CONTRIBUTION TO THE STUDY OF NUCLEAR REACTION WITH NEUTRONS AND CHARGED PARTICLES EMISSION

- A. I. Oprea[1], C. D. Oprea[1], A. Mihul[2], Yu. M. Gledenov[1], P. V. Sedyshev[1], M. V. Sedysheva[1]
- 1 – 141980 LNF JINR Dubna Russia
- 2 – Bucharest University, Faculty of Physics, Bucharest, Romania

Abstract. This work is a short presentation of the results obtained in the field of nuclear reactions with slow, resonance and fast neutrons. In the first part of the work we present the asymmetry effects obtained in the $^{35}Cl(n,p)^{35}S$ and $^{14}N(n,p)^{14}C$ for slow and resonance neutrons in the cases when we take into account first two levels and after many levels for the compound nucleus. The second part of the work is dedicated to the evaluation of the cross section in the (n, α) reactions with fast neutrons on ^{64}Zn and ^{147}Sm. In the both cases, asymmetry effects evaluation and of the cross sections the theoretical data are compared with experimental data. The experimental data were obtained at JINR Dubna Frank Laboratory for Neutrons Physics using a gridded ionization chamber.

ASYMMETRY EFFECTS IN THE (N,P) REACTIONS.

The asymmetry effects are an efficient tool for investigation of various phenomena in atomic and nuclear physics. In this paper we have obtained the asymmetry effects in the $^{35}Cl(n,p)^{35}S$ and $^{14}N(n,p)^{14}C$ reactions with thermal and resonance neutrons. The investigated effects are the forward – backward, left – right and parity non conservation. Each mentioned effect mathematically can be described by corresponding asymmetry coefficient and respectively they are the forward – backward, left – right and parity non conservation coefficients. For the incident neutron energy interval (up to some *keV* for $^{35}Cl(n,p)^{35}S$ reaction and to *1 MeV* for $^{14}N(n,p)^{14}C$ reaction) it is supposed that the *(n,p)* reaction is going by formation of a compound nucleus and this compound nucleus is described by defined quantum numbers and properties like spin, parity resonance energies, mass and others. An important step in the evaluation of the asymmetry effects is to obtain the differential cross section or the angular correlation. The cross section, differential cross section (or the angular correlation) and the asymmetry coefficients are obtained using the formalism of the mixing of the states of the compound nucleus with the same spin and opposite parities. With the help of asymmetry coefficients it is possible in principle to extract the matrix element of the weak interaction manifested between nucleons and this was very well illustrated in the present paper in the case of $^{35}Cl(n,p)^{35}S$ reaction in the two levels approximation.

For the evaluation of the asymmetry effects in the *(n,p)* reactions will be used the formalism of the mixing states of the compound nucleus with the same spin and opposite parities. This formalism was developed for fission and (n,γ) reactions with thermal and resonance neutrons for medium heavy nuclei. The main purpose of this approach is to describe the parity violation (PV) effects existing in the nuclear reactions due to the weak non leptonic interaction between nucleons [1], [2], [3].

CROSS SECTION EVALUATION WITH FAST NEUTRONS.

In this work will be evaluated the cross section in the $^{64}Zn(n,\alpha)^{61}Ni$ and $^{147}Sm(n,\alpha)^{143}Nd$ reaction with fast neutrons. For incident neutrons with energy of some *MeV* the experimental data are poor and therefore are of interest new theoretical and experimental investigations. For both nuclei we have chosen to start the evaluation using the Hauser – Feshbach approach [4]. In this formalism it is supposed that the nuclear reaction is going by formation of a compound nucleus CN) and the assumptions of the statistical model of nuclear reaction [5] are working.

After the interaction of the incident particle with the target nucleus the formed CN has a time of life much longer then the time necessary to the incident particle to traverse the target nucleus and therefore is considered that the CN “forgets” how was formed and decays on one of possible channels. The CN and residual nucleus is characterized by a large number of states. The nuclear potential is considered to act in a finite range. Outside of this range the nuclear potential is zero. The consequences of these assumptions are: there are not interference terms in the cross section and the differential cross section is symmetrical to 90^0 in the SCM.

