Contents

PSEUDOSPIN SYMMETRY AND STRUCTURE OF NUCLEI WITH $Z \geq 100$

R. V. Jolos and V. V. Voronov

The pseudospin symmetry [1–3] is known as approximate symmetry of the nuclear mean field. This symmetry manifests itself as quasi–degenerate doublets in the nuclear excitation spectra. At the same time, the existence of this symmetry strongly depends on the strength of the spin–orbit interaction term of the nuclear mean field, and therefore, to the next proton magic number. The strong spin–orbit interaction in nuclei and the presence of approximate pseudospin symmetry in the nuclear mean field are two sides of the same medal.
Any dynamic symmetry implies the existence of a characteristic multiplet structure. These multiplets are characterized by a magnitude of the multiplet splitting. The characteristic magnitude of a splitting of the pseudospin doublets in spherical nuclei is of the order of $0.1\hbar\omega_0$ where $\hbar\omega_0$ is a frequency of the single particle oscillator.
Single particle pseudospin doublets in deformed nuclei are characterized by a projection of the pseudo–orbital momentum on the symmetry axis. The splittings of these doublets are several times smaller than in spherical nuclei. The doublet structure is also observed in the rotational bands of odd deformed nuclei based on the pseudospin singlets, i.e., on the states with the projection of the pseudo–orbital momentum on the symmetry axis equal to zero. The doublet structure in these bands arises as a result of coupling of an odd particle pseudospin and a total pseudo–orbital momentum. This pseudo–orbital momentum is a sum of a core rotational momentum and a pseudo–orbital momentum of an odd particle. A splitting of these doublets is quite small and equals several tens of keV.
These facts mean that a particle–core coupling term in a phenomenological nuclear Hamiltonian is pseudospin independent with good accuracy. For this reason, the spectra of odd deformed nuclei and especially rotational bands based on the pseudospin singlets are the most interesting objects to look for pseudospin symmetry manifestations.

In [4], we investigated a pseudospin dependence of the particle–core coupling term of the nuclear Hamiltonian. It was found that the pseudospin dependent part of the residual forces δV_{res} can be presented as

$$\delta V_{res}(\mathbf{r_1},\mathbf{r_2}) = -2cb\chi\left(\tilde{\mathbf{l}}_\mathbf{1}\cdot\tilde{\mathbf{s}}_\mathbf{1}\right)\frac{\rho_0(r_1)}{\rho_{av}}\left(1-\frac{\rho_0(r_1)}{\rho_{av}}\right)$$
$$\times\frac{\rho_0(r_2)}{\rho_{av}}\left(1-\frac{\rho_0(r_2)}{\rho_{av}}\right)\sum_{\lambda,\mu}Y_{\lambda,\mu}(\mathbf{r}_1)Y^*_{\lambda,\mu}(\mathbf{r}_2).,\qquad(1)$$

where index "1"in (1) belongs to an odd particle whereas index "2"describes all other particles forming the core. The pseudospin independent analog of the Bohr–Mottelson particle–core coupling term with the radial form factor derived above is

$$\delta V_{res}(\mathbf{r_1},\mathbf{r_2}) = -c^2\chi\frac{\rho_0(r_1)}{\rho_{av}}\left(1-\frac{\rho_0(r_1)}{\rho_{av}}\right)$$
$$\times\frac{\rho_0(r_2)}{\rho_{av}}\left(1-\frac{\rho_0(r_2)}{\rho_{av}}\right)\sum_{\lambda,\mu}Y_{\lambda,\mu}(\mathbf{r}_1)Y^*_{\lambda,\mu}(\mathbf{r}_2).\qquad(2)$$

Comparing (1) and (2) one can see that the strength of the interaction term (1) is $2\frac{b}{c}\langle\tilde{\mathbf{l}}_i\cdot\tilde{\mathbf{s}}_i\rangle$ times smaller than that of the pseudospin independent particle–core coupling term. The matrix element of the particle–core interaction term in the Bohr–Mottelson model in the case of deformed nuclei can be estimated as $\sim$2.3 MeV. Then a splitting of the pseudospin doublets in the rotational bands of odd nuclei is $\sim 7\tilde{L}$ keV where $\tilde{L}$ is a total pseudo–orbital momentum of a state. This estimate is in correspondence with experimentally observed splitting.
Some possibilities for experimental studies of the pseudospin symmetry manifestations in the spectra of odd nuclei with $Z \geq 100$ were indicated in [4] as well.

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GENERATOR COORDINATE Q_n-Q_p STUDY OF LOW-LYING COLLECTIVE STATES IN NEUTRON-RICH OXYGEN ISOTOPES

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Experimental progress in the study of exotic nuclei stimulates new theoretical developments by opening a possibility for new collective modes which will affect the low-energy spectra of nuclei away from the β-stability line, among which are new deformation modes or a change of the magic numbers known in nuclei close to stability. The new phenomena are partly attributed to extreme isospin asymmetry. It is well known that the isoscalar quadrupole mode dominates the standard low-energy large-amplitude collective dynamics. How can it be affected by a neutron excess in neutron-rich nuclei ?

We have started such an exploration of this mode in ^{20}O [1]. Our analysis was based on constrained Hartree-Fock-Bogoliubov (HFB) calculations performed with the Skyrme SLy4 interaction and a density-dependent zero-range pairing interaction. We consider i) a single constraint on the total axial quadrupole moment Q which generates a one-dimensional deformation energy curve and ii) two independent neutron and proton quadrupole constraints generating a deformation energy surface. The HFB wave-functions for each set of values for the quadrupole moments are projected on good particle numbers (N,Z) and on the total angular momentum J.

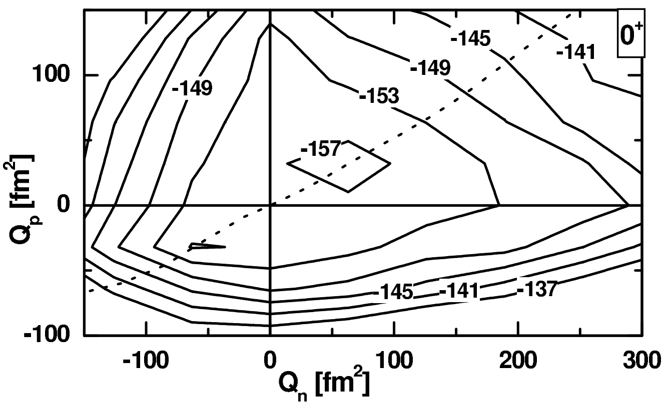

Рис. 1: Nucleus ^{20}O; contour lines of the $\{Q_n, Q_p\}$ deformation energy surface for $J = 0$. The curves are labelled by the absolute energy in MeV. The dashed line shows the deformation path associated with the standard isoscalar quadrupole constraint Q, where $Q = Q_n + Q_p$.

