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CONTRIBUTIONS

JOINT INSTITUTE FOR NUCLEAR RESEARCH

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CONTENTS

INCREASING COUPLING BETWEEN THE MODES OF MOTION IN ASYMMETRIC DINUCLEAR SYSTEM

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A formation of the long living dinuclear system in heavy ion collisions is well known [1]. Experimental data allow us to assume the retaining of individuality of the dinuclear system nuclei. A simple microscopical method has been proposed to derive the diagonal and nondiagonal components of the inertia tensor for a dinuclear system. The components of inverse inertia tensor for radial (R) and mass-asymmetry (η) modes of motion are:

$$(B^{-1})_{RR} = \frac{1}{m}\frac{A}{A_1A_2}\left(1 - \frac{AA_{neck}}{4A_1A_2}\right),$$

$$(B^{-1})_{\eta\eta} = \frac{1}{m}\frac{A_{neck}}{2\sqrt{2\pi}b^2A^2}$$

$$(B^{-1})_{R\eta} = \frac{1}{m}\frac{A_{neck}}{2\sqrt{\pi}b}\frac{A_2 - A_1}{AA_1A_2}$$

and

$$\frac{|B_{R\eta}|}{\sqrt{B_{RR}B_{\eta\eta}}} = \frac{|(B^{-1})_{R\eta}|}{\sqrt{(B^{-1})_{RR}(B^{-1})_{\eta\eta}}} = \sqrt{\frac{1}{\sqrt{2\pi}}\frac{A_{neck}}{A(A_1A_2 - AA_{neck}/4)}}(A_1 - A_2).$$

Here $A_1 \geq A_2$ and A_{neck} is the number of particles in the neck between two fragments. The value of A_{neck} is calculated microscopically. As it is seen from the last expression the nondiagonal component of inertia tensor $B_{R\eta}$ is very small for almost symmetric configurations but increases significantly if the mass asymmetry parameter η increases. The obtained results confirmed the previous ones [2] that the nondiagonal component of the mass tensor which connects the relative motion and mass asymmetry mode increases strongly with the increasing mass asymmetry parameter.

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Nonperturbative Shift of Atomic Energy Levels Induced by the Coulomb Self-Interaction

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In the method suggested recently by A.O. Barut [1] the interaction of electrons with radiation is described by the coupled system of differential equations for an electron wave function and electromagnetic potentials. The arising self-interaction (**SI**) terms lead inevitably to nonlinear Schrödinger equation for an electron wave function. These terms are responsible for such well-known effects as the Lamb shift, anomalous magnetic moment of an electron, radiative corrections to the Coulomb scattering *etc.* Usually, the **SI**-terms are taken into account using the second quantization formalism and the perturbation theory. The latter is not free of divergences [2]. The special subtraction and cut-off procedures are used to get rid off them. Using the method mentioned above we have succeeded in obtaining the non-perturbative shifts of the energy levels and the wave functions for the hydrogen-like one-electron atoms. The positions of the lowest levels with zero angular momentum ($l = 0$) are shown in the Table.

$n \backslash Z$	2	4	6	8	10	82	
1	0.232	0.354	0.400	0.424	0.439	0.492	0.500
2	0.057	0.089	0.101	0.107	0.110	0.123	0.125
3	0.026	0.039	0.044	0.047	0.048	0.05475	0.055

The energies are expressed in the units of $Z^2me^4/\hbar^2$. In these units the energies of the **H**-like atoms without the **SI**-terms are the same ($\epsilon_n^c = -1/2n^2$) for any charge Z. They are presented in the last column of the Table. In these units the influence of the **SI**-terms on the spectrum of the **H**-like atoms is rather small for a medium and large charges. In this case the **SI**-terms can be taken into account using the small number of iterations. However, for $Z < 6$ the number of iteration steps increases. The Table does not contain the energy levels of the hydrogen atom ($Z = 1$). The reason is that the self- interaction turns out to be so strong that the iteration procedure is not convergent in this case. But such an atom exists in Nature with its energies not very far from those of the **H** - atom without the self-interaction. Obviously, for the **H** atom the iteration procedure should be modified. Such investigations are in progress.

It is believed generally [3] that a static self-interaction considered here does not lead to the observable effects (it just renormalizes atomic levels and does not contribute to the radiative corrections). Nevertheless, the large values of the evaluated energy levels shifts suggests that the exact calculations of the physical effects (such as Lamb shift) should differ considerably from the perturbation theory ones. Recently an importance of the nonperturbative calculations was pointed out in Refs. [4,5].

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MICROSCOPIC STRUCTURE OF HIGH-SPIN SPECTRA OF NUCLEI IN THE Z ~ 42 - 45 AND N ~ 46 - 49 REGION.

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During the last few years, a lot of experimental data on medium-spin spectra ($I<20\ \hbar$) of nuclei with $Z\sim 42$-45 and $N\sim 46$-49 have been obtained (see e.g. [1]). These nuclei belong to a region in which superdeformed shapes were predicted at high-spin $I\sim 40\ \hbar$ [2]. Considering the fast development of experimental devices, a detailed theoretical investigation of the high-spin spectra of nuclei in the above-mentioned region has been performed within the configuration dependent shell correction method [3] using the cranked Nilsson potential. Pairing correlations were neglected so the calculations can be considered fully realistic first for high spin, say $I > 15$-$20\ \hbar$.

Due to the small single-particle level density, the shell structure effects manifest themselves in the A~90 mass region in a comparatively dramatic way than e.g. in the A~160 mass region. The shell effects give rise to strong shape variation as a function of both particle numbers and spin and lead to pronounced shape-coexistence effects. We concentrate mainly in the nucleus ^{89}Tc (Z=43,N=46) as a representative example while other nuclei are treated in a more schematic way. All yrast configurations of ^{89}Tc nucleus in the spin region up to 50 $\hbar$ are determined.

In the nuclei under study the states contributing to yrast line can conveniently be divided into three groups, each one corresponding to a particular spin region and a well defined location in deformation plane:

1. Aligned or near-aligned spherical or near-spherical states (spin region up to approximately 35-40 $\hbar$);

2. Near-prolate superdeformed ($\varepsilon_2 > 0.5$, $\gamma < |10^\circ|$) rotational bands in the spin region above approximately 50 $\hbar$;

3. Transitional region in which triaxial superdeformed bands as well as band terminating configurations with large quadrupole deformation ($0.25 < \varepsilon < 0.5$) contribute. These configurations are connected with the filling of intruder $h_{11/2}$ proton and neutron orbitals.

One should note, however, that each specific combination of N and Z leads to specific properties, e.g. well-defined maximum spins within the valence space or with one particle excited etc. It is also evident that the collectivity at low spins increases when going away from the N=50 closed shell.

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OCTUPOLE SHAPES IN HEAVY NUCLEI*

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ABSTRACT

Octupole vibrations were discovered[1] thirty years ago in the alpha decay studies of even-even Th and Ra nuclei and were well characterized as $K^{\pi}=0^-$ rotational bands. These octupole bands have very low excitation energies (below 300 keV) and have enhanced alpha decay rates. The octupole vibrations were later understood as arising from octupole-octupole correlations in nuclei. Just as quadrupole correlations in some nuclei give rise to permanent quadrupole shape, it was anticipated that certain nuclei will develop stable octupole deformation. The signature of octupole shape in even-even nuclei is the presence of interleaved positive and negative parity levels in the ground state band connected by large E3 matrix elements and usually by fast E1 transitions. In odd-mass and odd-odd nuclei, parity doublets provide the signature of octupole deformation. A parity doublet is defined as a pair of states with the same spin but opposite parities, again connected by transitions with enhanced E1 and E3 rates. In the limit of stable octupole shape the wave functions of the two members of the parity doublet are expected to be identical. More detailed calculations[2,3] predicted parity doublets in some odd-mass Ra, Th, Ac and Pa nuclei.

No even-even nucleus is known which has a 1^- level below its rotational 2^+ level, indicating that octupole shape does not exist in the ground states of even-even nuclei. At moderate rotation, between $\sim 8\hbar$ and $\sim 20\hbar$, many nuclei in the mass 220 and mass 144 regions display characteristics of octupole deformations.[4] These include alternating even and odd parity levels and enhanced E1 transition rates. More convincing evidence fof octupole deformation has been found in odd-mass Ac and Pa nuclei which exhibit parity doublets and fast E1 transitions between opposite parity levels. Another strong evidence of octupole shape in odd-proton nuclei is the enhanced alpha transition rates. In ^{227}Pa and ^{229}Pa alpha decays to ^{223}Ac and ^{225}Ac, alpha rates to the negative parity levels are comparable to alpha rates to the favored positive parity bands. Recently we have studied[5] alpha decay of ^{228}Pa to the daughter nucleus ^{224}Ac and find the enhancement in the alpha-decay rates even larger. All these data provide a picture of soft octupole deformation in ^{223}Ac, ^{224}Ac and ^{225}Ac.

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Nuclear Resonance Fluorescence at the Injector for the Moscow Race Track Microtron

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The continuous-wave racetrack microtron (RTM) injector have been recently brought into operation at the Institute of Nuclear Physics of Moscow State University. The injector is a room temperature accelerator and consists of 100 keV electron gun, line for formation of beam emittance, 7 linear accelerator sections and a system for beam output. The main parameters of the injector are summarized: duty cycle 100%, maximum beam energy 6 6 MeV, energy spread 20 keV, maximum average current 1 mA. In future the maximum beam energy of the injector will be increased up to 10 MeV with the help of a magnetic mirror system. This machine is well-suited for nuclear resonance fluorescence (NRF) experiments. The electron beam from the injector is bent through 180° and focused on a bremsstrahlung convertor consisting of a 0 ˑ7 g/cm^2 tantal plate followed by a 11 g/cm^2 carbon electron beam stop. After collimation bremsstrahlung photons fall on a NRF target. At the point of NRF target the flux of 3 MeV photons is equal 10^{12} photons/MeV sec if electron current is about 30 μA.

In the first experiments NRF photons were observed with 60 cm^3 Ge(Li) detector at scattering angle 110° relative to the incident beam. The background conditions allow us to observe easily the states with decay widths of 0.1 eV. The experiments demonstrated high quality of the RTM injector beam and showed that this machine is very useful one for NRF experiments. In the Table we compare the excitation strengths B(M1)↑ [μ_n^2] for pair of well-known M1 excitations of ^{48}Ti received in our experiment and by Giessen- Stuttgart NRF collaboration and also using e,e'-method at the S-DALINAC (Darmstadt).

^{48}Ti level [MeV]	Giessen-Stuttgart	Darmstadt	Moscow
3.739	0.45±0.06	0.50±0.08	0.42±0.05
5.640	0.59±0.20	0.50±0.08	0.76±0 07

Spin- and orbital-current contributions to $1\hbar\omega$ excitations in 1p-shell nuclei.

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Investigation of the interplay between orbital and spin currents in electroexcitation of $E1$, $M2$, $E3$ and $M4$ resonances in 1p-shell nuclei has been performed using the particle-core coupling version of the shell model which takes into account the fragmentation of hole configurations among the states of residual nuclei. The microscopic studies of excited states in open-shell nuclei ($A = 7$-15) have shown that this fragmentation is responsible for the energy distribution of multipole strengths.

The transverse form factors F_J for 1p-shell nuclei involve 3 types of multipole operators: $j_J(qr)[Y_J \cdot \nabla]_J$, $j_{J-1}(qr)[Y_{J-1} \cdot \sigma]_J$ and $j_{J+1}(qr)[Y_{J+1} \cdot \sigma]_J$, which correspond to orbital and spin components of nucleon current. $E1$-transitions are generated by the orbital mode at momentum transfers $q \leq 0.8$ fm^{-1}. In $M2$, $E3$, and $M4$ excitations spin modes dominate not only at high q, but also in low-q region.

$M2$ form factors are produced by the interplay of spin-dipole and spin-octupole modes. The spin-dipole component is responsible for the first maximum in $\sum F_{M2}^2$ (summed over all excited states) near $q = 1$ fm^{-1}, whereas the second one (approximately at $q = 1.7$-1.8 fm^{-1} is formed by both spin-dipole and spin-octupole modes [1].

The microscopic calculations predict that the weighted mean energies of $E1$ and $M2$ resonances grow as q is raised. The energy shift of $E1$ excitations is due to the increasing role of the spin-dipole mode [2]. The same tendency for $M2$ transitions may partly be explained by growing contribution of the spin-octupole component at higher q.

All multipole excitations are strongly fragmented among a number of states. Many of them carry only a small part of total multipole strengths, but the resultant effect is notable enough to be one possible source of the observed quenching of multipole resonances.

