ROT-EFFECT IN (n, α γ)-REACTIONS

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Abstract. Correlations of fission products such as ROT-effect and TRI-effect are expressed as P-even T-odd constructions of polarization observables and linear momenta. They are nozero because the final state interaction (FSI) of fission products simulates T-invariance break up. In the fission process these effects manifest themselves in extremely complicated events. At the same time the (n,αγ)-process looks essentially simpler and nevertheless may offer some analogous properties. So it may be used as an alternative object of the T-odd correlations study. In the present paper the ROT-effect in (n,αγ)-reactions are investigated. The sequential mechanism of the process is assumed. The final state interaction of the alpha-particle with the residual nucleus, the resonance mixing, and the actual T-noninvariant phase shift are considered as possible contributors of the correlation. The problem of suitable target isotopes is analyzed. Analogous correlations in other neutron- and proton-induced reactions are discussed.

INTRODUCTION

The five-vector P-even T-odd (pseudo-T-noninvariant) correlation of fission products, which takes the form $(\boldsymbol{k}_{ff} \cdot [\boldsymbol{\sigma} \times \boldsymbol{k}_{\alpha}])(\boldsymbol{k}_{ff} \cdot \boldsymbol{k}_{\alpha})$, where $\boldsymbol{\sigma}$ is the vector of the neutron polarization and symbols $\boldsymbol{k}$ denote the respective linear momenta (all vectors are unit ones) – so called ROT-effect – are now the subject of active investigations and discussions [1–3]. In this process however a huge number of possible exit microchannels which differ by the masses of fragments, their spins, relative angular momentum etc. contribute. The emission of some number of various unregistered light particles attends any fission event and introduces distortions. These and other properties make any correlation of fission fragments with other emitted particles very hard for interpretation. The (n,αγ)-process seems to be more or less "pure laboratory" of the same effect. The idea to consider such a reaction as a process which is reference one for the study of the TRI-effect in fission (the related correlation takes the form $(\boldsymbol{k}_{ff} \cdot [\boldsymbol{\sigma} \times \boldsymbol{k}_{\alpha}])$) is realized in the experiment [4]. The ^{10}B target is used. In the paper [5] a theoretical interpretation of the experimental result obtained in [4] – zero TRI-effect – is presented. It is shown that in arbitrary process the TRI-effect may appear either in the case of parity nonconservation or in the case of simultaneous tripartition of the decaying nucleus. In addition the fact that a T-odd effect is not necessarily an actual T-violating one is declared in [5]. It is also declared (before the observation of the ROT-effect) that five-vector and higher-rank T-odd correlations may manifest themselves in this reaction in the case that other targets are used.

In the current paper possible contributors of the ROT-effect which may manifest themselves in the (n,αγ)-process are considered in detail. The formalism of the angular correlations in sequential two-step reactions suitable for description of an arbitrary correlation is presented. Much attention is given to the selection rules classifying T-odd effects into zero and nonzero ones. A scheme which may be used to search for actual T-violating effect is demonstrated. Suitable target isotopes are proposed. The processes induced by both thermal and resonance neutrons are discussed. The reactions (n,pγ), (n, γα), and (p,αγ) are also considered.

FORMALISM OF THE ANGULAR CORRELATIONS

The definitions of angular correlations are formulated in a variety of ways. The correlation associated with the ROT-effect is defined by the five-vector form $(\boldsymbol{k}_\alpha \cdot [\boldsymbol{\sigma} \times \boldsymbol{k}_\gamma])(\boldsymbol{k}_\alpha \cdot \boldsymbol{k}_\gamma)$. Evidently it may be written explicitly in the form of the product of five *Y*-functions of the rank 1 with the proper vector-coupling. However, much more convenient expression appears after the convolutions of the *Y*-functions depending on one and the same arguments. If in addition the axis of quantization is chosen to be parallel to the vector of polarization $\boldsymbol{\sigma}$ the explicit kinematic form of this correlation is the following:

$$\sum_{m=-2}^{2}(2m2-m|10)(4\pi/5)\,\mathrm{Re}[Y_2^m(\vartheta_{ff},\phi_{ff})Y_2^{-m}(\theta_\alpha,\phi_\alpha)]. \qquad (1)$$