Finally, the properties of the ground and low-lying collective states were computed by a configuration mixing performed within the generator coordinate method [2]. Our results show that already for this neutron-rich nucleus the transition probabilities are modified when independent neutron and proton collective dynamics are allowed. Preliminary calculations [3] encouraged us to extend the calculation to all the oxygen isotope series.

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SPIN-ISOSPIN EXCITATIONS AND NUCLEAR MUON CAPTURE

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Distributions of the transition strength of spin-isospin operators $\left(\sum_{k=1}^{A}\sigma_k t_k^{\pm,0}\right)$ over the excitation energy in nuclei are studied experimentally in electromagnetic and hadronic processes [1]. Their low-energy part determines the rates of Gamow-Teller beta-decay, where $\sigma t^{\pm}$ transition operators work.

In many nuclei the distribution of the reduced probability of GT transition, $B^{-}(\mathrm{GT})$, over the excitation energy (GT strength function) calculated within the RPA agreed well with the distributions extracted from the experimental cross sections of (p,n) reaction. The only discrepancy was found that experimental $B(\mathrm{GT})$ summed over all states forms approximately 60% of the corresponding theoretical strength (the so called effect of *missed* or *quenched* GT strength) [1]. The coupling of particle-hole $(1p{-}1h)$ and $2p{-}2h$ configurations is usually considered as the cause of shifting a large fraction of GT strength from the GT resonance to higher energies [1,2]. However, the comparison of energy-weighted moments of the strength function calculated within the RPA, on the one hand, and within the "second" RPA or in the fragmentation approximation, on the other hand, shows that the transfer of a considerable fraction of the particle-hole transition strength to highly excited states, which may be caused by an interaction between the $1p{-}1h$ and $2p{-}2h$ configurations, must be accompanied by a large increase in the strength accounted for low-energy excited states and a decrease in their energies [3,4]. Therefore, the shift of the GT strength to higher energies should be produced by the interaction among the $1p{-}1h$ states only [4,5]. This interaction should mix the states in which the particle and hole levels are from the one major shell, $\Delta N = 0$ states, and the $1p{-}1h$ states with particle and hole from different major shells, $\Delta N \geq 2$ states. This specific feature of a nuclear effective spin-isospin interaction is necessary to explain the GT strength missing. The calculations with the corresponding effective interaction well reproduce the experimental GT strength function in a wide range of excitation energies [4, 5].

Such a feature of the residual interactions must also manifest itself in other processes with spin-isospin transitions involved. Our calculations [6] show that the total muon capture rate in nuclei depends mainly on spin-multipole nuclear transitions. Thus, the question of how different effective interactions influence the total OMC rates is of considerable interest. The calculations performed for medium nuclei (^{58,60,62}Ni, ^{90}Zr, and $^{116-124}$Sn) with different residual interactions yield practically the same values of the total OMC rates, which are in good agreement with experimental data. In heavier nuclei (^{140}Ce and ^{208}Pb) theoretical total OMC rates exhibit a noticeable dependence on the residual interactions and considerably exceed experimental values. The discrepancy between the theory and experiment becomes the largest if one uses the residual interaction which mixes intensively $\Delta N = 0$ and $\Delta N \geq 2$ particle-hole states [6]. Transitions to the high-lying 1^+ states provide the largest part of the excess.

The immediate comparison of the manifestations of spin-isospin transitions in different processes is possible in $N = Z$ nuclei. The isovector $0^+ \to 1^+$ transitions with different isospin projections were observed in the reactions $^{28}\mathrm{Si}(\mu,\nu)^{28}\mathrm{Al}$, $^{28}\mathrm{Si}(e,e')^{28}\mathrm{Si}$, and $^{28}\mathrm{Si}(p,n)^{28}\mathrm{P}$. The calculations [7] show that for the fastest transitions there is

a close agreement with experimental values of both the partial OMC rates and the reduced probabilities of magnetic dipole transitions, but theoretical $B(\mathrm{GT})$'s overestimate considerably the values obtained from the (p, n) reaction.
The analysis presented in [5] revealed that the distributions of the GT transition strength over the excitation energies extracted from (p, n) reactions and from the OMC rates are at variance. Probably, the relation between the cross sections of charge-exchange reactions and $B(\mathrm{GT})$ is quite complicated even for the strong GT transitions and the determination of $B(\mathrm{GT})$ from the cross sections of (p, n) and similar reactions needs to be reexamined.

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DEVELOPMENT OF THE WFM METHOD AND THE NUCLEAR SCISSORS MODE

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To understand the place of the method of Wigner Function Moments (WFM) among various methods describing the collective motion, the detailed comparison of the WFM with the Random Phase Approximation (RPA) and the Green Function (GF) methods was performed in [1-3]. This comparison was exemplified by the Harmonic Oscillator plus Quadrupole–Quadrupole (HO+QQ) force model. Under certain circumstances all three methods give essentially the same results. For example, all methods give in our model the same analytical expressions for energies and transition probabilities for all the excitations considered. It turns out that the WFM and GF methods are very close to one another. Contrary to RPA, both work in phase space and incorporate semiclassical aspects, with no need to introduce a single particle basis. Finally, both the methods yield identical sets of dynamical equations for the moments. For the harmonic oscillator with multipole–multipole residual interaction of arbitrary rank (multipolarity) the equations of both the methods can be derived without any approximations – the interaction of the multipolarity n generates a set of dynamic equations for tensors (moments) of the rank n. However, in the case of realistic forces the GF method loses its simplicity, whereas the WFM method continues to be a convenient and powerful tool for description of collective motions, as it was demonstrated in [4] by employing Skyrme forces.

The exact relation between the RPA and WFM variables and the respective dynamic equations were found. The analytical equivalence between the WFM and RPA methods was established by introducing the dynamic equations for transition matrix elements. They can be derived either from the RPA equations for the amplitudes X_{kq}, Y_{kq} or from the WFM dynamic equations for the moments. This proves the identity of eigenvalues in both the methods under the condition that a complete basis is used in both the cases. However, both the methods behave differently when the dimension of the space is reduced. Actually, the WFM is designed to use only rather a few moments of low rank. The restricted number of eigenvalues approximate the collective states in an optimal way, representing their strengths and centroid positions, as this was shown in [4]. On the contrary, in the RPA one needs in general rather large space to correctly account for the collectivity of, e.g., giant resonances. At the same time, a certain fine structure of the resonances is also obtained. Both the methods are thus complementary.