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COMPRESSIONAL AND TOROIDAL DIPOLE EXCITATIONS OF ATOMIC NUCLEI

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The method of Wigner function moments [1] is applied to the study of 1^- collective excitations of atomic nuclei with Skyrme forces. The system of dynamical equations for the irreducible dipole tensors is derived. We go beyond the long wave approximation taking into account the octupole Fermi surface deformation. The center of mass movement is excluded exactly. Theory gives seven 1^- resonances in the interval 7-40 MeV. Analyses of their excitation probabilities shows that:

1. Two excitations represent splitted GDR. Their centroid coincides practically with the corresponding experimental value.
2. Two other excitations are the isoscalar and isovector compressional GDR. The energy and contribution to the sum rule of the isoscalar excitation are rather close to the experimental data. There are no experimental data on the isovector resonance yet.
3. The lowest two resonances have the compressional isoscalar nature. Their joint contribution to the electromagnetic (Coulomb) and isoscalar sum rules agrees very well with the recent experimental results [2].
4. One excitation can be interpreted as the toroidal mode.

The energies of these resonances and probabilities of their excitations by the dipole compressional and toroidal operators are represented in the table (contributions to the EWSR are shown in compressional case).

E_x	compressional			toroidal		
MeV	em (%)	iv (%)	is (%)	em (μ_N)	iv (μ_N)	is (μ_N)
8.1	4.7	0.1	10.0	~ 0	~ 0	~ 0
8.6	2.8	0	4.2	2.1	52.5	30.9
	(9.8 exp)		(14.7 exp)			
10.0	0.1	0.7	~ 0	233.6	40.7	31.4
11.3	1.8	1.9	0.1	-	-	-
17.3	0	~ 0	0.3	-	-	-
24.8	21.7	7.1	74.2	~ 0	~ 0	~ 0
37.4	68.7	102.6	0.2	~ 0	~ 0	~ 0

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FLUID DYNAMICAL MODEL FOR ISOSCALAR COLLECTIVE MAGNETIC EXCITATIONS IN SPHERICAL NUCLEI

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The nuclear fluid dynamics describes the isoscalar magnetic twist resonances of orbital nature in terms of torsional vibrations of a spherical nucleus [1-4]. The predictions of the fluid dynamical model for centroids of energies and total excitation probabilities and the DALINAC data [5] are pictured in Fig.1. The basic conclusion of our analysis is that the nucleus may accommodate considerable values of magnetic strength by means of collective rotational oscillations of nucleons.

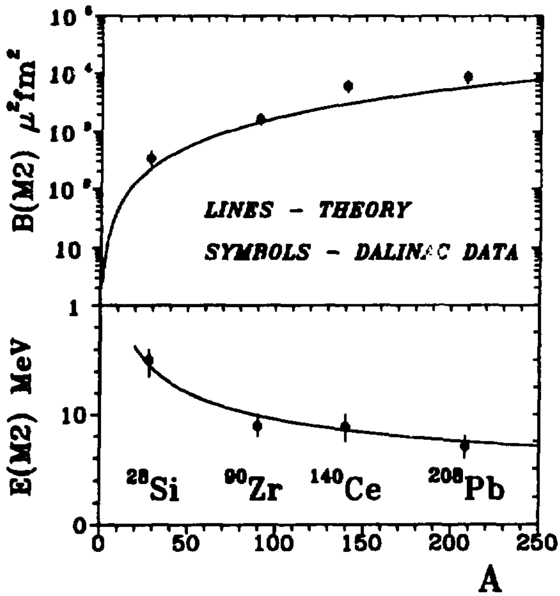

Fig. 1. Centroid of energy and total excitation probability for M2 collective states.

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DECAY MODES OF HIGH-LYING SINGLE-PARTICLE STATES

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In order to get insight into the microscopic structure and damping mechanisms of high lying single-particle states, the (α,^{3}He-n) reaction on ^{90}Zr, ^{120}Sn and ^{208}Pb nuclei has been investigated at 120 MeV incident energy. Neutrons in coincidence with ^{3}He particles emitted at 0° were detected by the multidetector array EDEN in the 68–168° angular range. Data about the neutron decay of single-particle states in the continuum were obtained up to about 25 MeV excitation energy, including branching ratios to discrete final levels in the target nuclei and total multiplicity. The high spin values of these high-lying giant states, inferred from previous inclusive experiments, are confirmed by the angular correlation analysis.

At high excitation energy, neutron spectra are fairly well reproduced by the predictions of the statistical model, with only a very weak contribution of elastic break-up phenomena. Neutron decay properties of the broad giant resonance-like structures observed in the ^{3}He spectra display large departures from a pure statistical decay, allowing extraction of direct branching ratios which can be compared to the predictions of microscopic calculations

(γ,n) CROSS SECTION IN HEAVY NUCLEI IN THE REGION OF THE GIANT QUADRUPOLE RESONANCE

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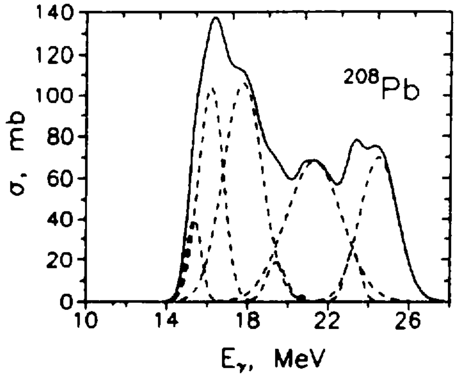
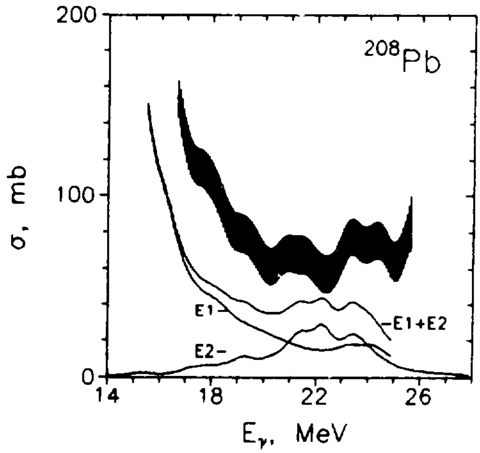
The yield of photoneutrons was measured in ^{208}Pb and ^{209}Bi by means of the bremsstrahlung radiation with the endpoint energy in the range 7–26 MeV. The energy step was 50–80 keV for ^{208}Pb and 100 keV for ^{209}Bi. The cross sections were calculated by the method of statistical regularization, based on use of the probabilistic character of the experimental value. The shape of the cross section was approximated by sets of resonance Gaussian or Lorentz lines, which allows one to estimate the contribution of different states to the total cross section (see for details ref. [1]).

The strength functions of photo-excitation of 1^- and 2^+ states in ^{208}Pb were calculated within the quasiparticle-phonon model. They were used for a detailed comparison with the experimental cross sections which had a rather complex behaviour in the whole energy range.

The data from the energy range 20–26 MeV were analyzed to obtain an information on the structure and parameters of the isovector GQR. Approximation of the experimental cross section in this energy region for ^{208}Pb by Gaussian lines is presented in the left figure. The width of lines vary from ~1. to 3.25 MeV. The calculated contribution of 1^- and 2^+ states to the photo cross section versus experimental findings is presented in the right figure.





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PARTICLE-HOLE STATES IN ^{138}Ba

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Experimental results were obtained at the former Physics Institute in geometry and other conditions similar to that of our parallel contribution. The previous level scheme of ^{138}Ba has been verified using $\gamma\gamma$-coincidence relationships. New levels were found by means of two-step cascades from capture state leading to the ground and first excited state. Among of 63 levels in ^{138}Ba our attention is concentrated on negative-parity states lying above 3.5 MeV. These states arise from the coupling of neutrons across the closed N=82 shell forming particle-hole multiplets. In zeroth order approximation the lowest multiplet is $(f_{7/2}, d_{3/2}^{-1}) = 2^-, 3^-, 4^-, 5^-$. The 4^- (3561 keV), 3^- (3647 keV) and 5^- (3857 keV) levels are in a qualitative agreement with the parabolic rule[1], while the 2^- strength is splitted over several states. The next higher lying multiplet is the $(f_{7/2}, s_{1/2}^{-1})=3^-, 4^-$ doublet which can be assigned to the 3^- (3922 keV) and 4^- (4165 keV) levels. It is followed by the multiplet $(p_{3/2}, d_{3/2}^{-1})=0^-, 1^-, 2^-, 3^-$ which could be assigned to the 1^- (4323 keV), 2^- (4279 keV) and 3^- (4564 keV) levels respectively, although it appears that the $(p_{3/2}, d_{3/2}^{-1})$ strength is splitted again among several levels. We have performed calculations by using the code IBFFM[2]. The effective collective field in the single closed shell core nucleus was simulated by an effective harmonic SU(5) limit with $\hbar\omega_1$=1.2 MeV. To make a more detailed comparison with available data we have also calculated spectroscopic factors for the (d,p) reaction using the IBFFM wave functions for ^{138}Ba and corresponding IBFM wave function for the ^{138}Ba target nucleus. The IBFFM provides a reasonable agreement with the experimental energy levels and the (d,p) transfer properties and, therefore, gives a good basis for understanding of high-lying states in ^{138}Ba (N=82) nuclide.

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LEVELS OF ^{137}Ba STUDIED WITH NEUTRON INDUCED REACTIONS

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As a continuation of our systematic study of Ba isotopes we make an attempt to describe ^{137}Ba having a single hole in the N=82 closed shell in terms of IBFM.

The measurements were carried out at the 5 MW light-water reactor of the former Physics Institute at Riga. Singles (n,γ) and $(n,n'\gamma)$ spectra as well as $\gamma\gamma$-coincidences were measured with HPGe detectors.

In contrast to the our previous study[1] of ^{135}Ba in a framework of O(6) limit the next heavier ^{136}Ba nuclide does not belong to the O(6) pattern. Therefore,we describe the boson core in the SU(5) limit. Values of the IBM parameters for SU(5) are N=4, h_1=0.8185 MeV, h_2=h_3=0, h_{40}=-0.029 MeV, h_{42}=-0.09615 MeV, h_{44}=0.00445 MeV. The boson-fermion interaction strengths are adjusted to the experimental position of the low-lying positive-parity levels of ^{137}Ba.For positive-parity, above the lowest doublet $3/2^+_1$ (g.s), $1/2^+_1$ (283 keV) there appears a quadruplet $7/2^+_1$(1252 keV), $5/2^+_1$ (1294 keV), $3/2^+_2$ (1464 keV), $5/2^+_2$ (1482 keV). In the next group of positive-parity states, the two lowest states are $1/2^+_2$ (1838 keV) and $3/2^+_3$ (1899 keV). Several states, namely ($3/2^+$), $5/2^+$ (2041.2 keV), $7/2^+$ (2228.8 keV), ($3/2^+$), $5/2^+$ (2270.8 keV), $7/2^+$ (2530.2 keV) and $5/2^-$ (2874.4 keV) may be connected to the ℓ=2,3,4 states previously known from neutron transfer reactions (p,d) and (d,p). Higher 2 MeV, we have observed 21 levels with spins 1/2 or 3/2 which are populated by *primary* transitions.

The calculated family of negative-parity states are included both the hole-type $h_{11/2}$ state and the *particle-type* $f_{7/2}$, $p_{3/2}$, $p_{1/2}$, $h_{9/2}$, $f_{5/2}$ and $i_{13/2}$ states. In calculations we have obtained 12 low-spin $1/2^-$, $3/2^-$ states below 5 MeV which are seen in experiment. The IBFM wave functions and calculated on this basis the cummulative (d,p) cross sections are in a good agreement with measured values.

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Measurements of Charge Radii and Nuclei Momenta for Hafnium Isotopes and High Spin Isomer ^{178m}Hf Using Laser Spectroscopy Methods

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Isotopic and isomeric shifts (IS) as well as hyperfine splitting (HFS) in optical transitions of Hf atoms have been measured using high resolution laser spectroscopy. The charge radii differences of Hf nuclei in the range of A = 174 - 182 were determined. A smooth dependence of the charge radius on the neutron number was observed. No break at the maximum quadrupole deformation was detected.(see fig)

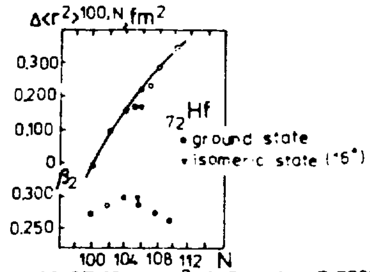
We report the first results on the $\Delta\langle r^2\rangle, \mu, Q_s$ values for stable Hf isotopes and ^{182}Hf ($T_{1/2}$ = 9x10^{6}y) deduced from the IS and HFS measured on the FLNR laser spectrometer. Tables 1 and 2 summarize the obtained results[1].

