# Differential cross section evaluation in (n,$\alpha$) reaction with fast neutrons using Hauser – Feshbach formalism

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**Abstract.** In this work we have analyzed the $^{64}Zn(n,\alpha)^{61}Ni$ reaction with fast neutrons. For incident neutrons energy from *1 MeV* up to *8 MeV* we have evaluated the cross section and differential cross sections using the computer codes Talys and his default parameters for mentioned reaction. The done evaluation established that the contribution to the cross sections are mainly due to the compound processes and direct processes can be neglected. For these reasons the cross sections were evaluated in the frame of Hauser – Feshbach formalism (HF).

The obtained results were compared with existing experimental data. These experimental data were in principal obtained at the electrostatic generators from JINR FLNP Dubna (EG-5) and from Institute of Heavy Ions Physics – Pekin University (China).

Theoretical and experimental data are in a satisfactory agreement but in the future it is necessary to try other parameters then Talys default to have a better agreement.

## Introduction

Researches of the nuclear reactions induced by fast neutrons with emission of charged particles like protons and alpha particles are important from theoretical point of view as well as for applications in the field material science for construction of reactors.

In the conventional classification of the neutrons fast neutrons are considered from *0.5 MeV* up to *20 MeV* [1]. In this neutron energy interval are few experimental data that differ from one group to another. Cross sections for *(n,p)* and *(n,$\alpha$)* reactions are of order of tens of milibarns or lower and difficult to measure or evaluate. The difficulties are coming from the background caused by many open channels. Further, in this energy interval, for incident neutrons usually together with compound processes are present other reaction mechanisms like direct or preequilibrium. Therefore it is of great interest for theory to establish the quote of each type of process (compound, direct, preequilibrium) to the cross sections. The experimental and theoretical evaluations are also important in the field of nuclear structure and astrophysics [2].

For practical purposes the knowledge of the cross sections induced by neutrons and emission of charged particles is of a great importance in material sciences field for nuclear reactors construction [2]. During the time takes place a process of accumulation of Hydrogen and Helium in the walls of reactor building, vessels and other object around the reactor ensemble. This accumulation leads to the changing of resistance parameters of these walls and in this light it is clear that the evaluation of accumulation process is direct related to the cross sections.

We have evaluated the differential cross sections for $^{64}Zn(n,\alpha)^{61}Ni$ reaction for neutrons energy from *1 MeV* up to *8 MeV* using the Talys computer codes [3]. The incident neutrons energy interval was chosen in relation with our experimental possibilities because in fact the codes allow in principal to study the nuclear reaction up to *200 MeV* including all necessary reaction mechanisms.

Talys codes can be very useful for theorist and experimenters in the field of nuclear reactions. In this software are implemented many nuclear reaction models, data basis for nuclear structure, density levels and others for quick and efficient analysis of nuclear reaction. Talys is an open project and many researchers may bring their contributions to the improvement of the codes [4].

**Theoretical background**

For the evaluation of the cross sections we used mainly the HF formalism [5]. This formalism is an efficient tool for cross section evaluation and first was developed in the '50 years of last century for binary reaction induced by neutrons with formation of an intermediate compound nucleus. For a binary reaction of type $\alpha+A\rightarrow C\rightarrow\beta+B$ ($\alpha$ – incident particle, $A$ – target nucleus, $C$ – compound nucleus, $\beta$ – emergent particle, $B$ – residual nucleus) the cross section has the following form:

$$\sigma_{\alpha\beta} = \pi\lambda_{\alpha}^{2} \frac{T_{\alpha}T_{\beta}}{\sum_{c} T_{c}} W_{\alpha\beta} \tag{1}$$

$T$ = transmission coefficient, $W_{\alpha\beta}$ = width fluctuation correction factor (WFC).

As it can be seen an important factor in the cross section evaluation are the transmission (or penetrability) coefficients in the incident channel and emergent possible open channels. This coefficient represents the probability for a particle to penetrate a potential barrier and can be evaluated using the so called "semi classical" approach or more accurate in the frame of a quantum mechanical formalism described in [6]. The authors have evaluated the penetrability coefficients in the both approaches in [7], respectively [8].

First expression of relation (1) was without of WFC [9]. This factor shows the correlation between the incident channel and outgoing channels. With the increasing of the incident particle energy the correlation also is increasing. Quantitatively WFC is equal to unity when no correlation yield and slowly decrease with energy.

