Measurement of the left-right asymmetry in integral spectra of γ-quanta in the interaction of nuclei with polarized thermal neutrons

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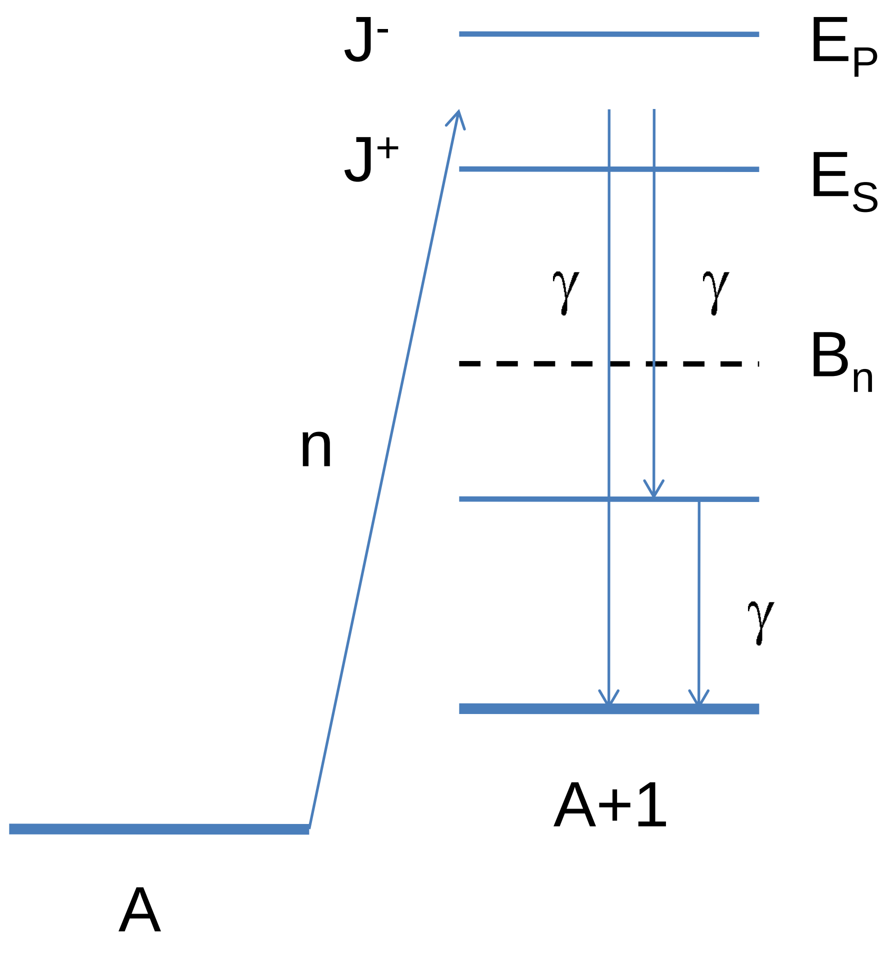
O. P. Sushkov, V. V. Flambaum. Angular and polarization correlations in the (n,γ) reaction. Nucl. Phys. A435 (1985) 352



Cross section for the (n,γ) reaction.

$$\frac{d\sigma(n_\gamma,\lambda)}{d\Omega}=\frac{1}{2}\ a_0+a_1(n_n\cdot n_\gamma)+\tilde{a}_2\sigma[n_n\times n_\gamma]+a_3[(n_n\cdot n_\gamma)^2-\frac{1}{3}]+\tilde{a}_4(n_n\cdot n_\gamma)\sigma[n_n\times n_\gamma]$$

$$+a_5\lambda(\sigma\cdot n_\gamma)+a_6\lambda(\sigma\cdot n_n)+a_7\lambda\times[(\sigma\cdot n_\gamma)(n_n\cdot n_\gamma)-\frac{1}{3}(\sigma\cdot n_n)]$$

$$+a_8\lambda[(\sigma\cdot n_n)(n_n\cdot n_\gamma)-\frac{1}{3}(\sigma\cdot n_n)]+a_9(\sigma\cdot n_\gamma)+a_{10}(\sigma\cdot n_n)$$