Dynamic form of any correlation must be constituted, evidently, as a bilinear form of the amplitudes of an investigated process. The overall (i. e. including all possible correlations) and general (i. e. valid for any sequential two-step cascade of an oriented or non-oriented sample) expression can be presented as:

$$W_{IJF}(\theta_\alpha,\theta_\gamma,\phi_\alpha,\phi_\gamma)=\sum\rho_j^0(I,I')\varepsilon_{j_\alpha}^{m_\alpha *}(L_\alpha,L'_\alpha)\varepsilon_{j_\gamma}^{m_\gamma *}(L_\gamma p_\gamma,L'_\gamma\, p'_\gamma)\varepsilon_{j'}^{m' *}(F)(j_\alpha m_\alpha j_\gamma m_\gamma\,|\,j0)$$
$$\begin{Bmatrix} J & L_\alpha & I \\ J & L'_\alpha & I' \\ j_\gamma & j_\alpha & j \end{Bmatrix}\begin{Bmatrix} F & L_\gamma & J \\ F & L'_\gamma & J \\ 0 & j_\gamma & j_\gamma \end{Bmatrix}\hat{I}^2\hat{J}^2\hat{j}_\alpha\hat{j}_\gamma^2\langle J|L'_\alpha|I'\rangle^*\langle J|L_\alpha|I\rangle\langle F|L'_\gamma\, p'_\gamma|J\rangle^*\langle F|L_\gamma p_\gamma|J\rangle; \qquad (2)$$

here the notation $\hat{b}=\sqrt{2b+1}$ is used; $(j_\alpha m_\alpha j_\gamma m_\gamma\,|\,j0)$ is the Clebsh-Gordan coefficient, 3×3 tables are 9*j*-syumbols; $\rho_j^m(I,I')$ is the statistical tensor of a state in which spins *I* and *I’* are mixed; *I* and *I’* denote the spins of initial compound nucleus state, *J* – the spin of an intermediate one, and *F* – a final state; $\langle J|L\,p|I\rangle$ is the amplitude of a transition; $L_{\gamma_i}p_{\gamma_i},L'_{\gamma_i}\,p'_{\gamma_i}$ are the angular momenta and parities of the amplitudes determining the multipolarities of the transitions; $\varepsilon_j^m(lp,l'p')$ is the m component of the efficiency tensor of the rank j which characterize the capability of a detector to register a product which appears in the transition described by the respective pair of the amplitudes. The sum is over all indexes contained in (3) besides *I, J, F*. A particular correlation is defined by the ranks of the statistical tensor *j* and the efficiency tensors of the detector system j_α, j_γ. For more details concerning the expression (2) and the formulas bellow see the monograph [6].

The efficiency tensor of an alpha-detector j_α can be expressed as:

$$\varepsilon_{j_\alpha}^{m_\alpha}(l,l')=(1/\sqrt{4\pi})(\hat{l}\hat{l}'/\hat{j}_\alpha)(-1)^{l'}(l0l'0\,|\,j_\alpha 0)Y_{j_\alpha}^{m_\alpha}(\theta_\alpha,\phi_\alpha). \quad (3)$$

