A study of neutron evaporation for excited compound nucleus via Poisson random processes

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The nuclear reactions induced by heavy ions at moderate excitation energies give rise to a variety of processes [1]. If energy of the incident ion is larger than the Coulomb barrier, it is absorbed by target nucleus forming a compound nucleus (CN). The energy and momentum of the incident heavy ions are shared among all the nucleons of the CN leading to the statistical equilibrium. The excited compound nucleus then decays to the final reaction product by emitting nuclear particles and/or gamma rays, and it assumed that, mode of decay of the compound nucleus is independent of the mode of its formation. This is referred to as the Bohr's independence hypothesis. It may be pointed out that independent hypothesis has been found to be valid at relatively lower excitation energies and as the energy is increased the pre-equilibrium (PE) processes becomes important [2]. The measured excitation function for a given channel reflects the interplay between CN and pre-equilibrium processes.

At moderate excitation energies, emission of charged particles from the compound nucleus is seriously hindered because of the Coulomb barrier. In such cases, the composite system formed by the amalgamation of the target nucleus with the incident ion de-excites by evaporation of many neutrons. The evaporation of neutrons may be considered to be random and it is reasonable to assume that the decay follows Poisson random processes. The compound nucleus releases a given fraction of its excitation energy which is independent of number of neutrons emitted in any other excitation energy interval. The average excitation energyε, carried away by an evaporated neutron has a constant value with respect to variation in the excitation energy of the compound nucleus and in the number x of evaporated nucleons. Thus, the neutron evaporation may be characterized by a constant ε^{-1} which is the average number of emitted nucleons per unit excitation energy. The mean number of emitted neutrons is given by $(E^*_p-\sum B_n)/\varepsilon$, where E_p^* is the excitation energy corresponding to the peak of the cross section and $\sum B_n$ is the binding energy of x evaporated nucleons. We now assume that the probability of x neutron emission is given by a Poisson distribution law with number of events x, random variable $(E^*-\sum B_n)$, and the frequency of occurrence ε^{-1}, given by Simbel [6] as

$$\mathrm{P(E^*,X)} \propto \frac{1}{x!}\left(\frac{E^*-\Sigma B_n}{\varepsilon}\right)^x \exp\left[-\left(\frac{E^*-\Sigma B_n}{\varepsilon}\right)\right]$$

Assuming that, the de-excitation of the compound nucleus in heavy ion induced reaction leading to xn channels follows independence hypothesis then, the cross section for this reaction may be represented as a combination of formation and decay terms,

$$\sigma_{xn} = C.\sigma_c.\, P(E^*,x)$$

where, $P(E^*,x)$ is the probability of decay via neutron evaporation given by Poisson random decay process and σ_c is the probability for the formation of compound nucleus calculated taking the radius, the incident energy and Coulomb barrier of the interacting ions into account. The term C, is a constant that may be specified by normalizing the peaks of the excitation function. Assuming that the neutrons evaporation follows Poisson random distribution, the expression for cross-section for a typical *xn* channel may be given as;

$$\sigma_{xn} = \frac{\pi R^2 C}{x!}\left(1 - \frac{V_c}{E_i}\right)\left(\frac{E^* - \sum B_n}{\varepsilon}\right)^x \exp\left[-\left(\frac{E^* - \sum B_n}{\varepsilon}\right)\right]$$

The two parameters ε and C may be varied to fit the experimental data with that calculated by above description. In order to study the dynamics of heavy ion interaction, we have undertaken a program of measurement and analysis of excitation functions of complete fusion (CF) and incomplete fusion reactions (ICF). The neutron emission channels in heavy-ion reactions may be considered to be from complete fusion processes. As such, the cross section for *xn*-channels (neutron evaporation only) may be considered to follow the Poisson random decay distribution given by above equation.

In the present work the experimental data for ^{181}Ta (^{12}C,3n)^{190}Au, ^{181}Ta(^{12}C,4n)^{189}Au, ^{181}Ta(^{12}C,5n)^{188}Au, ^{169}Tm(^{13}C,3n)^{179}Re, ^{169}Tm(^{13}C,4n)^{178}Re, ^{169}Tm(^{13}C,5n)^{177}Re, ^{169}Tm(^{13}C,6n)^{176}Re reactions [3,4] have been analyzed, within the framework as described above.

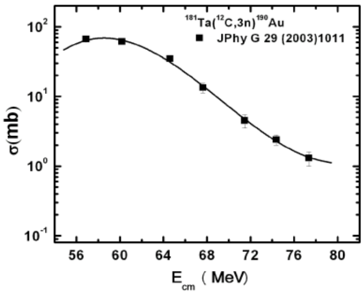

Fig-1: Experimentally measured and theoretically calculated excitation function, as discussed in the text.

In these calculations the parameter ε has been determined from the peak of the measured excitation function by taking the derivative of above equation for cross section with respect to excitation energy. The binding energies are calculated using the atomic mass tables of Wapstra and Gove [7].The best fit value of ε in the present work is found to be *3.5 MeV*, and has been retained through out the calculations. As a representative case, the calculated cross sections are compared with experimental data for *^{181}Ta(^{12}C, 3n)^{190}Au* channel in Fig. 1. As may be seen from this figure, the Poisson random decay assumption of the excited nucleus gives a good description of the experimental data over the entire range of energies. In these calculations the angular momentum effects are explicitly taken into account by Thomas expression [5] for average kinetic energy carried by each evaporated neutron. The calculation done for the neutron evaporation channels in ^{13}C+^{169}Tm are also found to agree reassembly well with the above given prescription as shown in Fig. 2, for 5n channel. Further details regarding the calculations and analysis will be presented.

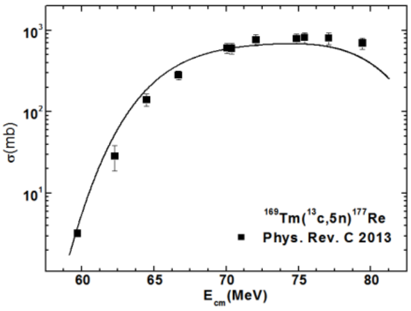

Fig-2: Experimentally measured and theoretically calculated excitation function.

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