The ^{64}Zn nucleus is medium one and the ^{147}Sm is heavy. The experimental differential cross section of ^{64}Zn(n,α) reaction [6] and some new unpublished data for ^{147}Sm suggests that the dominant mechanism for these reaction is by formation of a CN. It is obvious that for this incident neutron energy range of some *MeV’s* other reaction mechanisms can give their contribution but this can be confirmed by new experimental data on cross sections.

RESULTS.

The asymmetry effects in the *(n,p)* reactions in the two levels approximation for ^{35}Cl and ^{14}N have the form:

$$\alpha_{FB} = (X_n - Y_n)(X_p - Y_p)\, f_{FB}(E) \tag{1}$$

$$\alpha_{LR} = (X_n + \frac{Y_n}{2})(X_p - Y_p)\, f_{LR}(E) \tag{2}$$

$$\alpha_{PNC} = W_{SP}(X_p - Y_p)\, f_{PNC}(E) \tag{3}$$

$$\alpha_{FB} = -\left(X_n + 2\sqrt{2}Y_n\right)X_p\, f_{FB}(E_n) \tag{4}$$

$$\alpha_{LR} = \left(-X_n + 2\sqrt{2}Y_n\right)X_P\, f_{LR}(E_n) \tag{5}$$

$$\alpha_{PNC} = W_{SP}X_p\left(\frac{1}{2}c_1(E_n)\sqrt{\frac{\Gamma^n_{S_1}}{\Gamma^n_P}} + c_2(E_n)Y_n^2\sqrt{\frac{\Gamma^n_P}{\Gamma^n_{S1}}}\right)f_{PNC}(E_n) \tag{6}$$

The terms included in relations (1-6) are: (X_n, Y_n, X_p, Y_p) the partial reduced amplitudes for neutrons and protons, W_{SP} = the weak matrix element. The *f()* and *c()* terms are functions depending on the incident neutron energy. The partial reduced amplitudes have the properties (unknown parameters): $X_n^2 + Y_n^2 = 1$, $X_p^2 + Y_p^2 = 1$, $-1 \le X_{n,p}, Y_{n,p} \le 1$. If in the calculations of the asymmetry coefficients we take into account many resonance (more than two resonance) only numerical results can be obtained based on (1-6) relations.

For the cross section in (n, α) reactions with fast neutrons we used the Hauser – Feshbach formalism.

$$\sigma_{n\alpha} = \pi \lambda\!\!\!^{-}{}_n^2 \frac{T_n T_\alpha}{\sum_c T_c} F_{n\alpha}^{fluct} \tag{8}$$

The terms are: $\lambda\!\!\!^{-}{}_n$ = neutron reduced wave length, T = penetrability coefficient for different particles (PC), $F_{n\alpha}^{fluct}$ = widths correction fluctuation factor (WCF), c = channel.