The differential cross section in the HF formalism has the expression (for simplicity without WFC factor):

$$\frac{d\sigma}{d\Omega} = \pi\lambda^{2}(2l+1)T_{l}\sum_{J}\frac{A_{J}\left(l,j\,|\,l',j'\,|\,\theta\right)}{1+\sum_{p,q,r}\frac{T_{p}\left(E_{q}'\right)}{T_{l'}\left(E'\right)}} \tag{2}$$

$$A_{J}\left(l,j\,|\,l',j'\,|\,\theta\right) = \sum_{m,m'}\left|(l,j;0m\,|\,l,j;Jm)\right|^{2}\left|(l',j';m'm-m'\,|\,l',j';Jm)\right|^{2}\left|Y_{l'm'}(\theta,\varphi)\right|^{2} \tag{3}$$

We also have evaluated the contribution of direct processes but their contribution can be neglected in the mentioned neutron energy interval and therefore we do not show here the main formulas for these processes.

**Results**

We used the default Talys parameters and first we have evaluated the cross section and from cross section has resulted that the dominant processes are the compound ones.

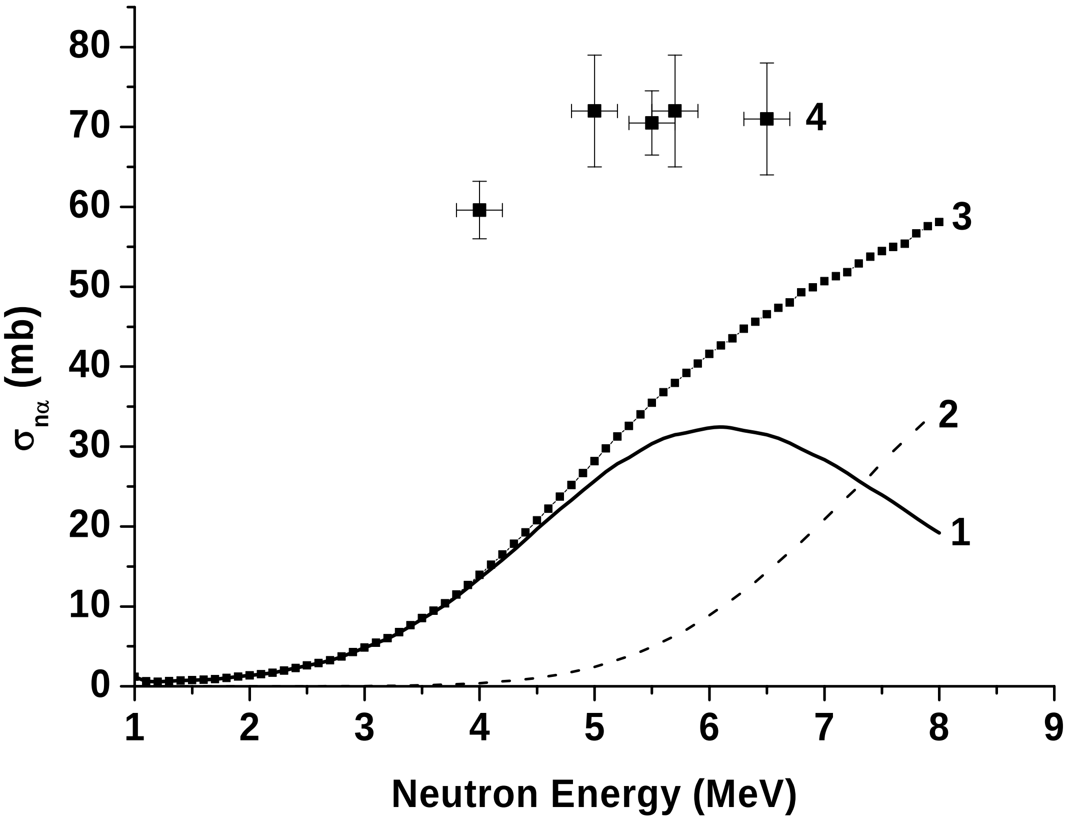


**Fig.1.** Cross section of $^{64}Zn(n,\alpha)^{61}Ni$ reaction. 1 – contribution of the compound processes on discrete states of residual nucleus (10 levels), 2 – contribution of the compound processes on continuum states of residual nucleus, 3 – contribution of all processes (inclusive neglected direct processes), 4 – experimental data.

In the beginning the compound processes on discrete states of residual nucleus are dominant but with the increasing of the energy they reach a maximum and after that they slowly decrease giving priority to the compound processes on continuum states (Fig.1). Here is not showed but higher than *8 MeV* processes on continuum also reach a maximum followed by a slow decreasing, direct and multiples processes (like *(n, 2n)*, *(n, np)* and others of such type) becoming dominant. Experimental data [10] (4 from Fig.1) are obtained mainly by our group using a double gridded ionization chamber and in the beginning can be considered in agreement with theoretical evaluation.

