Poisson random process for the explanation of neutron emission channels in heavy ion reactions

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Recently, in view of the proposed accelerator driven sub-critical (ADS) technology [1], there is increasing demand of the accurate cross-section data for almost all the projectile-target combinations over a wide range of energies. As a matter of fact, it is not possible to measure all the cross-section data needed for such applications. As an alternative the theoretical models, with suitable set of parameters, may be used to fill the gaps in experimental data. At moderate excitation energies the most common approach employs the compound nucleus (CN) model. In the compound nucleus approach it is assumed that the incident energy of the projectile is shared among all the nucleons of the composite system in statistical way, which may then decay. Here, the formation and decay are assumed to be independent of each other. The compound nucleus formed after the absorption of incident ion may decay via neutron/proton etc. emission channels.

The neutron evaporation from the excited nucleus may be considered to follow Poisson distribution as suggested by Simbel [2]. This assumption may be valid because the neutron emission is a random process at different excitation energies. Since, the number of neutrons evaporated, when the compound nucleus removes a given fraction of its excitation energy, is independent of the number of neutrons emitted in any other excitation energy interval, the process may be considered to be random. This assumption is valid when the excitation energy of the CN is large enough for emitting several neutrons. Further, the mean excitation energy 'ε' carried away by a neutron is nearly same for different channels, as shown in the compilations of Neubert [3]. As such, it may be assumed to be constant with respect to variations in the excitation energy of the compound nucleus and in the number of evaporated nucleons in the given *xn* channel. Thus, the evaporation process is characterized by a constant ε^{-1} which is average number of neutrons emitted per unit excitation energy. The evaporation of neutrons is, therefore, analogous to events occurring with a constant rate and hence the probability of emission of *x* number of neutrons may be described by Poisson distribution law. The mean number of the emitted neutrons is given by $(E_P^* - \Sigma B_n)/\varepsilon$; where, E_P^* is the excitation energy corresponding to the maxima of the excitation function and $\Sigma\ B_n$ is the binding energy of the *x* neutrons. The probability of emission of *x* number of neutrons, may be given by the Poisson distribution which is a function of random variable $(E^* - \Sigma B_n)$ and frequency of occurrence ε^{-1}, and may be represented as [2];

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

Assuming that de-excitation of the compound nucleus is via the Bohr's independent hypothesis, the cross-section for a given reaction may be represented as;

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

where, σ_c is the cross-section for compound nucleus formation and $P(E^*,x)$ is the decay probability given by above Poisson distribution function. The formation cross-section σ_c , may be given by, $\sigma_c = \pi R^2\ (1 - V_C/E_i)$, where the terms used have their usual meaning. As such, the cross-section for a given *xn* channel may be represented by;

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

The value of the constant of proportionality C, may be obtained by normalization at the peak of the measured excitation function.

In the present work an attempt has been made to determine the cross-sections for a large number of *xn* reaction channels using the above mentioned prescription given by Simbel [2] for different projectile-target combinations. In an ongoing programme on the study of heavy ion (HI) reactions at low energies [4,5,6], (HI, *xn*) excitation functions for a large number of cases have been measured. The details of these measurements are given elsewhere [5]. The experimentally measured excitation functions for a large number of *xn* reaction channels have been compared with those calculated based on Poisson distribution function [7]. As a representative case, the measured cross-section data for ^{159}Tb(^{12}C, 3n)^{168}Lu, channel has been compared in Fig.1, with calculations done using the above prescription. As can be seen from this figure that the calculations made using Simbel's prescription, in general, give a qualitative agreement of the experimental data. However, in these calculations the effect of angular momentum has not been taken into consideration. The angular momentum effects may be incorporated into these calculations employing the prescription given by Thomas [8]. Since a part of the excitation energy is consumed in the rotation of the nucleus and hence leaves the system with less energy for the emission of neutrons, the mean excitation energy may be different as compared to that calculated as discussed above and hence can be treated as a parameter, which may be varied to some extent to match the experimental data. The Fig.2, shows the satisfactory agreement of calculations by slightly varying the value of mean excitation energy ε with the experimental data. Further details and justification of the variation of the parameters of this prescription [2] will be discussed.

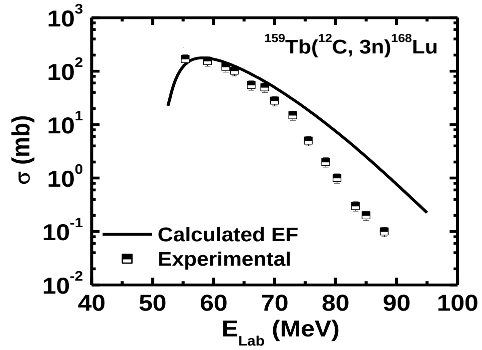

Fig.1 Experimentally measured and theoretically calculated excitation function, as discussed in the text.

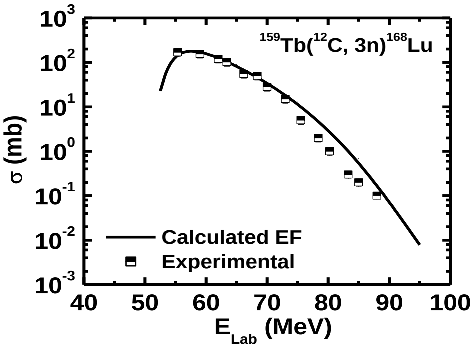

Fig.2 Theoretically calculated excitation function (EF) for 3n channel including angular momentum effects and experimental EF.

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