MAIN RESULTS ON NUCLEAR PHYSICS OBTAINED AT IPHENP NSC KIPT DURING 2002-2004 YEARS

S.N. Afanas'ev, A. S. Kachan, A.F. Khodyachikh, I.V. Kurguz, R.P. Slabospitsky, I.V. Ushakov, A.N. Vodin

National Science Center "Kharkov Institute of Physics and Technology", Kharkov, Ukraine
e-mail: vodin@kipt.kharkov.ua

The main experimental results on nuclear physics obtained at Institute of High Energy Physics & Nuclear Physics National Science Center "Kharkov Institute of Physics and Technology" during 2002-2004 years are presented.
PACS: 25.85.Ig, 27.90.+b, 25.30.Fj, 27.10.+h

1. INTRODUCTION

In 2001 we have published [1,2] review of experimental results, obtained at IHEPNP NSC KIPT within the last decade of the XX century. The main results of experiments, performed during 2002-2004 are presented below. They have been reported at the III Conference on high energy physics, nuclear physics and accelerators (Kharkiv, Ukraine, 2005).

2. DEEP PHOTODISINTEGRATION OF THE CARBON NUCLEUS

The (γ, N)-process of nucleon knockout from light nuclei in the intermediate energy region has been the subject of intensive studies, both by theory and experiment, over many years. However, even by the present time there is no unique answer to the question about the mechanism of nucleon ejection from the nucleus. Nonrelativistic calculations [3-6] have suggested that the direct knockout mechanism is incapable of explaining both the (γ,p)-reaction cross section value and the same shape of angular distributions in (γ,p)- and (γ,n)-reactions. It has been recognized that the main contribution comes from the process of γ-quantum interaction with a nucleon pair at the moment of nucleon-meson exchange. However, these conclusions are in contradiction with the calculations in the relativistic approximation [7-9]. With a few nuclei as an example, it has been demonstrated that the contribution to the (γ,p)-reaction from the direct mechanism is much higher than in the nonrelativistic approximation, and is in agreement with experiment. However, the agreement with the (γ,n)-reaction has not been discussed in the above-mentioned papers. The calculations in the nonrelativistic approximation [10,11] have led to the conclusion that the role of exchange currents is not great if the final nucleus is in the ground state, but it increases as the excitation energy of the nucleus increases. To verify this suggestion, experimental data on the reactions leaving the nucleus in a highly excited state are needed.

Here we present the results from studies into the reaction of four-body photodisintegration of the carbon nucleus $^{12}C(\gamma,n)^3He2\alpha$, henceforth denoted for brevity as (γ,n). The experiments were made using a diffusion chamber in the magnetic field, exposed to bremsstrahlung γ-quanta that had a maximum energy of 150 MeV. The chamber combined a target and a detector with a large-acceptance solid angle. To register low-energy particles, the chamber was filled with a methane-helium mixture in the ratio of 1 to 7. This permitted studies of the reaction in the near-threshold region, too.

Previously, we have presented a survey [12] on photodisintegration of the ^{12}C, ^{14}N and ^{16}O nuclei with nucleon separation from the *p*-shell. In the reaction considered here it is possible that the neutron may be separated from the *s*-shell. The data on photonuclear reactions with nucleon separation from the *s*-shell are practically absent.

Measurements of the excitation energy distribution of the α_1, α_2 and ^3He particle system were carried out. The excitation energy was determined as $E^* = M_{eff} - M_C$, where M_{eff} is the effective mass of three particles, and M_C is the ground state mass of the ^{11}C nucleus.

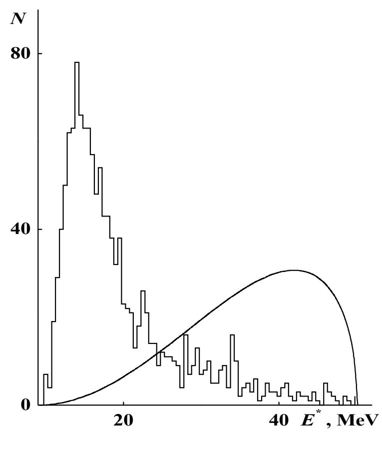

Fig. 1. *Excitation curve of ^{11}C*

The distribution is presented as a histogram shown in Fig. 1. The comparison between the histogram and the phase distribution (smooth curve) indicates that one state or several unseparated excited states of ^{11}C are formed. The distribution peak lies at the energy E_0 = 14.7(3) MeV and has the half-width Γ = 3.2(6) MeV. Thus, the reaction has a successive two-particle character. At the initial stage, the nucleon is knocked out to form the excited state of ^{11}C, which decays in a cascade manner into helium isotopes with the production of intermediate states of beryllium isotopes. It is known [13] that at these energies the ^{11}C nucleus has wide levels decaying with the emission of ^3He and ^4He nuclei. However, the resonance observed here cannot be identified with any particular level.

The two-particle character of the reaction at the initial stage enables us to determine the spin and parity of the excited ^{11}C nucleus, and also the multipolarity of the transition by analyzing the angular distributions. For this purpose, differential cross sections were measured in the center-of-mass $n + {}^{11}C$ system in the energy ranges of 32 … 36, 36 … 38, 38 … 40, 40 … 50, 50 … 70 and 70 … 100 MeV. The step of polar angle variation was 15°. The results of the measurements are shown in Fig. 2.

