Calculation of angular correlations in the $^{14}N(n, p)^{14}C$ reaction up to 1 MeV neutron energy region

A. I. Oprea, C. Oprea, Yu. M. Gledenov, P. V. Sedyshev, P. J. Szalanski[1]
FLNP, JINR, Dubna, 141980 Russia
[1]*University of Lodz, Poland*

Abstract. In this study we evaluated the asymmetry coefficients in the frame of model of the mixing states with opposite parities of the compound states in the case of the $^{14}N(n, p)$ reaction up to 1 MeV. The analyzed effects are the forward-backward, left-right and parity non-conservation and are taking into account all resonances in the mentioned energy range of incident neutrons. In our previous researches on $^{35}Cl(n,p)^{35}S$ reaction we took into account only two resonance of the compound nucleus.

Introduction. This work is continuation of the studies of the angular correlations and asymmetry effects in the (n,p) reaction on the medium nuclei. The main goals of this work is to obtain the energy dependence of the angular correlation and to use these dependence on the analysis of the experimental data. The theoretical basis of the mixing states with opposite parities of the compound nucleus is very well described in many papers [1, 2, 3]. Before, on this reaction were effectuated measurements of the angular correlation for polarized cold neutrons at the experimental basis from Gatchina, Saint Petersburg Nuclear Physics Institute [5]. Were obtained the following values for left right asymmetry, $\alpha_{LR} = (0.66 \pm 0.18) \cdot 10^{-4}$ and for the parity non conservation effect, $\alpha_{PNC} = (0.07 \pm 0.12) \cdot 10^{-4}$. The last value shows us that from experimental point of view spatial parity non conservation effect on $^{14}N(n, p)^{14}O$ were not observed. It is necessary to note the fact that parity non conservation effect was observed only on (n,p)reaction for ^{35}Cl [3]. In [5] was measured the P-odd correlation and for (n,p) reaction on ^{35}Cl has the value, $\alpha_{PNC} = -(1.51 \pm 0.34) \cdot 10^{-4}$. The weak matrix element for the same reaction on ^{35}Cl was $W_{SP} = 0.06$ eV [5]. The question of what makes the P-odd asymmetry effects for ^{14}N so little -the low value of the weak matrix element or the properties of the mixing compound states - remains open. The general problem for the interpretation of the results on the measurements of the P-odd effects is the absence of the information on the signs and magnitudes of the of the neutron and proton widths with the channels spins 1/2, 3/2. These data can be extracted from supplementary measurements on P-even effects like the forward – backward and left – right [4]. However, the values for P-even effects for low energy are of order of 10^{-5}-10^{-4} like P-odd effects and the systematical errors of the experiments make impossible their determination. On the other hand the measurements of these effects can be realized in the vicinity of the P-resonance where they have the order of 10^{-1} (the left-right and forward-backward effects). For the analysis of the all data on the polarized and angular correlation it is necessary to know the energy dependence of these coefficients in awide energy interval.

We analyzed the contribution of the all resonance in the cross section and interference terms [1,3] in the mentioned neutron energy interval and the evaluation shows us that only three resonances give contribution in the asymmetry effects. As results, in this paper was taken into account the contribution of three resonances, two S-resonance and one P-resonance ($^{15}N_7$ nucleus). The parameters for the reaction are: first S-resonance – E_S = -144 keV, J_S^π = $3/2^+$, second S-resonance – E_{S1} = 639 keV, J_{S1}^π = $1/2^+$, the P resonance – E_P = 492.6 keV, J_P^π=$1/2^-$, data for ^{14}N target nucleus – $I^\pi = 1^+$ and ^{14}C residual nucleus – $I'^\pi = 0^+$, Q = 0.62 MeV.

BASIC FORMULAS

The (n,p) reaction can be described by the following amplitude:

$$f = f_1 + f_2 + f_3 + f_4, \tag{1}$$

f_1, f_2 – amplitude for (n,p) reaction for S and P wave conserving the parity,

$f_3, f_4 \sim W_{SP}$ – amplitude for (n,p) reaction not conserving the parity,

W_{SP} – the weak matrix element.