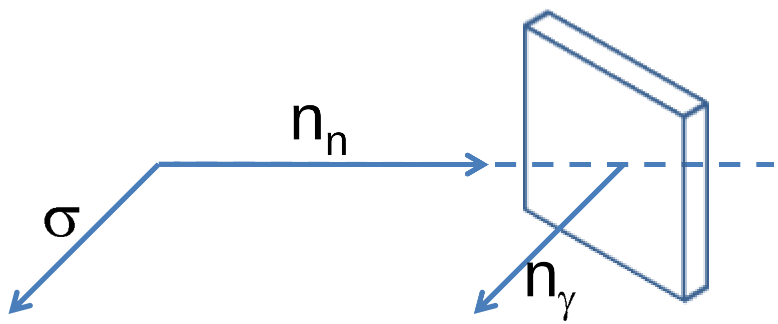
$$+a_{11}[(\sigma\cdot n_\gamma)(n_\gamma\cdot n_n)-\frac{1}{3}(\sigma\cdot n_n)]+a_{12}[(\sigma\cdot n_n)(n_n\cdot n_\gamma)-\frac{1}{3}(\sigma\cdot n_\gamma)]+a_{13}\lambda$$

$$+a_{14}\lambda(n_n\cdot n_\gamma)+\tilde{a}_{15}\lambda\sigma\cdot[n_n\times n_\gamma]+a_{16}\lambda[(n_n\cdot n_\gamma)^2-\frac{1}{3}]+\tilde{a}_{17}\lambda(n_n\cdot n_\gamma)\sigma\cdot[n_n\times n_\gamma]\}$$

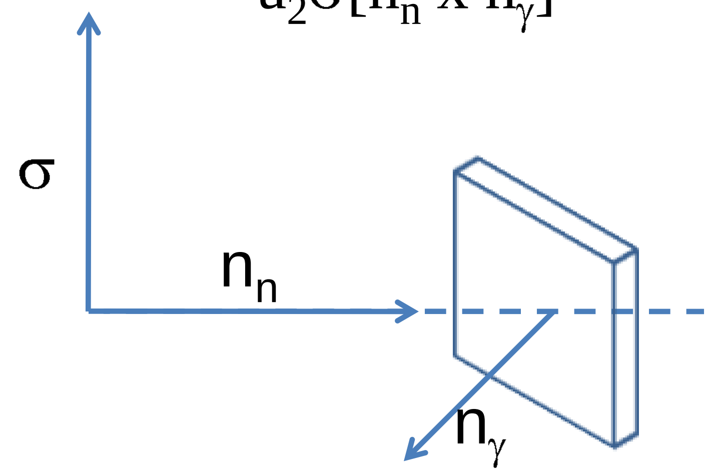
n_n, n_γ - the direction of the neutron and γ-quantum momentum;
σ - neutron spin;
λ - γ-quantum helicity.

a_1- a_8 – P-even correlations, a_9 - a_{17} – P-odd correlations; ~ - T-odd correlations

$a_9(\sigma \cdot n_\gamma)$



$a_2\sigma[n_n \times n_\gamma]$



$^{117}\mathrm{Sn}(n,\gamma)\,^{118}\mathrm{Sn} \quad 1^+ \xrightarrow{M1} 0^+ \quad 9.31\ \mathrm{MeV}$

$$a_1 = Re(U_1 U_2^*)(-2X + 1.4142Y)$$

$$a_2 = Im(U_1 U_2^*)(2X + 0.7071Y)$$

$$a_9 = 2\,Re(U_1 U_3^*) + Re(U_2 U_4^*)(-0.6666X^2 - 0.9428 \cdot 2XY + 1.667Y^2)$$

$$U_1 = \frac{1}{E - E_S + \frac{1}{2} i \Gamma_S}$$

$$U_2 = \frac{\sqrt{\Gamma_P^n(E) / \Gamma_S^n(E)} \cdot [A_{E1} / (A_{M1}(1+\alpha))]}{E - E_S + \frac{1}{2} i \Gamma_S}$$

$$U_3 = \frac{W(A_{E1} / (A_{M1}(1+\alpha)))}{(E - E_S + \frac{1}{2} i \Gamma_S)(E - E_P + \frac{1}{2} i \Gamma_P)}$$

$$U_4 = \frac{W\sqrt{\Gamma_P^n(E) / \Gamma_S^n(E)}}{(E - E_S + \frac{1}{2} i \Gamma_S)(E - E_P + \frac{1}{2} i \Gamma_P)}(1+\delta)$$

$$X = \frac{T_P(j = \frac{1}{2})}{\sqrt{\Gamma_P^n(E)}}, \qquad Y = \frac{T_P(j = \frac{3}{2})}{\sqrt{\Gamma_P^n(E)}}, \qquad X^2 + Y^2 = 1$$