Table 1. Changes in the nuclear charge radii for Hf isotopes

A	$\lambda^{178,A}$, rel	$\Delta\langle r^2\rangle^{178,A}$ fm^2
174	-1.698(27)	-0.126(6)
176	-0.853(13)	-0.063(3)
177	-0.617(14)	-0.046(3)
179	0.338(14)	0.024(2)
180	1.00	0.075(4)
182	1.656(62)	0.124(8)

Table 2. Ratios of nuclear moments for odd Hf isotopes

Level,cm	2357(a^{3}F$_3$)	19293(z^{3}G$^0_4$)
μ(177)/μ(179)	-1.214(6)	-1.240(14)
Q$_s$(177)/Q$_s$(179)	1.036(10)	1.036(13)



DEPENDENCE OF Δ<r²> AND β₂ ON NEUTRON NUMBER N FOR Hf ISOTOPES

The difference in the charge radius between the isomeric state of ^{178m}Hf (I = 16) and the ground state was evaluated as -0.059(9)fm^2. To obtain these data we used the method of collinear spectroscopy at P.A.R.I.S. mass separator in Orsay. A decrease of charge radius for the isomeric state in comparison with the ground state was observed. From a hyperfine splitting the values of the magnetic dipole and electric quadrupole momenta for odd Hf nuclei and high spin isomer ^{178m}Hf were obtained. The parameter of the quadrupole deformation for the isomeric state is 3% larger than for the ground state of ^{178}Hf. The reasons for the increase of the static quadrupole deformation for the isomeric state and the decrease of the charge radius are discussed [2,3].

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Angular Distribution of the Giant Dipole Resonance Photons from hot nuclei

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The study of nuclei at high excitation energy and angular momentum by the γ decay of the giant dipole resonance (GDR) has so far been based mostly on rather inclusive measurements of the γ ray spectra. Only recently, after the construction of more efficient experimental apparatus (as for example the HECTOR detector array), angular distribution measurements associated to selected intervals of angular momentum of the compound nucleus were made.

The angular distribution provides complementary information to the spectral distribution and its interpretation does not require a statistical model analysis. In addition, contrary to the strength function that can probe only thermal shape fluctuations, it allows to probe also orientation fluctuations.

Detailed experimental investigations of the angular distribution and γ-ray spectral shape in the temperature region T= 1- 2 MeV for the mass number A = 110 (characterized by spherical ground states) and A= 160-170 (characterized by prolate ground states) have been made. The goal has been to follow the gradual decline of the nuclear shell structure dominated by quantal features to hot nuclei described by macroscopic concepts as the liquid drop model.

Because of orientation fluctuations the effective deformations that one extracts directly from the spectra and angular distribution data can be very different, in particular at low angular momenta where the effects of thermal orientation fluctuations are found to be very large. This last finding suggests that it is not possible to interprete the data without model calculations of thermal fluctuations.

It will be demontrated that the spectra and angular distribution data so far obtained constitute a good testing ground of the current models of thermal fluctuations and in general a good agreement is found between the data and the predictions in the adiabatic regime.

THE ^{178m2}Hf HIGH-SPIN ISOMER

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The nucleus ^{178m2}Hf, with its long-lived ($T_{1/2}$ = 31y) high-spin isomeric state I^{π} = 16^{+} at a relatively low excitation energy (2.45 MeV) is a unique probe to study nuclear phenomena in a new way [1]. However, the great difficulties encountered in the production of the isomer in appreciable quantities prevented, up to a few years ago, to start any important physics program using this isomer as a target.

Due to the joint efforts of Dubna (FLNR) and Orsay (CSNSM and IPN) Laboratories in the field of high-intensity beam acceleration, high-purity chemistry, high-yield isotopic separation of the isomer, it is now possible to produce regularly 0.5 10^{15} to 1 10^{15} atoms of ^{178m2}Hf each year and to provide targets with microweight quantities suitable for various experiments.

A wide research program [2] using ^{178m2}Hf as targets has started involving 15 Institutes from 6 countries : JINR-Dubna, CSNSM Orsay, IPN-Orsay, CENBG-Bordeaux, GSI-Darmstadt, LMU and TU-Münich, Jagellonian Univ.-Cracow, Sussex Univ., Mainz Univ., Lab. A. Cotton-Orsay, Kurtchatov Institute-Moscow, CEA France (Bruyères-le Châtel), Princeton Univ., Dallas Univ.

The properties of the isomer itself have been studied by Coulomb excitation with ^{208}Pb, inelastic scattering with light particles, laser spectroscopy and nuclear orientation. Nuclear reactions using γ's, thermal and resonant neutrons, charged particles have been performed or are in progress.

The first experiments led to the knowledge of the basic nuclear parameters of the isomeric state as the quadrupole and magnetic moments, the moment of inertia of the rotational band built on it, the difference of the mean square charge radius between the isomeric and the ground states. Transfer reaction experiments have given information on pairing properties for this state. Thermal neutron capture cross-section and neutron resonance integral have been measured

The experimental results support the theoretical interpretations of the isomeric state as an almost pure four aligned quasiparticle state [3,4].

Prospective ideas will be given for future studies of a large scope of nuclear properties with this new possibility opened by the use of such an "exotic" target..

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NUCLEAR AND CLASSICAL CHAOS

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Presently there is a good understanding of classically chaotic systems. Those are the non-integrable ones with exponential trajectory instability to the initial condition variation which is characterized numerically by the Lyapunov exponent λ or by the stability exponent χ of the monodromy matrix. However the only presently accepted definition of the quantum chaotic system is "the quantum analogue of the classically chaotic one", which even causes widespread doubts whether quantum chaos really exists.

A brief review is given of the existing attempts to recognize the symptoms of classical chaos in quantum systems, which shows a necessity for a purely quantum definitions of regularity and chaos as well as for a numerical criterion of chaoticity in quantum systems. It is essential that such a criterion should lead to the above criterions λ and χ in the classical limit. In order to solve this problem we analyze our experience in nuclear physics where we intuitively use to associate chaoticity with "statistical properties" of compound-nucleus wave functions. This analysis allows to suggest that quantum chaoticity means a lack of symmetry (i.e lack of constants of motion or quantum numbers which arise from the symmetries of the system).

The numerical criterion of purely quantum chaoticity for any regular mode is given by the corresponding spreading width Γ for this mode. It is shown that in the classical limit

$$\frac{\Gamma}{\hbar} \to \lambda$$

and

$$\chi = 2\pi \frac{\Gamma}{D_0} \quad ,$$

where D_0 is the level spacing for this regular mode.

Possible implications of these definitions are analyzed.

Hexadecapole vibrations in deformed rare earth nuclei

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There has been much controversy concerning which types of collective vibrational motions are observed in deformed nuclei, beyond the well-known quadrupole and octupole vibrations. Soloviev and coworkers have shown[1-3] that the considerable amount of evidence for a predominant hexadecapole character of a number of $K^\pi = 3^+$ and $K^\pi = 4^+$ bands in the deformed rare earth region is well described by the QPNM. In a survey paper which demonstrates overwhelmingly the need for including g bosons, Devi and Kota have given[4] a corresponding description in terms of the IBM. After the B(E2) value connecting the lowest $K^\pi = 4^+$ band with the $K^\pi = 2^+$ γ-band in ^{168}Er was measured, and used to argue for a double-γ-phonon interpretation for the $K^\pi = 4^+$ state[5], several recent papers have attempted to extend this description to other nuclei. For example, it has been applied by Oshima et al[6] to ^{192}Os, and by Aprahamian et al[7] to ^{154,156}Gd and a number of other nuclei. The main argument for the double-γ-phonon interpretation is that the B(E2) values connecting the $K^\pi = 4^+$ states with the γ-bands are several Weisskopf units, much larger than would be expected if the $K^\pi = 4^+$ bands were pure two-quasiparticle states. However, this description is contradicted by results from single-nucleon-transfer reactions, which can populate two-quasiparticle and single-phonon states, but *cannot in first order* populate multiphonon states. In this paper it will be shown that for many of the nuclei considered (but not ^{168}Er) single-nucleon-transfer strengths for the $K^\pi = 4^+$ bands are very large, and can be reliably assigned to specific two-quasiparticle configurations. This indicates that the predominant components of these states are not double-γ-phonons. These data are consistent with the QPNM, in which the bands are described[1-3] as single phonons with $\lambda=4$, having microscopic structures which include the large two-quasiparticle components observed. Devi and Kota have shown[8] that in the SU(3) limit of the sdg IBM the $K^\pi = 4^+$ g-boson bands, which they call hexadecapole vibrations, are coupled to the γ-bands with large B(E2) values similar to those observed[8]. Thus, the measured B(E2) values do not distinguish well between the double-γ-phonon and the hexadecapole descriptions in this limit. As the double-γ-phonon description is in serious conflict with single-nucleon-transfer data, the best explanation of all the experimental results is that the $K^\pi = 4^+$ bands have a dominant hexadecapole vibrational character.

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PARTIAL WIDTH FOR THE ISOSCALAR MONOPOLE GIANT RESONANCE DECAY INTO THE GROUND STATE VIA THE e^+e^- PAIR PRODUCTION

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The systematic experimental study of integral characteristics of the isoscalar monopole giant resonance (IMGR) has been performed during recent years [1]. These characteristics are the energy E, the total width and fraction of the energy weighted monopole sum rule x exhausted by IMGR. There appear also the first experimental data on certain IMGR decay modes (on the IMGR partial neutron escape widths) [2,3]. One of the possible IMGR decay modes is the e^+e^- pair production accompanying the IMGR decay into the ground state. The partial width for this process Γ_{pair} can be easily evaluated, since the relevant nuclear matrix element for $E0$-transition is expressed via the mentioned sum rule. Starting from the known formula for the probability of the $E0$-transition accompanied by e^+e^- pair production [4] we obtain the following expression for Γ_{pair} (in eV):

$$\Gamma_{pair} = 0.63 \cdot 10^{-8} (\xi / sh\xi)^2 Z A^{2/3} x (E/1MeV)^4$$

where $\xi = \pi Z/137$, Z and A are the numbers of protons and nucleons respectively. Examples of applying this formula are: $\Gamma_{pair} = 0.24$, 0.22 and 0.20 eV for ^{90}Zr, ^{142}Nd and ^{208}Pb respectively.

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ON THE SEMIDIRECT PHOTONUCLEON REACTIONS AND DIRECT NEUTRON DECAY OF DIPOLE GIANT RESONANCE

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A method for the calculation of the semidirect part of the partial photonucleon reaction cross sections as well as for the evaluation of the relative intensities for the direct nucleon decay of the dipole giant resonance in medium-heavy nuclei is proposed.

The method is based on calculating within continuum-RPA the energy and decay parameters of the 1^- doorway states (dws) which exhaust the greater part of the relevant sum rule. The dws decay parameters are the partial radiative and nucleon escape widths. The doorway states corresponding to the DGR are found to be nonoverlapped on their total (nucleon) widths. This part of the method is the direct generalization of the approaches given in refs [1,2].

The formation of the DGR as a single bump in the relevant reaction cross sections is due to the dws coupling to manyparticle configurations. A phenomenological way for the description of this coupling is used basing (i) on the absence of the common channels for direct decay of dws and manyparticle configurations; (ii) on the reasonable statistical assumption: after energy averaging the spread (and shift) of each dws resonance in the semidirect reaction amplitudes takes place independent of one another (see e.g. ref.[2]). Two relevant phenomenological parameters can be found for each nucleus by the comparison of the calculated photoabsorbtion cross section with the experimental one. After performing this procedure there are no free parameters in the calculation of the energy-averaged semidirect photonucleon reaction amplitudes.

Using the nuclear mean field of the Saxon-Woods type and Landau-Migdal particle-hole interaction we have calculated the semidirect part of the $^{140}Ce(n\gamma_0)$ and $^{208}Pb(n\gamma_0)$ reaction cross sections. The results are in satisfactory agreement with the relevant rather old experimental data.

Bearing in mind the recent data on the relative intensities of the direct neutron decay of the DGR and region above obtained from the $^{208}Pb(^{17}O,^{17}O'n)$ reaction cross sections [3] we have evaluated these intensities. Main disagreement concerns with the decay to the $i_{13/2}$ state. Similar disagreement takes place in the description of the neutron decay of the isoscalar monopole resonance to this state [2]. The origin of these disagreements is not understood yet.