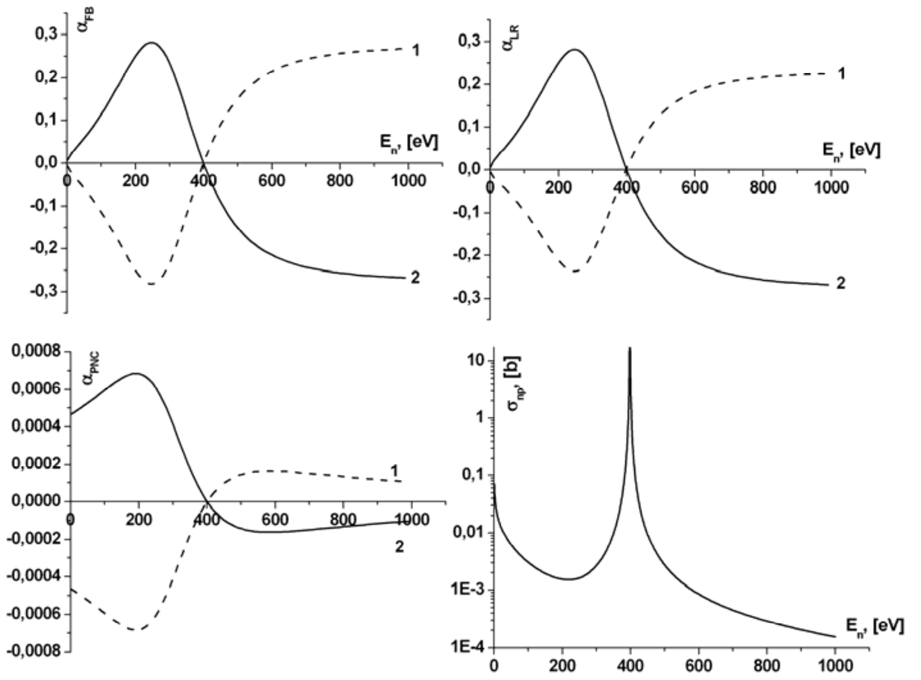

Fig 1. The asymmetry coefficients and cross section theoretical energy dependence (FB, LR, PNC) in the two levels approximation for $^{35}Cl(n,p)^{35}S$. 1 – ($Xn = Xp = -Yn = -Yp = 0.707$); 2 – ($Xn = Xp = -Yn = -Yp = -0.707$); $W_{SP} = 0.06$ eV.

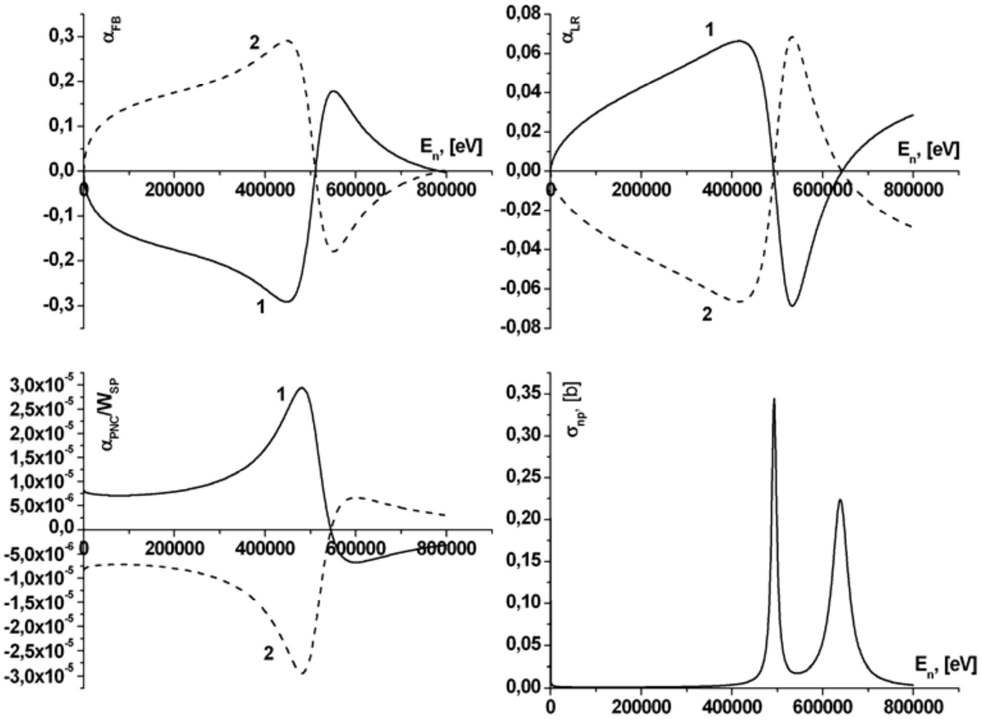

Fig. 2. The theoretical energy dependence of the asymmetry coefficients, FB, LR, PNC and of the cross section, in the two levels approximation for the $^{14}N(n,p)^{14}C$ reaction. 1 – ($Xn = Xp = Yn = 0.707$); 2 – ($Xn = Xp = -Yn = -0.707$). The weak matrix element is unknown and we divided the PNC effect to the weak matrix element