Table from O. P. Sushkov, V. V. Flambaum. Nucl. Phys. A435 (1985) 352

Correlations for the ^{117}Sn(n, γ) $\to$ ground state of ^{118}Sn

E [eV] =	0.01	0.025	$E_p - \frac{9}{2}\Gamma_p$ 0.295	$E_p - \frac{3}{4}\Gamma_p$ 1.158	E_p 1.330	$E_p + \frac{3}{4}\Gamma_p$ 1.503
$\frac{\lvert U_1\rvert^2 + \lvert U_2\rvert^2}{\lvert U_1\rvert^2}$	1.000	1.000	1.003	1.281	2.048	1.364
A_1	1.81×10^{-2}	2.9×10^{-2}	0.12	0.80	0	−0.86
A_2	4.2×10^{-4}	6.9×10^{-4}	3.7×10^{-3}	0.15	0.32	0.16
A_3	3.2×10^{-5}	8.2×10^{-5}	1.5×10^{-3}	0.12	0.28	0.14
A_5	1.00	1.00	1.00	0.97	0.93	0.96
A_6	9.2×10^{-3}	1.5×10^{-2}	6.3×10^{-2}	0.41	0	−0.44
A_7	1.3×10^{-2}	2.1×10^{-2}	9.0×10^{-2}	0.58	0	−0.62
A_8	4.4×10^{-5}	1.1×10^{-4}	2.1×10^{-3}	0.16	0.38	0.20
A_9	6.8×10^{-4}	6.8×10^{-4}	8.6×10^{-4}	2.8×10^{-3}	-5.5×10^{-5}	-2.6×10^{-3}
A_{10}	2.6×10^{-6}	4.2×10^{-6}	2.4×10^{-5}	1.1×10^{-3}	2.3×10^{-3}	1.2×10^{-3}
A_{11}	3.6×10^{-6}	5.9×10^{-6}	3.3×10^{-5}	1.5×10^{-3}	3.3×10^{-3}	1.7×10^{-3}
A_{12}	-5.4×10^{-9}	-1.4×10^{-8}	-2.6×10^{-7}	-2.0×10^{-5}	-4.7×10^{-5}	-2.5×10^{-5}
A_{13}	6.8×10^{-4}	6.8×10^{-4}	8.6×10^{-4}	2.8×10^{-3}	-6.4×10^{-5}	-2.7×10^{-3}
A_{14}	5×10^{-6}	8.1×10^{-6}	4.6×10^{-5}	2.0×10^{-3}	4.6×10^{-3}	2.3×10^{-3}
A_{15}	-2.4×10^{-8}	-3.9×10^{-8}	-2.1×10^{-7}	-8.2×10^{-6}	-1.8×10^{-5}	-8.8×10^{-6}
A_{16}	-4.0×10^{-9}	-1.0×10^{-8}	-1.9×10^{-7}	-1.5×10^{-5}	-3.4×10^{-5}	-1.8×10^{-5}
P_{10}					4.6×10^{-3}	

P-odd effects for a single γ-transition have been rarely observed because of complexity of selection of a γ-transition also because of smallness of these effects. P-odd asymmetry has been observed in the following reactions with polarized neutrons:

$^{113}Cd(n,\gamma)^{114}Cd$, the energy of γ-transition is ($1^{+} \xrightarrow{M1} 0^{+}$) 9.04 MэB:

$a_{P-odd} = (4.1 \pm 0.8) \cdot 10^{-4}$ *[Abov Yu.G., Krupchitsky P.A. et al. Phys. Lett. B27 (1968) 16; Yad.Fiz. 10 (1969) 558.]*;

$^{117}Sn(n,\gamma)^{118}Sn$, the energy of γ-transition is ($1^{+} \xrightarrow{M1} 0^{+}$) 9.31 MэB:

$a_{P-odd} = (8.1 \pm 1.3) \cdot 10^{-4}$ *[Danilyan G.V., Novitskii V.V. et al. JETP Lett. 24 (1976) 344.]*;

$^{113}Cd(n,\gamma)^{114}Cd$, the energy of γ-transition is ($2^{-} \xrightarrow{M1+E2} 2^{+}$) 8.58 MэB:

$a_{P-odd} = (1.57 \pm 0.53) \cdot 10^{-4}$ *[Avenier M., Bagieu G. et al. Nucl. Phys. A436 (1985) 83.]*.