The efficiency tensor of the gamma-detector insensitive to the polarization takes the form:

$$\varepsilon_{j_\gamma}^{m_\gamma}(lp,l'p')=(1/16\pi)\hat{l}\hat{l}'(-1)^{l'-1}(l1l'-1\,|\,j0)[1+pp'(-1)^{j_\gamma}]S(0)Y_{j_\gamma}^{m_\gamma}(\theta_\gamma,\phi_\gamma), \quad (4)$$

where $S(r)$ is a Stokes parameter. The parameter $S(0)$ signifies the polarization insensitivity. The residual nucleus is not registered therefore the tensor of the efficiency of such a “registering” $\varepsilon_{j'}^{m'}(F)$ should be written as:

$$\varepsilon_{j'}^{m'}(F)=\hat{F}\delta_{j'0}\delta_{m'0}. \quad (5)$$

The general expression of the statistical tensor produced by the polarized neutron capture has the form:

$$\rho_k^\kappa(I,I')=(1/4\pi)Q\sum_{ll'j}(-1)^{l'}\hat{l}\hat{l}'\hat{I}_0\hat{s}^{-1}\hat{k}_l\hat{k}_s\hat{I}\hat{I}'\hat{j}\hat{j}'(l0l'0\,|\,k_l0)\begin{Bmatrix} I & j & I_0\\ I' & j' & I_0\\ k & k & 0\end{Bmatrix}\begin{Bmatrix} l & s & j\\ l' & s & j'\\ k_l & k_s & k\end{Bmatrix}\times \quad (6)$$

$$(l0l'0\,|\,k_l0)(k_l0k_s\kappa\,|\,k_l\kappa)\langle I_0|j'|I'\rangle^*\langle I_0|j|I\rangle;$$

where Q is the degree of the neutron polarization, $\langle I_0|j'|I'\rangle, \langle I_0|j|I\rangle$ – the amplitudes of the capture, I, I' – spins of the mixed compound state, k,κ – the rank of the statistical tensor and the index of its component respectively, $s=1/2$ denotes neutron spin, l,l' and $j,\, j'$ – the orbital and the total contributed angular momenta. The quantum number I_0 is the spin of the initial nucleus state, k_l, k_s – the tensor characteristics of free neutron motion component contributing to the capture. This component is called radiation parameter. In the case that polarized s-nucleon is captured i. e. $l=l'=0,\ j=j'=s,\ k_l=0,\ k_s=k=1,\ \kappa=0$ (as it is done above the axis of quantization is chosen to be parallel to the vector of polarization $\boldsymbol{\sigma}$) the expression (6) is reduced to the form:

$$\rho_k^0(I,I')=(1/4\pi)Q\hat{I}_0^{-3}\hat{k}\hat{I}\hat{I}'\hat{j}^{-1}\begin{Bmatrix} I & j & I_0\\ I' & j & I_0\\ k & k & 0\end{Bmatrix}\times\langle I_0|j|I'\rangle^*\langle I_0|j|I\rangle. \quad (7)$$

The discussed correlation are characterized by the tensor ranks: $j_\alpha=2; j_\gamma=2; j=1$. The *Y*-functions, presented in the formula (1) are involved to the expression (2) through the expressions of the efficiency tensors.

The existence of the Clebsh-Gordan coefficients and the 9*j*-symbols in the formulas (2–7) determines the selection rules for the amplitudes of a certain correlation. Let us consider the first 9*j*-symbol in the expression (2) taking into account that $I' = I, I \pm 1$. Obviously the values of both spins of the compound states must be not less than 1/2 and the spin of the intermediate state must be not less than 1. Further if there is no parity mixing in the initial and the final states of the alpha-transition then the sum of the indexes of this symbol is odd with the proviso that $I' = I$ (case 1) and even – if $I' = I, I \pm 1$ (case 2).

Let us consider these two alternatives separately.