An interesting situation is observed for currents. In the RPA the current lines can even in the simple HO+QQ model be calculated only numerically (and only approximately because of the basis truncation) whereas by the WFM and GF methods they are found exactly.

The WFM method was generalized to take into account the pairing correlations in Ref. [5]. The equations of motion for angular momentum, quadrupole moment and other relevant collective variables were derived on the basis of the time dependent Hartree-Fock-Bogoliubov equations. Analytical expressions for energy centroids and transitions probabilities are found for HO+QQ model with the monopole pairing force. Deformation dependence of energies and $B(M1)$ values are correctly reproduced. The inclusion of pairing leads to a drastic improvement in the description of qualitative and quantitative characteristics of the scissors mode, which is demonstrated in the figure, where the calculated scissors mode energies E_{sc} and transition probabilities $B(M1)$ are compared with experimental data [6] for most of the nuclei where this mode is observed.

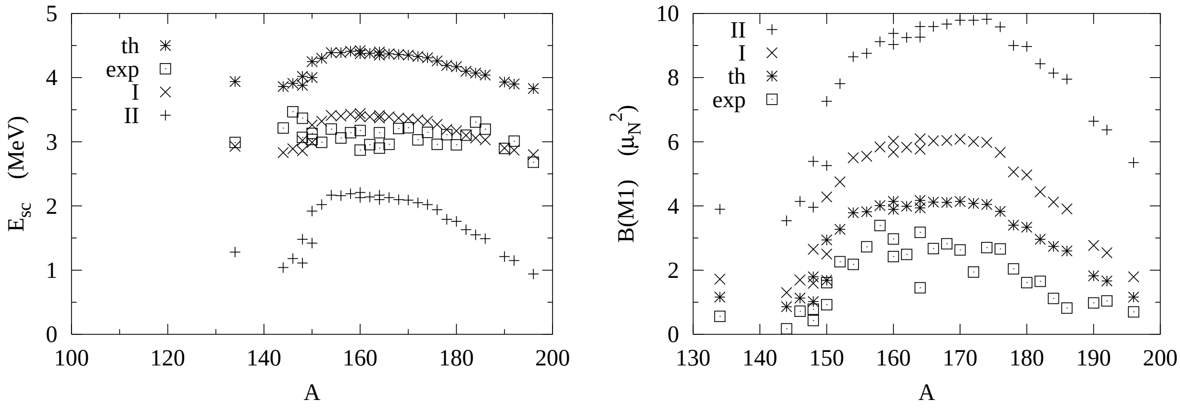

Рис. 1: Energies and transition probabilities of the scissors mode as a function of atomic number. th – full theory with pairing, I – the pairing gap is included but the deformation of the pairing field is not taken into account, II – theory without pairing.

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NUCLEAR REACTIONS AND NUCLEAR STRUCTURE WITHIN DINUCLEAR SYSTEM MODEL

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The theoretical model for describing the fusion of heavy nuclei, quasifission and transfer reactions was developed within the dinuclear system (DNS) concept. In this model, the fusion and quasifission are assumed as diffusion processes in the mass asymmetry $\eta = (A_1 - A_2)/(A_1 + A_2)$ (A_1 and A_2 are the mass numbers of the DNS nuclei) and internuclear distance R, respectively. The yields of transfer-type products accompanying cold fusion reactions were calculated in [1]. The cross section for these products increases with decreasing in neutron number of the projectile. Some of the products emit alpha particles with quite large energies which are comparable with energies of alpha particles emitted from superheavy nuclei. The measurement of the yield of transfer-type products in cold fusion reactions and the comparison with the theoretical predictions would be important for understanding the mechanism of fusion.

The decay of the DNS from the configurations more asymmetric than the initial one can result in unknown isotopes of the heaviest nuclei in actinide-based reactions (see [2]). In the reactions ^{48}Ca+^{238}U, ^{243}Am, and ^{244,246,248}Cm one can produce new isotopes of superheavies with $Z = 104 - 108$ which are not reachable in hot and cold complete fusion reactions with stable projectiles and targets. The production of these isotopes is also important for experimental identification of superheavy nuclei. The methods elaborated to describe asymmetry-exit-channel quasifission reactions are suitable for the analysis of production of various exotic nuclei, for example, of neutron-rich light nuclei.

The results of calculations show that the production cross sections of neutron-rich nuclei ^{52,54,56,58,60}Ca in the ^{48}Ca+^{197}Au reaction are much smaller than in the ^{48}Ca+^{238}U reaction [3,4]. Combining these results with our calculations of the diffusive nucleon transfer reactions ^{48}Ca+^{124}Sn,^{232}Th,^{248}Cm one can conclude that the production cross sections of neutron-rich isotopes of Ca increase with the charge (mass) number of the target in the transfer reactions with ^{48}Ca beam. This effect is quite strong and should be taken into consideration in the planned experiments. The reactions with actinide targets seem to be preferable. In the diffusive nucleon transfer reactions the production of a nucleus near the neutron drip line increases with the value of $E_{\text{c.m.}}$ up to the moment when the excitation energy of this exotic nucleus reaches the threshold for neutron emission. Therefore, the neutron separation energies for the unknown isotopes can be estimated by measuring their excitation functions.

Using the statistical model and recent theoretical predictions of nuclear properties, survival probabilities of superheavy nuclei with respect to the xn evaporation channel ($x = 1 - 4$) were calculated in [5]. Level densities of the Fermi-gas model and of a model with collective enhancement were used. The survival probabilities and the fusion cross-sections calculated within the DNS model were applied to obtain excitation functions of No isotopes in the reactions ^{48}Ca+^{204,206,208}Pb and production cross-sections of superheavy nuclei with $Z > 102$ in cold and hot fusion reactions. The results are in good agreement with the available experimental data.

The cluster interpretation of collective low-lying alternative parity states of the nuclei with $Z \geq 96$ was suggested in [6]. Within the cluster approach the α-cluster configuration gives a significant contribution to wave functions of low-energy nuclear states. The energies of the low-lying states of the even-even as well as the odd heaviest nuclei whose parity is opposite to the parity of the ground state were predicted. The lowest energies of these states are about 600–900 keV and 300–600 keV for the even-even and odd nuclei, respectively. The observation of these states would be a crucial test of correctness of the suggested approach. Our predictions for spectra and intrinsic transition multipole moments are helpful for the present and future experimental works regarding the spectroscopy of superheavy nuclei.