The sign of coefficients of P-odd asymmetry and left-right asymmetry and P-odd varies randomly as a function of the final nuclear state; thus the effects are statistically suppressed down. Effects in integral spectra of γ-quanta are suppressed due to this averaging; however their observation is feasible due to high counting statistics. Calculations show that the ratio of the coefficients of P-odd and left-right asymmetry for a monochromatic line should coincide with the ratio of the coefficients of these asymmetries in integral spectra.

Nucleus	$E_{p,}$ eV	$a_{P-odd} \cdot 10^6$	$a_{lr} \cdot 10^6$
^{nat}Cl	398	-27.6 ± 4.9 [1]*	-3.5 ± 2.9 *
^{nat}Br	0.88	-19.5 ± 1.6 [1]*	-6.5 ± 1.7 *
^{nat}La	0.75	-17.8 ± 2.2 [1]*	3.9 ± 3.3 *
^{nat}Fe	11.47	4.04 ± 0.83 [2]**	5.4 ± 5.5 *
^{117}Sn	1.33	2.4 ± 1.6 [1]*	0.9 ± 4.1 *
^{nat}Cd	7	1.64 ± 0.36 [2]** 2.52 ± 0.46 ***	- -

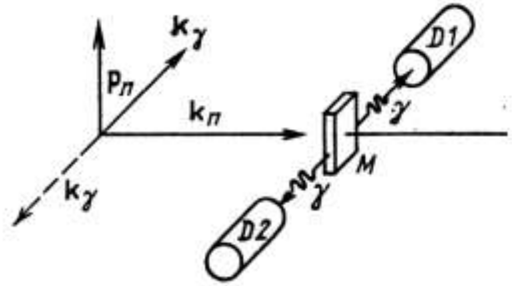
*The reactor VVR-M in Gatchina (the mean neutron wavelength is 2.7 Å)
** The reactor VVR-M in Gatchina (4.2 Å)
***The reactor ILL in Grenoble (4.7 Å)

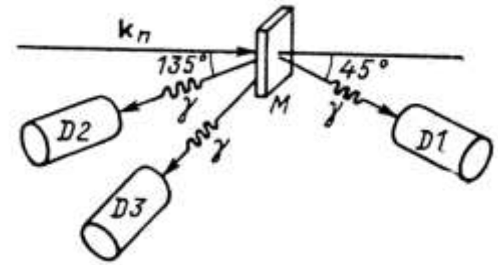
[1] Vesna V.A., Kolomenskii E.A. et al., JETP Letters 36(5) (1982) 209.
[2] Vesna V.A., Lomachenkov I.A. et al., Yad.Fiz. 52, 3(9) (1990) 620.

The given results show that in all cases with non-zero P-odd asymmetry observed, the coefficient of left-right asymmetry appeared to be much smaller than the coefficient of P-odd asymmetry. On the other hand, these coefficients should be approximately equal for integral spectra at the thermal neutron energy for the same nucleus.

Left-right asymmetry has not been reliably observed in any studied nucleus except for bromium. As the measured values of the coefficients a_{lr} of left-right asymmetry are much smaller for ^{nat}La , ^{nat}Cl, ^{nat}Br than expected from calculations one has to continue these investigations at beams with high neutron fluxes in order to get statistically significant results for the coefficients of left-right asymmetry as well as to understand the reasons for the discrepancy between calculations and experiments.