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ON THE DIRECT DECAY OF HIGH SPIN SUBBARRIER SINGLE-PARTICLE STATES

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After intensive experimental [1] and theoretical [1,2] studies on the high energy single-quasiparticle state spread in medium-heavy spherical nuclei, the main interest is now shifted to the investigation of direct decays of these states. The experimental data on direct nucleon decays of high spin subbarrier single-particle states in ^{91}Nb and ^{209}Pb populated in $(^7Li, ^6He)$ and $(\alpha, ^3He)$ reactions respectively have been reported recently [3].

In the presented work we try to describe certain of these data: the relative intensities (branching ratios) for the neutron decays of the $1k_{17/2}$ single-neutron state in ^{209}Pb into the ground (0^+) and first excited (3^-) states of ^{208}Pb. Respectively the simple optical model and the simplest (one-phonon) version of the coupled channel approach (see e.g. ref.[4]) have been used for the evaluation of the mentioned branching ratios. The experimental data concerned with the direct neutron decay of the ^{209}Pb excitation region $(8.5 - 12 MeV)$ to the mentioned final states can be qualitatively described using the realistic optical-model parameters.

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Pairing and Coriolis Attenuation in Deformed Nuclei

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The many-particles plus rotor (MPR) model provides a particularly appropriate framework for studying the interplay between single-particle and collective degrees of freedom in strongly deformed nuclei. The main problem with this model is the treatment of the pairing correlation of the valence nucleons in the intrinsic deformed field. On the one hand the model space dimensionalities generally preclude a standard diagonalization procedure, on the other hand the use of the BCS approximation may well result in a poor description of the intrinsic structure.[1]

We have succeeded in overcoming this difficulty by developing a new method,[2] the chain-calculation method (CCM), which provides a highly effective way for cutting down the size of the energy matrices while yielding extremely accurate results. This opens up the possibility of assessing the real scope of the MPR model.

As a first application we have carried out a study of the odd-A erbium isotopes,[3] with A ranging from 161 to 167. After having treated the pairing Hamiltonian by the CCM, we have diagonalized the recoil term within the set of seniority-one states and then taken into account the Coriolis interaction. We have considered nineteen valence neutrons distributed over eighteen single-particle levels. The intrinsic deformed field has been described by a nonspheroidal axial and reflection symmetric Woods-Saxon potential.

We shall discuss the results of these calculations focusing attention on the decoupled $i_{13/2}$ band. The study of this band, whose structure changes significantly when going from ^{161}Er to ^{167}Er provides the opportunity of understanding the role of the various terms of the model Hamiltonian. In this context, of particular interest is the mechanism that leads to the attenuation of the Coriolis interaction.

We are currently carrying out a similar study in the actinide region. We shall also present some results of this study and emphasize once again that a proper treatment of the intrinsic structure is of the utmost importance.

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Transition Probabilities in Superdeformed Bands

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Superdeformation is one of todays most interesting subjects in nuclear structure physics. Much experimental and theoretical effort was devoted to it up to now and many superdeformed (SD) bands were found in the A=150 and A=190 mass regions. Lifetime information mainly obtained from mean Doppler shift data proved that one deals with deformations about β = 0.5 – 0.6 . One of the still open questions in this field is addressed to the sudden decay out of the SD bands. Lifetimes of the lowest SD states where this decay takes place are well suited to obtain a better understanding of the decay mechanism involved.

Due to the relatively low transition energies inside the SD bands in the A=190 mass region it is possible to employ the recoil distance Doppler shift (RDDS) technique to measure the lifetimes. With this method transition probabilities can be measured without any assumption on the actual nuclear structure and without problems connected to Doppler shift attenuation (DSA) measurements arising from uncertainties in the used stopping power.

We want to report on two RDDS measurements performed in γ- γ coincidence mode for ^{192}Hg (1) and ^{194}Pb using the GASP spectrometer (2) at the LNL Legnaro. In both experiments the Cologne plunger was used which was especially constructed for γ-γ coincidence measurements. It was possible to determine the lifetimes of two and three levels at the bottom of the observed SD bands in ^{192}Hg and ^{194}Pb, respectively. These results are used to discuss the decay out of the SD bands in terms of mixing of normal deformed (ND) states to the SD ones.

In addition we want to report on a DSA measurement for the two SD bands in ^{146}Gd. It was possible to determine for both bands the intrinsic quadrupole moments Q_0 which are consistent with those calculated by Ragnarsson (3).

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CLUSTER CHARACTER OF INTERMEDIATE STATE IN $^{115}In^{m}$ WITH ENERGY 4.15 MeV

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Photoactivation of the isomer states of nuclei proceeds through excitation of intermediate states (IS). A central problem for these IS below the particle threshold is whether the IS is a single nuclei level or a group of closely lying levels within an energy range of 0.1-0.2 MeV, depending on the experimental resolution. Complementary nuclear resonance fluorescence (NRF) studies with a high energy resolution may settle this question to some degree [1,2].

Photoactivation of the $\frac{1}{2}^-$ isomer in $^{115}In^{m}$ via IS from the energy range of 3.0-5.0 MeV was measured at the pulsed betatron at Institute of Physics, St.Petersburg State University. In addition to the IS at the energy about 3 MeV [1] we found out only one strong IS at the energy 4.15 MeV with the integrated isomer production cross section 20±7 eV·b (we made use of the IS cross section value around 3 MeV [1]). The interesting result is that no g.s. transitions with the integrated cross section above 5 eV·b (experimental limit) were identified in the energy range 3.8-5.0 MeV in the NRF studies [1].

The $^{115}In(\gamma,\gamma')$ reaction was analyzed in the framework of quasiparticle-phonon model [3]. The 'quasiparticle⊗two-phonons' configurations were included in determination of the structure of excited states. Distribution of the M1-, E2- and E1- radiation strength are consistent with NRF data [1] for the strong g.s. transitions. Furthermore, the calculations manifested the concentration of the radiation strength of the M1-, E2→g.s. transitions (the overall cross section is about 40 eV·b) and the E1→g.s. transitions (20 eV·b) in the range 3.9-4.3 MeV as the result of a great number of the transitions with moderate radiation strength below experimental limit in the NRF studies.

To some degree, the calculated radiation strength would suffice to describe the activation data in the energy range around 4 MeV with reasonable values of the isomeric ratio of order of 0.1-0.3. The unexpected result, that the strong IS with the energy 4.15 MeV is not identified in NRF spectrum, may be ascribed to a cluster character of this state.

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THE IBM1 DISCRIPTION OF BAND CROSSING IN 102-Ru

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We have measured lifetimes of yrast line levels for ^{102}Ru. For interpretation of energy and B(E2) values in the band-crossing region the modification of the IBM1 model is proposed. Apart from usual quadrupole type (*d*- and *s*-bosons) states, the additional phonon states- $b_\lambda^+|0\rangle$ with λ= 6^+ and 8^+ have been considered. The total number of bosons and phonons is $\Omega = n_d + n_s + n_8$. Let's take into account only states with $n_6 + n_8 = 0$ and 1. Therefore the model space includes the usual IBM1 space - $|\Omega\rangle$ with Ω bosons and $b_\lambda^+ |\Omega - 1\rangle$ states, were collective part is formed from Ω-1 bosons. Corresponding Hamiltonian that ensures the bound of states with different phonon number b_λ can be represented as a following:

$$H = H_{IBM1} + \varepsilon_6 \hat{n}_6 + \varepsilon_8 \hat{n}_8 + (\upsilon_6 \sum_\mu b_{6\mu}^+ s^+ s^+ (ddd)_\mu^{(6)} + \upsilon_8 \sum_\mu b_{8\mu}^+ s^+ s^+ s^+ (dddd)_\mu^{(8)} + h.c.),$$

where H_{IBM1} - IBM1 Hamiltonian, $\hat{n}_\lambda = \sum_\mu b_{\lambda\mu}^+ b_{\lambda\mu}$, ε_λ - phonon energy, υ_λ - interaction constants. The calculation of matrix elements of H has been performed in two steps. Firstly the boson part of Hamiltonian with Ω=9 and 8 has been diagonalized. For Ω=9 the parameters of H_{IBM1} have been found by fitting energies of collective states in ^{102}Ru up to $I^\pi = 6^+$ and up to $I^\pi = 6^+$ and for Ω=8 the collective states in ^{102}Mo have been taken into account. Secondly low energy states have been bound with b_λ phonon; after that full Hamiltonian has been diagonalized for total system. In first versions of calculation only phonon with λ=6 has been considered, in the second - phonon with λ=8. In both cases' the parameters ε_λ and υ_λ have been fitted under the condition of best reproducing of yrast state energies from 8 to 16. The calculation of B(E2) has been performed with operator used in IBM1, when parameters have been found from ^{102}Ru and ^{102}Mo. Theoretical and experimental energies and B(E2) along yrast bandare in a good agreement each other.

I^π	E(MeV)			B(E2)		
	th1	th2	exp.	th1	th2	exp.
2^+	0.476	0.476	0.475	1.0	1.0	1.0
4^+	1.108	1.108	1.106	1.54	1.54	1.48
6^+	1.877	1.885	1.873	1.77	1.80	$1.7^{+0.7}_{-0.6}$
8^+	2.706	2.705	2.704	1.23	1.64	$1.3^{+0.5}_{-0.3}$
10^+	3.379	3.414	3.431	1.14	1.27	$1.3^{+0.6}_{-0.4}$
12^+	4.099	4.064	4.052	1.98	1.46	$2.0^{+0.4}_{-0.4}$
14^+	4.885	4.821	4.803	2.30	1.81	$2.2^{+0.6}_{-0.5}$
16^+	5.639	5.708	5.713	2.32	2.04	

A NEW SORT OF "IDENTICAL BANDS" PHENOMENA IN THE CASE OF 2p-2h PROTON EXCITATION IN Sn ISOTOPES

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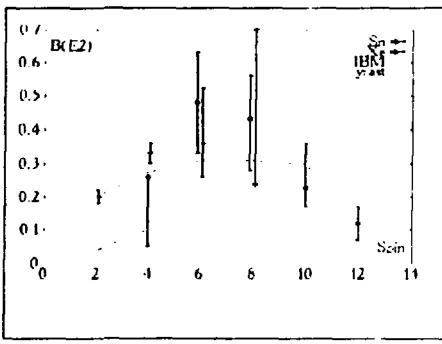
It's well known, that "identical rotational bands" phenomena firstly was discovered for superdeformation states of even-even and odd nuclei. Later it was been appeared, that this effect was not limited of stable deformation region, but may be develop in such pair of even-even nuclei, that belong to areas of fast structure and phase reconstruction (for example ^{156}Dy and ^{180}Os /1/). We have found arguments on existent of new sort of "identical band" phenomena, connected with 2p-2h excitation in semimagical nuclei. In particular, this effect is take place in the case of bands, building on 0_2^+ states in *Sn* isotopes and ground states bands in corresponding *Xe* nuclei. The first evidence based on analysis of band energy structure, i.e. $R_\gamma(I)$ (defined in /1/) for different pairs of *Sn* and *Xe* isotopes with the same number of neutrons: $^{112-118}Sn_{62} \leftrightarrow {}^{116-122}Xe_{62}$. In particular for transitions $8^+ \rightarrow 6^+$ and $10^+ \rightarrow 8^+$ for each pair under consideration the condition $|R_\gamma(I)| \leq 1$ is fulfilled. Another, independed criteria based on the analysis of experimental B(E2) values inside bands, built on intruder 0_2^+ states (recently we have measured the lifetimes of $^{116,118}Sn$ /2/ and before that - for $^{112,114}Sn$).



In a result of comparison of B(E2) in *Sn* and *Xe* bands it is possible to conclude, that corresponding values are close each other, as it is illustrated at the picture for the case $^{116}Sn \leftrightarrow {}^{120}Xe$ pair. These values are significat increase the B(E2) for yrast states 2^+, 4^+ of ^{116}Sn. That is evidence on strong increasing of collectivity in semi-magic *Sn* nuclei after jumping over a proton pair (bound in zero moment) in upper shell. From point of view of IBM1 this type of "independent band" phenomena may be connected with the change of boson configuration of *Sn* nuclei states with neutron number N=62-68 from Np=0, Nn=6,7,8,7 to Np=2, Nn=6,7,8,7. The last one are the same characteristics as for corresponding *Xe* isotopes. The B(E2) values, calculated in the frame of IBM1 are given in the picture (full line).

