RESEARCH OF ANALOG RESONANCES IN NSC KIPT

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The review of the results received at research of isobar-analog resonances in NSC KIPT in 1967-2002 is carried out. The basic accent is made on the data received at studying of γ-decay of analog resonances in nuclei of 1*d*2*s*-shell. The questions connected with *M*1 transitions between analog and antianalog states, core polarization states, *E*1 and *l*-forbidden *M*1 transitions with $\Delta T = 1$, compound-compound transitions and constants of isospin interaction are considered.

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INTRODUCTION

Rapid development of the nuclear physics area connected with isospin began after discovery by J. Anderson [1] in 1961 isobaric analog resonances (AR) in average and heavy nuclei. It became clear, that the isospin concept could be used for description of nuclei of all the periodic system. The even greater interest was caused with revelation of analog states (AS) by J. Fox [2] as resonances in compound nuclei.

Works on studying AR practically at once have been started in KIPT (for the first time in the USSR). Presence of the precision electrostatic accelerator of protons on 3 MeV has created necessary conditions for development of works on research of AR in the (pγ) reaction. The initial cycle of researches was stimulated by work of V.Yu. Gonchar, E.V. Inopin and S.P. Tsytko [3] devoted to a question of applicability of generalized model to light nuclei.

The problem has been put to investigate analog resonances in nuclei of 1*d*2*s*-shell in the (pγ) reaction. By development of the formulated problem the experimental technics has been created and methods of reception, processing and analysis of experimental data are developed.

2. EXPERIMENTAL PROCEDURE

Researches were performed at the Nuclear Spectroscopy Laboratory of NSC "KIPT" with the proton beam from the 3 MeV Van de Graaf accelerator which provided high monochromaticity of a beam and possibility of smooth adjustment of energy.

In experiments were used isotope (up to $A = 40$) targets by thickness ~ 2-5 keV at $E_p = 2$ MeV on tantalum.

On the basis of NaJ(Tl) and Ge(Li) detectors has been created the complex of the equipment which allows carrying out full studying properties of the γ-radiation observed in the (pγ) reaction. For the created γ-spectro-meters the basic characteristics have been measured (the energy resolution, efficiency), calibrations on energy are carried out and recommendations concerning a set of calibrating γ-lines from stable sources and from nuclear reactions are given.

Methods of the analysis and processing of the experimental data received from reaction of proton radiation capture by light nuclei, resulted in Table 1 are developed.

***Table 1**. Light nuclei investigated in the (pγ) reaction*

№	Target	Compound nuclei	E_p, MeV	E^*, keV
1	^{20}Ne	^{21}Na	1.0 - 3.0	3544 - 5030
2	^{22}Ne	^{23}Na	1.0 - 3.0	9206 - 11650
3	^{24}Mg	^{25}Al	1.0 - 3.0	2485 - 4570
4	^{26}Mg	^{27}Al	1.5 - 3.0	8552 - 11143
5	^{27}Al	^{28}Si	2.3 - 3.2	13840 - 14661
6	^{28}Si	^{29}P	1.0 - 2.2	3102 - 4764
7	^{29}Si	^{30}P	1.0 - 3.0	5913 - 8461
8	^{30}Si	^{31}P	0.5 - 3.0	7780 - 10189
9	^{31}P	^{32}S	1.8 - 3.0	9207 - 11775
10	^{32}S	^{33}Cl	0.5 - 2.0	2850 - 4790
11	^{34}S	^{35}Cl	0.6 - 3.0	7065 - 9295
12	^{36}S	^{37}Cl	1.4 - 3.2	9184 - 11483
13	^{36}Ar	^{37}K	1.0 - 2.0	2750 - 4523
14	^{40}Ar	^{41}K	1.0 - 2.0	8832 - 9734

For the mentioned compound nuclei decay schemes of resonant states have been offered, values of spins and parities are determined, multipole mixing ratios and values of matrix elements of electromagnetic transitions are established. Set of the received data allowed revealing the basic features of γ-decay of AR.