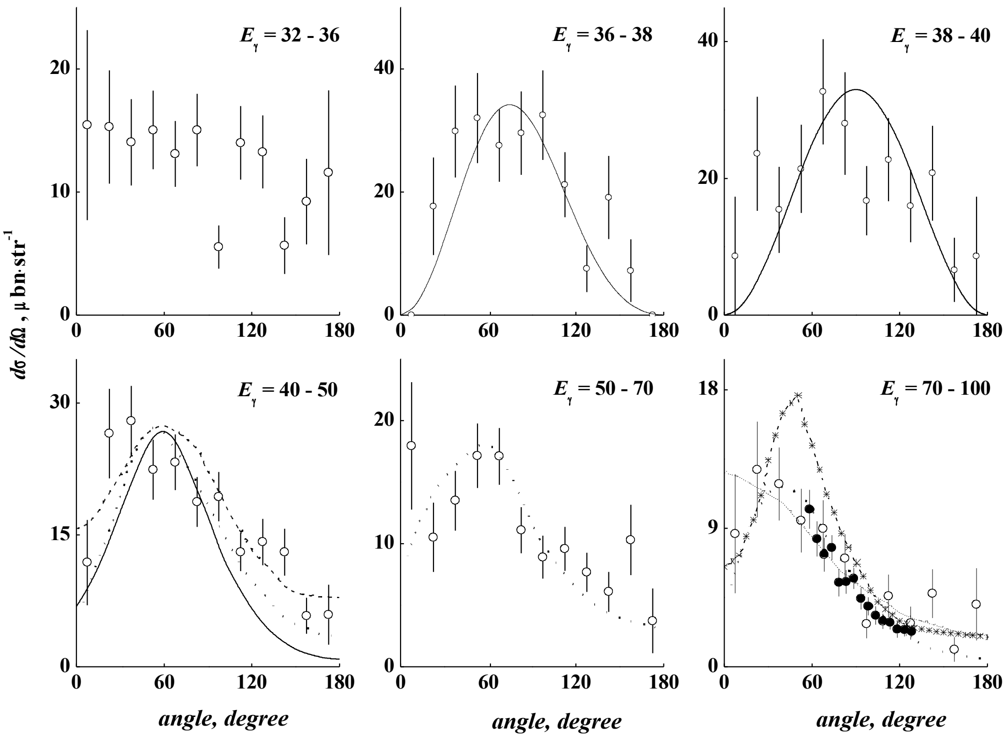

Fig. 2. *Angular distributions of neutrons from the $^{12}C(\gamma,n)^{11}C$ reaction*

The points are plotted in the middle of the range and correspond to the average cross-section value within the range. The errors are statistical only. In the 70… 100 MeV energy range, comparison was made with the results of Ref. [8] for the $^{12}C(\gamma,p)^{11}B^*$ reaction with the 13 MeV excitation energy of the residual nucleus that decays with γ-quantum emission. The results have been normalized and are presented by dark circles. In the near-threshold region up to 36 MeV the distributions are close to isotropic. This behavior may be explained by centrifugal potential suppression of the yield of neutrons with a non-zero orbital momentum. In the 36…40 MeV energy range, the differential cross-sections are proportional to the distribution of $\sin^2\theta$ type shown by a solid curve in the figure. The ground state of the carbon nucleus has the quantum numbers $J^\pi = 0^+$. With the use of the direct mechanism model and the tables of Ref. [14] it can be stated that this shape of angular distributions is possible only in the electric dipole approximation and only if the final nucleus ^{11}C is produced in the ½$^+$ state. Taking into consideration a high excitation energy of the final nucleus and its quantum numbers $J^\pi = 1/2^+$, it can be concluded that the neutron is separated from the *s*-shell of the carbon nucleus. This type of angular distributions is observed only in the 36 … 38 MeV range. An appreciable isotropic constituent is present at other energies.

This statement does not agree with the data [15] on the mirror reaction $^{12}C(\gamma,p)^3H2\alpha$. Those data present the angular distributions of protons measured by the photoemulsion technique in the bremsstrahlung beam with maximum γ-quantum energy of 70 MeV. In the whole energy interval they are close in shape to the $\sin^2\theta$ type distribution.

In the 40…50 MeV energy range, the solid curve shows the calculation by the model of direct mechanism of proton knockout from the *s*-shell of the carbon nucleus, the calculation being normalized to the experimental data. A fair agreement is seen between the angular distribution shapes. In the 40 … 100 MeV energy range, the dotted curve shows the phenomenological quasideuteron model calculations, where the differential cross sections in the $\gamma + np$ were taken to be the same as in the deuteron photodisintegration [17]. The calculation by the model of pair absorption with a predominant contribution from meson exchange currents [7] is shown by a dashed line, the direct mechanism model calculation is shown by crosses. All calculations were normalized to the area under the experimental curve. It may be concluded that in the intermediate energy region the pair absorption model calculation [7] is in better agreement with the experimental data that the direct mechanism model calculation [9].

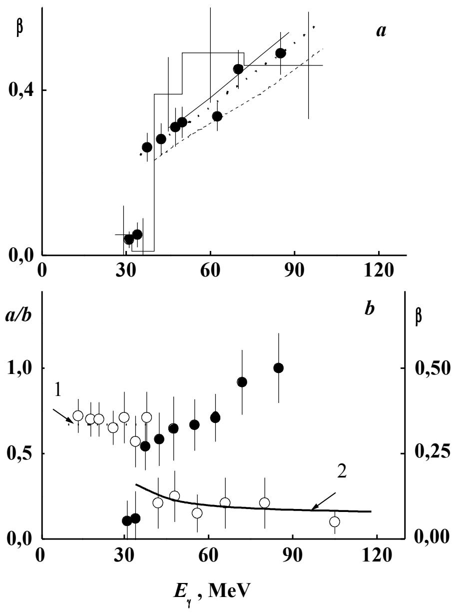

Fig. 3. *The asymmetry coefficient β vs the photon energy and the a/b ratio vs the photon energy*