Skoy V. R., Sharapov E. I. P-even angular correlations in resonance (n,γ)-reactions.
(PEPAN 22 (1991) 1400)





$\tilde{a}_2 \sigma [n_n \times n_\gamma]$

$a_1 (n_n \cdot n_\gamma)$ $\quad$ $a_3 [(n_n \cdot n_\gamma)^2 - \frac{1}{3}]$

^{117}Sn(n,γ), Eγ = 9.32 MeV, E_P = 7 eV,

^{113}Cd(n,γ), Eγ = 9.04 MeV, E_P = 1.33 eV,

$$X = \frac{T_P(j=\frac{1}{2})}{\sqrt{\Gamma_P^n(E)}}, \qquad Y = \frac{T_P(j=\frac{3}{2})}{\sqrt{\Gamma_P^n(E)}}, \qquad X^2 + Y^2 = 1$$

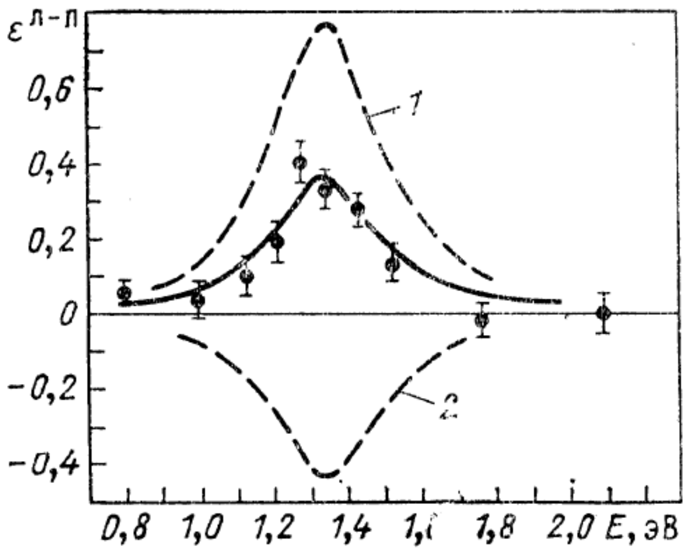


Рис. 13. Асимметрия $\varepsilon^{л-п}$ на ^{117}Sn в области резонанса 1,33 эВ. Гладкие кривые — расчетные, поясняемые в разд. 5

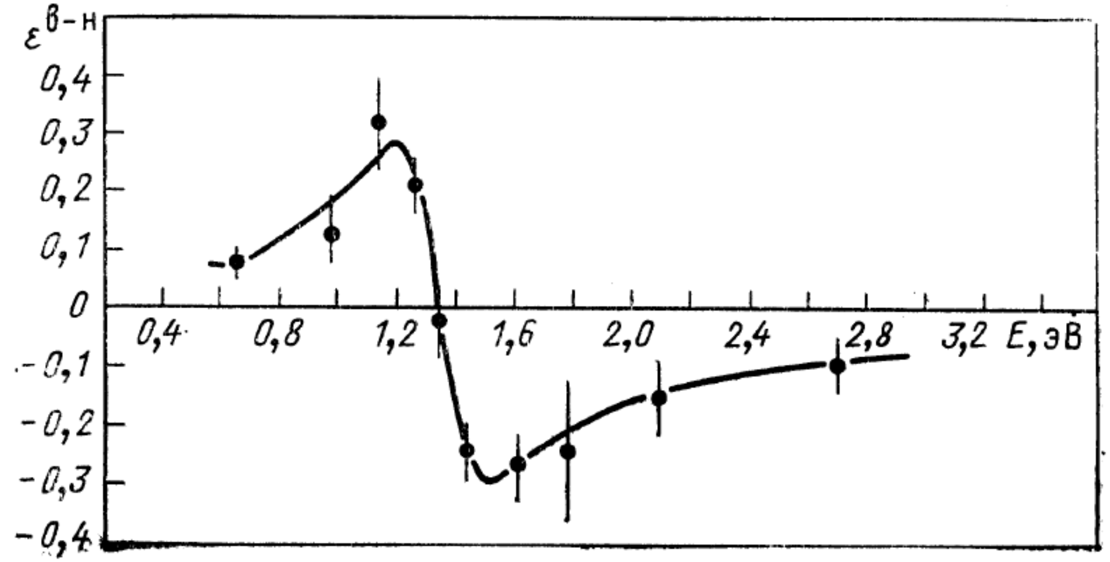


Рис. 14. Асимметрия $\varepsilon^{в-н}$ на ^{117}Sn в области резонанса 1,33 эВ

$$x = 0{,}528 \pm 0{,}037; \quad y = -0{,}813 \pm 0{,}027;$$
$$x = 0{,}009 \pm 0{,}009; \quad y = +0{,}999 \pm 0{,}021.$$