3. GAMMA-DECAY OF ANALOG STATES IN LIGHT NUCLEI

3.1. IRREGULARITIES IN EXCITATION FUNCTION OF THE (pγ) REACTION

Experimental studying of excitation function enables to receive the important data on density of nuclei states. Executed in KIPT researches of reactions of proton radiation capture in the vicinity of nuclei of 1*d*2*s*-shell have allowed to determine experimental values of density of resonant states of 14 nuclei mentioned in Table 1.

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One of the possible processes influencing on stochastic distribution of levels in resonant area, is occurrence of AR. The important assumption of properties of resonant states in compound nuclei is the assumption of their complex nature whereas AR usually have rather simple structure. Besides number of AR is not enough in comparison with full number of resonant states and they cannot affect on statistical distribution of resonant states significantly.

However strength of AR is much more above the average values of strengths of surrounding resonances. Investigating distribution of density of levels depending on energy of nuclear excitation the effect of reduction of density of levels of nucleus with odd mass number *A* close to AR is found out [4]. On the basis of existing nuclear models at present it is impossible to carry out detailed calculation of excitation function of (pγ) reactions and by that to try to explain the reason of occurrence of irregularities in density of observable levels. It is possible to assume only, that the observable effect is connected to feature of configurations of AS and with display shell properties of a nucleus.

3.2. FINE STRUCTURE OF AR

Results of many researches show that majority of AR have fine structure which is distinctly displayed in precision experiments on (pp), (pγ) and (^{3}He,d) reactions. Its existence grows out mixing of analog state $T_> = T_0 + 1/2$ with levels $T_< = T_0 - 1/2$ of compound nucleus that is caused by presence in a nucleus of forces not keeping isospin (Coulomb forces). It results to that isospin parts of wave functions will include a component of fine structure of AR both $T_>$, and $T_<$ component, i.e. will not already be pure on isospin conditions. The analysis of probabilities of γ-transitions from components of fine structure of AR on low lying state $T_<$ enables to establish value of isospin, giving the dominating contribution to wave function of initial state, concerning γ-transition.

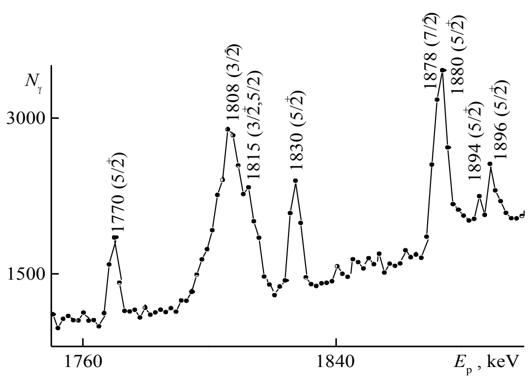

***Fig. 1**. Fine structure of $d_{5/2}$ resonance in the $^{30}Si(p\gamma)^{31}P$ reaction, $\theta_{lab} = 55°$*

Really, if isospin part of wave function of this resonant state is defined, basically, by isospin $T_>$ then relative intensities of γ-transitions to the given level from the excited states corresponding to different components of fine structure of AR, should be proportional to contributions of $T_>$ to wave functions of components, i.e. are proportional to Γ_p values. At absence of linear correlation between partial radiation widths of decay $\Gamma_{\gamma i}$ and width of elastic scattering of protons Γ_p it is possible to assume, that isospin parts of wave functions of resonant states contain isospin $T_<$ as main component.

γ-Decay of components of fine structure of AR in ^{23}Na, ^{27}Al, ^{31}P and $^{35, 37}$Cl nuclei is investigated [5-9]. As an example, the excitation function of the ^{30}Si(pγ)^{31}P reaction in the vicinity of $d_{5/2}$ resonance is shown on Fig. 1. Correlations between partial widths of decay of fragmented AR are investigated, that has allowed revealing for what channels the analog state is the common entrance state.