In Fig. 3, the dots show the γ-quantum energy dependence of the asymmetry coefficient β determined as:

$$\beta = \left(\int_0^{\pi/2} (d\sigma / d\Omega)\, d\theta - \int_{\pi/2}^{\pi} (d\sigma / d\Omega)\, d\theta \right) \Big/ \int_0^{\pi} (d\sigma / d\Omega)\, d\theta \, . \quad (1)$$

At energies up to 38 MeV, the β value is small, while at energies of 38 to 40 MeV it quickly increases, and after 40 MeV its rise slows down. The stepwise variation of the coefficient has been observed by us earlier in the $^{12}C(\gamma,n)\alpha^{7}Li$ reaction [12], the results from which are presented by the histogram. The direct mechanism model predicts that owing to the smallness of the effective quadrupole charge of the neutron, the neutron angular distributions should show predominant yield at large angles. This prediction is consistent with the β value only in the energy interval up to 38 MeV. Fig. 3a shows the β coefficient derived from the angular distributions of protons in the $^{12}C(\gamma,p)^{11}B^*$ reaction with a final-nucleus excitation energy of 7 MeV ([7,8]). In the figure the solid curve shows the pair absorption model calculation, and the dotted curve represents the calculation in the framework of the phenomenological quasideutron model.

The both calculations adequately describe the behavior of the coefficient at energies above 40 MeV. The jump like variation of angular distribution parameters in the same energy range has previously been observed in the reactions $^{12}C(\gamma,p)^{11}B$ [18] and $^{16}O(\gamma,p)^{15}N$ [19], where the *a*/*b* ratio of differential cross-section expansion coefficients was measured as:

$$d\sigma / d\Omega = a + b\sin^2\theta + c\sin^2\theta\cos\theta \, . \quad (2)$$

The angular distributions have this form at a direct mechanism of nucleon knockout in the electric dipole approximation. The open circles in Fig. 3b show the energy dependence of the *a*/*b* ratio for the $^{16}O(\gamma,p)^{15}N$ reaction [19] in comparison with the β coefficient. The direct mechanism model predicts the *a*/*b* ratio to be 2/3 [19]. In the figure, the *a*/*b* ratio is shown by line 1 and is found to be in agreement with experiment at energies below 40 MeV. Curve 2 shows the calculation by the phenomenological quasideutron model, which adequately describes the experimental results at energy higher than 40 MeV. The energy regions of quick variation of the parameters are coincident. The jump like variation in the parameters of angular distributions in other experiments has not been observed previously. However, in the studies on the reaction $^{12}C(\gamma,p)^{11}B$ with production of the ^{11}B ground state [20] differential cross sections were measured at the giant resonance energy (29.9 MeV) and in the quasi-deuteron energy range (37.2 MeV). From Fig. 5 of Ref. [20] a substantial difference in their shape is evident, just as it is expected from our experiment. So, the variation in the energy dependence of angular distribution parameters can be attributed to the change in the mechanism of interaction between the electromagnetic radiation and the nucleus. At energies up to 40 MeV the mechanism of direct knockout of nucleons prevails, while at higher energies the mechanism of pair absorption is dominant. Previously, we have found the dependence of the asymmetry coefficient on the excitation energy of the intermediate nucleus. The present experiment makes it possible to observe this dependence in a wider excitation energy range.

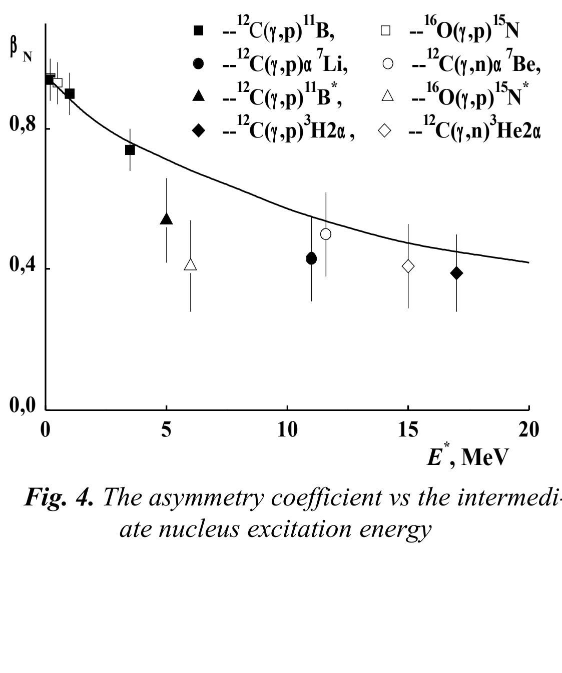

Fig. 4. *The asymmetry coefficient vs the intermediate nucleus excitation energy*

Thus, the data presented in Fig. 4 corroborate the trend we observed previously for the angular distribution asymmetry coefficient to decrease with increasing excitation energy of the final nucleus. The line shows the calculation in the framework of the phenomenological quasideutron energy. A qualitative explanation of the effect can be found in the quasideutron kinematics: a higher energy in the system made up by the nucleon that has not left the nucleus plus the nucleus without the *np*-pair extends the range of admissible angles between the nucleon momenta in the laboratory system.