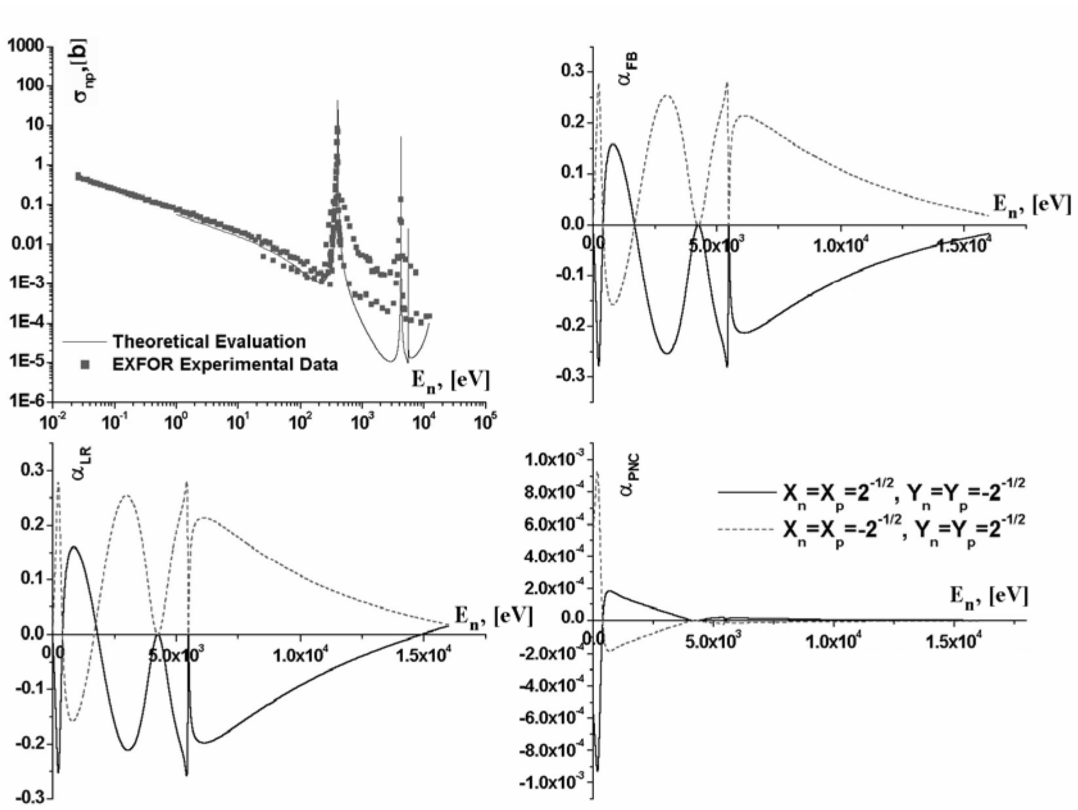

Fig. 3. The cross section, FB, LR, PNC effects (five resonance) for $^{35}Cl(n,p)^{35}S$ reaction

