, it hinder the formation of the ER. Recent studies using the heavy ion induced reactions in the mass region A ∼ 200 show there is a relative lowering of the ER cross sections of the same compound nuclei formed through different entrance channel with varying incident channel properties due to the presence of this non compound nuclear reactions.

Isospin asymmetry is the difference in the N/Z ratio of the target and projectile. In this work a systematic analysis of $P_{CN}P_{survival}$, the true ER formation probability, has been carried out from the experimentally measured ER cross sections for six set of systems, each set form same compound nuclei with different neutron number. The dependence of $P_{CN}P_{survival}$ on entrance channel isospin asymmetry are studied.

Methodology

The ER cross section measurement for the reaction ^{30}Si + ^{176}Y b has been carried out using the HYRA facility at IUAC[1]. The cross section maesurement has been carried out in the energy range 125.7 to 203.0 MeV in lab frame. The measured ER cross section and capture cross section predicted by the CCFULL along with the corresponding data for ^{28}Si+^{176}Yb has been compared. The fusion cross section data of 12 systems have been plotted and analyzed using CCFULL. All the selected systems form compound nuclei in the mass 200 region, where the competition between ER formation, fusion - fission and quasi-fission are prominent. The systems are so selected such that all of them have measured fission and ER cross sections more over at the same excitation energy. The fusion cross section, the sum of the fission and ER cross section is reproduced using the coupled channels code CCFULL. The CCFULL program code has been used to calculate the total fusion cross section. CCFULL includes the couplings to full order and thus it does not introduce the expansion of the coupling potential. The potential parameters in the ccfull codes are fixed by reproducing the experimentally measured fusion cross sections. This program code uses Woods-Saxon parametrization for the nuclear potential V_N (r), which is given by,

$$V_N(r) = V_0/(1 + \exp((r - R_0)/a)) \qquad (1)$$

where,

$$R_0 = r_0 (A_P^{(1/3)} + A_T^{(1/3)}) \qquad (2)$$

V_0 is the depth parameter of the Woods-Saxon potential, R_0 is the radius parameter, and *a* is the surface diffuseness parameter. Akyus Winther potential parametrization has been used for the calculation.

The ER cross section can be considered as the combination of three processes; capture, fusion and survival against fission. Hence the ER cross section can be written as

$$\sigma_{ER} = \sigma_{capture} P_{CN}P_{survival} \qquad (3)$$

Where P_{CN} is the complete fusion probability and $P_{survival}$ is the survival probability of of the compound nucleus against fission. Hence the correct ER formation probability can be written as the product of these two contributions $P_{CN}P_{survival}$.

This is calculated for all the set of reactions using the formula,

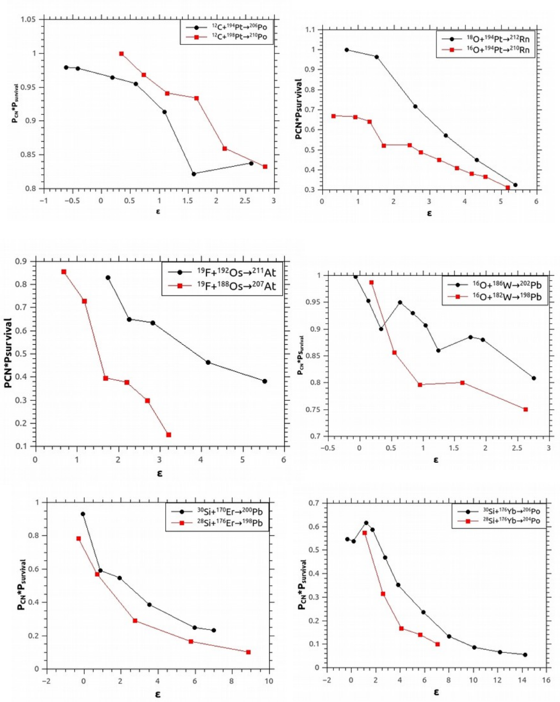
$$P_{CN}P_{survival} = \sigma_{ER}/\sigma_{capture} \qquad (4)$$

Since the energy imparted for the same compound nucleus produced by different projectile in the entrance channel are different, $P_{CN}P_{survival}$ is uniformly plotted against the reduced energy. To have a uniform picture of reaction mechanism at available energy of the systems the reduced cross sections are used. To calculate the reduced cross section, the fusion function method is used. In this method the energy and the cross sections are taken the following transformations.

$$E = (E - V_B)/\hbar\omega \qquad (5)$$

$$\text{and } \Sigma = 2E[\sigma/\hbar\omega\, R_B^2] \qquad (6)$$

where, is the curvature of the potential when the potential V_s deformation curve is fitted using a parabola. V_B is the maximum barrier height and R_B is the fusion radius.



Discussion

In set of figures all parameters like entrance channel mass asymmetry, Coloumb repulsion, effective fissility of the entrance channel, mean fissility of the compound nuclei are same for the reactions in a single group. The ER formation probability is decreasing with increase in the excitation energy for all set of reactions. The rate of decrease is increasing with increase in the mass asymmetry and charge product of the systems. This rapid decrease in the ER production can be due to the increased contribution from fission and/or quasi-fission.

For the same compound nuclei as the neutron number of the compound nuclei increases the ER formation probability also increases. The neutron binding energy decreases as the N/Z ratio of the compound nucleus increases. The effect of isospin asymmetry is predominant for systems forming compound nuclei, ^{200}Pb ,^{210}Po, ^{212}Rn and ^{211}At. All these nuclei have neutron shell closure. For the three nuclei (^{210}Po, ^{212}Rn and ^{211}At) have neutron magic number. The effect of isospin can be prominent if the compound nuclei formed is with neutron shell closure, in this mass region. channel properties of the system varies there is a large deviation in the value of ER formation probability.

The ER formation probability is increasing with increase in the Coulomb repulsion decrease in the mass asymmetry. There is a rapid decrease in the ER formation probability as the entrance channel mass asymmetry decreases. According to Bohr's independent hypothesis, P survival is a function of energy and angular momentum of the excited nuclei. Hence the dependence of ER formation arises only due to the dependence of P_{CN} on entrance channel properties. In the mass symmetric systems, the di-nuclear system favors the premature breaking before going to complete equilibration. The increased Coulomb repulsion between the interacting nuclei also result in the premature breaking of the di nuclear system. As the Coloumb repulsion increases and mass asymmetry decreases the ER formation probability is decreasing due to the increased contribution of non compound nuclear reaction process like quasi-fission.

Conclusion

The ER cross section has been measured for the reaction ^{30}Si + ^{176}Yb. The $P_{CN}P_{survival}$ values are calculated for this reaction. The comparison of $P_{CN}P_{survival}$ values calculated for the similar systems shows that the effect of isospin asymmetry on the ER formation probability is prominent only for nuclei with neutron shell closure.

Reference

1. K. Hajara et.al, Physical Review C 105, 044619 (2022)