The excitation function of the $^3He2\alpha$ system of the $^{12}C(\gamma,n)^3He2\alpha$ reaction has been measured. It has been established that the reaction has a successive character. At the first stage, the nucleon is separated and one or several unseparated excited states of the ^{11}C nucleus are formed, which then decay to produce beryllium isotopes in the $^{11}C^* \rightarrow {}^8Be + {}^3He$ or $^{11}C^* \rightarrow {}^7Be^* + \alpha$. Angular distributions of neutrons have been measured in the following energy ranges: 32…36, 36 … 38, 38 … 40, 40 … 50, 50 … 60, 60 … 70 and 70 … 100 MeV. The results obtained at energies up to 38 MeV are explained in the direct mechanism model. It has been established that the excited state of the ^{11}C nucleus has the quantum numbers $J^\pi = 1/2^+$. A high excitation energy of the intermediate nucleus ^{11}C and the shape of angular distributions indicate that the neutron is knocked out from the *s*-shell. At energies above 40 MeV the results are in agreement with the predictions of the model of photon absorption by a nucleon par in the assumption that the main contribution comes from the interaction with meson exchange currents. The asymmetry coefficient of angular distributions has been measured. At energies up to 38 MeV it is close to zero, and this finds its explanation in the model of the mechanism of direct knockout of the neutron. In the 38…40 MeV range, the coefficient value increases abruptly, and above 40 MeV it slowly increases with increasing γ-quantum energy. Above 40 MeV, the β value and its energy dependence are explained by the pair absorption model. The jump like variation of the coefficient at 38 to 40 MeV is a consequence of the change in the mechanism of interaction between electromagnetic radiation and the nucleus in a narrow energy interval.

3. GIANT *M*1 RESONANCE IN ^{23}Na AND ^{39}K NUCLEI

During the last years the reactions of proton inelastic scattering and radiation capture have started to be applied intensively for researching giant multipole resonances located at the most low excitation energy and consequently getting in area of discrete states in a nucleus [21]. They are *M*1 and *E*2 octupole resonances. One of the most interesting among the low laying giant resonances is the *M*1 resonance. It is connected with that *M*1-transitions carry the most complete information on spin and isospin dependences of nuclear forces [22]. In real nuclei the *M*1 force is distributed on near states and that allows studying connection of one-partial motion with collective one. The role of collective motion is insignificant for the *sd*-shell nuclei, therefore the *M*1 resonance is distinctly shown in these nuclei. At present time the position and fine structure of magnetic dipole resonance (MDR) in even-even $4N$ and $4N + 2n$ nuclei of *sd*-shell are well known [23, 24]. It is also established, that the basic excitation mechanism of MDR is connected with transitions between spin - orbital partners [22].

In previous work [25], studying the γ-decay of resonance-like structures (RLS) in the proton radiation capture reaction by ^{21}Ne, ^{25}Mg, ^{29}Si and ^{34}S, we have found out the new phenomenon connected with existence of triplet pairing between odd neutron and proton taking place on the same orbit. It is shown that the position of the centre of gravity ($E_{c.g.}$) of the MDR in odd-odd nuclei $4N + np$ was found to be 3 MeV below than in even-even nuclei $4N$ and it practically does not depend on A (it is commonly assumed, that the dependence should be like $E = 40{\cdot}A^{-1/3}$ [21]). In the same works the model for explanation of the given phenomenon has been offered. From this model follows, that odd *sd*-shell nuclei can be divided into two groups depending on in what state the odd particle is, in $d_{5/2}$- or $d_{3/2}$-subshell. In the first case the position of $E_{c.g.}$ of MDR will be in the range of excitation energy about 5…6 MeV since it is determined only by energy of spin-orbital splitting. In the second case it will be at excitation energy approximately 8…10 MeV since in this case (*nn*)- or (*pp*)-pairs of $d_{5/2}$-subshell will be involved in formation of MDR. This conclusion while is confirmed by the data of published works [26-28] ($E_{c.g.}$ of MDR in nuclei $^{35,37}Cl$, ^{31}P is at 9 …10 MeV, and in ^{27}Al that is at 6 MeV). For confirmation and the further development of modeling representations on nature of MDR and its excitation mechanisms the new experimental data on position, fine structure and total force of MDR are necessary in those even and odd nuclei in which it has not been found yet. After the publication of review [29], the new data on properties of MDR in nuclei ^{23}Na and ^{39}K are received.

The γ-decay of resonance-like structure (RLS) observed at the excitation energy region 9…12 MeV was investigated in the $^{22}Ne(p,\gamma)^{23}Na$ reaction. The excitation function measurements of the reaction in the proton energy region $E_p = 0.8…2.5$ MeV were carried out. To measure the yield of γ-quantums with $E_\gamma \geq 2.6$ MeV ∅ 150 × 100 mm^2 NaI(Tl) detector was used. Spectra and angular distributions of γ-rays were measured at decaying of resonances at E_p = 851, 948, 1593, 1721, 1835 and 1906 keV, forming the RLS, by Ge(Li)-detector in the angular interval 0…90° with $\Delta E_\gamma = 3.2$ keV for E_γ=1332 keV. Strengths of resonant states, determined as:

$$S = (2J+1)\frac{\Gamma_p \Gamma_\gamma}{\Gamma}, \qquad (3)$$

its spins and parities, branching ratios, multipole mixing ratios, probabilities of γ-transitions were determined from the analysis of experimental data. As a result of the carried out measurements the RLS has been found (Fig. 5), similar to what were observed in odd nuclei ^{27}Al, ^{31}P, $^{35,37}Cl$, investigated by us earlier [30].