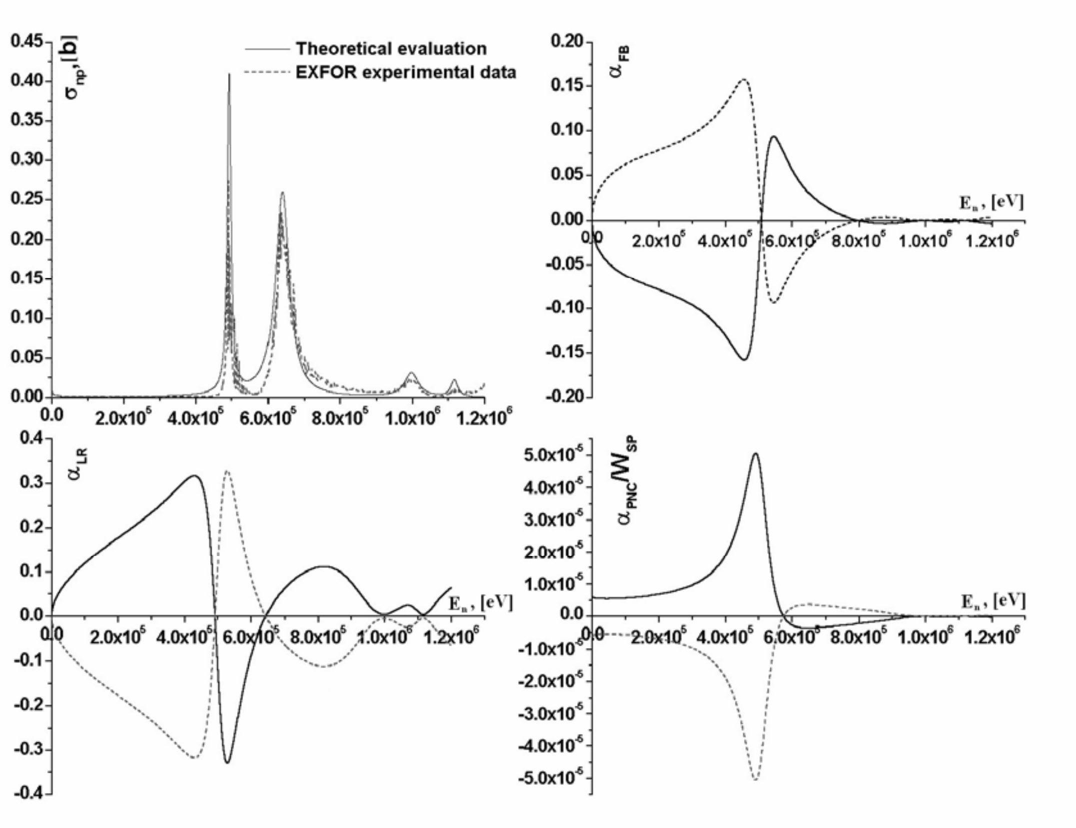

Fig. 4. The cross section, FB, LR, PNC effects (five resonance) for $^{14}N(n,p)^{14}C$ reaction