The cluster decay process involves the motion in mass asymmetry coordinate η and the relative separation coordinate R. Using the decay probabilities of the DNS by tunneling through the barrier in nucleus-nucleus potential and the calculated spectroscopic factors, half-lives of cluster decays were obtained in [7].

Within our cluster approach it was shown that the bimodality or multimodality of fission can be related to variations of the charge and mass splittings in the small interval of charge and mass numbers [8]. The suggested explanation of bimodal fission is rather simple and allows us to describe well the available experimental data. Based on potential energy calculations of ternary systems at scission and on statistical analysis the model of ternary fission was developed in [9]. The formation of the ternary system is considered as the second step after the formation of the binary system by means of extracting one or several α-particles and neutrons from one or both binary fragments in the region of their interaction. Within the model, the charge distributions for fission of the heavy nucleus ^{252}Cf and the light nucleus ^{56}Ni accompanied by various light charged particles were described.

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CONTINUUM SPECTROSCOPY OF TWO-NEUTRON HALO NUCLEI

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One of the most interesting questions in the physics of radioactive beams is that of the structure of halo nuclei at the limits of nuclear existence. In Borromean two-neutron halo nuclei, like ^{6}He and ^{11}Li, the nature of the three-body continuum is currently most intriguing. The concentration of transition strength, experimentally observed in these nuclei at low excitation energy, may contain information on three-body resonances or new kinds of collective motion, such as a soft dipole mode corresponding to oscillations of the core against the halo neutrons. The continuum is usually explored via responses induced by transitions from the ground state to the continuum. A viable way to study the continuum properties is to explore nuclear reactions under conditions where one-step transitions dominate. This is, however, still a rather comprehensive task, because of the intertwining of the ground state and continuum structures, influenced by reaction mechanisms.

Due to the unstable nature of halo nuclei their experimental studies have so far been performed by reactions involving collisions in inverse kinematics. The theoretical analysis of such reactions involves the strong nucleon-nucleon interactions. The strength and complicated character of strong interactions bring ambiguities in disentangling the reaction mechanism and nuclear structure. In spite of a considerable amount of nuclear structure information on halo nuclei extracted from collisions with other nuclei, cleaner ways to study aspects of their structures are greatly needed. Thus, a theory for electron scattering from Borromean two-neutron halo nuclei with full inclusion of final state interactions was developed in [1]. The halo nucleus was described as a three-body system. Nuclear wave functions for bound state and low-lying three-body continuum excitations were calculated by the method of hyperspherical harmonics. The model was applied to explore electron scattering on ^{6}He leading to nuclear excitations near the three-body breakup threshold.

The task of continuum spectroscopy is to determine which modes of nuclear excitations are dominant at given excitation energy or in some region of excitation energies. In kinematically complete experiments, in parallel to the excitation spectrum, we can study many different angular and energy correlations between fragments. Thus continuum spectroscopy implies a consistent analysis of a variety of exclusive and inclusive cross sections accessible in kinematically complete experiments. Experimental data on different angular and energy correlations of the three fragments from breakup of ^{6}He on lead target at collision energy 240 MeV/nucleon, obtained recently at GSI, reveal a very interesting picture. The low-energy spectrum of ^{6}He shows a smooth behaviour, while with increasing excitation energy, the shape of some correlations changes dramatically along the spectrum. Energy- and angular correlation distributions of the three fragments in ^{6}He were discussed in [2] within the microscopic four-body distorted wave model and compared with experimental data. The calculations describe the experimental data for fragment correlations near the breakup threshold rather well and the physics is contained in a few elementary modes, but with increasing excitation energy of ^{6}He some striking deviations from experimental distributions are encountered. Possible reasons for this were pointed out.

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MICROSCOPIC OPTICAL POTENTIAL FOR NUCLEUS-NUCLEUS ELASTIC AND INELASTIC SCATTERING AT INTERMEDIATE ENERGIES

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The double-folding (DF) microscopic model of an optical nucleus-nucleus potential was suggested in [1], where a dependence on the energy and atomic numbers of colliding nuclei was taken into account. Basing on this model a set of potentials $U_{opt} = N_r V^{DF} + iN_{im} W^{DF}$ was obtained in [1, 2], where only the pairs of strength coefficients N_r, N_{im} were fitted to experimental data [3,4] on elastic scattering of the ^{16,17}O heavy ions at energies E about 100 MeV/nucleon off different target-nuclei. When calculating the corresponding differential cross-sections, the high-energy approximation (HEA) method [5] developed for nucleus-nucleus scattering was applied. Then, the obtained potentials for elastic scattering were used to get the transition potentials and to calculate inelastic scattering with excitations of low lying collective states of nuclei with $E_{ex} \ll E$. The corresponding HEA amplitudes were constructed basing on the adiabatic approach and using rotational wave functions [6].

The results [7] were compared with the experimental data from [4] and the adjusted deformation parameters were established. These examples show that one achieves the fairly good agreement with experimental data introducing no more than two normalization parameters of the microscopic optical potential. Thus, the suggested model has encouraging perspectives for application in further analysis of experimental data.

Figure 1 shows a comparison of the experimental data with the results of calculations of elastic and inelastic differential cross sections with excitations of 2^+ collective states in the target-nuclei.