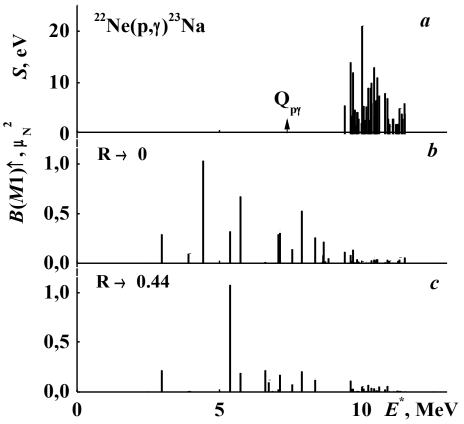

Fig. 5. *Gamma-decay of RLS in the ^{22}Ne(p,γ)^{23}Na reaction: a is the resonance strengths (S ≥ 1 eV); b is the reduced γ-transition probabilities from the ground state in ^{23}Na (R→0); c is the reduced γ-transition probabilities from the first excited state in ^{23}Na (R→440)*

The centre of gravity:

$$E_{c.g.} = \sum_k E_k B_k(M1)\uparrow \Big/ \sum_k B_k(M1)\uparrow \qquad (4)$$

for given RLS depends linearly on A:

$$E_{c.g.} = 11.84 - 0.05A\,. \qquad (5)$$

All transitions investigated by us are basically $M1$ transitions with small admixture of the $E2$ multipolarity. The received strength distribution of $M1$ transitions in ^{23}Na to the ground and the first excited states has the resonant character. The $E_{c.g.}$ position of $M1$ resonance on the ground state is found to be equal 5.6(2) MeV and is in the excitation energy region for nuclei with unfilled $d_{5/2}$-subshell, i.e. it is determined only by the energy of spin - orbital splitting.

The analysis of RLS observed in the ^{38}Ar(p,γ)^{39}K reaction at excitation energy region 7…9 MeV was also carried out. The investigation of excitation function of the given reaction allowed identifying the resonance-like structure (Fig. 6) for the first time.

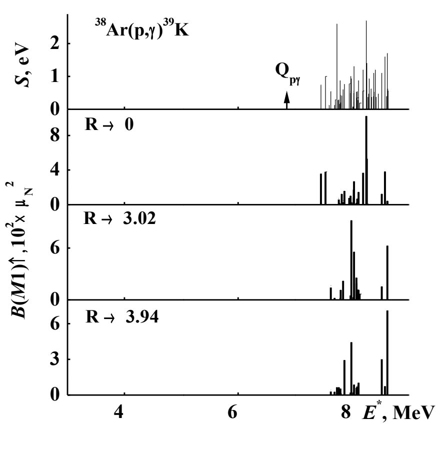

Fig. 6. *Gamma-decay of RLS in the ^{38}Ar(p,γ)^{39}K reaction*

The analysis of spectra and γ-quantum angular distributions at decaying of resonances, forming given RLS with the analysis of excitation function allowed to receive the distribution of $M1$ transition probabilities to the ground state, 3.02 and 3.94 MeV states (see Fig. 6). These distributions have the resonant character. The $E_{c.g.}$ position of $M1$ resonance on the ground state is found to be equal 8.3(9) MeV, and it lays in the region expected for nuclei with filled $d_{5/2}$-subshell (Fig. 7) where the $E_{c.g.}$ position of $M1$ resonance is influenced by the value of $nn(pp)$-pairing.

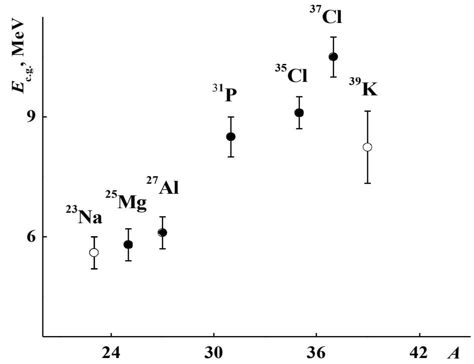

Fig. 7. *The $E_{c.g.}$ position of giant M1 resonance in odd-nuclei of the sd-shell. ^{23}Na and ^{39}K - the present work*

4. ISOVECTOR *l*-FORBIDDEN *M*1 TRANSITIONS

It is known that $M1$ transitions with $\Delta l = 2$ are strictly forbidden in the pure shell model [31]. Nevertheless, such transitions are experimentally observed in all mass regions that make them the good tool for checking the theoretical approaches in describing properties of the excited states of nuclei.

Till now the isoscalar l-forbidden $M1$ transitions between low excited states without isospin changing $\Delta T = 0$ represent special interest for researches [32]. However, the previous analysis of experimental data [33] allows to state that among $M1$ transitions the other group of the single particle l-forbidden $M1$ transitions at which isospin of initial state $T_> = T_0 + 1/2$ and isospin of final state $T_< = T_0 - 1/2$ change by one unit (T_0 is the isospin of a nucleus core) is allocated also. The present work is a part of investigations of the isovector l-forbidden $M1$ transitions which include the results of our experiments on research of the γ-decay of analogue resonances (AR) in nuclei of the $1d2s$-shell [34,35] and also searching of the systematic tendencies for all known data on the mentioned type of transitions in nuclei with $A < 70$.

The feature of considered mass region is the presence both spherical and deformed nuclei [36]. This fact considerably complicates the problem of identification of the pure single particle l-forbidden $M1$ transitions, and especially in our case, when the transition goes between the resonance and excited levels in a nucleus with changing of isobaric spin on unit. Therefore, the objective criteria of the selection of experimental data need to be established.

Identification of configurations was carried out on intensity of state population, measured in reactions with passing of one nucleon or out of experiments on scattering nucleons on nuclei. However, such information was missing for some analog levels. In this case the values of spectroscopic factor S_n of parent states [37] were used.