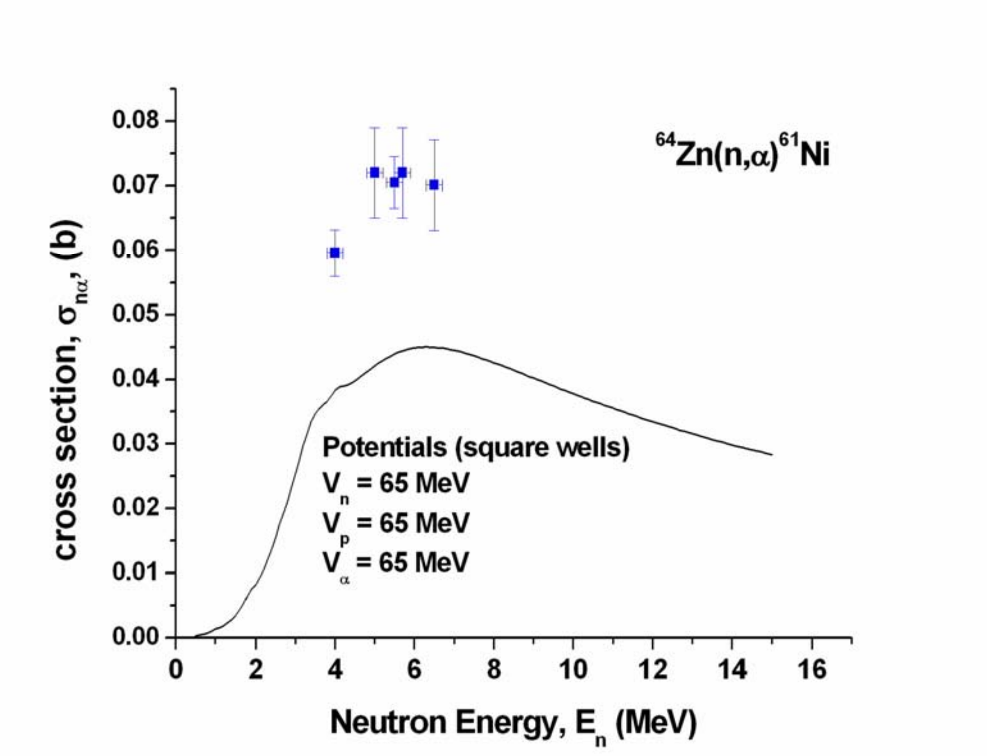

Fig. 5. The $^{64}Zn(n,\alpha)$ cross section. The HF evaluation (continuous line) is compared with experimental data [7].

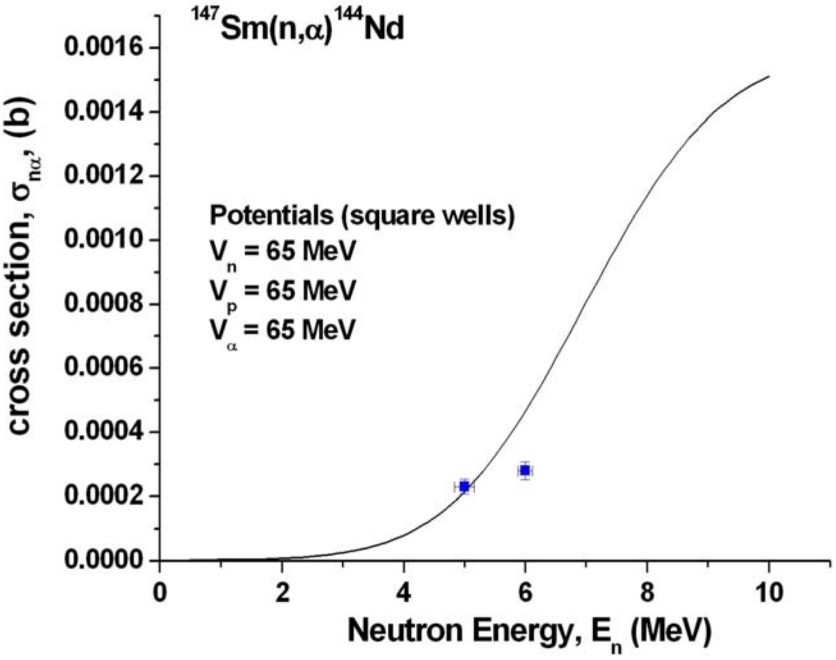

Fig. 6. The $^{147}Sm(n,\alpha)$ cross section. The HF evaluation (continuous line) is compared with experimental data [7].

DISCUSSION AND CONCLUSSION.

The evaluation of the asymmetry coefficients in *(n,p)* reactions are difficult because the effects are large where the cross section is small and the effects are small where the cross section is high. In the both cases the measurements are affected by a serious background. For these reason experimental data for asymmetry coefficients are a few (just some experimental points in thermal and resonance region). The theoretical evaluations have the expected shape of the energetic dependence and they are in a good agreement with existing experimental data.

For the cross section evaluations in (n, α) reactions with fast neutrons also we have only a little number of experimental data. For fast neutrons the cross sections are of order of tens of *mb* and lower and the measurements are influenced by other open channels. The used theoretical formalism supposes that the reaction is going by formation of a compound nucleus with many excited states but in this energy region it is possible to action other reaction mechanisms. With these considerations we consider that the agreement between theoretical and experimental evaluations is good. In the future it will be of interest to evaluate the differential cross section and the cross section taking into account the other open channels and possible mechanisms of nuclear reaction in the fast neutron energy region.

In the both problems studied it is necessary to have experimental energy dependences for asymmetry effects and cross sections for further theoretical improvements.

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