1. The angular correlation – unpolarized neutrons

$$\frac{d\sigma}{d\Omega} \sim 1 + \alpha_{FB} P_1(\cos\theta) = \left|f_1^S\right|^2 + \left|f_1^{S_1}\right|^2 + \left|f_2^P\right|^2 + 2\,\mathrm{Re}\, f_1^{S_1} f_2^{P*}, \tag{2}$$

f_1^S, f_2^P – the (n,p) reaction amplitude for S- and P-wave amplitude [3],

α_{FB} the forward-backward coefficient.

The forward-backward effects, in the frame of used formalism, is a results of interference of the f_1 and f_2 amplitude.

2. The definition of the forward-backward coefficient

$$\alpha_{FB} = \frac{\dfrac{d\sigma}{d\Omega}(\theta = 0) - \dfrac{d\sigma}{d\Omega}(\theta = \pi)}{\dfrac{d\sigma}{d\Omega}(\theta = 0) + \dfrac{d\sigma}{d\Omega}(\theta = \pi)}. \tag{3}$$

After not so difficult transformation we obtain the forward-backward effect take the form:

$$\alpha_{FB} = \frac{2\,\mathrm{Re}\, f_1^{S_1} f_2^P(\theta = 0)}{\left|f_1^{S_1}\right|^2 + \left|f_1^S\right|^2 + \left|f_2^P\right|^2}. \tag{3a}$$

3. Total cross section

$$\sigma_{np} = \sigma_{S_1} + \sigma_S + \sigma_P, \tag{4}$$

where each term has the Breit-Wigner form:

$$\sigma = g\pi\lambda^2 \frac{\Gamma_n^{S(P)}\Gamma_p^{S(P)}}{(E - E_{S(P)})^2 + \dfrac{\Gamma_{tot}^2}{4}}, \tag{5}$$

$\Gamma_n^{S(P)}, \Gamma_p^{S(P)}$ – the neutron and proton widths for the S and P wave respectively. The interference term responding to forward-backward effect is:

$$2\,\mathrm{Re}\, f_1^{S_1} f_2^P P_1(\cos\theta) \sim \left(X_n + 2\sqrt{2}Y_n\right)\times$$
$$\times\left((E - E_{S_1})(E - E_P) + \frac{\Gamma_{S_1}\Gamma_P}{4}\right)\cos\Phi - \left((E - E_{S_1})\frac{\Gamma_P}{2} - (E - E_P)\frac{\Gamma_{S_1}}{2}\right)\sin\Phi, \tag{6}$$

$$\Phi = ArcTan\,\eta + ArcTan\frac{\dfrac{\Gamma_S}{2}}{E - E_S} + ArcTan\frac{\dfrac{\Gamma_{S_1}}{2}}{E - E_{S_1}} - ArcTan\frac{\dfrac{\Gamma_P}{2}}{E - E_P} \tag{7}$$

is the phase shift.

$$\eta = \frac{Z_l Z_f e^2}{\frac{h}{2\pi} v} \qquad (8)$$

– the Coulomb phase (v – velocity of emitted protons). The X and Y parameters are the reduced partial widths amplitude for neutrons with total orbital momentum j=1/2, 3/2 in the entrance channel: $X_n = \frac{T_n^P(\frac{1}{2})}{\sqrt{\Gamma_n^P}}, Y_n = \frac{T_n^P(\frac{3}{2})}{\sqrt{\Gamma_n^P}}$. The T coefficients are the reduced partial amplitude for neutrons with total orbital momentum j=1/2, 3/2, in the entrance channel. See for more details [3, 6].

4. The left-right coefficient

The definition of the left-right coefficient.

$$\alpha_{LR} = \frac{\frac{d\sigma}{d\Omega}(\theta = \frac{\pi}{2}) - \frac{d\sigma}{d\Omega}(\theta = \frac{3\pi}{2})}{\frac{d\sigma}{d\Omega}(\theta = \frac{\pi}{2}) + \frac{d\sigma}{d\Omega}(\theta = \frac{3\pi}{2})}. \qquad (9)$$

Working in the same way like in the case of the forward-backward coefficient we obtain the formulae:

$$\alpha_{LR} = \frac{2\,\mathrm{Im}\, f_1^{S_1} f_2^P (\theta = \frac{\pi}{2}, \phi = \frac{\pi}{2})}{\left|f_1^{S_1}\right|^2 + \left|f_1^S\right|^2 + \left|f_2^P\right|^2}. \qquad (9a)$$

The left-right asymmetry effect is a results also, of the interference of the S and P wave of the strong interaction amplitudes (f_1, f_2).