As an indirect way for the selection of the single particle l-forbidden $M1$ transitions with $\Delta T = 1$ the values of mixing ratios $\delta(E2/M1)$ were used. Unfortunately, the experimental data about these parameters are utterly fragmentary and it does not give an opportunity to estimate the contribution of collective components in the structure of AR. On the basis of the available data it is possible to note that impurities of the $E2$ components in the l-forbidden $M1$ transitions are insignificant. For cases when spin of AR is equal to 1/2, the assumption that parameter $\delta(E2/M1) = 0$ for transitions $s_{1/2} \to d_{3/2}$ was accepted. The rules formulated were used for the selection of data (see Table in [33]) shown in Fig. 8.

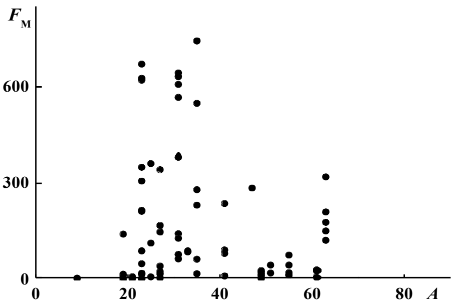

Fig. 8. *Distribution of F_M in nuclei with $A < 70$*

There are also a number of γ-transitions which do not answer strictly to the selection rules mentioned above, but they allow to reveal systematic tendencies for l-forbidden $M1$-transitions $T_> \to T_<$ in light nuclei with odd A. The data on total radiation widths Γ_γ of AR decay are taken, mainly, from the data on integrated cross sections of (pγ)-reactions. In the case, if the proton width Γ_p of a resonant level is not known, it is supposed that $\Gamma_p >> \Gamma_\gamma$.

For AR laying on excitation energy lower than the energy of bound proton, the evaluation of the l-forbidden $M1$ transition rate was carried out from the life time τ of the given states [37]. The inaccuracy in value Γ_γ ($M1$) includes the determination errors of Γ_γ, values of branching ratio $b(\gamma)$ and parameter $\delta(E2/M1)$. At presence of several sets of experimental data for specific γ-transition the preference was given to results with the least inaccuracies.

For the quantitative determination of the decay probability of the l-forbidden $M1$ transitions in comparison with single-particle evaluations, the factor of forbideness F_M was used:

$$F_M = \frac{B(M1)^{th}}{B(M1)^{exp}} . \quad (6)$$

The evaluation of the $B(M1)^{th}$ value was taken from Moszkowski estimate [38] with the statistical factor $S(J_i, L, J_f) = 1$ as the γ-transitions forbidden on l in the single-particle shell model are considered. In such approximation we have [31]:

$$B(M1)^{th} = \frac{1}{\pi} M_\mu \mu_N^2 , \quad (7)$$

where for transitions such as $l \pm 1/2 \leftrightarrow l \mp 1/2$

$$M_\mu = (\mu - \frac{1}{2} g_l)^2 . \quad (8)$$

Here μ is the magnetic moment of a nucleon; g_l is the orbital gyromagnetic ratio. The analysis of the collected experimental data on the given $M1$ transitions in considered nuclei allows formulating some general conclusions. It is established that l-forbidden $M1$ transitions with $\Delta T = 1$ are observed in all region of odd nuclei with $A < 70$. There are two types of isovector l-forbidden $M1$ transitions. Their intensity, in some cases, is comparable with the intensity of the single-particle $M1$ transitions between the analog and antianalog states [39] ($B(M1) \sim 1{,}78\ \mu_N^2$).

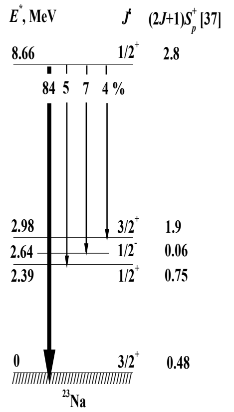

Fig. 9. *Gamma-decay of $s_{1/2}$ analogue state in ^{23}Na*

Transitions such as AR → 0 are concerned to the first type of the investigated ones (see Fig 9). The nature of such transitions is caused by that the giant $M1$ resonance, which centre of gravity is placed in the region of excitation energy of analogue states in light nuclei, takes part in formation of total radiation width of AR.

To the second type $M1$ transitions from AR on the low-excited states in nuclei related to the core-polarized. Really, the γ-transitions to these states are possible. For example, the distribution of $B(M1)$ values for direct transitions from an analog $d_{5/2}$-state on low-lying levels in ^{31}P is shown in Fig. 10. It is visible from distribution of $B(M1)$ that excited states with $J^\pi = 3/2^+$, $5/2^+$ and $7/2^+$ are most intensively populated. Its centre of gravity lays at $E^* \approx 4.41$ MeV. This maximum in distribution is caused by population of core-polarized states (CPS), which are fragmented on a spectrum of the ^{31}P nucleus, and it lies in region of excitation energy expected from microscopic calculations [40]:

$$E_{AR} - E_{CPS} = \frac{V_1}{A}(T_0 + 1/2) + P_n , \quad (9)$$

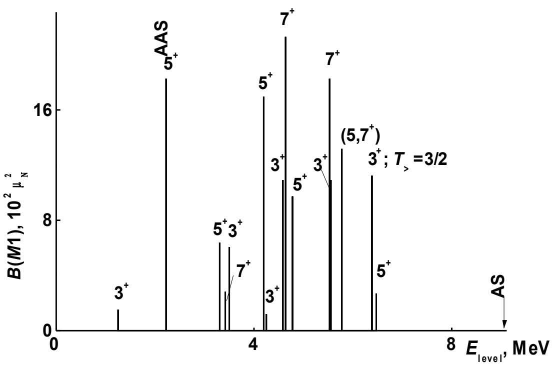

Fig. 10. *Distribution of B(M*1*) values for direct transitions from analog $d_{5/2}$ state on levels ^{31}P*