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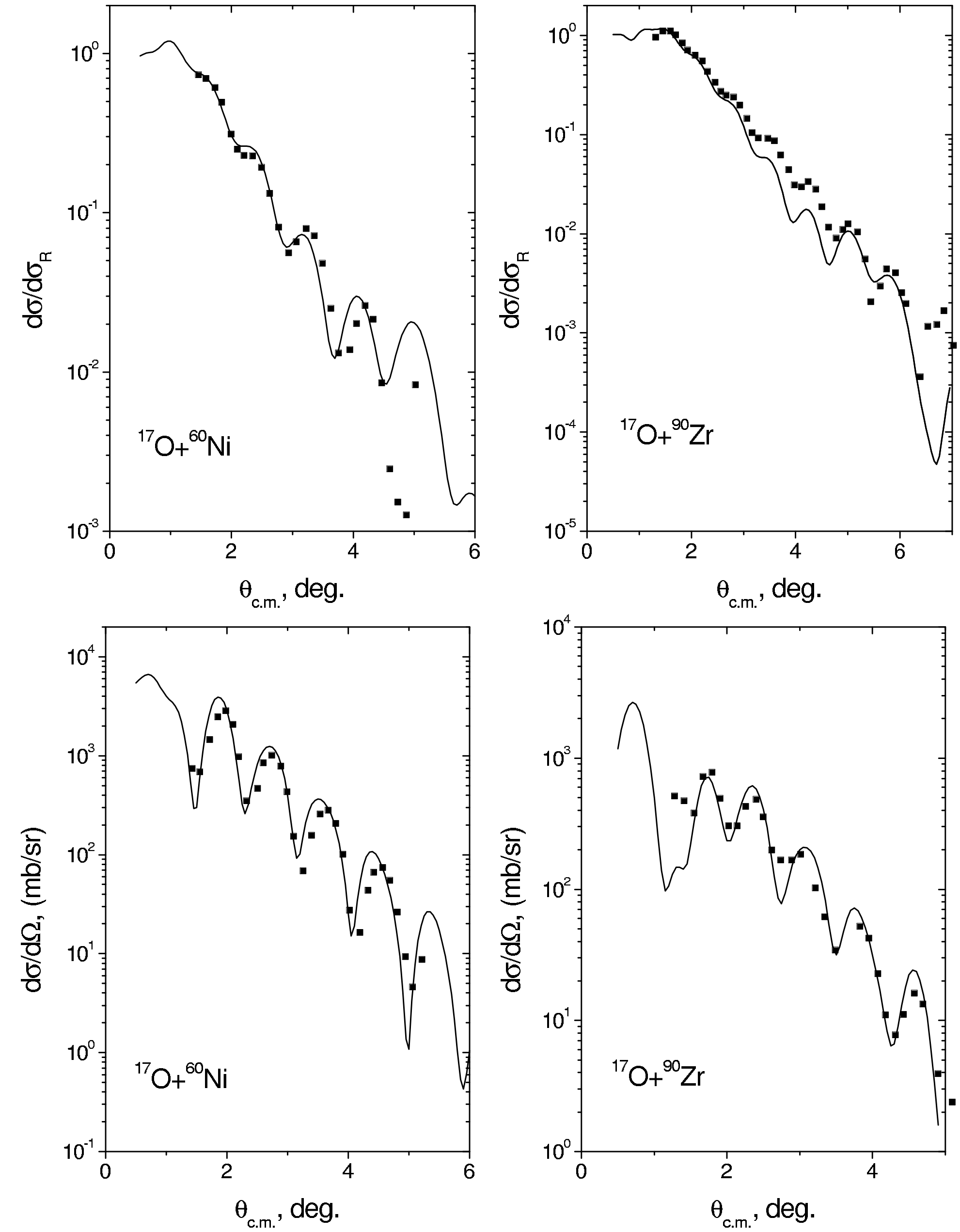

Рис. 1: Elastic (upper row) and inelastic (bottom row) differential cross sections for reactions ^{17}O+^{60}Ni,^{90}Zr at E_{lab}=1435 MeV calculated in [7]. The parameters N_r and N_{im} of the DF microscopic optical potentials are equal to 0.6 and 0.6 for ^{60}Ni, and 0.6, 0.5 for ^{90}Zr. Nuclear deformation is $\beta_n = 0.4$ (^{60}Ni) and $\beta_n = 0.16$ (^{90}Zr). Experimental data are from [4].

ALPHA PARTICLES ACCOMPANYING WEAK DECAY OF ${}^{10}_{\Lambda}$Be AND ${}^{10}_{\Lambda}$B HYPERNUCLEI

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Hypernuclei are a convenient laboratory to study the baryon-baryon weak interaction and the associated effective weak Hamiltonian. The strangeness changing process, in which a Λ-hyperon in nuclear matter converts into a neutron with a release of up to 176 MeV, provides a clear signal for a conversion of an s-quark to a d-quark.

It was proposed [1] to use the unique feature of the ^{9}Be nucleus: after removing a neutron from its ground state *several groups of α-particles* appear from different excited states of the residual nucleus ^{8}Be. Due to their salient cluster structure — $\alpha\alpha N\Lambda$ — it may be possible to measure in the $^{10}_{\Lambda}$Be and $^{10}_{\Lambda}$B hypernuclei the partial "alpha-decay widths" $\Gamma^{n\,(p)}_{\alpha\alpha\,i}$ corresponding to states of the residual nucleus $^8\mathrm{Be}(E_i; J^{\pi}_i, T_i)$ which decays through the $\alpha\alpha$-channel. These branching fractions $\Gamma^{n\,(p)}_{\alpha\alpha\,i}$ depend on various combinations of four matrix elements; hence, their study offers a unique possibility of determining all needed matrix elements of the weak interaction and in such a way localizing the difficulties of the hypernuclear nonmesonic decay puzzle.

The calculations [2] have shown that measurement of the partial widths $\Gamma^{n\,(p)}_{\alpha\alpha\,i}$ of the decays of the $^{10}_{\Lambda}$Be and $^{10}_{\Lambda}$B hypernuclei into the $(0^+,0)_{\mathrm{g.s.}}$, $(2^+,0)_{1,2}$, $(2^+,1)_1$, and $(1^+,1)_1$ states of ^{8}Be will make it possible to determine all the matrix elements of the effective weak interaction $\Lambda N \to nN$ which are necessary to describe the weak nonmesonic decays of any p-shell hypernucleus. The dependence of the theoretical widths $\Gamma^{n\,(p)}_{\alpha\alpha\,i}$ on the nuclear models used in the calculations was studied, too. It was shown that the neutron spectroscopic factors calculated with wave functions of the relevant states of the ^{8}Be and ^{9}Be nuclei depend only slightly on the used residual interactions.

Having at our disposal a set of data on weak decays into several states of ^{8}Be, we found combinations that carry bulk of information about weak ΛN-interaction. We showed [2] that using some additional approximations one can relate the ratios of the α-decay widths for the isodoublet of the $^{10}_{\Lambda}$Be and $^{10}_{\Lambda}$B hypernuclei to the calculated features of the nonmesonic decays of the $^4_{\Lambda}$H and $^4_{\Lambda}$He hypernuclei and thereby to choose an adequate model for weak ΛN-interaction.

So it is shown how the nuclear structure aspects of the problem, often an unwelcome detail of calculations attempting to understand a basic two-body $\Lambda N \to nN$ interaction, can be used to pick out components of the effective weak Hamiltonian.