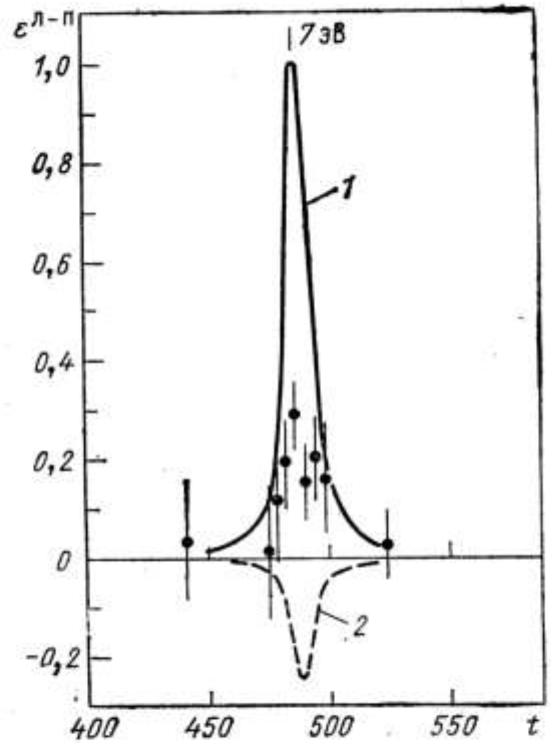


Рис. 15. Асимметрия $\varepsilon^{л-п}$ на ^{113}Cd:

1, 2 — расчетные кривые, поясняемые в разд. 5

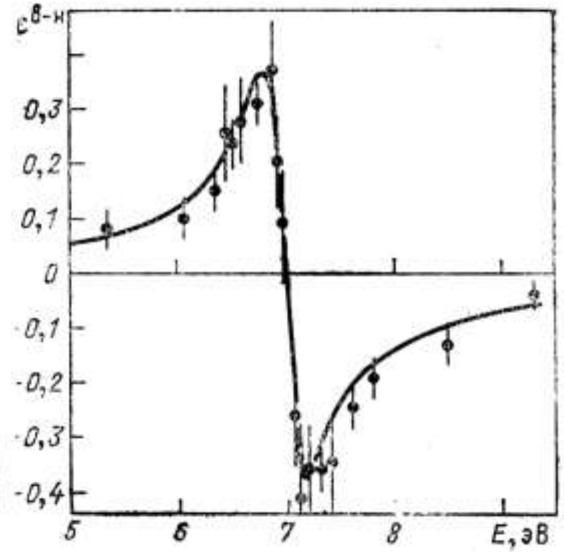


Рис. 16. Асимметрия $\varepsilon^{в-н}$ на ^{113}Cd в области резонанса 7 эВ

$$x = 0{,}975; \qquad y = 0{,}222;$$

$$x = 0{,}100; \qquad y = -0{,}995.$$

A SEARCH FOR P-ODD AND P-EVEN CORRELATIONS IN THE 35Cl(n,p)35S REACTION Yu.M.Gledenov, R.Machrafi, A.I.Oprea, V.I.Salatski, P.V.Sedyshev, P.I.Szalanski, V.A.Vesna, I.S.Okunev. Nucl. Phys. A654 (1999) 943c.

$$\alpha_{PNC} = \pm W_{SP} \frac{\sqrt{\Gamma_S^n \Gamma_S^p \Gamma_P^n \Gamma_P^p}}{\Gamma_S^n \Gamma_S^p [P] + \Gamma_P^n \Gamma_P^p [S]} \frac{\sqrt{\Gamma_P^n}}{\sqrt{\Gamma_S^n}} u_1(E) \left(\frac{\Gamma_S^n}{\Gamma_P^n} \frac{u_2(E)}{u_1(E)} + \frac{\sqrt{10}}{5} Y_n^2 \right) \left(X_p - Y_p \right),$$

$$[S] = \left(E - E_S\right)^2 + \frac{\Gamma_S^2}{4}, \qquad [P] = \left(E - E_P\right)^2 + \frac{\Gamma_P^2}{4},$$

$$u_1(E) = \left(E - E_S\right)\cos(\Delta\varphi) - \frac{\Gamma_S}{2}\sin(\Delta\varphi), \quad u_2(E) = \left(E - E_P\right)\cos(\Delta\varphi) - \frac{\Gamma_P}{2}\sin(\Delta\varphi)$$