where $V_1 \approx 100$ MeV, P_n is the pairing energy of a neutron in the daughter nucleus. In fact the given analogue state has a configuration $\left|(s_{1/2}^2)^n_{J_0T_0} d_{5/2}\right\rangle_{J=5/2,T=3/2}$, i.e. it may be considered as one $1d_{5/2}$ nucleon connected with two $2s_{1/2}$ neutrons, coupled in $(J_0T_0) = (01)$ over the inert core of ^{28}Si. Then the transition of the core from $(s_{1/2}^2)_{01}$ to $(s_{1/2}^2)_{10}$ is possible, and in this case the probability of $M1$ transition is large according to [39] since transition includes a $2s_{1/2}$ particle. It should be noticed that there is the core-core $M1$ transition without changing state of a valent $d_{5/2}$ particle. Thus, it is necessary to conclude, that the mechanism removing *l*-forbideness for the mentioned $M1$ transitions occurs due to the collective effects connected with the excitation of core-polarized states and the giant $M1$ resonance.

REFERENCES

1.A.Yu. Buki et all. Main results on nuclear physics obtained at IPHENP NSC KIPT during the last decade // *Problems of Atomic Science and Technology. Series: Nuclear Physics Investigations*. 2001, v. 1(35), p. 15-25.

2.A.F. Khodyachikh. Multiparticle photonuclear reactions on p-shell nuclei in the intermediate energy interval // *Problems of Atomic Science and Technology. Series: Nuclear Physics Investigations*. 2001, v. 1(35), p. 13-14.

3.H. Hebach, A. Wortberg, M. Gari. Photonuclear reactions at intermediate energies // *Nucl. Phys*. A. 1976, v. 267, p. 425-460.

4.D.G. Ireland, G.van der Steenhoven. Comparison of the quasielastic (e, e´p) reactions // *Phys. Rev*. C. 1994, v. 49, p. 2182-2190.

5.K. Mori, P.D Harty, Y. Fujii. ^{12}C(γ,p_{0+1})^{11}B cross section from 44 to 98 MeV // *Phys. Rev*. C. 1995, v. 51, p. 2611-2615.

6.G.J. Miller, J.C. McGeorge, J.R.M. Annand. The ^{16}O(γ,p)^{15}N at E_γ = 60 and 72 MeV // *Nucl. Phys*. A, 1995, v. 586, p. 125-139.

7.G.M. Lotz, H.S. Sherif. Relativistic calculations for photonuclear reactions. (I) The direct knockout mechanism // *Nucl. Phys*. A. 1992, v. 537, p. 285-302.

8.J.I. Johansson, H.S. Sherif, G.M. Lotz. Relativistic calculations for photonuclear reactions. (III) A consistent relativistic analysis of the (e,e´p) and (γ,p) // *Nucl. Phys*. A. 1996, v. 605, p. 517-530.

9.J.I. Johansson, H.S. Sherif. Importance of the direct knotout mechanism in relativistic calculations for (γ,p) reactions // *Phys. Rev*. C. 1997, v. 56, p. 328-337.

10.J. Ryckebusch, K. Heyde, L. Machenil et al. Meson exchange currents and high resolution (γ,p) reactions // *Phys. Rev*. C. 1992, v. 46, p. 829-832.

11.P.D. Harty, J.C. McGeorge, I.J.D. MacGregor et al. ^{12}C(γ,p)^{11}B cross section from 80 to 157 MeV // *Phys. Rev*. C. 1995, v. 51, p. 1982-1990.

12.A.F. Khodyachikh. Photonuclear reactions on *p*-shell nuclei at intermediate energies // *Problems of Atomic Science and Technology. Series: Nuclear Physics Investigations*. 2003, v. 2(41), p. 45-49 (in Russian).

13.F. Ajzenberg-Selove. Energy levels of light nuclei *A* = 11-12 // *Nucl. Phys. A.* 1990, v. 506, №1, p. 1-158.

14.R.W. Carr, J.E.E. Baglin. Table of angular-distribution coefficients for (gamma, particle) and (particle, gamma) reactions // *NDT*. 1971, v. 10, p. 143-204.

15.V.N. Maikov. Some photo-reactions on light nuclei // *ZhETF*. 1958, v. 34, p. 1406-1419 (in Russian).

16.V.V. Balashov, V.N. Fetisov. Role of nucleon clusters in deep photodisintegration of light nuclei // *Nucl. Phys*. 1961, v. 27, p. 337-343.

17.A.E. Torlacius, H.W. Fearing. Phenomenological fit to deuteron photodisintegration data in the medium energy region // *Phys. Rev. C*. 1986, v. 33, p. 1830-1833.

18.V.V. Kirichenko et al. The ^{12}C(γ,p)^{11}B reaction at E_γ^{max} = 120 MeV // *Yad. Fiz.* 1978 v. 27, p. 588-597 (in Russian).

19.A.F. Khodyachikh, P.I. Vatset, I.V. Dogyust, V.V. Kirichenko. The reaction ^{16}O(γ,p)^{15}N at $E_\gamma \le 120$ MeV // *Ukr. Phys. Journ*. 1980, v. 25, p. 229-234 (in Russian).

20.H. Ruijter, J-O. Adler, B-E. Andersson et al. Angular distributions for the ^{12}C(γ,p)^{11}B reaction // *Phys. Rev*. C. 1996, v. 54, p. 3076-3087.

21.B.S. Ishhanov, N.P. Yudin, R.A. Ermgjan. Giant resonances in atomic nuclei // *PEPAN*. 2000, v. 32 (2), p. 313-351 (in Russian).