The angular correlation

$$\frac{d\sigma}{d\Omega} \sim 1 + \alpha_{LR} \sin\theta \sin\phi = \left|f_1^S\right|^2 + \left|f_1^{S_1}\right|^2 + \left|f_2^P\right|^2 + 2\,\mathrm{Im}\, f_1^{S_1} f_2^{P*}. \qquad (10)$$

$$\alpha_{LR} \propto 2\,\mathrm{Im}\, f_1^{S_1} f_2^P P_1 \sim \left(-X_n + \sqrt{2} Y_n\right) \times$$
$$\times \left((E - E_{S_1})(E - E_P) + \frac{\Gamma_{S_1}\Gamma_P}{4} \right) \sin\Phi + \left((E - E_{S_1})\frac{\Gamma_P}{2} - (E - E_P)\frac{\Gamma_{S_1}}{2} \right) \cos\Phi \qquad (11)$$

5. The parity non conservation coefficient

The definition of the parity non conservation coefficient:

$$\alpha_{PNC} = \frac{\frac{d\sigma}{d\Omega}(\phi = 0) - \frac{d\sigma}{d\Omega}(\phi = \pi)}{\frac{d\sigma}{d\Omega}(\phi = 0) + \frac{d\sigma}{d\Omega}(\phi = \pi)}. \qquad (12)$$

After simple and analogue calculations like to the other asymmetry effects we obtain:

$$\alpha_{PNC} = \frac{2(\mathrm{Re}\, f_1 f_3^* + \mathrm{Re}\, f_2 f_4^*)(\phi = 0)}{\left|f_1^{S1}\right|^2 + \left|f_1^S\right|^2 + \left|f_2^P\right|^2}, \qquad (12a)$$

$$\alpha_{PNC} \sim 2(\mathrm{Re}\, f_1 f_3^* + \mathrm{Re}\, f_3 f_4^*) \sim W_{SP}\left(\frac{c_1}{2}\sqrt{\frac{\Gamma^n_{S_1}}{\Gamma^n_P}} + c_2 Y_n^2 \sqrt{\Gamma^n_P}\right), \quad (13)$$

$$c_1(E) = \left(E - E_{S_1}\right)\cos\Phi - \frac{\Gamma_{S_1}}{2}\sin\Phi \text{ and } c_2(E) = \left(E - E_P\right)\cos\Phi - \frac{\Gamma_P}{2}\sin\Phi \quad (14)$$

$$W(\theta,\phi) \sim \left|f_1^S\right|^2 + \left|f_1^{S_1}\right|^2 + \left|f_2^P\right|^2 + 2(\mathrm{Re}\, f_1 f_3^* + \mathrm{Re}\, f_2 f_4^*) \sim 1 + \alpha_{PNC}\cos\phi\,. \quad (15)$$

The parity non conservation effect is a results of the S and P wave interference in the reaction amplitude corresponding to the weak interaction (f_3, f_4). The weak matrix element is of order of 10^{-2} eV. This means that expected value for the parity non conservation coefficient will be two times lower than the values for the forward-backward and left right coefficients.

RESULTS

In this paragraph we will present the results obtained in the frame of the used formalism. In the figures 1-5 there are the energy dependences of the cross section, phases and asymmetry effects. For the asymmetry coefficients the X, Y parameters are unknown ant we choose them in such a way to obtain maximum values for the coefficients. The forward-backward and left-right coefficients change their sign if the X, Y parameters are changing their sign also. For this reason in the corresponding figures we put only one curve for one set of X, Y parameters. Changing the sign of X and Y we obtain the same curve symmetrically to the neutron energy axis.