3.3. *M*1 TRANSITIONS AS → AAS

The special place in studying AR is occupied with γ-transitions between AS and antianalog states (AAS). Energy splitting of analogue-antianalogue is caused by interaction of particle isospin *t* with core isospin T_0, and has been explained phenomenologically by A. Lane [10] by introduction in optical potential of an additional term:

$$\frac{V_1}{A}\mathbf{t}\cdot\mathbf{T}_0 \qquad (1)$$

At research of AR in reaction of proton radiation capture 30 pairs of states like analogue-antianalogue are identified. The most full information on structure of AS and AAS is received at studying electromagnetic transitions between them. One-partial evaluations of matrix elements for magnetic dipole transitions AS → AAS appeared good enough approximation [11]. Observed deviations between experimental values and one-partial estimations have been explained by various authors with the help of complication of wave functions of AS and AAS.

3.4. THE MODIFIED NILSSON'S MODEL

It has been shown [12], that for the description of probability of *M*1 transition between AS and AAS can be used the generalized model in Nilsson scheme. Modification of the Nilsson's model will consist in that at calculation of probability of *M*1 transitions initial and final states of system are considered as states with various deformations. Then at transitions the state not only an odd particle (as in Nilsson scheme), but also states of all particles of a core changes. To these states there correspond the determinants constructed from two various sets of Nilsson one-partial wave functions.

In this connection the programs which have allowed processing an experimental material have been developed and to carry out calculations of own functions and own values of energy on Nilsson's model for continuous values of parameters of deformations. To expect energy of levels without taking into account and in view of mixing strips because of interaction of Coriolis forces, and also to receive probabilities electric quadrupole transitions in modified Nilsson's model.

Thus, within the framework of this model the analysis of matrix elements of electromagnetic transitions between the excited states in nuclei ^{23}Na, $^{25, 27}$Al, $^{29, 31}$P and $^{35, 37}$Cl is carried out. It is shown, that dependence of deformations on mass number (from $A \approx 25$ up to $A \approx 37$) for the ground and excited states of light nuclei is observed.

From the analysis of $E2$ transitions between low lying states of ^{23}Na where Coriolis interaction is entered, it is shown, that these transitions are more sensitive to the contribution of a one-partial part of the wave function which are taking into account dependence on deformation, than to Coriolis mixing.

3.5. *M*1 TRANSITIONS AS → CPS

However later in a number of precision experiments it has been established, that in some nuclei $M1$ transitions $(J_i^\pi, T_>) \rightarrow (J_f^\pi, T_<)$ are considerably slowed down in comparison with one-partial estimations. The explanation of these facts needed introduction in modeling representations of a new degree of freedom of a nucleus, states such as core polarization state (CPS).

The detailed calculations which have been carried out within the framework of multiparticle shell model with effective various residual interaction [11], have shown, that the full probability of γ-decay of AS in odd nuclei with $21 < A < 41$ is allocated between $M1$ transitions on AAS and CPS. This conclusion appeared sufficient for interpretation of radiation widths of AS decay, known by then in this vicinity of nuclei.

Isobaric collective 1^+ states forming narrow group are lower AR, have been found out for nuclei ^{31}P and ^{37}Cl [13, 9]. These states are sharply allocated with great value of matrix elements of $M1$ transitions and settle down on 4…5 MeV below AR. Originally they tried to associate it with Gammov-Teller resonance (GTR), however now it is clear, that it is necessary to compare them with splitted CPS which agrees to quasiparticle estimation lies in this energy area.

It has been found out in the first experiments on the (^{6}Li,^{6}He) reaction on ^{48}Ca. From the new data on the (pn) reaction it follows, that, apparently, it is necessary to compare CPS with 1^+ resonance laying below AR and observable together with GTR in light and average nuclei. As collective 1^+ states with such excitation energy have $B(GT) \approx 1$, and for GTR $B(GT) \approx N - Z$ it is natural, that they can compete with GTR on section of excitation only in the field of light nuclei. As an example distribution of experimental values of $B(M1)$ for γ-transitions from AR on levels ^{31}P is shown on Fig. 2. We can see that γ-decay of AR has selective character. Except for AAS the group of states with $J^\pi = 1/2^+, 3/2^+$ and $5/2^+$ which centre of gravity lies at $E^* \approx 4.41$ MeV is populated by direct γ-transitions. It corresponds to position of CPS in ^{31}P, appreciated under the formula:

$$E_{AS} - E_{CPS} = (T_0 + 1/2)\frac{V_1}{A} + P_n, \qquad (2)$$

where P_n - pairing energy of a neutron.