22.S. Raman, L.W. Fagg, R.S. Hicks. Giant magnetic resonance In: Speth. J. Electric and magnetic giant resonances in nuclei // *International review of nuclear physics*. 1991, v. 7, p. 355-533.

23.L.W. Fagg. Electroexcitation of nuclear magnetic dipole transitions // *Rev. Mod. Phys.* 1975, v. 47, p. 683-694.

24.U.E.P. Berg, K.A. Acksermann, K. Bangert at al. Bound state $M1$ transitions in *sd*-hell nuclei // *Phys. Lett.* 1984, v. 140, p. 297-322.

25.A.S. Kachan, B.A. Nemashkalo, V.E. Storigko. *M*1 resonances in *sd*-shell nucleus // *Yad. Fiz.* 1989. v. 49, p. 367-371 (in Russian).
26.A.S. Kachan, A.N. Vodin, V.M. Mischenko, R.P. Slabospitsky. Fain structure of *M*1 resonances in ^{35}Cl nuclei // *Yad. Fiz.* 1996, v. 59, p. 775-779 (in Russian).
27.A.S. Kachan, A.N. Vodin, V.M. Mischenko, R.P. Slabospitsky. Searching and investigation of fain structure *M*1 resonances in ^{35}Cl and ^{31}P nuclei // *Izvestiya RAN, Ser. phys.* 1998, v. 62, №1, p. 48-53 (in Russian).
28.A.S. Kachan, A.N. Vodin, V.M. Mischenko, R.P. Slabospitsky. Searching and investigation of fain structure *M*1 resonances in ^{27}Al nuclei // *Izvestiya RAN, Ser. phys.* 1999, v. 63, № 5, p. 1027-1038 (in Russian).
29.A.Yu. Buki et al. Main results on nuclear physics obtained at IPHENF NSC KIPT during the last decade // *Problems of Atomic Science and Technology. Series: Nuclear Physics Investigations*. 2001, v 1 (37), p. 15-25 (in Russian).
30.A.S. Kachan, A.N. Vodin, V.M. Mischenko, R.P. Slabospitsky. *M*1 resonances in odd-*A* *sd*-shell nuclei // *Izvestiya RAN, Ser. phys.* 2001, v. 65, № 5. p. 682-686 (in Russian).
31.M.E. Voykhansky. *Gamma-ray.* Col. ed. by L.A. Sliv. Moscow, publ. AN USSR. 1961, p. 5-43 (in Russian).
32.N.A. Bonch-Osmolovskay, V.A. Morozov, M.A. Dolgopolov, I.V. Kopytin. Magnetic dipole *l*-forbidden transitions in odd-*A* nuclei // *PEPAN.* 1987, v. 18, part 4, p. 739-776 (in Russian).
33.A.N. Vodin, I.V. Ushakov. *l*-Forbidden *M*1 transitions in decay of analogue resonances in odd-nuclei with $A < 90$ // *Izvestiya RAN, Ser. phys.* 2004, v. 68, № 2, p. 213-217 (in Russian).
34.A.N. Vodin et al. Isobaric analog resonances in ^{22}Ne(pγ)^{23}Na reaction // *Izvestiya RAN, Ser. phys.* 2004, v. 68, № 2, p. 189-195 (in Russian).
35.A.N. Vodin, I.V. Ushakov. Isovector *l*-forbidden magnetic dipole transitions in nucleus ^{31}P // *Uzhgorod university scientific herald, Ser. phys.* 2003, part 14, p. 83-90 (in Ukrainian).
36.A. Bohr, Ben R. Mottelson. *Nuclear structure.* M.: “Mir”. 1977, v. 2, 664 p.
37.P.M. Endt and C.van der Leun. Energy levels of nuclei $A < 44$ // *Nucl. Phys. A,* 1990, v. 521, p. 1 - 873.
38.S. Moszkovski. Lifetimes of nuclear isomers // *Phys. Rev.* 1953, v. 89, p. 474-482.
39.S. Maripuu. Shell model calculation of *M*1 probabilities from isobaric analogue states // *Nucl. Phys. A.* 1969, v. 123, p. 357-364.
40.Yu.V. Gaponov, Yu.S. Lyutostansky. The microscopic description of Gamow-Teller resonance and collective isobaric 1^+ states of spherical nuclei // *PEPAN.* 1981, v. 12, part 6, p. 1324-1363 (in Russian).

ОСНОВНЫЕ РЕЗУЛЬТАТЫ ПО ЯДЕРНОЙ ФИЗИКЕ, ПОЛУЧЕННЫЕ В ИФВЭЯФ ННЦ ХФТИ В ТЕЧЕНИЕ 2002-2004 гг.

С.Н. Афанасьев, А.С. Качан, А.Ф. Ходячих, И.В. Кургуз, Р.П. Слабоспицкий, И.В. Ушаков, А.Н. Водин

Представлены основные результаты экспериментальных исследований по ядерной физике, полученные в ИФВЭЯФ ННЦ ХФТИ в течение 2002-2004 гг.

ОСНОВНІ РЕЗУЛЬТАТИ ПО ЯДЕРНІЙ ФІЗИЦІ, ОТРИМАНІ В ІФВЕЯФ ННЦ ХФТІ ПРОТЯГОМ 2002-2004 рр.

С.М. Афанасьєв, О.С. Качан, О.Ф. Ходячих, І.В. Кургуз, Р.П. Слабоспицький, І.В. Ушаков, О.М. Водін

Представлено основні результати експериментальних досліджень по ядерній фізиці, отримані в ІФВЕЯФ ННЦ ХФТІ протягом 2002-2004 рр.