14 MeV NEUTRON INDUCED (n,p) REACTION CROSS SECTION ANALYSIS

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Abstract. Using the statistical model, Griffin's exciton model and PWBA are deduced simple and convenient formulae for theoretical explanation on existence of a systematic regularity which was observed in the fast neutron induced (n,p) reaction cross sections. It was shown that theoretical total (n,p) cross sections are satisfactorily in agreement with known experimental values for the 14.5 MeV neutrons.

INTRODUCTION

Investigation of the fast neutron induced (n,p) reaction is of interest to study of nuclear reaction mechanisms. On the other hand, it is often necessary in practice to evaluate the neutron cross sections of the nuclides, for which no experimental data are available. Because of this, in last decade we carried out the systematic analysis of the known (n,p) cross sections and observed so-called isotopic effect in the wide energy interval of neutrons and for the broad mass range of target nuclei [1,2].

In this paper for the systematic analysis of the fast neutron induced (n,p) reaction cross sections are used the statistical model, exciton model and PWBA.

THEORETICAL MODELS OF NUCLEAR REACTIONS

Compound mechanism

The constant nuclear temperature evaporation model, Weizsacker's formula for nuclear binding energy, semi-classical approach to an inverse reaction cross section and $\Gamma \approx \Gamma_n$ approximation were used. Also, the secondary particles and γ-emission were neglected. Then, the (n,p) cross section can be obtained as follows [3]:

$$\sigma_{np}^{com} = C\pi(R+\lambda\!\!\!^{-})^2 e^{-K\frac{N-Z+1}{A}} \quad (1)$$

Where

$$C = \exp\frac{1}{\Theta}\left(\gamma\frac{2Z-1}{A^{1/3}} + \frac{\Delta}{A^{3/4}} - V_p\right) \quad (2)$$

$$K = \frac{4\xi}{\Theta} \quad (3)$$

R, *Z*, *N* and *A* are the radius, proton, neutron and mass numbers of target nuclei, respectively; $\lambda\!\!\!^{-}$ is the wavelength of incident neutrons divided by 2π; V_p is the Coulomb potential for protons; Θ is the thermodynamic temperature of nuclei; $\Delta = \delta_i - \delta_f$; ξ, γ, δ_i and δ_f are the constants of Weizsacker's formula.

Pre-equilibrium mechanism

Griffin's exciton model is used [4]. For the transition rates is used following approximation:

$$\lambda_n^+ >> \lambda_n >> \lambda_n^- \tag{4}$$

We also assume the probability of nucleon emission from state with n-excitons $\gamma_n \approx 0$ and depleting factor $D \approx 1$. Then, the (n,p) cross section formula can be obtained as follows:

$$\sigma_{np}^{pre} = 68.3 \frac{\pi^6}{\hbar^2} R^2 \sigma_r(E_n) \frac{2M_p}{K_0 A} \frac{\left[(E_n + Q_{np}) - V_p\right]^3}{(E_n + B_n)^3} \tag{5}$$

where $\sigma_r(E_n)$ is the neutron induced reaction total cross section; $K_0 \approx 400\,\text{MeV}^3$; M_p is the mass of proton; E_n and B_n are the kinetic and binding energy of neutron, respectively; Q_{np} is the reaction energy.

Direct reaction mechanism

The plane wave Born approximation is used. The Coulomb interactions, spins of the nuclei and particles are neglected. Also, we assume the perturbation operator is equal to a constant and energy of protons is

$$E_p = E_p^{\max} = E_n + Q_{np} \tag{6}$$

In the case of $E_n >> Q_{np}$ for asymptotic (n,p) cross section we before used [5] geometrical cross section

$$\sigma_{np} = \sigma_{tot} = \pi R^2 \tag{7}$$

Formula (7) gives several barn for nuclei with A~100, at the same time experimental values are several mbarn [6]. If we use formula (7) for direct (n,p) reaction cross section are naturally obtained overestimated values than experimental results, because total cross section is determined as sum of all possible reaction cross sections

$$\sigma_{tot} = \pi R^2 = \sigma_{np} + \sigma_{n\alpha} + \sigma_{nn'} + \sigma_{n\gamma} + \sigma_{n2n} + \ldots \tag{8}$$

Therefore, we introduced fitting parameter C_0 and derived following formula for direct (n,p) reaction cross section

$$\sigma_{np}^{dir} = C_0 \pi R^2 \sqrt{1 + \frac{Q_{np}}{E_n}} \tag{9}$$

SYSTEMATICS OF THE 14.5 MEV NEUTRON INDUCED (n,p) REACTION CROSS SECTIONS

The systematics of the known experimental (n,p) cross sections by formulae (1), (2) and (3) at 14.5 MeV is shown in Figure 1.

The experimental data were taken from compilation [7]. It is seen that some discrepancies there are between the experimental data and the theoretical values calculated by statistical model.

The comparison of the exciton model calculation results with the known experimental data is given in Figure 2. It was obtained, also, that discrepancy between the experimental and the theoretical values increases with growth of the parameter $(N - Z + 1)/A$.

