A NEW ESTIMATED SEMI EMPIRICAL FORMULA OF (n,p) REACTION CROSS SECTIONS ABOUT 14.5 MeV NEUTRONS

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Abstract

A new semi-empirical formula for the calculation of the (n,p) cross section at 14.5 MeV neutron energy is proposed. Derived from the evaporation statistical model, the formula includes five parameters and shows a strong dependence of the (n,p) cross section on terms of the parameters (N-Z+1)/A, (2Z-1)/A and $\sqrt{A}$. Fitting this formula to the existing cross section data on 159 nuclei (between A=40 and 209), the adjustable parameters were determined and the systematics of the (n,p) reaction were studied. The predictions of this formula are compared with those of the existing formulae and with the experimental data. The formula with five parameters is found to give a better fit to the data than the previous comparable formulae.

1. Introduction

The data of neutron activation cross-sections are very important for 14.5 MeV at fusion reactor technology, especially, at nuclear transmutation calculations and additionally test of nuclear models. Generally, for all of the reactions, many experimental data were reported [1] and great works are given to compilations and evaluations. There are discrepancies among these data [2]. Various cross sections of the neutron–induced reactions are measured at 13.5-14.9 MeV neutron energy range using SAMES T-400 d-T neutron generator at Cekmece Nuclear Research and Training Center, Department of Physics. [3-6]

The aim of this work is to develop a semi empirical formula, which depends on the mass and charge numbers in order to calculate the (n,p) reaction for 14.5 MeV neutrons. The evaporation statistical model [7] shows that the (n,p) cross section depends on the reaction energy Q, the nuclear temperature T and the Coulomb barrier V_p. The use of the effective reaction energy Q shows for the important dependence of the (n,p) cross section on the (2Z-1)/A term describing the Coulomb diffuseness energy and also a dependence on an additional (N-Z+1)/A term that describes surface asymmetry effect. [13] Thus an analytical expression was derived and the parameters of the formula were determined with least-squared analysis of the existing cross section values for different nuclei.

2. Empirical Formula

The systematics for (n,p) reaction cross sections in literature had been obtained by using approximation models such as statistical evaporation or direct reaction processes. [8-11] These estimations depend on the neutron number (N), atomic number (Z) and mass number (A) of target nucleus and have (N-Z/A) term in all semi-empirical formulae.

In entire advised empirical formulas, asymmetry parameter described with (N-Z+1)/A, (2Z-1)/A term describing the Coulomb diffuseness energy have been expressed with an exponential function in (n,p) reaction cross-sections. For the first time, an important dependence of the (n,p) cross section on (2Z-1)/A term deduced from the Coulomb diffuseness effect was shown and an additional parameter for describing the surface asymmetry effect was introduced in Ref. 13. It is possible to understand this situation from nuclear physics point of view.

At 14.5 MeV, the total reaction cross section σ_R can be written as

$$\sigma_R = \pi R_0^{\,2}(A^{1/3}+1)^2 \tag{1}$$

where R_0 is radius constant of nuclei. In order to develop the systematics for the (n,p) reaction cross section at 14.5 MeV, the following expression is suggested

$$\sigma_{n,p} = a_1(A^{1/3}+1)^2.\exp\left[a_2\left(\frac{N-Z+1}{A}\right)+a_3\left(\frac{N-Z+1}{A}\right)^2+a_4\sqrt{A}+a_5\left(\frac{2Z-1}{A}\right)\right] \tag{2}$$

3. Fitting Procedure

The data for experimental (n,p) reaction cross sections at 14.5 MeV for 159 nuclei with 40≤A≤209, were used to determine the parameters a_1, a_2, a_3, a_4, and a_5 of Eq.(2). The best fit obtained with the five free parameters in order to provide the maximum value of the following expression [12]

$$\Sigma = \sum_{i=1}^{N}\left(\frac{\sigma_i^{\exp}-\sigma_i^{cal}}{\Delta\sigma_i^{\exp}}\right)^2 \tag{3}$$

where $\sigma_i^{\exp}$ and $\Delta\sigma_i^{\exp}$ are, respectively, the experimental cross section and its uncertainty and σ_i^{cal} is the cross section calculated through Eq. (2)

The experimental values of (n,p) reaction cross sections at 14.5 MeV neutron energy for target nuclei are taken from the compilations of Konobeyev et.al. [8] The minimum value, corresponding to the best fit, of χ^2 was deduced through

$$\chi^2 = \Sigma/(N-M) \tag{4}$$

where Σ is defined in Eq.3, N is the number of experimental data and M is the number of free parameters. The comparison between the experimental and calculated data is illustrated in Fig.1.

4. Comparison with Other Systematics

Among the various relations proposed to describe the (n,p) cross section, the formula established by Forrest [9], for nuclei with 40≤A≤209, was considered to be the best systematic with the minimum χ^2 value and is given by

$$\sigma_{n,p} = a_1(A^{1/3}+1)^2.\exp\left[a_2\left(\frac{N-Z}{A}\right)+a_3\left(\frac{N-Z}{A}\right)^2+a_4\sqrt{A}\right] \quad (5)$$

Bychkov et.al [10] presents formula with minimum χ^2 value as

$$\sigma_{n,p} = a_1(A^{1/3}+1)^2.\exp\left[(A/145)^{1/2}\left(a_2\left(\frac{N-Z}{A}\right)+a_3\frac{Z-1}{A^{1/3}}\right)+a_4\right] \quad (6)$$

An other relationship, deduced by Ait-Tahar [11] from the evaporation model, with two parameters and including only the term (N-Z+1)/A describing the asymmetry effect, is given by

$$\sigma_{n,p} = a_1(A^{1/3}+1)^2.\exp\left[a_2\left(\frac{N-Z+1}{A}\right)\right] \quad (7)$$

The results of fitting of parameters from Eqs. 5-7 to the experimental values of cross sections are given in Table 1. The comparison of the data presented in Table 1 shows that Eq. 2 derived in this work best describes the experimental data.