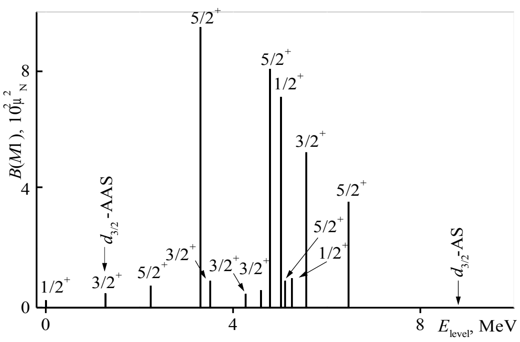

Fig. 2. *Distribution of B(M1) values for direct transitions from analog $d_{3/2}$ state on levels ^{31}P*

3.6. ANALOG γ- AND β-TRANSITIONS

It is known, that in view of isobaric symmetry there is a fundamental ratio between probability $\Lambda(M1)$ of γ-transition from AR and probability $\Lambda(GT)$ for Gammov-Teller β-transition in the same final state of a nucleus [14]:

$$\Lambda(M1) = C\left(1 + 0.11\frac{\langle f | l\tau | i\rangle}{\langle f | s\tau | i\rangle}\right)^2 \Lambda(GT), \qquad (3)$$

which is correct in the case if the analog resonance is pure $T_> = T_0 + 1/2$-resonance. Then the $\Lambda(M1)$ value is determined only by a spin σ-part of the operator of isovector $M1$ transition. The $\Lambda(M1)$ value of γ-transition is expressed as follows:

$$\Lambda(M1) = \frac{4\pi}{3}\left(\frac{2Mc}{e\hbar}\right)^2 B(M1). \qquad (4)$$

For the $\Lambda(M1)$ value of β-decay we have:

$$\Lambda(GT) = \frac{4390}{ft}. \qquad (5)$$

This statement is checked for nuclei with $A = 23$, 31 and 37. In Table 2 values of $\Lambda(M1)$ calculated under the formula (4) on the basis of known data on values ft for β-transitions to levels of final nuclei and experimental $\Lambda(M1)$ for corresponding γ-transitions from AR [9] are resulted. For all considered γ-transitions significant excess of the $\Lambda(M1)$ value is observed in comparison with its value appreciated under the formula (4). It testifies to the essential contribution of an orbital l-part to probability of the considered $M1$ transitions, caused by mixing AAS and CPS in ^{23}Na, ^{31}P and ^{37}Cl.

__Table 2.__ Comparison of analog β- and γ-transitions in nuclei with 20 < A < 40

Isobaric nuclei	$E_i^* \to E_f^*$, MeV	J^π	lg *ft*	$\Lambda(M1)$, W.u.	
				"exp"	"β"
^{23}Ne - ^{23}Na	7.89→ 0	$3/2^+$	5.28	0.20	0.022
	→0.44	$5/2^+$	5.40	0.11	0.017
^{31}Si - ^{31}P	6.81→ 0	$1/2^+$	5.52	$0.28\cdot10^{-2}$	$0.32\cdot10^{-3}$
	→1.27	$3/2^+$	5.6		0.082
^{37}S - ^{37}Cl	10.22→3.10	$7/2^-$	4.38	3.7	0.81
	→3.74	$5/2^-$	6.15	$7.8\cdot10^{-2}$	$1.4\cdot10^{-2}$
	→4.27	$7/2^-$	5.98	$6.1\cdot10^{-2}$	$2.0\cdot10^{-2}$
	→4.40	$5/2^-$	6.54	$11.5\cdot10^{-2}$	$0.13\cdot10^{-2}$

Note: *Both at β- and γ-transitions have other branches of decays (not represented in Table 2) which lead on the excited states of* ^{23}*Na,* ^{31}*P and* ^{37}*Cl*