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Electromagnetic Dissiociation of Relativistic and Radioactive Beams

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The process of dissociation of nuclei in peripheral heavy-ion collisions at high energies has developed into a new field of nuclear structure investigations. The underlying mechanisms are that of electromagnetic excitations or diffractive scattering, but also more complex reactions may be considered. At GSI, a method was developed which allows for kinematically complete measurements of dissociation products emerging after projectile excitation. This concept is particularly useful it applied to secondary radioactive beams. The method involves a measurement of momenta of coincident heavy fragments and of emitted neutrons, thus allowing to determine cross sections, fragment and neutron distributions, fragment-neutron and neutron-neutron correlations for specific reaction channels. This technique was applied at GSI in a study of light neutron-rich isotopes at or near the neutron-drip line. Secondary beams of $^{6,8}He$, ^{11}Li, $^{10,11,14}Be$ (240-400 A·MeV) were produced by means of the Fragment Recoil Separator and few neutron-removal reactions, e.g. $^{11}Li \to {}^{9}Li + 2n$, were studied using light and heavy targets. Emphasis was paid to isotopes (e.g. ^{11}Li, ^{11}Be), for which a neutron halo structure has been claimed in a number of earlier experiments. Results such as cross sections, fragment and neutron momentum distributions and fragment-neutron (-neutron) correlations will be discussed in the context of neutron-halos. The experiments were performed in a collaboration of institutes at Århus, Cracow, TH Darmstadt, Frankfurt, Göteborg, Madrid, Mainz, CERN, KIAE Moscow, IPN Orsay and GSI Darmstadt.

PARTICLE DECAY OF THE PHOTONUCLEAR GIANT RESONANCE

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The Giant Dipole Resonance decay characteristics, particularly if the states of the final nucleus are fixed, contain detailed information about the microscopic structure of the giant resonance. Data on the partial photodisintegration channels are obtained in two types of experiments. One measures either the spectra of the emitted particles x or the spectra of the gamma quanta reducing the excitation of the final nuclear states populating as a result of emission of the particle x. Both methods were compared to each other in Ref.[1].

The simultaneous application of both methods to 15 2s-1d shell nuclei allowed to obtain the detailed quantitative information about the integrated partial photonucleon cross sections and correlate them to the spectroscopic factors of the ground state of the target nucleus.

For some 1f-2p-nuclei the fast neutron spectra were measured [2]. This allowed to get the partial cross sections to the low-laying states of the residual nucleus. It appears that the decay of the high energy part of the giant resonance in this region of nuclei leads preferentially to the population of the excited rather then the ground state. Moreover their parity is opposite to that of the ground state. It could be the indication that the configurational splitting of the giant dipole resonance occurs in this region of nuclei too.

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THEORETICAL INVESTIGATIONS OF NEUTRON EXCESS NUCLEI OF THE MAGICITY REGION CLOSE TO ^{132}Sn.

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By the present time there appeared a noticeable experimental activity concerning investigations of neutron excess nuclei close to the region of double magicity near ^{132}Sn (Z=50, N=82) /1,2/. We carried out comprehensive theoretical investigation of even-A nuclei nearest to ^{132}Sn the nuclides ^{134}Sn, ^{134}Te, ^{134}Sb (with the structure core plus two nucleons), ^{130}Sb, ^{130}Cd, ^{130}In (core minus two nucleons) and nuclei ^{132}Sb, ^{132}In (core $\pm\pi \mp \nu$) were considered parallel with the core nuclei. The computation scheme is based on the random phase-type approximation. The corresponding equations are deduced as equations for poles of the two particle Green function (pairs of nuclei $^{134}Sn - ^{130}Sn$, $^{134}Te - ^{130}Cd$, $^{134}Sb - ^{130}In$) or for poles of particle hole Green function ($^{132}Sb - ^{132}In$ and the core nucleus). The approximation consists in substitution of irreduceable blocks by the effective finite range effective interaction the same in particle-particle and particle hole channels. Antisymmetrization and exchange effects are properly taken into account. The results of calculation of the energy spectra and the electromagnetic and weak transition probabilities reveal a good agreement with the experiment /3, 4/.

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ON THE EFFICIENCY OF THE SOLAR NEUTRINO DETECTION BY THE ^{98}Mo NUCLEI

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The experiments on the detection of solar neutrino (R.Davis, GALLEX, SAGE, Kamiokande) revealed the lack of the observed neutrino flux as compared to the predictions of the standard solar model (SSM). This fact offers the essence of the solar neutrino problem. A geochemical experiment based on the $\nu_e + {}^{98}Mo \rightarrow {}^{98}Tc + e^-$ reaction was prorosed in the work /1/ for the determination of the solar neutrino flux with the counting rate evaluated as $\sum_i \sigma_i \Phi_i = 5$ SNU (SNU, solar neutrino unit equals to 10^{-36} events/atom.s). In work /2/ one can find an estimate $\sum_i \sigma_i \Phi_i = 17^{+19}_{-11}$ SNU, based mainly on the experimental data for the ${}^{98}Mo\,(p,n)^{98}Tc$ reaction. We performed counting rate computations based on the predictions of SSM /2/ and on our calculations of the strength functions of weak Fermi and Gamow Teller transitions. The last calculations were based on the RPA method for odd odd nuclei considering BCS correlations, the universal finite range interaction and the large basis including all quasistationary states. The counting rate is given by the formula

$$\sum \sigma_i \Phi_i = 10^{36} \frac{m_e^2}{\pi h^4} \sum_{k,\lambda} \Phi_k G_\lambda^2 \int_0^{q^k_{max}+(\Delta m_n - m_e)c^2} S_\lambda(E)\, dE \times$$

$$\times \int_{m_e c^2}^{q^k_{max}+\Delta m_n c^2 - E} \frac{\varepsilon}{m_e c^2} \sqrt{\left(\frac{\varepsilon}{m_e c^2}\right)^2 - 1} \cdot F(Z,\varepsilon)\; f_k(\varepsilon - \Delta m_n c^2 + E)\, d\varepsilon,$$

where $\lambda = A, V$; Φ_k and $f_k(\omega)$ the total flux and the neutrino spectrum from the k th reaction in the Sun, $S_\lambda(E)$ strength function, $F(Z,\varepsilon)$ screening function. Our result is $\sum_i \sigma_i \Phi_i = 28^{+15}_{-8}$ SNU /3/. It specifies the findings /2/ and contradicts the predictions /1/ which appear to be underestimated.

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Full - Folding Model for Nucleon Quasielastic Reactions at Intermediate Energies

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Nucleon-nucleus reactions at intermediate energy are important, often unique, source of information about nuclear structure, effective interactions, reaction mechanisms. Spin observables, which are sensitive to relative phases, play a crucial role in such studies. Quality of data from new generation of experimental facilities claim a more rigid requirements to theoretical description if you want to keep a microscopic approach. The important issues such as off-shell behavior and medium modifications of the effective interaction, relativistic effects, other nonlocalities are in process of wide discussions. Impulse approximation and distorted wave impulse approximation are the basic approach to study elastic scattering and quasielastic nucleon-nucleus reactions at intermediate energies. This approaches follow from a single scattering approximation to multiple scattering theory and demand convolutions of a fully-off-shell two nucleon scattering amplitude and the nuclear (transition) density matrix. Such forms for optical potential and reaction amplitude one can call as the full-folding models. In a case of elastic nucleon-nucleus scattering at intermediate energy the full-folding model for optical potential were developed /1-3/ and rather good description of experimental data were obtained, especially in the momentum-transfer range where the target wave functions are most reliable.

The full-folding model for inelastic and charge-exchange nucleon-nucleus reactions at intermediate energies are evolved. The effective interaction between projectile nucleon and struck nucleon in nucleus is a nucleon-nucleon t-matrix which describe a free NN-scattering. The t-matrix is obtained by solving the Lippmann-Scwinger equation with one-boson exchange Bonn potential. The distorted waves are calculated from a full-folding model for an optical potential. For self-consistency between elastic and inelastic calculations the same realistic NN-interaction which induce an inelastic transition are used for calculation an optical potential. All calculations are carried out in impulse space. The model are applied for description of polarization observables for nucleon charge-exchange reactions on light nuclei.

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Inelastic scattering of heavy ions in the high-energy approximation

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A method is developed for calculating the inelastic scattering cross sections of light and heavy ions with excitation of the collective nuclear states. For this purpose the DWBA is used with relative-motion quasiclassical functions whose phases are calculated within the high-energy approximation developed in [1,2]:

$$\Psi^{(\pm)} = exp\{i\vec{k}\vec{r} \pm i[a_0 \pm \frac{a_1}{k}(\vec{k}\vec{r}) + \frac{a_2}{k^2}(\vec{k}\vec{r})^2 \pm \frac{a_3}{k^3}(\vec{k}\vec{r})^3]\}, \quad (1)$$

where a_n are the known functions of r and parameters of potentials. The DWBA-amplitude is transformed to the form, where the integrand includs terms with the Woods-Saxon potential and the Fermi charge density distribution. Thus, the integrand function becomes to be proportional to

$$V_{int} = \alpha_{\lambda\mu} Y_{\lambda\mu} \frac{dF}{dR}; \qquad F = (1 + e^{\frac{r-R}{a}})^{-1}, \quad (2)$$

where $\alpha_{\lambda\mu}$ are the collective nuclear variables. So, the final DWBA-amplitude consists of the structure factor $< I_f M_f | \alpha_{\lambda\mu} | I_i M_i >$, leading to the transition probability in the cross section, and the dynamical factor

$$T_{fi} \sim \frac{d}{dR}[e^{-a\pi(\theta-\theta_c)} F(\theta, \theta_c, R)]. \quad (3)$$

Thus, we have obtained the final result in an analytical form which gives an exponential slope of the angular distribution on the right hand side of the critical deflection angle θ_c, and oscillations determined by the known function $F(\theta, \theta_c, R)$. It is shown how one can make calculations in the case of large energy transfers, when high-lying nuclear levels are excited and the corresponding classical trajectories are different in the initial and final channels. Also, the method is generalized when one uses transition matrix elements with the r-dependence obtained by the microscopical nuclear models. Examples of numerical calculations and comparison with experimental data are done, and the mechanism of this kind of processes is discussed.

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INVESTIGATION OF THE INTERACTIONS AND SELF-INTERACTIONS OF MESONIC FIELDS IN THE RELATIVISTIC HARTREE-FOCK APPROXIMATION FOR NUCLEAR STRUCT''RE

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Many qualitative nuclear ground state properties have been reproduced within the linear relativistic model suggested by J.D. Walecka. The original version of the model included only Yukawa type mesonic fields coupled directly to the corresponding nucleon currents. However, to obtain a detailed quantitative description of the nuclear ground state properties, it appeared to be essential to extend the Walecka model by introducing into the theory some kind of density dependence. In the present paper we consider a model including not only purely Yukawa type mesonic forces but also self-interactions of the scalar meson field, self-interactions of the vector meson field and interactions of the scalar and vector fields. This model is based on the following effective Lagrangian

$$\mathcal{L} = \mathcal{L}_0(\psi, \sigma, \omega, \rho, \pi) + \sum_{\text{mesons}} \mathcal{L}^{\text{int}}_{\text{N-meson}} + b\sigma^3 + c\sigma^4 + d\sigma\omega^2 + e\sigma^2\omega^2 + f\omega^4, \quad (1)$$

where ψ is the nucleon field; σ, ω, ρ, π - scalar, vector, vector-isovector, pion meson fields; b, c, d, e, f - coefficients.

We have applied model (1) to investigation of the nuclear structure (nuclear matter and finite nuclei) in the framework of the relativistic Hartree-Fock (RHF) approach.

One of the manifestations of the σ^3-, σ^4-, $\sigma\omega^2$-, $\sigma^2\omega^2$-, and ω^4- terms in Eq. (1) is the effect of "dressing" of the scalar and vector mesons in the nuclear medium: the values of m^*_σ and m^*_ω are different from the corresponding bare masses and become density dependent. The other effect of these terms is the modification of the expression for the total binding energy.

To obtain the ground state properties of finite nuclei, we have solved numerically the Lagrange-Euler equations for model (1) in the RHF approach.