Table 1. The parameters of different systematics with their corresponding χ^2, resulting from the fit to the 159 experimental cross sections.

Formula	Parameters					χ^2	Eq. No
	a_1	a_2	a_3	a_4	a_5		
This work	0.038	-16.743	-74.030	0.134	6.348	2.56	2
Forrest	5.5562	-24.061	-79.723	0.24483	-	2.62	5
Bychkov	42.807	-50.385	0.58916	-3.2374	-	3.40	6
Ait-Tahar	92.297	-35.789	-	-	-	4.19	7

5. Conclusion

This work attempts to derive a new estimated semi-empirical formula to systematize (n,p) cross section values. This formula was tested for 159 nuclei with $40 \leq A \leq 209$. It shows an improvement in describing the (n,p) data compared with the existing relationships.

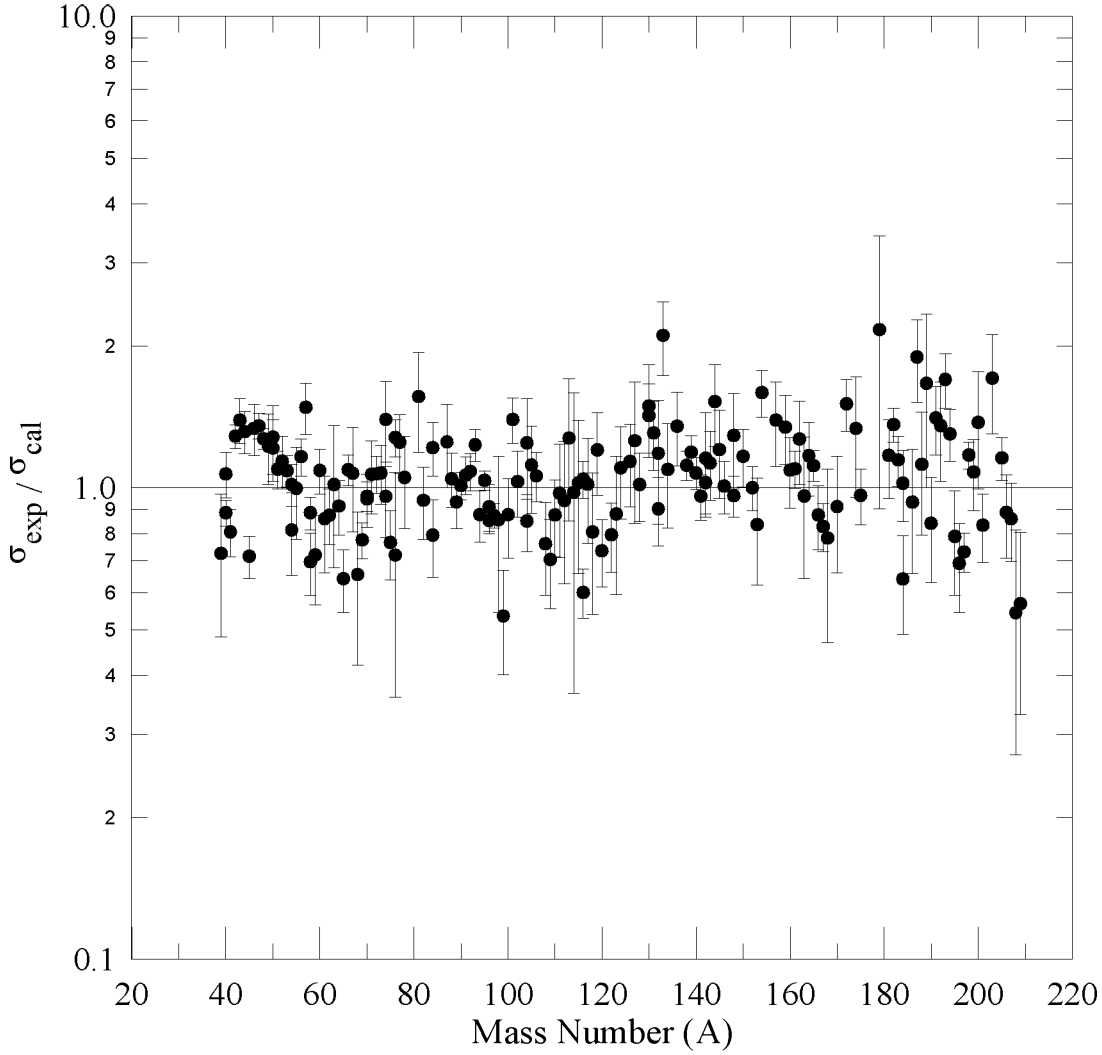

Figure 1. Ratios of the experimental cross sections to the cross sections calculated through Eq.2 with parameters from Table 1.

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