$$\alpha_{LR} = \pm \frac{\sqrt{\Gamma_S^n \Gamma_S^p \Gamma_P^n \Gamma_P^p}}{\Gamma_S^n \Gamma_S^p [P] + \Gamma_P^n \Gamma_P^p [S]} u_{LR}(E) \left(X_n + \frac{Y_n}{2} \right) \left(X_p - Y_p \right),$$

$$u_{LR}(E) = \left[\left(E - E_S\right)\left(E - E_P\right) + \frac{\Gamma_S \Gamma_P}{4} \right] \sin(\Delta\varphi) - \left[\left(E - E_S\right)\frac{\Gamma_P}{2} - \left(E - E_P\right)\frac{\Gamma_S}{2} \right] \cos(\Delta\varphi)$$

$$\alpha_{FB} = \pm \frac{\sqrt{\Gamma_S^n \Gamma_S^p \Gamma_P^n \Gamma_P^p}}{\Gamma_S^n \Gamma_S^p [P] + \Gamma_P^n \Gamma_P^p [S]} u_{FB}(E) \left(X_n - Y_n \right) \left(X_p - Y_p \right)$$

$$u_{FB}(E) = \left[\left(E - E_S\right)\left(E - E_P\right) + \frac{\Gamma_S \Gamma_P}{4} \right] \cos(\Delta\varphi) - \left[\left(E - E_S\right)\frac{\Gamma_P}{2} - \left(E - E_P\right)\frac{\Gamma_S}{2} \right] \sin(\Delta\varphi)$$

$$X_{n(p)} = \frac{T_{n(p)}^{j=1/2}}{\sqrt{\Gamma_P^{n(p)}}}, \qquad Y_{n(p)} = \frac{T_{n(p)}^{j=3/2}}{\sqrt{\Gamma_P^{n(p)}}}$$