In the case 1 the amplitudes related to one and the same resonance may contribute. The above-mentioned 9*j*-symbol changes sign in this case under the two-line permutation. This coefficient is zero if the first and the second lines are equivalent. Thus the interference of two amplitudes of the alpha-transfers with different multipolarities is in this case one of the necessary conditions of the effect. Bilinear combination of these amplitudes in the sum (2) contains the complex conjugated terms. Due to the change of sign of the 9*j*-symbol under the transposition $L_\alpha \leftrightarrow L'_\alpha$ the imaginary part of this combination is survived only. As a result the dependence of the correlation formula on the amplitudes of α-transition takes the form:

$$\mathrm{Im}(\langle J|L`_\alpha|I\rangle^* \langle J|L_\alpha|I\rangle - \langle J|L`_\alpha|I,p\rangle \langle J|L_\alpha|I\rangle^*) = 2[\Gamma(L`_\alpha)\Gamma(L_\alpha)]^{1/2} \times$$
$$[\sin(\Delta\beta) - w_t \cos(\Delta\beta)], \quad (8)$$

where w_t denotes the actual T-noninvariant alpha-transition amplitude which is involved in the formula for generality. The value $\Delta\beta = \beta_1 - \beta_2$ is the difference of phase shifts of two amplitudes. For one-resonance case if the time-reversal invariance is assumed it is this difference simulates pseudo-T-noninvariant effect. This is the second necessary condition of its existence.

Usually correlations are considered in another form being normalized by the respective cross section. In that case the additional dependence on the amplitudes turns out to be involved in the denominator:

$$\frac{2[\Gamma(L`_\alpha)\Gamma(L_\alpha)]^{1/2}}{\Gamma(L`_\alpha) + \Gamma(L_\alpha)}[\sin(\Delta\beta) - w_t \cos(\Delta\beta)], \quad (9)$$

The asymptotics of the diverging wave of a charged particle is written as:

$$G_l(\eta, kr) + iF_l(\eta, kr) \sim \exp(i[kr - \eta \ln 2kr - l\pi/2 + \beta_l]); \quad (10)$$

where $\eta = \alpha Z_1 Z_2 \sqrt{\mu c^2/(2E)}$ is the Coulomb parameter. As a result the difference of phase shifts has the form:

$$\Delta\beta = \sum_{\lambda = L_<}^{L_>} arctg \frac{\eta}{\lambda + 1}, \quad (11)$$

where $L_< = \min\{L_\alpha, L'_\alpha\}; L_> = \max\{L_\alpha, L'_\alpha\}$. In the typical case that $\Delta L = 2$ the formula looks very simple:

$$\Delta\beta = arctg\frac{(2L_< + 3)\eta}{(L_< + 1)(L_< + 2) + \eta^2}. \qquad (12)$$

The widths contained in the correlation formula can be expressed more or less accurately [7] as $\Gamma_\alpha = (\hbar\omega/\pi)S_\alpha P$.

Thus all values involved into the formula of the correlation are known except the spectroscopic factors S_α. The idea to calculate the alpha-particle spectroscopic factor of a neutron resonance in a certain theoretical approach looks hopeless because the components of the wave function of any resonance are legion. Nevertheless there is another way. For the most part analyzing the penetrability *P* one may believe that one of two amplitudes is dominating. In that case only the ratio of these two amplitudes is the value of interest. This value may be in some cases a subject of the independent study. Using (n,αγ)-reaction induced by the unpolarized neutron beam one can measure the eight-vector correlation which may be roughly denoted as $(\boldsymbol{k}_\alpha \cdot \boldsymbol{k}_\gamma)^4$. This notation is not adequate enough because being written explicitly in the form of the product of eight *Y*-functions of the rank 1 it includes the scalar products of the $\boldsymbol{k}_\alpha$- and $\boldsymbol{k}_\gamma$-dependent tensors of the ranks 0, 2, and 4 while only the last product is the proper correlation by definition. More precisely this correlation can be expressed through the components of irreducible tensors $Y_4^m(\vartheta_\alpha,\phi_\alpha)$ and $Y_4^{-m}(\vartheta_\alpha,\phi_\alpha)$ in the kinematic form:

$$\sum_{m=-4}^{4}(4m4-m|00)(4\pi/9)\,\mathrm{Re}[Y_4^m(\vartheta_\alpha,\phi_\alpha)Y_4^{-m}(\theta_\gamma,\phi_\gamma)]. \qquad (13)$$

