Semi-empirical systematics for the (n, 2n) reaction cross-sections around 14.5 MeV

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Introduction

Nuclear reaction cross-section data are important due to its usability in reactor applications, dose estimation, rare isotope production, radiation damage studies etc. The neutron data around 14.5 MeV are vital for the design of fusion reactors essentially for the estimation of secondary particle production, radiation damage to the first wall, toroidal coils and surrounding materials [1]. Tremendous amount of data are available at EXchange FORmnat (EXFOR) library [2] related to (n, 2n) reaction cross-sections for fusion reactor applications. The data contains discrepancies and irregularities due to the need of relative measurements and to get monoenergetic source of neutrons. Different authors have used different techniques to measure the reaction data, which in turn reflect in the enhanced uncertainties. Alongside the experimental measurements, different theoretical model codes have constantly being used for the better prediction of the nuclear data, which has been found suitable to many cases. On the other hand, semi-empirical approaches have also been applied to predict the data more accurately [1]. It has been found that the use of these systematic formulas result in better description of the data and they even predict the cross-sections for a large range of nuclei. In the present work, a new semi-empirical systematic formula has been developed to calculate and to predict the (n, 2n) reaction cross-sections around 14.5 MeV incident particle energies for the nuclei with in the mass range of $45 \leq A \leq 232$. The results have been compared with the systematics proposed by other authors [3–7] in previous years and with the experimental data taken from the EXFOR database for ≈ 14.5 MeV for different (n, 2n) reactions within the given mass range.

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Semi-empirical formula for (n, 2n) reaction cross-sections

A general semi-empirical formula for (n, 2n) reaction cross-section can be given as [3],

$$\sigma_{n,2n} = \sigma_R \Big(\frac{2S_{2n}+1}{2S_n+1}\Big)\frac{M_{2n}}{M_n} \times \exp\Big(\frac{a_1}{T} + a_c\Big(\frac{Z^2}{TA^{1/3}} - \frac{Z^2}{T(A-1)^{1/3}}\Big) + a_a\Big(\frac{(A-2Z)^2}{AT} - \frac{(A-2Z-1)^2}{(A-1)T}\Big)\Big)$$

where, $T = (E_n/a)^{1/2}$ MeV is the nuclear temperature with the level density parameter $a = (A/25)\ MeV^{-1}$. $\sigma_R = \pi r_0^2(1+A^{1/3})^2$ is the reaction formation cross-section with $r_0 = 1.4$ fm. S_{2n} and M_{2n} are the spin statistical function and mass of emitted 2n particles, respectively. a_c, a_a, and a_1 are coulomb, asymmetric parameters and a constant respectively.

Fitting of the (n, 2n) reaction cross-section systematics

A good fit for the cross-section values obtained by the present formula taking into account the odd–even effect correction is given by the following formula:

$$y = P \times \exp(Qx + Rx^2)$$

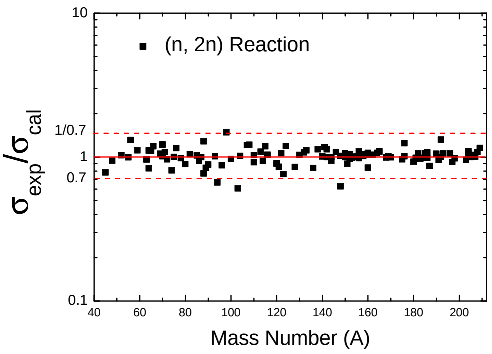

FIG. 1: Ratios of the experimental cross-sections to the cross-sections calculated with new systematic formula

where,

$$y = \sigma/(1 + A^{1/3})^2; \text{ and } x = \frac{A - 2Z}{A}$$

the value for the constants P, Q and R were found to be,

for Odd-A nuclei,

$$P = 0.004397; \quad Q = 27.77; \quad R = -82.26$$

for Even-A nuclei,

$$P = 0.001344; \quad Q = 40.53; \quad R = -116.5$$

Results and Discussion

The present systematic formula has been developed for the prediction of the (n, 2n) reaction cross-sections of different isotopes within the atomic mass range $45 \leq A \leq 232$. The calculated cross-sections were tested against the experimentally measured cross-section data taken from the EXFOR library. The ratio $\sigma_{exp}/\sigma_{calc}$ is plotted in Fig 1 for the given mass range. It can be observed from the figure that the results from the present systematic formula show minor deviation from the experimental data. To present a test case, the (n, 2n) reaction cross-section is calculated at 14.5 MeV for ^{100}Mo isotope, which is vital for the production of most commonly used medical isotope ^{99}Mo, using the present and the systematics from other authors [3–7]. The results are shown in Table 1 and are also compared with a recent study [8]. It is obvious from the table that the present formula is successful in order to reproduce the experimental data satisfactorily.

TABLE I: A comparison of the $^{100}Mo(n, 2n)^{99}Mo$ reaction cross-sections calculated from the present work, systematics developed by authors [3–7] and the average cross-section calculated using experimental EXFOR data [2].

Author	Cross-section (b)		
	σ_{calc}	σ_{exp}(EXFOR)	Exp. Data [8]
Chatterjee	1.312	1.503 ± 0.045	1.422 ± 0.191
Lu and Fink	1.394		
Luo	1.451		
Bychkov	1.311		
Habbani	1.255		
Present Work	1.419		

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