3.7. *E*1 TRANSITIONS IN SELF-CONJUGATED NUCLEI

Electromagnetic transitions in the self-conjugated nuclei carry the information about isospin structure of states in a nucleus. *E*1 transitions in the self-conjugated nuclei between states with identical isospins, that is with $\Delta T = 0$, are forbidden. *E*1 transitions with $\Delta T = 0$ observable on experiment it is possible to explain by existence of mixing of states with various isospins. The estimation of intensity of mixing of states with isospins $T = 0$ and $T = 1$ is possible to determine as the ratio of average value of a square of a matrix element of the forbidden *E*1 transition to average value of a square of a matrix element of the allowed *E*1 transition:

$$\alpha_1^2(0) = \frac{\langle |M(E1)|^2 \rangle_{\Delta T=0}}{\langle |M(E1)|^2 \rangle_{\Delta T=1}} \qquad (6)$$

Such estimation of a degree of mixing carries cleanly a statistical character as at averaging probabilities of *E*1 transitions dependence of a matrix element of γ-transition on other quantum numbers which are distinct from isospin is ignored. So, for reception of the most reliable values of mixing at calculation of average value of probability of *E*1 transition it is necessary to use probably greater number of transitions. Usually average values of squares of the resulted matrix elements are calculated under the formula:

$$\lg\langle |M(E1)|^2 \rangle = \frac{1}{n}\sum_{i=1}^{n} \lg|M(E1)|_i^2 \qquad (7)$$

where *n* - number of transitions on which averaging is carried out. From value of intensity of mixing it is possible to receive value of a matrix element of Coulomb interaction resulting to mixing, using expression:

$$H_{10}^c \approx \alpha_1(0)\cdot\Delta_{10} \qquad (8)$$

where Δ_{10} - distance between levels having identical spins and parities, but different isospins.

The received experimental data [15] have allowed carrying out an estimation of intensity of mixing in nuclei of 1*p*- and 1*d*2*s*-shells (see Table 3). Such estimation specifies dependence of mixing on isospin from mass number. On the basis of a rule of selection on isospin for *E*1 transitions in the self-conjugated nuclei the effect of decreasing of intensity of mixing on isospin in the closed shells and subshells is established. It explains dependence of isovector Coulomb energy from mass number.

Table 3. *Average values of forbidden and allowed on isospin E1 transitions and intensities of mixing of states with various isospins for the self-conjugated nuclei* $18 \le A \le 40$

Nucleus	$\langle \lvert M(E1)\rvert^2 \rangle_{\Delta T=0}$	$\langle \lvert M(E1)\rvert^2 \rangle_{\Delta T=1}$	$\alpha_1^2(0)$
^{18}F	$1.24\cdot10^{-4}$	$1.33\cdot10^{-3}$	0.090
^{20}Ne	$5.3\cdot10^{-5}$	$4.37\cdot10^{-3}$	0.011
^{24}Mg	$9.52\cdot10^{-5}$	$7.38\cdot10^{-4}$	0.129
^{26}Al	$2.87\cdot10^{-4}$	$1.11\cdot10^{-3}$	0.259
^{28}Si	$7.46\cdot10^{-5}$	$6.35\cdot10^{-4}$	0.117
^{30}P	$1.96\cdot10^{-4}$	$1.09\cdot10^{-3}$	0.179
^{32}S	$1.79\cdot10^{-4}$	$1.64\cdot10^{-3}$	0.109
^{36}Ar	$1.55\cdot10^{-4}$	$4.73\cdot10^{-4}$	0.327
^{40}Ca	$1.95\cdot10^{-4}$	$1.97\cdot10^{-3}$	0.099

3.8. *E*1 TRANSITIONS WITH Δ*T* = 1 IN ODD NUCLEI

Meanwhile in experiments of last years are found out isovector γ-transitions which have not found the reflection in existing theoretical approaches. To them, first of all, concern *E*1 and the *l*-forbidden *M*1 transitions such as $T_> \to T_<$. Now in the modeling description of *E*1 radiation widths of decay of AS for near magic nuclei with $A > 40$ achieve significant progress. In this connection represents special interest studying and statement of this question for nuclei of 1*d*2*s*-shell where there is a hope for the adequate description of *E*1 widths of analog resonances within the framework of existing theoretical representations.

