Effect of Nuclear Density Distribution on Neutron Emission

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Introduction

Study of nucleon emission from a heavy ion induced hot nuclear system has started several decades back. But the results are yet to be understood fully in the light of reaction mechanism. Heavy ion reactions at intermediate energies show higher nucleon emissions than that yielded by the evaporation decay mode. At higher projectile energies pre-equilibrium (PEQ) emissions contribute to this increase in particle emissions [1]. A number of phenomenological and theoretical formalisms have been proposed [2] to predict the experimental yield and effective energy-angle distribution of nucleons at intermediate energy range. In the old version of our model HION, PEQ neutron distribution was estimated from two-body scattering kinematics in an exciton system [2]. Subsequent emission was calculated from the empirical relation proposed by Blann [3]. Time evolution of the system was not considered. This formalism resulted in overprediction of neutron emission at back angles. Secondly, neutron distribution with intermediate energies at forward angles is underpredicted.

In the present work, emission probability is determined from nucleon collision rates calculated from nucleon density distribution. In order to determine nucleon density distribution we have used two approaches: relativistic mean field (RMF) theory and semi-phenomenological formalism. Density distributions for the compound nuclei ^{185}Ir (from ^{20}Ne+^{165}Ho) and ^{177}Ta (from ^{12}C+^{165}Ho), associated emission probabilities and neutron multiplicity are calculated.

Method of calculation

PEQ emissions in heavy ion reactions at intermediate energy ranges and corresponding energy-angle distribution of the emitted neutrons are estimated from two-body scattering kinematics using the code HION [2,4]. The detailed formalism can be found in Nandy et. al [2]. Total neutron emission from the non-equilibrated system is calculated from the weighted sum of neutron energy-angle distribution for different impact parameters l, folded with neutron emission probability. Emission probability $P_C^\nu(\varepsilon)$ of ν type particle at emission energy (ε), calculated using emission rate $\lambda_C^\nu(\varepsilon)$ and collision rate $\lambda_t^\nu(\varepsilon)$, is given by

$$P_C^\nu(\varepsilon) = \frac{\lambda_C^\nu(\varepsilon)}{\lambda_C^\nu(\varepsilon) + \lambda_t^\nu(\varepsilon)} \quad (1)$$

In the present work $\lambda_t^\nu(\varepsilon)$ is calculated from the nucleon mean free path obtained from density distribution determined using the RMF [5] and semi-phenomenological [6] approaches. Free nucleon-nucleon scattering cross section is adopted from [7]. A simultaneous multiple PEQ prescription using the probabilistic approach proposed by Blann and Vonach, 1983 [8] has also been incorporated in the study.

Results and discussion

The experimental neutron multiplicities are compared with the theoretical results, as discussed in the earlier section. Evaporation contributions are calculated using the PACE4 code. Nucleon density distributions for composite nuclei ^{185}Ir and ^{177}Ta are shown in Fig. 1. The semi-phenomenological approach shows a near consistent central nucleon density with neutron density of ~0.09 fm^{-3} and proton density of ~ 0.07 fm^{-3}, both for ^{185}Ir and ^{177}Ta. In RMF approach the density distribution pattern of neutrons as well as of protons show lesser density in the central region followed by a double hump.

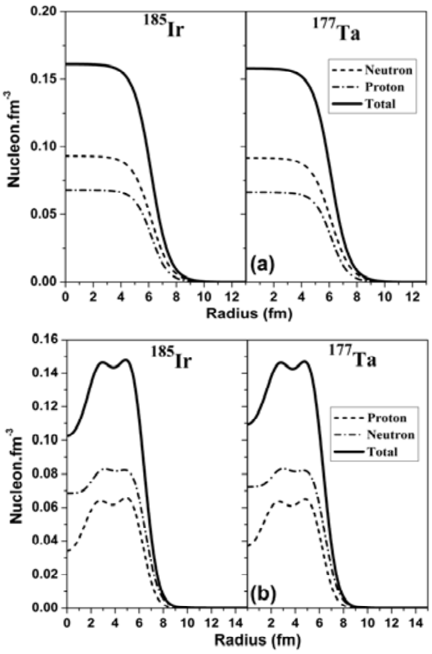

Fig. 1 Nucleon density of compound system (a) semiphenomenological and (b) RMF approach

Nucleon emission probability calculated from density dependent collision rates for both the systems are given in Fig. 2. The dotted line shows probabilities obtained with [3] and solid line from RMF approach.

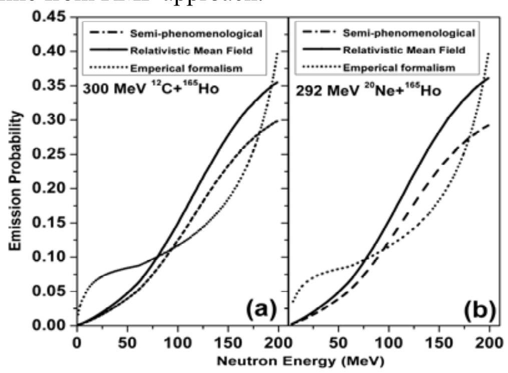

Fig.2 Emission probability of compound systems (a) $^{12}C+^{165}Ho$ and (b) $^{20}Ne+^{165}Ho$ systems

The emission probabilities obtained from the semi-phenomenological approach are given with dashed lines. The empirical calculation gives a higher yield up to 70 MeV emission energy compared to other two formalisms. RMF results in higher emission probability compared to semi-phenomenological approach. Neutron multiplicity obtained using these probabilities for $^{20}Ne+^{165}Ho$ system at 292 MeV are given in Fig. 3. The black circles with error bars are experimental data [9] and dotted line represents calculations using Blann empirical formulae [3].

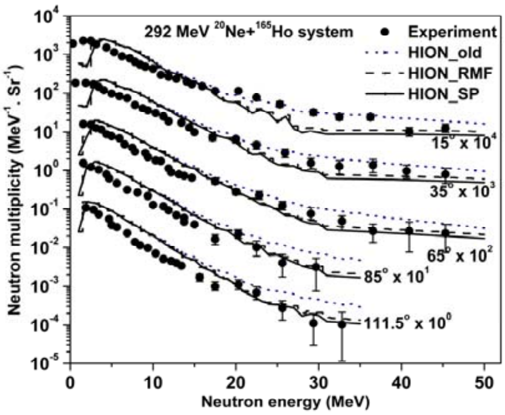

Fig.3 Comparison of experimental and estimated neutron multiplicities with HION code.

The solid and dashed lines represent neutron multiplicities with semi-phenomenological and RMF approach respectively. Figure clearly depicts that modified approach provides a better agreement at higher emission energies compared to the earlier estimates at back angles.

Conclusion

Incorporation of two body collision rates calculated from nucleon density dependent mean free path approach using the RMF and semi-phenomenological formalisms shows significant difference in the results. Improvement at larger emission angles is evident. The RMF formalism results in a higher yield. The modified emission probabilities provide a closer agreement with experimental measurements except at the forward angle.

References

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