We have obtained the differential cross section for all energies but in Fig.2.are shown only the cases for *5.5 MeV* and *8 MeV*. From Fig.1. it is expected that the differential cross section will be symmetric around $90^0$ due to the contribution of the compound processes. For indicated neutrons energy interval in the evaluation were taken into account neutrons with orbital momentum greater than zero and as results the differential cross section has an anisotropy (the presence of Legendre polynomials of second order or fourth, sixth, eight,…, orders for higher energies if is necessary).

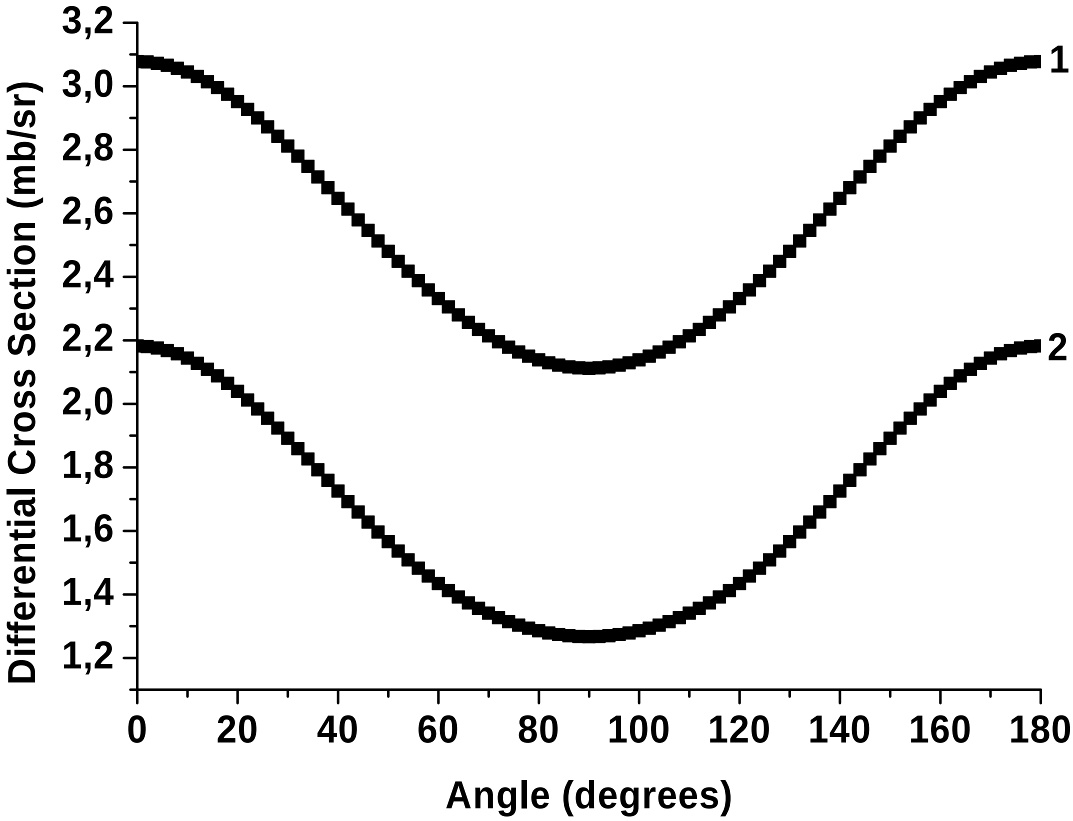


**Fig.2.** Differential cross section for $^{64}Zn(n,\alpha)^{61}Ni$ reaction. 1 – for *5.5 MeV*, 2 – for *8 MeV*

**Discussion and Conclusions**

Theoretical evaluations presented in this work are not final. First, it is necessary to try other parameters than defaults suggested by Talys in order to describe better the experimental data. In future a set of experimental data in a large energy interval will be of a great help in the selection of necessary optimal parameters.

Also will be of great interest a set of experimental data for differential cross section for different energies to verify the presence of the anisotropy and / or the existence of a forward – backward asymmetry. This asymmetry will confirm or infirm our statement concerning the presence and the contribution of the direct processes.

The $^{64}Zn(n,\alpha)^{61}Ni$ reaction is a part of a research program for nuclear reactions induced by neutrons with emission of charged particles (protons, alpha particles) on medium and heavy nuclei developed at JINR FLNP Dubna for many years.

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