The analysis of the collected experimental material has allowed formulating some common conclusions [16].

1. Regular difference of experimental values of an effective charge $e^2_{exp} = \Gamma^{exp}_\gamma(E1)/\Gamma^{sp}_\gamma(E1)$ from unit is observed. Here [17]

$$\Gamma^{exp}_\gamma(E1) = \frac{16\pi}{9}e^2\left(\frac{E_\gamma}{\hbar c}\right)^3(2T)^{-1}\frac{S_i S_f}{2j_i+1}\left|M^\beta_{fi}\right|^2 \quad (9)$$

Here M^β_{fi} is the matrix element for first-forbidden Fermi β-transition and within the single-particle approximation it is equal to

$$M^\beta_{fi}(\text{sp}) = \left\langle j_f l_f \left\| Y_1 \right\| j_i l_i \right\rangle \left\{\chi_f r \chi_i\right\}, \quad (10)$$

where $\left\langle j_f l_f \left\| Y_1 \right\| j_i l_i \right\rangle$ is the reduced matrix element.

It testifies to an essential role of the polarizing effects caused by virtual excitation of $T_>$ and $T_<$ components of electric dipole giant resonance during $E1$ radiation decay of AS.

2. The shell effects affecting on values of $\Gamma_\gamma(E1)$ in process of approximation of number of neutrons in researched nuclei to magic number $N = 20$ are revealed. Values $\Gamma_\gamma(E1)$ are minimal in the vicinity of nuclei $A \approx 37$.

3. Appreciable correlation between values of $\Gamma_\gamma(E1)$ and values of spectroscopic factors of AS is not found out. At the same time absolute value $\Gamma_\gamma(E1)$ essentially depends on an orbit occupied with an unpaired nucleon. The most intensive appeared $E1$ transitions which are observed at decay of AS with $J^\pi = 3/2^-$.

4. It is established, that one-partial $E1$ transitions with spin overturn $j_i = l_i \pm ½ \rightarrow j_f = l_f \pm ½$ appeared more poorly the transitions keeping relative orientation of spin and orbital moment $j_i = l_i \pm ½ \rightarrow j_f = l_f \mp ½$. This selection rule is fairly for all area of odd nuclei with $20 < A < 40$.

3.9. *l*-FORBIDDEN *M*1 TRANSITIONS WITH Δ*T* = 1 IN ODD NUCLEI

Other situation has developed for *l*-forbidden *M*1 transitions with $\Delta T = 1$ in nuclei of 1*d*2*s*-shell. The regular calculations explaining the mechanism of removal of *l*-interdiction, even in simple model have not been executed and, probably, by virtue of a seeming theoretical inconsistency, to them have not given due attention. It is possible, that mixing 1*d* and 2*s* configurations imposes some technical difficulties on calculations in 1*d*2*s*-shell. However more essential reason constraining the further development of modeling representations for this type of γ-transitions, is not so much difficulty of basic character as deficit of experimental data about *l*-forbidden *M*1 transitions with $\Delta T = 1$ in this area of nuclei.

The analysis of the collected experimental material [18] allows to formulate some general conclusions following from carried out studying of the given *M*1 transitions in considered area of nuclei.

1. It is established, that *l*-forbidden *M*1 transitions with change of isospin on unit are observed in all area of odd nuclei $A \le 70$. Their intensity, in some cases, is comparable under the order of size to intensity of one-partial *M*1 transitions between analog and antianalog states.

2. In distribution of factors of forbidenness

$$F_M = \frac{B(M1)^{calc}}{B(M1)^{exp}} \quad (11)$$

from mass number A it is traced two maxima, connected with γ-transitions in nuclei with $20 < A < 40$ ($F_M \sim 800$) which are practically spherical, and in nucleus with $60 < A < 90$ ($F_M \sim 300$). It evidently illustrates Fig. 3. For the γ-transitions observed at decay of AR in nuclei with $A < 20$ and $40 < A < 60$ factors of an interdiction F_M are minimal (~ 10).