CHANGES IN NUCLEAR CHARGE RADII OF Ti ISOTOPES DETERMINED BY LASER RESONANCE FLUORESCENCE

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Isotope shifts (IS) and hyperfine structure (hfs) in optical transitions of TiI have been investigated by using high resolution laser spectroscopy. From the isotope shifts data, changes of the mean square charge radii of $^{46-50}$Ti isotopes have been extracted for the first time. The nuclei investigated lie within the very interesting shell $20 \le Z, N \le 28$. This is just in that Z region with a large lack of optical information on nuclear properties. The experimental techniques used is laser excited resonance fluorescence on a collimated orthogonal atomic beam with laser atomization of the samples [1]. Measurements of the IS and hfs were made in optical transitions $4s^2\ a^3P_J - 3d^34p\ y^3D^0_J$ and $4s^2\ a^3P_J - 4s4p\ z^3P^0_J$ on 7 spectral lines between 586.6nm and 594.2nm.

A	$\lambda^{A,48}_{rel}$	$\delta\langle r^2\rangle^{A,48}$, fm^2	$\langle r^2\rangle^{1/2}$, fm
46	1	0,108(6)	3.6139(26)
47	0,16(10)	0,017(27)	3.6019(27)
48	-	-	3.5990(26)
49	-1,31(38)	-0,142(42)	3.5809(36)
50	-1,53(41)	-0,165(44)	3.5760(30)

The root-mean square charge radii changes were deduced from IS by using the well known procedure [2] and model independent combined analysis of muonic X-ray and electronic scattering data [3]. Model independent rms radii of the odd-even isotopes were predicted by combined analysis of model independent radii absolute values $\langle r^2\rangle^{1/2}$ of even isotopes from [3] and model independent $\delta\langle r^2\rangle$ changes from our measurements. The results are listed in the table. As can see from the table nuclear charge radii values decreases with adding of neutrons like in the case of Ca isotopes with the same neutron numbers. Taking into account the data on nuclear deformations β_2 can not explain the value of this decreasing but the tendency only.

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EVIDENCE FOR THE ISOSCALAR GIANT DIPOLE RESONANCE IN ^{208}Pb USING INELASTIC α SCATTERING AT AND NEAR 0°

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The Isoscalar Giant Dipole Resonance (ISGDR) is best described as a "hydrodynamical density oscillation" in which a compression wave oscillates back and forth through the constant volume of the nucleus (the "squeezing mode") [1]. Since the energy of ISGDR is related to the nuclear compressibility, a detailed and systematic investigation of the ISGDR is expected to provide additional information, contributing to a more precise determination of the incompressibility of nuclear matter.

The ISGDR lies very close in energy to the high-energy octupole resonance (HEOR) and unambiguous identification of the ISGDR is possible only at angles near 0° because of its characteristic angular distribution at these angles. Our measurements employed a 200 MeV α beam from IUCF incident on an enriched ^{208}Pb target. Inelastically scattered particles were detected in the focal plane of the K600 magnetic spectrometer operating in the transmission (0°) mode; the available excitation-energy bite in this mode was 14-29 MeV, appropriate for the aforementioned resonances which are expected to lie at excitation energies of 20-22 MeV in ^{208}Pb.

A broad "bump", comprising the two resonances, is clearly visible above background in our spectra. By using software cuts, it has been possible to split the 2° angular acceptance of the K600 into energy spectra from the (0°-0.5°), (0.5°-1.0°), (1.0°-1.5°) and (1.5°-2.0°) angular bins, thus providing an angular distribution for the two components of the "bump". Indeed, the angular distributions for the two components are strikingly different and in qualitative agreement with the expected angular distributions for the ISGDR and HEOR. In addition, the "difference-of-spectra" technique has been employed to extract the parameters of the ISGDR. This technique, previously used to great effect in the investigation of the giant monopole resonance [3], takes advantage of the roughly flat angular distribution of the HEOR over the (0°-2°) range as compared to that of the ISGDR which has a monotonously increasing cross section over the same angular range: The spectrum corresponding to the (0°-1°) scattering angle range, when subtracted from the normalized spectrum corresponding to (1°-2°) scattering angle range results in an energy spectrum made up almost entirely of contribution from the ISGDR. Our measurements have confirmed the efficacy of this technique in the study of the ISGDR and provided a clear evidence for this resonance in ^{208}Pb.

*In collaboration with B.F. Davis, W. Reviol (University of Notre Dame); A. Bacher, G. P. A. Berg, C.C. Foster, E. J. Stephenson, Y. Wang (IUCF, Bloomington, USA); J. Jänecke, K. Pham, D. Roberts (University of Michigan, Ann Arbor, USA); M. N. Harakeh (KVI, Groningen, The Netherlands); H. Akimune, M. Fujiwara (RCNP, Osaka, Japan); and, J. Lisantti (Centenary College, Shreveport, USA).

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THE INVESTIGATION OF THE GIANT DIPOLE RESONANCE DECAY IN (γ,n) REACTION FOR fp-SHELL NUCLEI.

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The energy spectra and the cross sections for photoneutrons with energy ≥ 3.7 MeV have been obtained for the fp-shell nuclei ^{51}V, ^{52}Cr, ^{54}Fe, ^{56}Fe, ^{58}Ni, ^{64}Zn, using a scintillation neutron spectrometer [1]. In contrast with total cross sections the cross section for selected neutrons consists of separate resonances and have no smooth part. The resonances are located in the same places as in the total cross sections (see fig.1 and references [1,2]).

The photoneutron spectra, obtained by using continuous bremsstrahlung, have considerable structure [1,2]. The energy resolution of the spectrometer was sufficient to separate transitions to the different low laying states of the daughter nuclei. The decay of the resonances to these states turns out to have a selective character. The existence of the intruder states is one of the possible reasons for such a selectivity [2].

The upper estimation for individual resonances widths in ^{58}Ni turns out to be about 80 keV (see fig.2 and reference [1]). This estimation agrees with doorway state lifetime calculation (^{64}Cu with three excitons) in preequilibrium decay model [3].

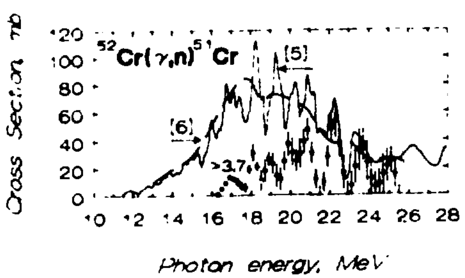

Fig.1

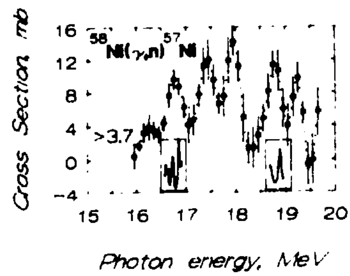

Fig.2

There are no transitions to ground state and low laying daughter nuclei states with excitation energies lower than 3.0 MeV for ^{51}V and 3.5 MeV for ^{58}Ni if photon energy is higher than DGR maximum. Perhaps it can be explained by the well studied in sd-shell nuclei configuration splitting effect [4].

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Investigation of the decay of ^{194}Pb and ^{192}Hg superdeformed bands using EUROGAM

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The high efficiency EUROGAM multidetector array has been used to investigate the superdeformed (SD) bands in the ^{192}Hg and ^{194}Pb nuclei. A wealth of new exciting spectroscopic information on these two nuclei concerning their SD and normally deformed (ND) bands has been gathered. In particular, for the first time, using high fold data, it has been possible not only to caracterize more precisely the SD structures (γ-ray energies, intensities, nuclear level lifetimes) but also to extract the spectra of γ rays emitted in the decay of these SD nuc'ei. The main results of these experiments and the perspectives will be discussed.

Octupole Deformation and Chaos

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Recent experimental data of superdeformed K isomers in nuclei and electronic shell structure effects in metallic clusters clearly underline the importance of octupole deformation. In order to understand the physical reason why nuclei or metallic clusters tend to break the reflection symmetry we investigate a simplified model [1] classically and quantum mechanically. The single particle motion is considered in the axial harmonic oscillator model with an octupole term

$$V(\rho, z) = \frac{m\omega^2}{2}\left(\rho^2 + \frac{z^2}{b^2} + l\frac{2z^3 - 3z\rho^2}{\sqrt{\rho^2 + z^2}}\right) \tag{1}$$

where $\rho^2 = x^2 + y^2$ and an octupole term, written in the cylindrical coordinates (ρ, z, φ). For $l = 0$ and $b > 1$ ($b < 1$) we have the mean field potential of a prolate (oblate) nucleus. Note, that choosing another set of parameters, we could deal with a metallic cluster.

If $|l| < l_{crit}$ we are dealing with a proper bound state problem. Here l_{crit} is defined to be the value for which the potential no longer binds, for $|l| > l_{crit}$ the potential tends to $-\infty$ along one or two directions. The direction and the value of l_{crit} depend on the quadrupole deformation b.

The results of the numerical integration of the equations of motion show that for the superdeformed prolate nucleus ($b = 2$) there is hardly any chaotic behaviour discernible in the classical motion for all $l < l_{crit}$. For decreasing value of b the motion becomes increasingly chaotic up to the maximally chaotic case at $b \approx 0.58$. We have compared results for $l = \beta l_{crit}(b)$ with $\beta =$ 0.2, 0.4, 0.6 and 0.9.

The statistical analyses shows that the quantum mechanical results are in line with the classical cases. The level repulsions in the superdeformed prolate case are very weak thus giving rise to a nearest neighbor distribution (NND) which appears closer to an integrable case than to the typical Wigner distribution. Of physical interest are the pronounced new shell structures that emerge for instance near to $l = 0.5 l_{crit}$ and $l = 0.65 l_{crit}$. Since we have left out terms like spin-orbit coupling and l^2 we cannot claim that such structures arise exactly where we find them. However, the essential point is the fact that such structures will always emerge. These findings nicely contrast with the oblate case where the spectrum and in particular the NND have all signatures of chaos. For sufficiently large values of the octupole strength l all periodic structure is destroyed and there is no scope for new magic numbers.

In summary, for the prolate and in particular the superdeformed prolate case, there is a remarkable stability against chaos when octupole deformation is switched on.

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On the Nature of New Excitation Modes in Nuclei

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We present here the results of an extensive investigation of $K = 1^+$ states using both collective model and microscopic descriptions within the framework of a Quasi Particle Random Phase Approximation employing Skyrme forces. This elaborate study represents the only fully self-consistent QRPA investigation using realistic forces yet undertaken and is directed at establishing the underlying physical character of states recently observed and those currently under examination in both rare earth and light nuclei. In particular we attempt answers to the following questions:

a) To what extent do the experimental observations obtained for the group of states in the 2-4 MeV region in rare earth nuclei support any given picture? Are such states indeed of collective origin? Can a collective state be compatible with a small B(M1) value?

b) What mechanism is responsible for the splitting of the B(M1) strength observed for the 1^+ states found in the 5-10 MeV region in rare earths? What is the nature of these states? Do they represent new giant resonances?

c) Have 1^+ states in light nuclei a collective character or are they of a different nature?

d) What is the high energy counterpart to the low energy 1^+ states?

THE n-p INTERACTION IN ODD-ODD DEFORMED NUCLEI

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Experimental data and configuration assignments for quasiparticle excitations in these nuclei have been critically surveyed. Included are data from new averaged-resonance neutron- capture measurements on 160Tb made in collaboration with colleagues at the Brookhaven National Laboratory. A set of most reliable values for Gallagher-Moszkowski matrix elements have been compared with calculated values. After many years of study and with the inclusion of many forms for the nucleon-nucleon force, the n-p interaction, as manifested in the nuclear structure of odd-odd nuclei, still has not been characterized with sufficient precision to allow satisfactory predictions of unmeasured matrix elements. We find that the empirical matrix elements, when compared with central force calculations, show potentially useful correlations with the degree of difference in the Nilsson orbital quantum numbers of the unpaired nucleons. It appears that these correlations also extend to the Newby shift matrix elements.