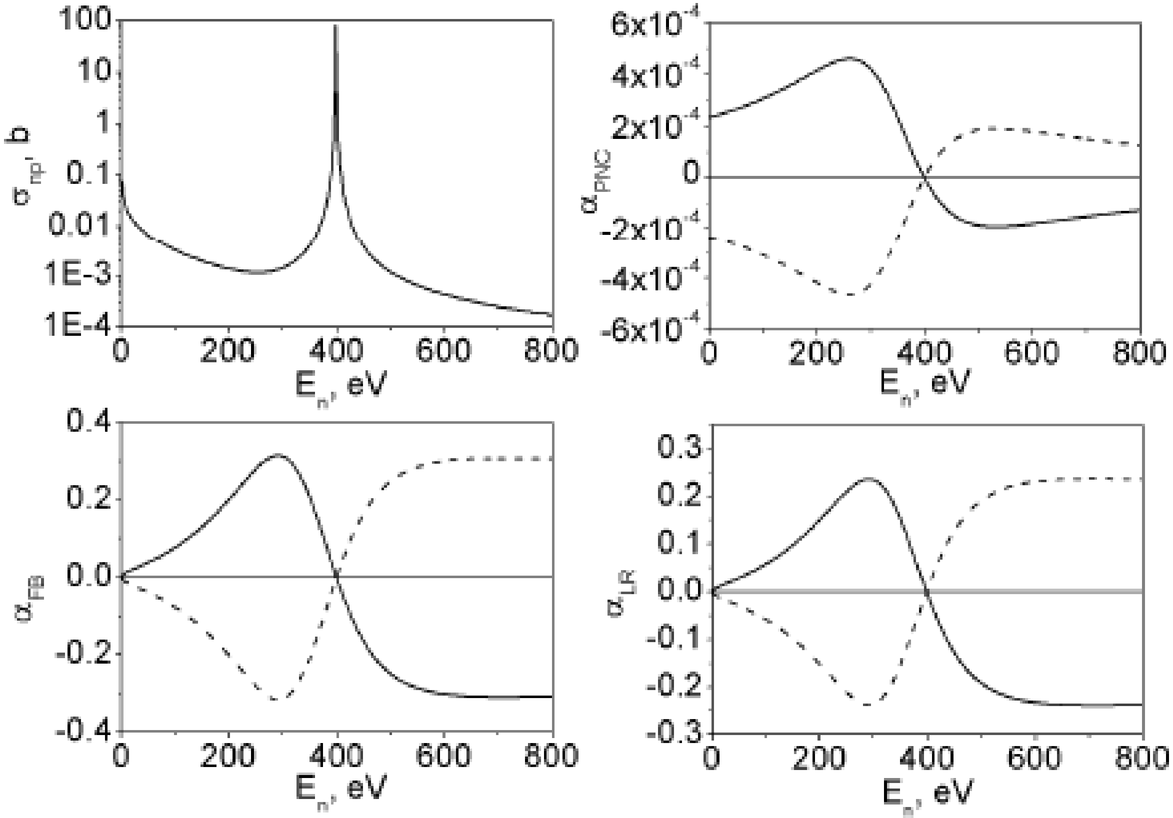


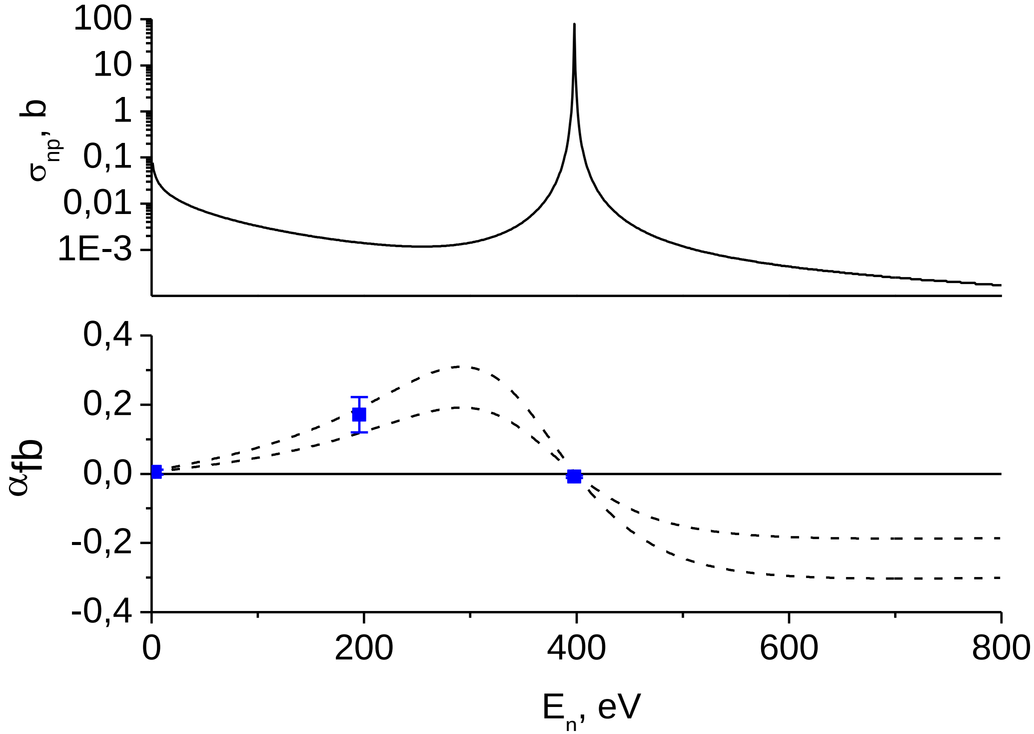
Рис. 2. Энергетическая зависимость сечения реакции $^{35}Cl(n,p)^{35}S$ и коэффициентов корреляций.

WWR-M, Gatchina

IBR-30, Dubna

$\alpha_{PN} = -\ (1.51\ \ 0.34)\cdot 10^{-4}$

$\alpha_{LR} = -\ (2.40\ \ 0.43)\cdot 10^{-4}$.



element (material)	α_{PNC}	
	present work	other data
^{35}Cl (NaCl) ^{nat}Br (KBr) ^{nat}Cd (metal)	$-(3.9 \pm 0.4) \cdot 10^{-5}$ $-(1.6 \pm 0.3) \cdot 10^{-5}$ $-(2.4 \pm 0.4) \cdot 10^{-6}$	$-(2.8 \pm 0.5) \cdot 10^{-5}$ [13] $-(2.0 \pm 0.2) \cdot 10^{-5}$ [13] $-(1.6 \pm 0.4) \cdot 10^{-6}$ [14]

Thank you for your attention.