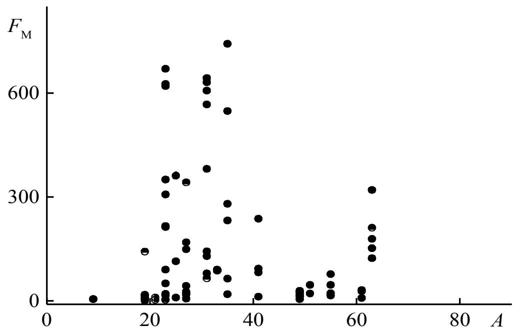

Fig. 3. *Behavior of the factor of forbidenness* F_M *depending on mass number A*

3. It is not revealed appreciable correlation between values F_M and values of spectroscopic factors C^2S of AR. It allows to assume, that *l*-forbidden *M*1 transitions $T_> \rightarrow T_<$ are carried out due to an impurity of other configurations to an initial or final state of a radiating particle. That fact, that these transitions are observed in immediate proximity from the filled shells, forces to draw a conclusion that collective effects should not play an essential role in removal of *l*-forbidenness. However easing of *l*-forbidenness in the vicinity of nuclei $A \sim 25$ and $40 < A < 60$ is connected by obvious image to a growing role of collective effects, in the latter case, first of all collective isobaric 1^+ configurations of $p\bar{n}$ type (a condition such as CPS).

3.10. COMPAUND-COMPAUND TRANSITIONS

Doubtless interest represents researches of γ-transitions between high excited compound states of nuclei concerning from each other on ~ 1-2 MeV. Here both initial and final states are complex on structure and practically any component of wave function can give the contribution in the probability of γ-transition between them.

In this connection there are some questions about the nature of such γ-transitions. Whether they are determined by "tails" of giant multipole resonances (GMR)? Or at energy of transitions, which is significant smaller energy of maximum of GMR, the last already do not play an essential role, and it allows to be shown to other mechanisms of γ-transitions? What is hierarchy on multipolarities of γ-transitions? Whether show multyquasiparticle components of wave functions of compound state itself in these transitions? Or it is the transitions determined any allocated component, for example AS fragmented on compound stets?

All available material on partial γ-transitions between compound states of nucleus of 1*d*2*s*-shell is systematized and analyzed. On the basis of the received results the following conclusions [19] are formulated.

1. Soft ($E_\gamma^{*`} = E_c^* - E_{c'}^* \approx 2$ MeV) γ-transitions between high excited compound states are found out in all area of nuclei of 1*d*2*s*-shell. Their greatest number falls at nuclei, which have rather low on energy (< 3 MeV) values S_p. Selective character in population by direct γ-transi-tions of final compound states takes place.

2. γ-Transitions such as *M*1 appeared the most essential here. It is possible, that in formation of their widths can take place GMR. Value of radiating power function $S_\gamma^{cc'}(M1)$ appeared equal $2 \cdot 10^{-8}$ MeV^{-3}.

3. In the vicinity of nuclei $Z = 20$ and $N = 20$ abnormal change of hierarchy of multipolarities of γ-transitions is observed. γ-Transitions such as *E*1 and *E*2 appeared here the basic. However this conclusion is preliminary because of deficit of the data and demands the further experimental confirmation.

3.11. CONSTANTS OF ISOSPIN INTERACTION V_1 AND f_0'

Experimental data on energy splitting of AS and AAS in nuclei can serve as good check of realness of those or other representations about AR. The available data about such energies are compatible with expected of the theory for some AS, but full check of all forecastings is not carried out. In [20] the opportunity of the description of the data on energy position of AS and AAS is in part appreciated by the example of odd nucleus with $A < 70$ from positions of the ideas advanced in microscopic approaches and shell model of a nucleus. In this connection independent check of value of a constant f_0' of isospin-isospin part of δ-functional universal amplitude of interaction of quasiparticles which is used in calculations [21] for the description of AS in the nuclei close to a strip of β-stability is carried out. The f_0' values are determined from formula:

$$E_{AAS} = \Delta\varepsilon_F \frac{1+f_0'}{1+(1-c)f_0'} = \frac{E_{AS}}{1+(1-c)f_0'}, \qquad (12)$$

where $\Delta\varepsilon_F$ is the width of layer of excess neutrons.