Experiment for the $^{35,37}Cl(\gamma,x\gamma')$-Reaction

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We present the results of the first $(\gamma,x\gamma')$ experiment for the $^{35,37}Cl$ nuclei (a photon γ' is recorded and its energy measured, and x is an unobserved particle emitted from the nucleus). A 390 g LiCl-target was bombarded with 32 MeV bremsstrahlung beam. The decay photons were detected at angle 140° relative to the incident bremsstrahlung radiation by means of a Ge(Li) detector with a sensitive volume of 100 cm^3. The experimental spectrum contains information about partial $^{35,37}Cl(\gamma,p_i)$, $^{35,37}Cl(\gamma,n_i)$, and $^{35,37}Cl(\gamma,\alpha_i)$ reactions in the region of the giant dipole resonance (i labels the level of the final nucleus). The integrated cross sections for individual partial channels were obtained by means of the relative method in which a comparison is made with the yeild of photons from the well studied reaction $^{16}O(\gamma,p_3\gamma')$ measured under the same experimental conditions as the $^{35,37}Cl(\gamma,x\gamma')$ reaction. The integrated partial cross sections (in MeV mb/sr) are presented in the Table

^{34}S level		cross section	^{34}Cl level		cross section	^{31}P level		cross section
2.13 MeV,	2^+	1.4	0.67 MeV,	1^+	0.8	1.27 MeV,	$3/2^+$	1.8
3.30	2^+	4.3	2.38	4^+	0.8	2.23	$5/2^+$	0.8
3.92	0^+	0.9	4.45	4^-	0.1	5.56	$3/2^+$	0.2
4.07	1^+	1.7	4.46	$(2,3)^-$	0.1			
4.62	3^-	0.9						
4.69	4^+	1.5	^{36}Cl level			^{33}P level		
4.89	2^+	1.3	0.79	3^+	0.4	1.43	$3/2^+$	0.7
5.76	1^-	0.3	1.96	2^+	2.1	2.54	$3/2^+$	0.3
7.22	1^-	0.6	2.68	1^+	0.6	5.97		0.4
^{36}S level			2.86	3^+	0.6			
3.29	2^+	1.7	2.99	$(1,2)^-$	2.3			
			4.03	$(0-2)^-$	0.1			

These data will be used to extract information about the role of nucleons from various shells in production of the giant dipole resonance in the $^{35,37}Cl$ nuclei, and also about the relation between the semidirect and statistical mechanisms of the photonuclear reaction.

Giant Dipole Resonance in ^{45}Sc through De-Excitation Gamma Rays

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New data on 21 partial photonucleon channels (γ,n_i) and (γ,p_i) for the ^{45}Sc nucleus (i numbers the levels of the final nucleus) received in $(\gamma,x\gamma')$ experiment [1]) become possible to gain greater understanding of the mechanism for the formation and decay of the giant dipole resonance (GDR) of the light fp-shell nuclei. We used a method of analysis developed in [2,3]).The method isolates the semidirect (SD) decay contribution in experimental photonuclear cross sections. The remainder of the cross sections is due to the statistical decay (pre-equilibrium and equilibrium). The realization of the method requires information about the partial photonucleon cross sections for population of individual levels of the final nuclei and the spectroscopic characteristics of the populated states taken from single-nucleon pick-up reactions. The results of our analysis are as follows. Outer shell (1f2p) of ^{45}Sc are populated by 5 nucleons (1 proton and 4 neutrons) They form 10% photoproton and 10-20% photoneutron cross sections. Decay of this GDR branch (^{1}f2p $\Rightarrow$1g2d3s) proceeds mainly through the nucleon escaping to the continuum and the forming of the final nucleus in a hole state,i.e. for this GDR branch SD decay is predominant. However in the main the GDR of ^{45}Sc is formed by nucleons of the inner 1d2s shell.As this GDR branch (1d2s $\Rightarrow$1f2p) decays mainly by means of the statistical mechanism the statistical decay prevails for the GDR of ^{45}Sc on the whole. The statistical mechanism is responsible for 70-90% of the integrated photoabsorption cross section. It is necessary to note that for the nearest nuclei investigated such a method (^{40}Ca and ^{58}Ni) the probability of the statistical decay is lower (about 40% and 20-80% respectively).

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Study of Low-Lying Dipole Excitations in ^{48}Ti by Photon Scattering

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The experiment was carried out with the cw bremsstrahlung photon beam from the newly constructed electron injector for the 175 MeV Moscow racetrack microtron. Continuous wave electron beam of energy 6.6 MeV and 30-50 μA intensity was used to produce photon beam. The experimental details may be found elsewhere [1,2]. Photons scattered by a 2.5 g/cm^3 target of natural titanium (a disc of 4 cm diameter) were detected with a 60 cm^3 Ge(Li)- spectrometer at an angle of 110° relative to the incident beam. The radiation dose was 4.7 C.

The nuclear resonance fluorescence spectrum shows seven levels. The results are summarized in the Table. All observed transitions are of dipole character. The transition strengths reported earlier [3] by Giessen-Stuttgart collaboration agree well with the results of the present experiment.

Level energy [MeV]	J^π	Γ_0^2/Γ [meV] Giessen-Stuttgart	Moscow	B(M1)↑ [μ_n^2]	B(E1)↑ [$10^{-3}e^2fm^2$]
3.700	$1^{(-)}$	12±2	10±3	(0.14)	(1.5)
3.739	1^+	58±7	54±5	0.42±0.05	
4.310	1^+	70±20	34±10	0.19±0.05	
5.526	1	70±30	<50±10	(<0.07)*	(<0.9)*
5.640	1^+	200±70	208±20	0.76±0.07	
6.126	1	160±60	173±10	(0.19)	(2.2)
6.138	$1^{(+)}$	90±40	65±10	0.07±0.01	

* Values were extracted assuming $\Gamma_0/\Gamma=1$

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Low-Lying Excitations in ^{56}Fe Studied by Nuclear Resonance Fluorescence

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The nuclear resonance fluorescence experiment have been performed using unpolarized bremsstrahlung produced by 6 6 MeV cw electron beam from the injector for the Moscow racetrack microtron Photons scattered by a natural 2 4 g/cm^2 iron target were observed with a 60 cm^3 Ge(Li) detector at 110° relative to the incident beam The data were accumulated with an average current of about 30 μA The radiation dose was 4 32 C Values of Γ_0^2/Γ, $B(M1)\uparrow$ and $B(E2)\uparrow$ for seven levels were extracted They are summarized in the Table We assumed J=1, π=+1 and $\Gamma_0/\Gamma=1$ where not measured For each transition, the effects of Doppler broadening and of atomic and nuclear resonant absorption in the target were taken into account numerically For ^{56}Fe in the energy region 0-6 5 MeV we obtained $\Sigma\ B(M1)\uparrow=(0\ 99\text{-}1\ 21)\mu_n^2$ The magnetic dipole excitation of energy 3 449 MeV and $B(M1)\uparrow\approx 1\mu_n^2$ is the strongest M1-transition below 6 5 MeV This distinctive low-lying M1-transition is the best candidate to be a scissors mode

level energy [MeV]	J^π	Γ_0^2/Γ [meV]	$B(M1)\uparrow$ [μ_n^2]	$B(E2)\uparrow$ [e^2fm^4]
3 449	1^+	79±8	0 994	
3 602	2^+	5±2		78 7
4 847		9±3	0.020	
5 227	1	35±4	0.063	
5 257	2	24±3		37 1
5 404	>0	<29±6	<0.047	
5 853		23±8	0 030	
6 250	1	53±13	0.056	

$\Sigma\ B(M1)\uparrow = (0.99\text{--}1.21)\ \mu_n^2$

Nuclear Deformation Parameters for ^{48}Ti and ^{56}Fe from Scissors-Type Excitations

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There are some reasons to regard strong low-lying M1 excitations in even-even Ti isotopes as a manifestation of orbital isovector ones, commonly called "scissors mode" [1]. Such low-lying scissors-type excitations may be a more general phenomenon in fp- shell nuclei In nuclear resonance fluorescence (NRF) experiments on ^{48}Ti [2,3] two significant M1 excitations were observed below 6 MeV. Their energies are 3.739 nd 5.640 MeV, excitation strengths B(M1)↑=0.42 and 0.76 μ^2_n respectively [3]. In recent NRF experiment on ^{56}Fe [3] we observed the only strong low-lying M1 excitation for the same energy region. It lies at 3.449 MeV and its B(M1)↑=0.994 μ^2_n. If one considers three above mentioned M1 excitations as scissors-type levels one may extract easily deformation parameters δ and γ for ^{48}Ti and ^{56}Fe (parameter γ describes the deviation from axial symmetry). Really, in a symmetric rotator the only strong scissors-type excitation must exist. In an symmetric rotator the scissors excitation must split into two basic branches. Using two-rotor model [4] and RPA [5] formulas we extracted deformation parameters for ^{48}Ti and ^{56}Fe. They are presented in the Table together with the deformation parameters received for ^{48}Ti from inelastic α-scattering [6].

^{48}Ti	δ = 0.23	γ = 21°	our values
	δ = 0.27	γ = 24°	(α,α')
^{56}Fe	δ= 0.18-0.20	γ = 0°	

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FRAGMENTATION AND SPLITTING OF GAMOW-TELLER RESONANCES IN Sn(^{3}He,t)Sb CHARGE-EXCHANGE REACTIONS, A=112 to 124

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Fragmentation and splitting of Gamow-Teller (GT) strength has been observed in a systematic study over the entire range of stable Sn isotopes. The experiment was carried out at the Indiana University Cyclotron Facility with the K=600 high-resolution magnetic spectrometer at E(^{3}He) = 200 MeV near $\Theta = 0°$. Triton spectra centered near 0° and 2° were measured simultaneously. This provides a powerful signature for both non-spin-flip and spin-flip L=0 transitions because of the sharp decrease of the cross section with increasing angle.

Fragmentation of the Gamow-Teller (GT) strength in the Sn isotopes into three (or more) fragments has been predicted theoretically [1]. In addition to the most collective main GT resonance located a few MeV above the isobaric analog state (IAS), two fragments (pygmy resonances) were predicted at lower excitation energies. The three GT components are usually referred to in the literature as direct-, core-polarization-, and back-spin-flip components. The pygmy resonances were observed for all targets. The excitation energies are about -2 to -6 and -5 to -8 MeV below the IAS, and the widths are 1-3 MeV. Essentially all resonances are further fragmented into typically ten components each which are interpreted as doorway states.

The main GT resonances were observed above the IAS with lorentzian line shapes of widths $\Gamma \approx 5$ MeV. A theoretically predicted splitting [2] of this resonance into two components could not be confirmed (see also [3], possibly due to the fact that the predicted splitting is smaller than the observed width. However, the systematics of the measured centroid energies may nevertheless reflect upon the predicted effect. The splitting is due to the proximity of the energies of the main collective configuration of the GT resonance (mostly $1g_{9/2} \rightarrow 1g_{7/2}$ and $1d_{5/2} \rightarrow 1d_{3/2}$) and the $1h_{11/2} \rightarrow 1h_{9/2}$ configuration. The transition of the strength from the energetically lower to the upper component is related to the fullness and emptyness of the respective shell-model orbits and the destructive and constructive interference between the two components, and it should occur near the onset of the $1h_{11/2}$ neutron orbitals in the Sn ground states configurations. The characteristics of the observed decrease of E_x(GT)-E_x(IAS) from 3 to 1 MeV may be related to such an effect.

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Ground state correlations and charge transition densities

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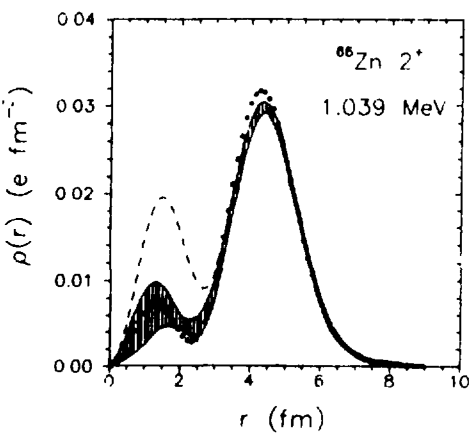
It is well known that many basic features of the nuclear vibrational states can be described within the Random Phase Approximation (RPA), which enables one to treat some correlations in the ground state. Being the spatial overlap between the ground state wave function and the excited state wave function the charge transition density provides a good test for nuclear models. Recent experimental and theoretical (based on the RPA) studies [1] of the charge transition densities to investigate the interplay between single–particle and collective degrees of freedom in the excitation of the low-lying states in some spherical nuclei are in reasonable agreement, but the theory gives fluctuations of the transition densities in the interior region. In RPA, as in the Hartree-Fock approach, the theoretical fluctuations are too large in the nuclear interior, which indicates a systematic problem of a more fundamental nature.

The effect of ground state correlations on the charge transition densities of vibrational states in spherical nuclei is studied. The problem for the ground state correlations (GSC) beyond RPA leads to a non-linear system of equations [2], which is solved numerically. The influence of the correlations on the pairing is taken into account too. As one can see from a figure the inclusion of ground state correlations beyond RPA (dotted curve) results in an essential suppression of the charge transition density in the nuclear interior in comparison with the RPA calculations (dashed curve) and enables one to reproduce the experimental data (dashed area).



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Vortex Waves in Nuclear Systems

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Experimental studies of heavy ion reaction have aroused the great interest in analyzing the large amplitude collective motion (high excited states, large spin excitations, super- and hyper-deformed states) and exotic modes of motion (solitons, bubbles, rings etc.) in nuclear systems (for instance, see Refs. in the recent review [1]). Special attention has been paid to describing stable or long lived vortical nuclear excitations.