Recently, the JINR Nuclotron has supplied the first extracted beam of medium energy ions. This opens new opportunities of performing hypernuclear experiments. With the new trigger tuned to search for two α-particles, the branching fractions $\Gamma^{n}_{\alpha\alpha\,i}(^{10}_{\Lambda}\mathrm{Be})$ and $\Gamma^{p}_{\alpha\alpha\,i}(^{10}_{\Lambda}\mathrm{B})$ will be measured [3].

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PROPERTIES OF THE ^{12}C NUCLEUS WITHIN THE FRAMEWORK OF THE α-CLUSTER MODEL

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A variety of low-energy nuclear properties can be successfully described within the framework of the α-cluster model. The effective two-body and, for more than two α-particles, at least three-body potentials must be determined as an input for the model. The calculations of the three-α scattering provide important information on the effective $\alpha - \alpha$ interactions which is of interest for the α-cluster calculations. Thus, the effective potentials should be chosen by fitting the main characteristics of the ^{12}C nucleus to the experimental values. Of particular importance is the description of the ultra-narrow near-threshold three-body resonance (0_2^+ state), which is responsible for the helium burning in stars. During the last years, also the wide 0_3^+ resonance state of ^{12}C is under experimental and theoretical study.

In Ref. [1], properties of the lowest 0^+ states in ^{12}C were calculated to study a role of the three-body interactions in the α-cluster model. The ^{12}C nucleus was treated as a system of three α-particles. The main question to be answered was to what extent the α-cluster model is able to reproduce the experimental energies and sizes of the corresponding states. A more challenging problem was to describe the fine characteristics, such as the width Γ of the near-threshold 0_2^+ state and monopole $0_2^+ \to 0_1^+$ transition matrix element M_{12}, which are extremely sensitive to the choice of the potentials. Furthermore, the effective three-body interactions could be used to take into account the non-α-cluster structure of the nucleus at short distances in addition to the effect of α-particle distortions at large distances. Clearly, the choice of the effective two-body and three-body potentials must be governed by the results of the three-body calculations aimed at optimal description of the ^{12}C characteristics.

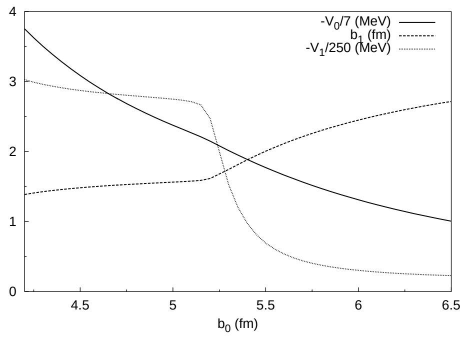

Рис. 1: Relation between the parameters of the three-body effective potential $V_3(\rho) = V_0 e^{-\rho^2/b_0^2} + V_1 e^{-\rho^2/b_1^2}$.

The method of calculation was based on the expansion of the total wave function in a series of eigenfunctions on the hyper-sphere that provides an accurate determination of fine characteristics of ^{12}C. Calculations were performed for the two families of local two-body potentials, which provide the experimental energy of the α-α resonance (the ground state of ^{8}Be). The first family of the two-body potentials with a soft repulsive core used provides the width of the α-α resonance in the range 6.4 eV $\le \gamma \le$ 6.8 eV and there was

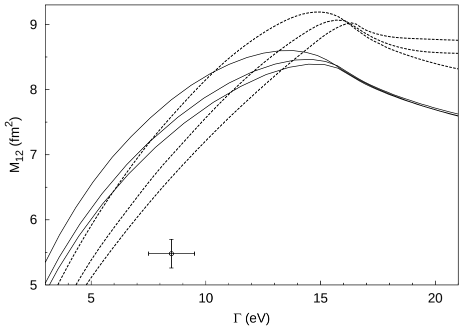

Рис. 2: Relation between the width Γ of the 0_2^+ state and the monopole $0_2^+ \to 0_1^+$ transition matrix element M_{12}. The point with error-bars shows the experimental data.

no special care to describe experimental $\alpha-\alpha$ scattering phase shift. The second family of the two-body potentials with a comparatively hard repulsive core provides the ^{8}Be width within the limits 5.57 eV $\leq \gamma \leq$ 5.82 eV and a good description of the α-α scattering phase shift up to the energy $E_{cm} < 12$ MeV.

Given the two-body potential, one constructs a one-parameter set of the three-body potentials which reproduce the experimental energies of the ground and excited 0^+ states and the ground-state root-mean-square radius of ^{12}C. The relations between the parameters (the strengths $V_{0,1}$ and the ranges $b_{0,1}$) of the effective three-body potentials are exemplified in Fig. 1. Using a particular set of the three-body potentials, one obtains the different sets of calculated Γ and M_{12}. The relations between Γ and M_{12} are depicted in Fig. 2 by the dashed and solid lines for the first and second family of two-body potentials, respectively. One should mention that a change of the parameter b_0 within the interval 4 fm $< b_0 <$ 6 fm corresponds to a change of the width within the interval 5 eV $< \Gamma <$ 20 eV.

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SUPPRESSION OF QUANTUM SCATTERING IN STRONGLY CONFINED SYSTEMS

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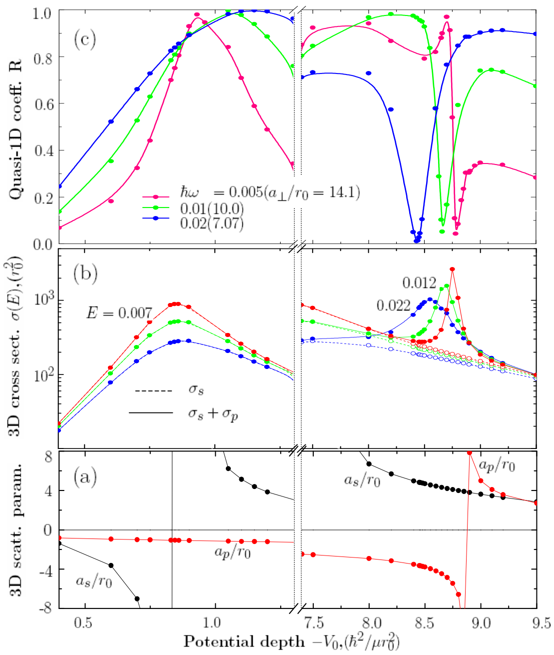