Parameter V_1 responsible for isospin part of one-partial potential in a nucleus [22] is appreciated. Its value is determined by the splitting energy of AS and AAS:

$$\Delta E = E_{AS} - E_{AAS} = \frac{V_1}{A}(T_0 + 1/2) \qquad (13)$$

As a result of the carried out analysis of experimental data about energy splitting of AS and AAS in odd nuclei with $A < 70$, it is possible to draw the following conclusions:

1. It is revealed, that average value $f_0' = 1{,}9$ for resonances with $T_> = 3/2$ will be coordinated under the order to value $f_0' = 1{,}53$ used in modeling calculation [21]. This fact is a little bit unexpected as in microscopic approach [21] for an estimation of energy of AS and AAS is used approximation $N - Z >> 1$ which not absolutely adequately represents a situation in considered area of nuclei.

2. It is established, that in nuclei with $20 < N < 28$ the maximal divergence (in 6 times) a theoretical estimation f_0' with its values received on the basis of experimental data about energy splitting isobar-analog $2p_{3/2}$, $1f_{7/2}$, and $1g_{9/2}$ resonances is observed. It evidently illustrates Fig. 4.

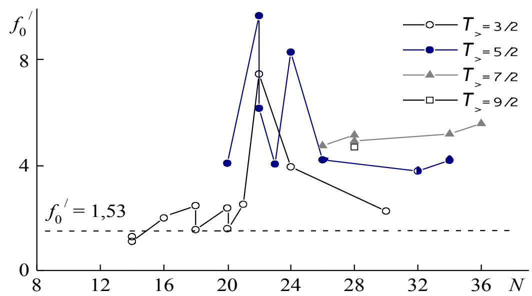

Fig. 4. *Experimental values f_0' from energy distance between AS and AAS in nuclei with A < 70*

3. Linear dependence of growth of values f_0' on splitting energy of AS which is approximated by function $f_0' = 1{,}03\Delta E - (1{,}53)^2$ is found out.

4. In the field of nuclei with $N > 28$ for AS with $T_> = 5/2$, 7/2 and 9/2 is observed an appreciable deviation f_0' from theoretical value aside the big sizes. However it is impossible to determine dependence of size f_0' on number of neutrons *N* as the data will insufficiently well be coordinated among them.

5. In considered area of nuclei the significant divergence of experimental values of parameter V_1 (Fig. 5) with value $V_1 \sim 100$ MeV, used in modeling calculations [22] is observed. Meanwhile, it is necessary to note, that average value of parameter V_1 for $1f_{7/2}$ resonances is

equal to 105 MeV. However as a whole dependence of parameter V_1 on mass number A which is well described by the empirical formula $V_1 = 220(1 - 6A^{-2/3})$ is observed.

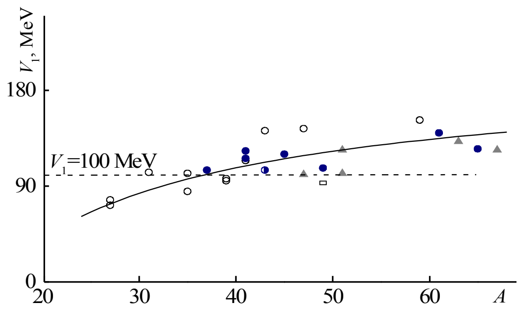

Fig. 5. *Systematization of parameters V_1 from energy splitting AS and AAS in nuclei with A < 70. Designations of experimental points as well as on Fig. 4*

CONCLUSION

The further researches of γ-decays of AR are connected to studying $E1$ and l-forbidden $M1$, $M2$ and $E2$ transitions that allows to receive the information on structure of conditions of parent nuclei and degrees of infringement isotopic symmetry of AS. It is reasonable to expect, that there should be certain laws and that their detection will help to systematize, at least, knowledge on the given γ-transitions and by that to determine the further prospects of researches of these questions in wide area of nuclei. Obvious interest to these γ-transitions is caused by fundamentality of problem – finding out a role of charging dependence of nuclear forces in the mechanism of mixing of levels on isospin in nuclei.

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