Neutron emission in heavy ion reaction

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Introduction

Neutron distribution in light and heavy ion reactions is a subject of interest for many decades as it provides important information on reaction mechanism, structure of nuclei, abundance of elements, nuclear medicine application, nuclide inventory, radiation dose to personnel, equipment and environment. In heavy ion (HI) collisions at energies of 10 MeV/amu onwards it has been observed that the yield of energetic nucleons and light particles is higher than predicted by the evaporation model for emission from equilibrated compound nucleus. These preequilibrium (PEQ) emissions occur from the initial stages of relaxation of the target+projectile composite nucleus and constitute a forward peaked high energy part of the ejectile spectrum. While the direct nucleon emission and the evaporation are well explained by the quantum mechanical models and the statistical models, energy angle distribution of PEQ nucleons are yet to be fully understood.

Boltzmann Master equation with various modifications, nucleon exchange transport model, and other formalisms have been used to explain the double differential nucleon spectra from low to intermediate energy HI reactions by several workers and reproduce the measured spectra to different degrees of accuracy.

We have developed a model (HION) to calculate double differential neutron distribution from HI reaction at energies of few tens of MeV per nucleon [1,2].

Heavy Ion Reaction Model

The role of nucleon-nucleon scattering in the energy angle distribution of emitted nucleons was investigated by De et al [3]. We have extended this formalism for HI reactions in the range of ~10 – 50 MeV/amu. In the case of HI reaction relaxation of the composite nucleus is followed through the number (N) of two-body interactions. The probability of a nucleon of having energy ε moving in the direction ω is determined from the kinematics of two-body scattering. In order to take into account the excitation of the composite system it is considered to be subdivided into two sub-systems – a hot spot, described by a finite temperature Fermi distribution and a cold spot with a zero temperature Fermi distribution of its constituents. The two sub-systems are in partial equilibrium.

$$P(\varepsilon,\omega) = \xi P(\varepsilon,\omega) + (1-\xi) P(\varepsilon,\omega)$$

where ξ is the fraction of the hot spot, $P_H(\varepsilon,\omega)$ and $P_{K\text{-}K}(\varepsilon,\omega)$ are respectively the scattering kernel for the hot spot and the cold spot.

At each stage of two-body interactions the entropy and the temperature of the hot spot is determined from the number of excitons present at that stage. In the case of HI, reaction starts through overlap of nuclear potential even before the onset of any nucleon-nucleon scattering. The number of excited degrees of freedom at this stage has been determined from the momentum space consideration.

In the earlier version of our HI reaction model an empirical expression was used to calculate the rate of two body collisions. Later in order to investigate the influence of nuclear mean field on heavy ion reactions we have nucleon density distribution is determined from relativistic mean field (RMF) theory [4]. Nucleon density distribution is also determined from a semiphenomenological model [5]. Nucleon mean free path and subsequently the two-body collision rate is obtained from nucleon density at different impact parameters and nucleon interaction cross section.

First version of the model reproduces the double differential neutron yield. But the back angle emissions are overpredicted. With the RMF theory calculated density distribution introduced to estimate the collision rate this overprediction is removed. But the calculated neutron yield at intermediate energies underpredicts the measured data at forward angles for ion energies ~ 25 – 30 MeV/amu and onwards.

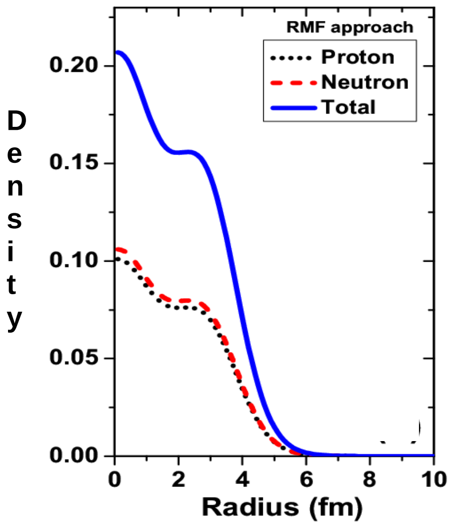

Fig. 1 Nucleon density distribution calculated from RMF, theory for ^{43}Sc (^{16}O+^{27}Al).

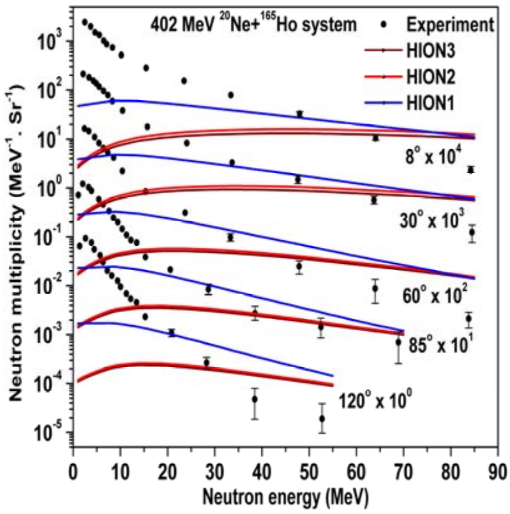

Fig. 2 Comparison of calculated (HION1 – old model, HION2 – DD from RMF, HION3 – semiphenomenological DD) and experimental [6] neutron multiplicity.

In order to resolve this issue multiple PEQ nucleon emission has been introduced in the model in two forms – i) simultaneous two-nucleon PEQ emission from the same composite system, and ii) two sequential PEQ emission.

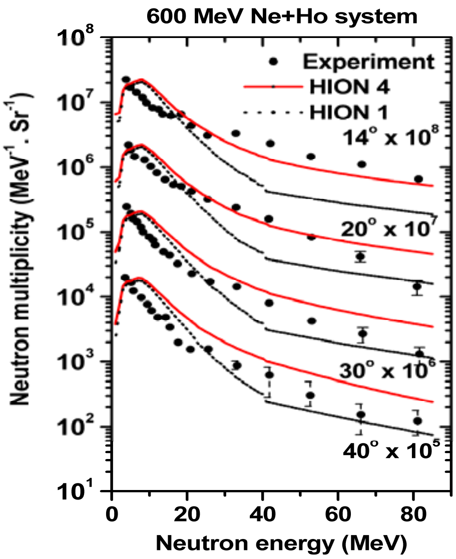

Fig. 3 Comparison of calculated (HION1 – old model, HION4 – DD from RMF and multiple PEQ included) and experimental [6] neutron multiplicity

For the two sets of available experimental data of neutron double differential distribution for beam energies between 25 – 30 MeV/amu the forward angle underprediction is removed on inclusion of multiple PEQ emission. The comparison is shown in figure 3. The model fairly well predicts the neutron distribution also at energies a little below 10 MeV/amu.

References

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