Estimation of neutron emission branching ratios in heavy ion reactions using Poisson random processes

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In heavy ion (HI) reactions, even at low excitation energies, several (HI, xn) channels are populated simultaneously. It is because at low and moderate excitations, the emission of charged particles is considerably suppressed due to the Coulomb barrier. As such, study of excitation functions for (HI, xn) channels and their satisfactory reproduction by some theoretical code, using the same set of parameters for all evaporation channels, provides a critical tool for testing the codes. The knowledge of cross-sections for neutron emission from different targets and at different excitation energies is very important from the point of view of producing isotopes for medical and agriculture applications on one hand and for the design of reactors on the other. These cross-sections are urgently required for the design of recently proposed sub-critical accelerator driven energy amplifiers. Though, it is desirable to have cross-section data for all targets, but it is not possible. Therefore, it is required to have a simple theoretical code, with minimal free parameters, that may predict the neutron emission cross-sections. One such attempt has been made by Simbel[1] where neutron emission from an excited nucleus is assumed to follow Poisson random distribution characterized by the average number of emitted neutrons per unit excitation energy ϵ^{-1}. According to the compound reaction mechanism, the total cross section for all neutron emission channels σ_{xn} may be given by; $\sigma_{xn} = \mathrm{C}\cdot\sigma_c\cdot\mathrm{P}(E^*, \mathrm{x})$, where, C is a constant specified by normalizing the peaks of the excitation function, σ_c is the cross-section for the compound neucleus formation and $\mathrm{P}(E^*,\mathrm{x})$ is the probability of decay via neutron evaporation at a given excitation energy. In the present approach of calculating cross-sections assuming Poission random decay, the ϵ and C are the important parameters which may be varied to reproduce the data. Further, the average excitation energy ϵ may be determined from the peak position of the excitation function using $\mathrm{d}\sigma_{xn}/\mathrm{d}E^* = 0$, which gives;

$$\epsilon_x = (E_i - V_c)[\frac{V_c}{E_i} + x\{\frac{(E_i - V_c)}{(E_p^* - \Sigma B_n)}\}]^{-1} \quad (1)$$

Using the above formulation, the mean value of ϵ for different values of x, may be estimated. The normalization factor may be used for the approximate extimation of neutron emission branching ratios. If the neutron emission is the only channel open for the de-excitation of the compound nucleus, then for C as unity; $\sum_{x=1}^{\infty} \sigma_{xn} = \sigma_c$. It may be pointed out that on the basis of energy consideration, the sum of the binding energies of all the evaporated neutrons must not exceed the excitation energy of the compound nucleus. Here the summation over x varies from 1 to x_{max}, then the constant C may be given by;

$$C = [\sum_{x=1}^{x_{max}} \{\frac{(E^* - \Sigma B_n)}{\epsilon}\}^x \frac{1}{x!} \cdot exp\{\frac{-(E^* - \Sigma B_n)}{\epsilon}\}]^{-1} \quad (2)$$

If the other channels are open, then one may estimate the competition between neutron emission and other decay modes of the compound nucleus[2]. In the absence of other

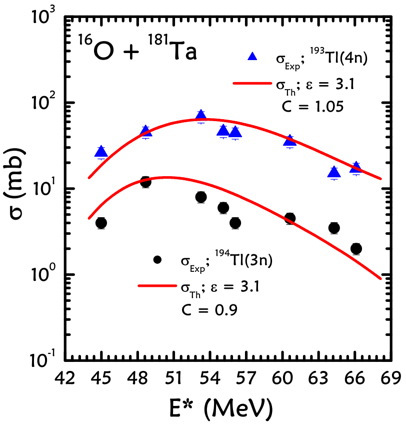

FIG. 1: Excitation functions for the reactions $^{181}Ta(^{16}O, \text{xn})^{197-x}Tl$ with x = 3-4.

TABLE I: Parameters used in fitting the cross-sections of $^{181}Ta(^{16}O, \text{xn})^{197-x}Tl$ reactions and corresponding neutron emission branching ratios;

x	ϵ (MeV)	C	$\overline{(\Gamma_n/\sum\Gamma_i)}$
3	2.29	0.9	1.52
4	3.17	1.05	1.11
5	3.95	2.0	0.75

opened channels, the cross-section for x neutron emission may be related to the observed values by multiplying the former by a product of the branching ratios of the emission of first-, second-, third- and so on till the x^{th} neutron, and may be represented as G_{n1} G_{n2} G_{n3},........G_{nx}, where, $G_n = \Gamma_n/\sum\Gamma_i$ is the ratio of the level width for neutron emission to the total level width. The quantities G_{ni} may be replaced by their geometrical average $\overline{G}$ so that the cross-section of xn reaction is proportional to $(\overline{G})^x$. Then the normalization factor will be given by;

$$C = \overline{(\Gamma_n/\sum\Gamma_i)} \cdot [\sum_{x=1}^{x_{max}}\{\frac{(E^*-\Sigma B_n)}{\epsilon}\}^x\frac{1}{x!} \cdot exp\{\frac{-(E^*-\Sigma B_n)}{\epsilon}\}]^{-1} \quad (3)$$

As such, the value of C obtained from the normalization of the data, may be used to calculate the ratio of the level width for neutron emission to the total level width. In the present work, an attempt has been made to obtain the branching ratios for neutron emission in the reactions induced by ^{16}O on ^{181}Ta, ^{169}Tm, ^{159}Tb. The experimental data has been taken from[3, 4]. In order to determine the above branching ratios, the experimental data has been fitted using the prescription of neutron emission to follow Poisson random distribution. The best fit values of the normalization constant and the average excitation energies were deduced to estimate the neutron emision branching ratios. As a representative case, Fig. 1 shows the comparison between the experimentally measured and theoretically calculated cross-sections using Poission random distribution for $^{181}Ta(^{16}O, \text{xn})^{197-x}Tl$ reactions with x = 3 & 4 with the parameter ϵ = 3.1 MeV. As can be seen that there is a satisfactory agreement between the theory and the measured data in the entire studied energy range, in general. For the various Thallium nuclides populated by neutron evaporation (x = 3-5) from ^{197}Tl compound nuclei in ^{16}O + ^{181}Ta system, the values of ϵ, fitting parameter C and the deduced neutron emission branching ratios are given in the TableI. Details on the significance of these values and further results will be presented.

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