The dynamic form of this correlation is defined by the formula (2). The special feature of it is the ranks of the measured tensors: $j_\alpha = j_\beta = 4$ and *j*=0. If the dominating amplitude is related to the angular momentum $L < 2$ then the eight-vector correlation appears due to the minor amplitude only and the ratio $[\Gamma(L`_\alpha)\Gamma(L_\alpha)]^{1/2}$ determines the normalized $(\boldsymbol{k}_\alpha \cdot \boldsymbol{k}_\gamma)^4$ correlation. Thus this ratio turns out to be measurable.

If the ratio of the amplitudes is known it is possible to calculate the coefficient of the correlation $(\boldsymbol{k}_\alpha \cdot [\boldsymbol{\sigma} \times \boldsymbol{k}_\gamma])(\boldsymbol{k}_\alpha \cdot \boldsymbol{k}_\gamma)$ using the formalism presented above and after that to measure the ROT-effect. A discrepancy between the experimental and calculated results if it took place would be an evidence of the T-noninvariant effect. So it is possible in principle to estimate an upper limit of the actual T-noninvariant phase shift after the discussed measurements and calculations.

Let us consider now the case 2. In the monograph [8] it is pointed out that overlapping of resonances of different spin may be an origin of T-odd correlation. The TRI-effect is discussed. In the case of the ROT-effect, the correlation changes sign due to the permutation property of the 9j-symbol in (7). Therefore only the imaginary part of this combination is the contributor to the correlation. However the interference of the alpha-emission amplitudes with one and the same angular momentum may contribute in this instance. So the dependence of the correlation formula on the amplitudes of alpha-transitions takes the form:

$$\frac{\mathrm{Re}\,\Omega[(E-E_1)\Gamma_{tot(2)}-(E-E_2)\Gamma_{tot(1)}]+\mathrm{Im}\,\Omega[(E-E_1)(E-E_2)+\Gamma_{tot(1)}\Gamma_{tot(2)}/4]}{[(E-E_1)^2+\Gamma^2_{tot(1)}/4][(E-E_2)^2+\Gamma^2_{tot(2)}/4]}, \quad (14)$$

where

$$\Omega=\sqrt{\Gamma_1^n\Gamma_2^n\Gamma_1^\alpha(L_\alpha)\Gamma_2^\alpha(L'_\alpha)} \quad (15)$$

and the imaginary part appears in (15) in the case that the actual T-invariance break up displays itself in the neutron and/or alpha amplitudes. Here E_i is the energy and $\Gamma_i^n, \Gamma_i^\alpha(L_\alpha), \Gamma_{tot\{i\}}$ are the neutron, alpha and total widths of the related resonance. The energy dependence of the formula (14), which is in fact E^{-3}, result in a strong suppression of the effect. That is why one may expect very small effect in the most part of examples. However, an interesting exclusion appears. In the neighbourhood of the resonance point the discussed value has the form:

$$\frac{\Gamma_{tot(1)}\sqrt{\Gamma_1^n\Gamma_2^n\Gamma_1^\alpha(L_\alpha)\Gamma_2^\alpha(L'_\alpha)}}{[(E-E_1)^2+\Gamma^2_{tot(1)}/4](E_2-E_1)}=\frac{\sigma_{res}\Gamma_{tot(1)}\sqrt{\Gamma_2^n\Gamma_2^\alpha(L'_\alpha)}}{\pi\lambda\!\!\!^{-2}\sqrt{\Gamma_1^n\Gamma_1^\alpha(L_\alpha)}(E_2-E_1)} \quad (16)$$

in the case that one disregards the small values of the widths squared. In other words the discussed effect is proportional to the resonance cross section. Thus the sole suppressing factor involved in the expression of the effect is $A=\Gamma_{tot(1)}/(E-E_1)$. Unfortunately the actual T-noninvariant effect is extremely small in this point.