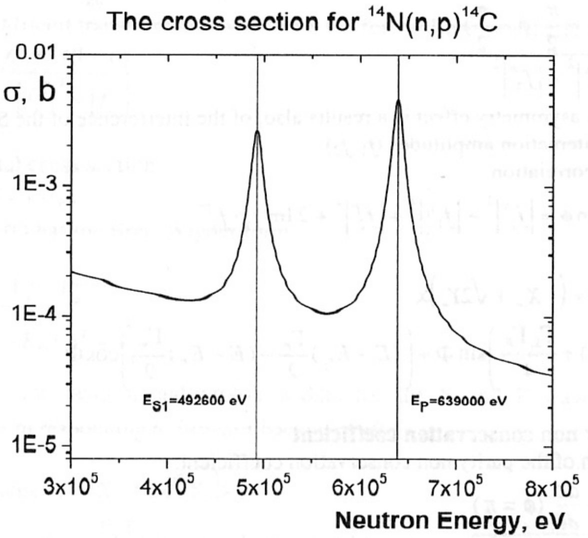

Fig.1.The energy dependence of the cross section

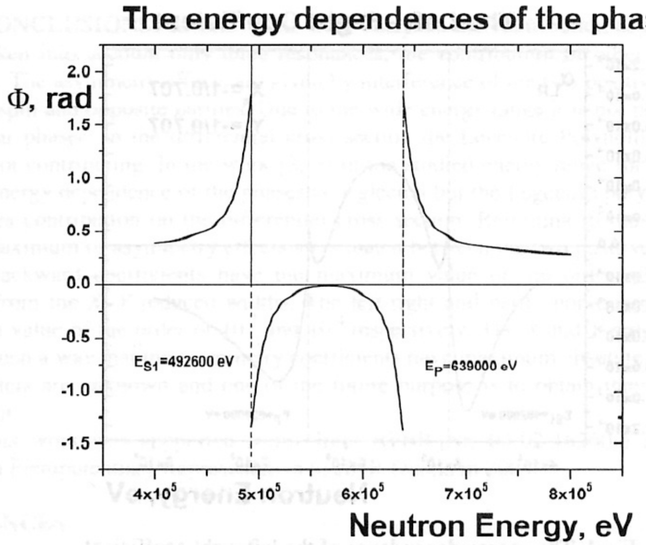

Fig.2.Energy dependence of the phases

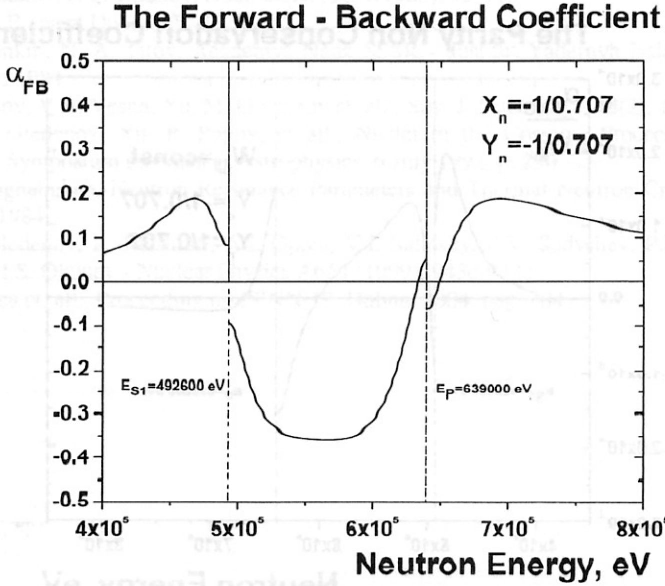

Fig.3.The energy dependence of the forward – backward coefficient

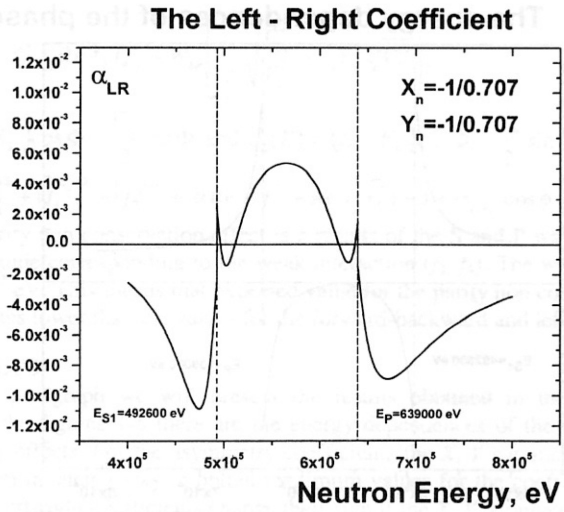

Fig.4. The energy dependence of the left-right coefficient

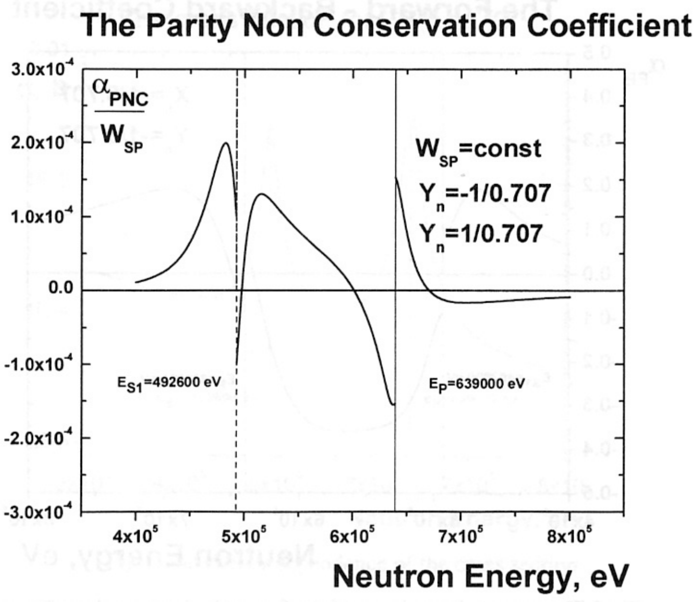

Fig.5. The energy dependence of the parity non conservation coefficient

CONCLUSIONS. In this work were analyzed the contribution of many resonances. Where taken into account only three resonances, the contribution of other resonances were neglected. The asymmetry effects are given by interference of the two positive resonance with the same spin and opposite parities. Due to the wide energy range it is not possible to neglect the nuclear phases. In the differential cross section the Legendre Polynomial of the second order is not contributing. In the work [2, 5] in the studied energy range for (n,p) reaction on ^{35}Cl the energy dependence of the phases is neglected but the Legendre polynomial of second order gives contribution on the differential cross section. Returning to the (n,p) reaction on ^{14}N the maximum of asymmetry effects are situated between the two positive resonances. The forward-backward coefficients have the maximum value of the order of 0.4. This