We have found [1] that the atom-atom interaction or the scattering of an electron off a fixed impurity can be virtually switched off by the impact of a geometrical confinement. By tuning the width $a_\perp = \sqrt{\hbar/\mu\omega}$ of optical or magnetic trap $U(\rho) = \frac{1}{2}\mu\omega^2\rho^2$ one can turn off the ultracold atom-atom scattering in the confining trap. This happens if the fundamental atom-atom two-body interaction is rather strong and the two-body s- and p- scattering lengths $a_s \sim -a_p$ reach the order of the confinement width $a_\perp = 1.45a_s$.
By using the scattering on the screened Coulomb potential $V(r) = V_0\frac{r_0}{r}\exp\{-\frac{r}{r_0}\}$ as an example, the figure illustrates how the harmonic trap can transform the pure p-wave resonance in the 3D free space to the free particles flow in the quasi-1D geometry. At that, the maximum in the 3D scattering cross section $\sigma(E)$ (at the point $a_p \to \mp\infty$) transforms into the minimum of the reflection coefficient R, describing the particle flow in a quasi-1D trap, if $a_\perp = 1.45a_s$ and $a_s \sim -a_p$.
This effect might be useful for improving the sensitivity of guided atom interferometers, for controlling properties of quasi-1D quantum gases and decreasing the heat dissipation in tiny electronic devices.

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SCATTERING LENGTH FOR HELIUM ATOM-DIATOM COLLISION

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The two-body scattering length in a dilute gas of alkali atoms can be varied by changing the external magnetic field close to a Feshbach resonance. In this way, one may force the two-body s-wave scattering length to go from positive to negative values through infinity. Therefore, the magnetic field is an appropriate tool in modeling the Efimov effect which was experimentally observed in an ultracold gas of caesium atoms by Kraemer et al. [1] (see also [2]) more than 35 years from the initial prediction [3]. Recall that this effect occurs in case of infinite two-body scattering lengths, manifesting itself in an infinite number of three-body bound states. The role of the magnetic field combined with a Feshbach resonance may be mimicked by varying the coupling constant (a multiplying factor λ) of the two-body interaction within a three-body system that is not necessarily subject to a magnetic field. In this context the system of three helium atoms appears to be the best candidate. Actually, it was shown that the excited state of the ^{4}He trimer was already of Efimov nature. To get the complete Efimov effect, it suffices to weaken the He–He interatomic potential only by about 3%.

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ON RELATIVISTIC ANALYSIS OF THE EXCLUSIVE ELECTRODISINTEGRATION OF THE DEUTERON

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The electrodisintegration of the deuteron in the framework of the Bethe-Salpeter approach with a separable kernel of the nucleon-nucleon interaction was considered. This conception keeps the covariance of a description of the process. Firstly, the relativistic impulse approximation in the plane-wave approximation was investigated. The factorization of the cross section of the reaction was obtained analytically. It was shown that the photon-neutron interaction plays an important role. Then the contribution of the final-state interaction to the differential cross-section of exclusive deuteron electrodisintegration was considered. The Bethe-Salpeter formalism with a phenomenological rank-one separable interaction was used for the final *np*-pair vertex obtained by analyzing the phase-shifts in every partial-wave channel for J=0,1. The approximations made were the neglect of two-body exchange currents, negative-energy components of the bound-state vertex function, and the scattering T matrix. The effects of the final-state interaction with J=0,1 were discussed. The relativistic results were compared with the nonrelativistic ones both in the plane-wave approximation and in every partial-wave channel. It was found that the relativistic effects change the magnitude of the final-state interaction from several per cent to several tens of per cent.

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EQUATION OF STATE AND HEAVY-ION COLLISIONS

V. D. Toneev

Mainly two related issues of relativistic nuclear physics were investigated during this time: the equation of state (EoS) of hot and dense nuclear matter and its manifestation in dynamics of heavy ion collisions.

Based on the quasiparticle description of the QCD medium at finite temperature and density we formulate the phenomenological model for the equation of state that exhibits crossover or the first order deconfinement phase transition [1]. The models are constructed so as to be thermodynamically consistent and satisfy the properties of the ground state nuclear matter complying with constraints from intermediate heavy–ion collision data. As exemplified in Fig. 1, our equations of states show quite reasonable agreement with the recent lattice findings on the temperature and baryon chemical potential dependence of the relevant thermodynamic quantities in the parameter range covering both the hadronic and quark–gluon sectors.

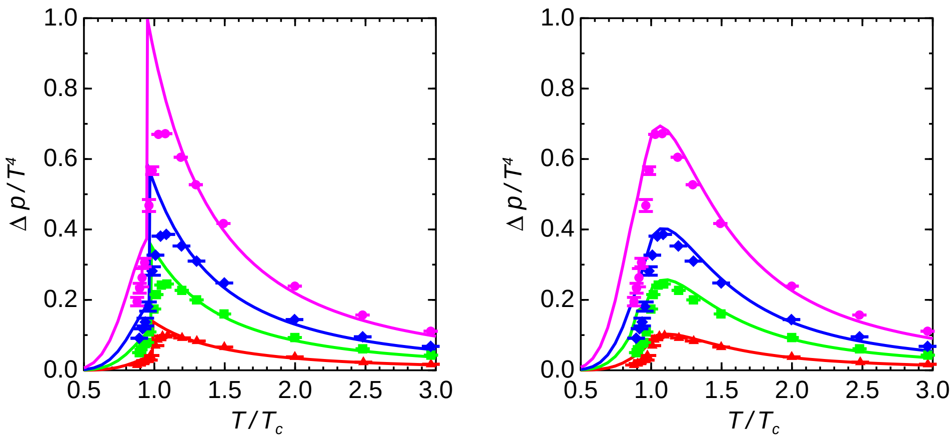

Рис. 1: Temperature dependence of the reduced pressure $(p(\mu_B) - p(0))/T^4$ at the baryon chemical potential $\mu_B = 210$, 330, 410 and 530 MeV (from the bottom) within two-phase (left panel) and mixed phase (right panel) models. Points are lattice data for the (2+1)–flavor system (Z.Fodor et al., 2002).

It is shown that the model predictions on the isentropic trajectories in the phase diagram are consistent with the recent lattice results. When our EoS is extrapolated to conditions of neutron stars ($T = 0$, β equilibrium matter), this agreement with the lattice QCD data puts essential constraints on existence of hybrid and quark stars [2].