Presented energy dependence make this mechanism strongly deferent from the one related to the case 1. Obviously this mechanism is the subject of the resonance neutron investigations. Perhaps even more promising looks the study of the proton resonances. Indeed, typical values of the coefficient *A* for the observed resonances in ^{32}S nucleus are larger than the ones typical for neutron resonance spectra.

The multi-resonance problem should be mentioned for completeness. If several resonances contribute significantly to the correlation then all quantum numbers characterizing the amplitudes should be indexed by the resonances numbers, the sum over these indexes appears. The respective resonance amplitudes should be involved in the formalism. We do not present such a cumbersome formalism because summing over the resonance numbers does not bring a qualitative novel to the picture of the process.

PERFORMED EXPERIMENT AND PROMISSING EXAMPLES

The capabilities of experimental tools in the studies under discussion may be estimated due to the experiment devoted to the measurement of TRI-correlation which has been carried out yet [6]. The following reaction was used:

$$^{10}\mathrm{B}(\mathrm{n},\alpha\gamma)\,^{6}\mathrm{Li} \quad (\mathrm{E}_\gamma=478\,\mathrm{keV}).$$

The upper limit of the effect $\sim 0.5 \cdot 10^{-4}$ was established. Unfortunately it was testing experiment. The matter is that the spin of the intermediate state of ^{6}Li is 1/2 therefore in consequence of the selection rules $j \le 1$ and thus not only the TRI- but also the ROT-effect is precisely zero in this case. Experiments with other isotopes are significantly harder because the heavier the target nucleus the lower the contribution of the $(n,\alpha\gamma)$-channel. So the problem of more or less suitable target isotope turns out to be a basic one. Continuous searching for an optimal reaction allowed us to extract two promising examples.

Among the stable targets the reaction on Zn seems to be the best. The characteristics of the reaction under study are the following:

$$^{67}\mathrm{Zn(n,}\alpha\gamma\mathrm{)}^{64}\mathrm{Ni} \quad (\mathrm{E}_\gamma = 1340\ \mathrm{keV});\ I_0 = {}^{5}\!/_{2}{}^{-};\ I = 3^{-};\ J = 2^{+};\ F = 0^{+};\ L_\alpha, L'_\alpha = 1{,}3$$

The compound state spin $I = 3^{-}$ is chosen because the alpha-decay of $I = 2^{-}$ resonances is not observed in ^{68}Zn. The abundance of the ^{67}Zn isotope is 4.1 %, the thermal neutron cross section – σ_{therm}=6.9 b. Unfortunately even in this case the flux of the gamma-quanta produced by (n,γ)-reaction on ^{67}Zn and the admixtures of all other Zn isotopes is about 10^5 times more intensive (σ_γ=1.1 b for the natural Zn) than the gamma-flux of the reaction under study ($\sigma_{\alpha\gamma}$=160 μb [9]). Thus a very fast gamma-detector such as BaF_2 is required for such measurements. The enriched target makes the situation slightly better.

An interesting example is the reaction on the radioactive target ^{41}Ca ($t_{1/2} = 1.03 \cdot 10^5$ y, γ-rays are not observed):

$$^{41}\mathrm{Ca(n,}\alpha\gamma\mathrm{)}^{38}\mathrm{Ar} \quad (\mathrm{E}_\gamma = 2167\ \mathrm{keV});\ I_0 = {}^{7}\!/_{2}{}^{-};\ I;\ J = 2^{+};\ F = 0^{+};\ L_\alpha, L'_\alpha = 3{,}5$$

A number of the resonances are known in the ^{42}Ca compound nucleus. Unfortunately the values of spins *I* are not determined for them. For the first glance the example looks more promising because the ratio of the cross sections $\sigma_{\alpha\gamma}$=140 mb (σ_γ=4 b) is large enough, thus the use of this target is free of the disadvantage mentioned above. However such an experiment requires: extremely powerful reactor-producer to create a sample of satisfactory mass, isotope separation to obtain a significant resulting percentage of the isotope and to get rig of the radioactive ^{45}Ca admixture, a high-flux beam of polarized neutrons to achieve a satisfactory value of the counting rate on the small sample, and a well-developed technology of the experimental work with the targets which are soft radioactive sources of high intensity. At last the value $L_\alpha(\min) = 3$ prevents the use of the presented above method of measurement of the minor alpha-width.