value depends from the *X*, *Y* reduced widths. The left-right and parity non-conservation have the maximum value of the order of 10^{-2} and 10^{-4} respectively. The *X* and *Y* reduced widths were taken in such a way that the asymmetry coefficients have maximum absolute value. The *X* and *Y* parameters are unknown and one of the future purpose is to obtain their values from the experiment

This work was supported from Grant RFBR Nr. 05-02-16260-a and the grant of Romanian Plenipotentiary Representative to JINR Dubna in 2004.

REFERENCES

[1] V.V. Flambaum, O.P. Sushkov, Nucl. Phys. A412 (1984) 3-13
[2] V. E. Bunakov, V. P. Gudkov, Nucl. Phys. A401(1983), 93-116
[3] G. Rigol, Preprint Dubna, P4-85-70
[4] S. V. Zenkin, N. A. Titov, Academya Nauk SSSR – Institut Yadernyh Issledovanii - P 0367 Moskva 1984
[5] A. Antonov, V.A. Vesna, Yu. M. Gledenov et. all., Sov. J. Nucl. Phys. **48**(2), 1988, p.193
[6] Yu. M. Gledenov, Yu. P. Popov, et all., Nuclei in the Cosmos, Proceeding on the International Symposium on Nuclear Astrophysics, 6 July 1992, p. 230
[7] S. F. Mughabghab, Neutron Resonance Parameters and Thermal Neutron Cross Section, Acad. Press 1984
[8]. Yu.M. Gledenov, R. Mashrafi, A.I. Oprea, V.I. Salatsky, P.V. Sedyshev, P.I. Szalanski, V.A. Vesna, I.S. Okunev - Nuclear Physics A654 (1999), 943c-948c
[9] A. I. Oprea et. all., Proceeding on ISINN-12, Dubna, 2004, pag. 204