A hybrid model is put forward for describing relativistic heavy ion collisions [3]. The early interaction stage responsible for the entropy creation is calculated within the transport quark-qluon String Model resulting in the initial state. The passage to subsequent isentropic expansion proceeds with exact account for all conservation laws. Relativistic 3D hydrodynamics of state is applied to this expansion stage. The developed mixed phase EoS is considered as an input to this dynamical model describing the production and the time evolution of a thermalized medium created in heavy ion collisions. The model reproduces global characteristics of nuclear interactions in a large range of colliding energies.

In connection with the claim made at the Quark Matter 2005 Conference that the in-medium modification of ρ-meson properties, the so-called Brown-Rho scaling, is ruled out

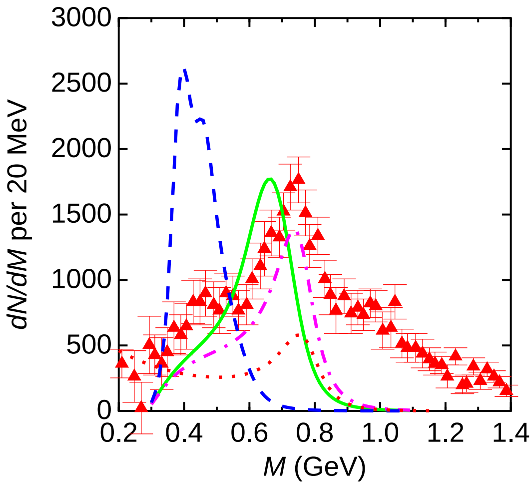

Рис. 2: Invariant mass distribution of dimuons from semi-central In+In collisions at the beam energy 158 A·GeV. Experimental points are the NA60 data (S. Damjanovic et al., 2005). The solid and dashed curves are calculated using the ρ-mass modification factors (1) and (2), respectively. The dash-dotted curve neglects any in-medium modification. The dotted line indicates the hydrodynamically calculated ρ-meson decay at the freeze-out.

by NA60 data, we considered the dimuon production from semi-central In+In collisions in a full dynamical model [4]. As it is shown in Fig. 2, if only a modification of the density-dependent ρ-mass

$$m_\rho \to m^*_\rho(x) = m_\rho(1 - 0.15 \cdot n_B(x)/n_0) \tag{1}$$

is allowed, the maximum of dimuon invariant mass spectra is just slightly below the experimental one. The additional inclusion of the temperature-dependent modification factor

$$m^*_\rho(x) = m_\rho \left(1 - 0.15 \cdot \frac{n_B(x)}{n_0}\right) \left(1 - \left[\frac{T(x)}{T_c}\right]^2\right)^{0.3} . \tag{2}$$

shifts the spectrum maximum towards lower invariant masses making calculation results incompatible with data. A further study is needed to disentangle the Brown-Rho dropping ρ mass scaling and strong broadening scenario.

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Θ^+ FORMATION IN INCLUSIVE $\gamma D \to pK^- X$ REACTIONS

A. I. Titov

The first evidence for the pentaquark hadron Θ^+, discovered by the LEPS collaboration at SPring-8 [1], was subsequently confirmed in some other experiments. However, many other high-energy experiments failed to find the Θ^+ signal. These null results at high energies were not so much surprising because it is natural to expect a sizable suppression in the production of a more complicated five-quark system compared to the conventional three-quark hyperons. But the state of affairs became dramatic after the recent publication of the high statistics results of the CLAS collaboration [2]. This experiment is designed to search for the Θ^+ signal in $\gamma p \to \bar{K}^0 n K^+$ and $\gamma p \to \bar{K}^0 p K^0$ reactions. Within the experimental significance no Θ^+ signal was observed.

In Refs. [3,4], we analyzed a possible manifestation of the Θ^+ formation process in inclusive $\gamma D \to pK^- X$ reactions. We found that if Θ^+ exists, then in the $[\gamma D, pK^-]$ missing mass distribution there must be a distinct Θ^+ peak. Its strength depends on the Θ^+ spin and parity and has a maximum value for $J_\Theta^P = 3/2^-$. We found that at forward angles of the pK^- pair photoproduction the signal-to-noise ratio is most favorable.

We showed that the recent negative results of the CLAS collaboration could be explained by non-favorable experimental condition for Θ^+ formation processes at this experiment. The corresponding signal-to-noise ratio is small and the Θ^+ signal is comparable to the statistical fluctuations due to the experimental acceptance.

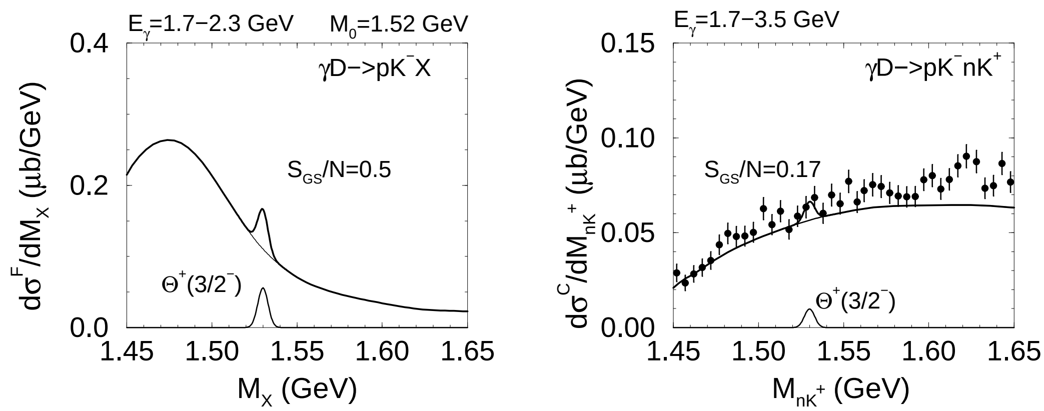

Рис. 1: Θ^+ formation in γD reactions.

For illustration, in Fig. 1 we exhibit simultaneously the missing mass distribution in the inclusive $\gamma D \to pK^- X$ reaction, averaged over the interval $E_\gamma = 1.7 - 2.3$ GeV with the forward pK^- photoproduction angles and the nK^+ invariant mass in the exclusive $\gamma D \to pK^- NK^+$ reaction for the CLAS experimental conditions(right panel) together with the available experimental data [2].

In summary, it seems more reliable to detect the Θ^+ signal in the $KN \to \Theta^+$ fusion reaction realized in associated $\Lambda^*\Theta^+$ photoproduction, which may be seen in inclusive $\gamma D \to pK^- X$ reaction for certain experimental conditions.

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