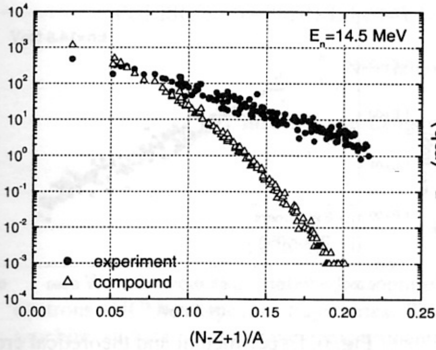

Fig. 1. The dependence of the experimental and calculated by statistical model (n,p) cross sections on the relative neutron excess parameter at 14.5 MeV.

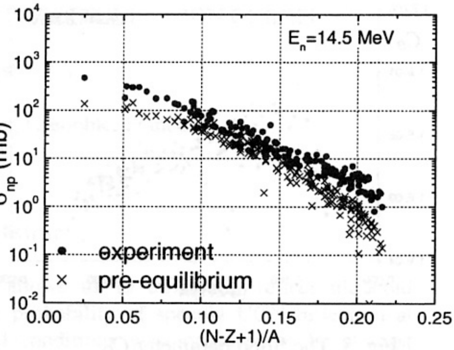

Fig. 2. The same as in Figure 1 for the exciton model

The results of the PWBA calculations in comparison with experimental data are shown in Figure 3. In this case, on contrary of the statistical and exciton models, theoretical value lies higher than experimental one. Such fact is, perhaps, explained by use of formula (7) which gives overestimated results

In the case of direct reaction cross section we have two possibilities to obtain the parameter C_0 in formula (9). At first, it can be considered for all nuclei $C_0=const$. Then from Figure 3 it is seen that $C_0 \approx 10^{-3}$ *at* $(N-Z+1)/A \approx 0.22$. If we use this value of C_0 for all nuclei the theoretical and experimental cross sections are satisfactorily in agreement at $E_n = 14.5\,\mathrm{MeV}$ (Figure 4). In this case the theoretical total cross section is expressed as

$$\sigma_{np}^{tot} = \sigma_{np}^{com} + \sigma_{np}^{pre} + \sigma_{np}^{dir} \qquad (10)$$

At second, we can choose the parameter C_0 as a best fit to experimental data for each nucleus. Here should be considered all three mechanisms of nuclaer reactions (10).

From (1), (5), (9) and (10) the fitted parameter C_0 for each nucleus was obtained (Figure 5). Using these values of the parameter C_0 we can obtain σ_{np}^{dir} and compare experimental and theoretical total (n,p) cross sections, which are in agreement (Figure 6).

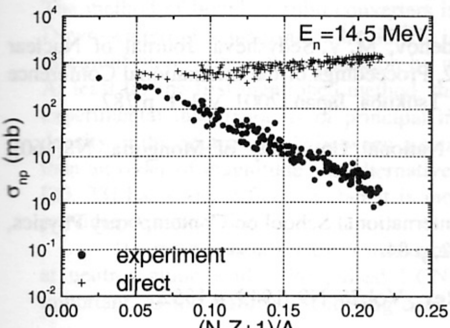

Fig. 3. The same as in Fig. 1. for the PWBA calculation.

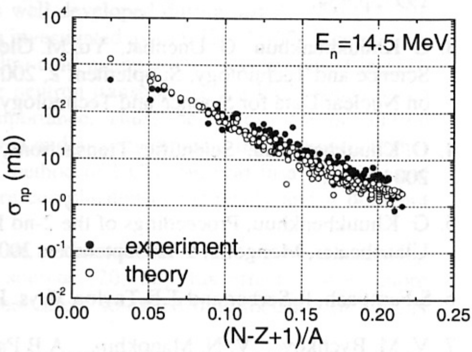

Fig. 4. Theoretical total and experimental (n,p) cross sections.

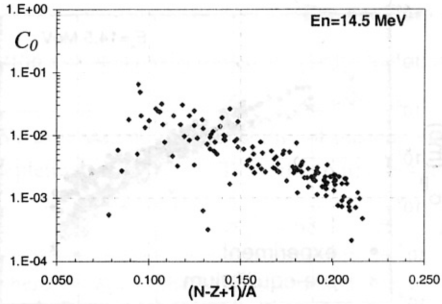

Fig. 5. The fitted parameter C_0.

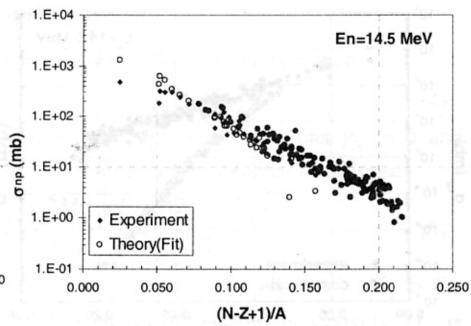

Fig. 6. Experimental and theoretical cross sections with fitted parameter C_0.

CONCLUSION

Using the statistical model, exciton model and PWBA are deduced formulae for the fast neutron induced (n,p) reaction cross sections.

It was shown that the theoretical and experimental (n,p) cross sections at 14.5 MeV are satisfactorily in agreement.

ACKNOWLEDGMENTS

This work was carried out in the framework of the "Nuclear Reactions" project supported in part by Mongolian Science and Technology Foundation.

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