What about the resonance neutron investigations the low-laying 3^{-} resonance in ^{150}Sm compound nucleus may be considered as a candidate to perform such experiments because the alpha-decay to the first excited level of the ^{146}Nd nucleus is well displayed and there is very close resonance 4^{-} in ^{150}Sm spectrum. However the problem of the extremely intensive background of gamma-quanta produced by the (n, γ)-reaction looks drastic. Perhaps it is reasonable to begin the study of the discussed effect with the search for convenient examples in lighter nuclei.

There is a broad spectrum of reactions (p,αγ) in the proton resonance area (targets with the masses $\mathrm{A} \sim 30$ – 40) which can be analyzed for the discussed purpose (see for example

[10]). One of the significant advantages of proton resonances is the absence in actuality the gamma-quanta background. This analysis is however beyond the scope of the current paper.

An example of the reaction (n,pγ) or (n, γα) suitable for the investigation of the ROT-effect is not found.

CONCLUSIONS

Summing up the discussions presented in the current and preceding papers it is important to stress the following points:

1. The ROT-effect is a natural property of (n,αγ), (n,pγ), (n, γα), and (p,αγ) reactions, ternary fission and triple events in the ordinary fission.
2. The ROT-effect may be manifested both in sequential and simultaneous processes. The contribution of the latter ones differ fission from other listed reactions.
3. If the time-reversal invariance is not violated in a sequential cascade, the interference of two amplitudes of the alpha or proton transfer with different multipolarities or the interference of the amplitudes of resonances of different spin is necessary for the existence of the ROT-effect.
4. The effect seems to be accessible to observation in (n,αγ)- and (p,αγ)-reaction.
5. If the basic effect is accurately taken into account one may, in principle, search for the contribution of the actual time-reversal noninvariant amplitudes.

References

1. Goenenwein F., Muterer M., Gagarski A., Guseva I.., Phys. Lett. B, 2007, V. 652, P.13.
2. Danilyan G. V., Klenke J., Krakhotin V. A. et al. in: Proceedings of International Seminar on Interaction of Neutrons with Nuclei, Dubna, 2012, P. 11.
3. Gagarski A., Goenenwein F., Guseva I. et al., et al., in: Proceedings of International Seminar on Interaction of Neutrons with Nuclei, Dubna, 2012, P. 277.
4. Gagarski A. M., Val’ski G. V., Petrov G. A. et al., JETP Lett., 2000 V. 72, P. 286.
6. Barabanov A. L., Bunakov V. E.., Guseva I. S., Petrov G. A., Phys. At.. Nucl. 2003 V. 63, P. 679.
6. Ferguson. A., Angular correlation methods in gamma-ray spectroscopy, Amsterdam: North-Holland Publishing. Co., 1965.
7. Kadmenski S. G., Furman W. I., Alpha-decay and related nuclear reactions. Moscow: Energoatomizdat, 1985 (in Russian).
8. Barabanov A. L., Symmetries and spin-angular correlations. Moscow: Fizmatgiz, 2010 (in Russian).
9. Emsallem A., Asghar M., D’Hondt P., Wagemans C., Z. Phys. A, 1984, V. 315, P. 201.
10. Feng D Proton Resonance Spectroscopy in ^{32}S (Ph. D.Thesis, Funden: Fuden Univ.), 1987.