In this report, we discuss the pure vor l motion in nuclear systems excluding the usual approximation on smallness of the excitation amplitude and the additional assumptions on the shape of a nuclear system. The semiclassical nuclear hydrodynamics based on the current $\boldsymbol{j}$ and density ρ algebra and the soliton concept are used. Gradient terms of the "pressure" drop out of the equations of motion on separating the curl component of the velocity field $\boldsymbol{v} \equiv \boldsymbol{j}/\rho$ and the equation of motion for a vorticity $\zeta \equiv rot\boldsymbol{v}$ is formally reduced to the pure kinematic Euler-like form, at least, for the Skyrme type forces.

We consider here two-dimensional analog of a nuclear disk [2], a plane nuclear vortex, a new type of a pure vortical state of incompressible $\rho(\boldsymbol{r}, t) = \rho_0$ nuclear matter. It is the finite area of the constant vorticity on a plane $\zeta(r, \phi, t) \equiv \zeta_0$, within the uniform-rotating contour $\Gamma(r, \phi) \equiv r - R(\phi) = 0$. These states can be considered as the generalization of the elliptic Kirchhoff vortex [3].

The following nonlinear integro-differential equation for the vortex boundary has been derived ($\Omega dR/d\phi + v_r - v_\phi S(\phi) = 0$, $S(\phi) \equiv R^{-1} dR/d\phi$.) [2]

$$\frac{2\pi\Omega}{\zeta_0}\frac{dR}{d\phi} = \int_0^{2\pi} d\phi' R(\phi') \ln(|\boldsymbol{r} - \boldsymbol{r}'|)[(1 + S(\phi)S(\phi'))\sin(\phi' - \phi) + (S(\phi) - S(\phi'))\cos(\phi' - \phi)],$$

where Ω is the angular velocity of the uniform - rotation of a contour. This equation together with the definition of the velocity fields will describe the motion of the contour as the propagation of a nonlinear dispersion wave on a plane.

The contour velocity depends on the symmetry of a contour. Recently [4] we have proved that the solutions having the symmetry relative to the turn by the angle $2\pi/l$ with integer parameter $l = 2, 3, 4 \ldots$ can exist. These vortexes may be two-dimensional analogs of rotating nuclear systems which have stable quadrupole, octupole, hexadecupole ... deformation, respectively.

As we have found recently, equivalent solutions have been derived first by Deem and Zabusky [5]. They have found a class of uniformly rotating and uniformly translating solutions to the Euler equations in two dimensions. Such stable vortical states have been called the "V states" or "vortons". The special contour-dynamics algorithm has been developed. Computations have been demonstrated the existence of $V(l, T)$ states, the stable vortex waves, having l-fold symmetry and period T. So we have an interesting task in trying to find analogs of the V states, nonlinear vortex waves in nuclear systems.

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Use and Misuse of the "Completeness" Concept in Nuclear Spectroscopy

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Completeness is a concept which was introduced following the development of the Average Resonance Capture (ARC) technique in neutron capture gamma-ray spectroscopy. It has enjoyed a great popularity since the availability of complete level schemes is of high relevance for testing nuclear models. It was claimed that other non-selective reactions also have this property. When a subject becomes "fashionable", it can be used inevitably in some more criticizable or unprecise way. This will be the subject of the paper.

Starting from the ARC method, the ranges of validity of completeness claims will be discussed. Examples will be given illustrating their reliability and how conclusions have sometimes been proposed which are beyond their range of validity or relevance. Then the question of completeness in fusion reactions will be addressed.

Low Energy Photon Scattering: E1 and M1 Strength Distributions in Deformed Nuclei

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Systematic nuclear resonance fluorescence (NRF) experiments have been performed at the bremsstrahlung facility of the Stuttgart Dynamitron to investigate the distribution of *magnetic* and *electric* dipole strengths in deformed nuclei. Precise excitation energies, transition strengths, spins and decay branching ratios were deduced for numerous low lying dipole excitations in deformed nuclei. Measurement s of the linear polarization of resonantly scattered photons using a Compton polarimeter enabled model independent parity assignments.

The experir ents during the last years revealed the following new spectroscopic informations:

- The systematics and strength fragmentation of the orbital $M1$ mode, the socalled *"Scissors Mode"*, in deformed rare earth and actinide nuclei could be established. The linear increase of the total $M1$ strength with the square of the deformation parameter (*"δ^2-law"*) for the transition from spherical to deformed SU(3) nuclei as shown by the Darmstadt group for even Sm-Nuclei could be confirmed by polarization measurements in Nd-isotopes. The transition from spherical nuclei to γ-soft rotors (O(6)-nuclei) has been studied recently in even Ba-isotopes (^{138,136,134}Ba).

- For the first time the *"Scissors Mode"* excitation could be detected in an odd mass nucleus (^{163}Dy). Th.se results together with new data for ^{161}Dy and ^{157}Gd will be discussed by H.H. Pitz.

- Low lying electric $\Delta K = 0^-$-transitions of remarkable strengths have been observed in all investigated even-even, deformed nuclei near 1.5 MeV. These 1^- states are discussed in terms of a $K = 0$ rotational band based on an octupole vibration.

- Enhanced *electric* dipole excitations in deformed nuclei cou' ' be systematically observed at excitation energies near 2.5 MeV. As a common feature these states show systematically decay branching ratios which hint at K-mixing. These strong $E1$ excitations can be interpreted as two phonon excitations due to the coupling of octupole ($J = 3^-, K = 1$) and quadrupole-γ-vibrations ($J = 2^+, K = 2$).

- In the spherical even N=82 isotones strong $E1$ excitations are known which can be interpreted as transitions to the $J^\pi = 1^-$ members of $2^+ \otimes 3^-$ multiplets. The coupling of an additional neutron to these two-phonon excitations has been studied in ^{143}Nd. In this nucleus recent experiments succeeded in the first identification of dipole excitations to a $2^+ \otimes 3^- \otimes$ particle multiplet.

LIGHT NEUTRON-RICH NUCLEI PROPERTIES AND ISOSPIN-ISOSPIN INTERACTION.

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The semimicroscopic approach (SMA) [1,2] to low energy heavy ion interaction is applied to investigate isospin-isospin interaction of the light neutron-rich nuclei with stable nuclei. The real optical potentials and formfactors of the inelastic transition are constructed on the basis of the effective nucleon-nucleon force. The single-exchange effects are taken into account in the local approximation of density matrix formalism. The density matrix is taken in the modified Slater approximation with the account of the surface effects.

The SMA is generalized to take into account the isospin effects and the difference in proton and neutron matter distributions for both nucleus-projectile and nucleus-target. For all the light neutron-rich projectiles, the ground state density is calculated within the self-consistent theory of finite Fermi systems [3]. For all the nuclei-target, the densities are taken as two- or three-parameters Fermi distributions.

The direct and exchange potentials have been calculated in the SMA for the systems $^{x}Li+^{28}Si$, $^{x}Li+^{48}Ca$, $x=6,7,8,9,11$ and for the systems $^{x}Li+^{58}Ni$, $^{x}Li+^{94}Mo$, $^{x}Li+^{116}Sn$, $x=8,9,11$, by using the full finite-range effective M3Y interaction. Both the isoscalar and isovector channels are under consideration. The calculations have been performed with projectiles energies ranging from 15 MeV/n to 90 MeV/n. In the case of the systems $^{x}Li+^{48}Ca$ the target nucleus neutron skin effect is also investigated.

It has been shown in the framework of the SMA that the role of the difference in proton and neutron matter distributions is most important in the description of the isospin-isospin interaction properties.

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Quantum and Thermal Fluctuations in Nuclear Fermi Liquid

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The traditional one-body transport models that exploit the phase-space distribution of nucleons situated in a self-consistent mean field with some form of a collision term provide a good description for the average values of the oservables. They cannot however describe the fluctuation properties which arise whenever one deals with a reduced description.

We are starting with an extended Landau-Vlasov-Langevin (ELVL) equation where the retardation effects in the collision integral and the random force for the quadrupole deformation of the Fermi-surface are taking into account. The ELVL equation is reduced to the stochastic fluid-dynamical equations where the pressure tensor $\Pi_{\nu\mu}(\vec{r},t)$ includes the Fermi-surface distortion effects and random pressure tensor $S_{\nu\mu}(\vec{r},t)$. The hydrodynamic-like correlation properties of the random pressure tensor $S_{\nu\mu}(\vec{r},t)$ is established and the correlations of fluctuations of the local density, displacement field and Fermi-surface distortion are investigated.

The stochastic fluid-dynamical equations are transformed into Langeven equation for the shape deformation parameters of Fermi-liquid drop. This equation includes the retarded friction and macroscopic random force $\Gamma(t)$ that are connected with a pressure tensor $\Pi_{\nu\mu}(\vec{r},t)$. In the quantum limit $\hbar\omega > T$, (T is the temperature of nucleus) the spectral correlation function $\overline{\Gamma^2_\omega}$ of random force $\Gamma(t)$ depends on the collisional regime in the Fermi-liquid. In the first-sound regime ($\omega\tau >> 1$, where τ is the relaxation time) we obtain $\overline{\Gamma^2_\omega} = (\hbar/2\pi)\omega\tau$ (blue noise), whereas the zero-sound regime ($\omega\tau >> 1$) leads to $\overline{\Gamma^2_\omega} = (\hbar/2\pi)(1/\omega\tau)$ (red noise). These both regimes produce the quantum fluctuations of the observables. In particular, the including of the random force into classical equation of motion recoveries in our case the quantum uncertainty principle for the shape deformation parameter q and conjugate momentum p.

The TFD extension of the quasiparticle – phonon nuclear model to finite temperature

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The description of the properties of collective excitations in hot nuclei and their changes with increasing temperature T is still an actual theoretical problem[1-3]. We propose an approach to the problem based on the extension of the quasiparticle – phonon nuclear model (the QPM) [4] to $T \neq 0$ by using the formalism of the thermo field dynamics (the TFD) [2,5]. According to the prescriptions of the TFD one has firstly to double formally the number of nuclear degrees of freedom by introducing the so-called tilde states in addition to the ordinary Fock states. The doubling is necessary to express the statistical ensemble average of A as an expectation value $\ll A \gg = \langle 0(\beta)|A|0(\beta)\rangle$ over appropriately defined thermal vacuum $|0(\beta)\rangle$ [5]. The time - translation operator of the system in the space spanned by usual and tilde states is now the thermal Hamiltonian $\mathcal{H} = H - \tilde{H}$, and the properties of the system excitations are obtained by the diagonalization of $\mathcal{H}$. The state $|0(\beta)\rangle$ is the vacuum for the thermal quasiparticle annihilation operators $\beta, \tilde{\beta}$ that are connected with the creation and annihilation operators of nucleons through two consequent canonical transformations, namely, the standard Bogoliubov transformation to the quasiparticles and the thermal Bogoliubov transformation. The coefficients of these transformations are found by minimizing the grand thermodynamic potential of the system of nucleons only with pairing interaction [3,6]. The coefficients of the thermal Bogoliubov transformation coincide with the thermal Fermi occupation numbers of Bogoliubov quasiparticles. Knowing the coefficients one gets an expression of the whole Hamiltonian $\mathcal{H}$ (including particle – hole interaction) through the operators $\beta^+, \tilde{\beta}^+$. The structure of $\mathcal{H}$ in terms of $\beta^+, \tilde{\beta}^+$ is the same as that of H in terms of the usual Bogoliubov quasiparticles. The main difference is redefinition of vertices corresponding to terms of the same operator structure. So it is easy to extract, from $\mathcal{H}$, the *thermal random phase approximation part* $\mathcal{H}_{TRPA}$. *After introducing the thermal phonon* operator

$$Q^+_{\lambda\mu i} = \frac{1}{2} \sum_{j_k j_{k'}} (\Psi^{\lambda i}_{j_k j_{k'}} [\beta^+_k \beta^+_{k'}]_{\lambda\mu} - (-)^{\lambda-\mu} \Phi^{\lambda i}_{j_k j_{k'}} [\beta_k \beta_{k'}]_{\lambda-\mu}) .$$

(here β, β^+ stand for both usual and tilde operators) the $\mathcal{H}_{TRPA}$ is diagonalized within the space spanned by the thermal one-phonon states, and one gets the equation for the phonon energies and expressions for the amplitudes Ψ Φ [6]. These equation and expressions are of the same form as those derived before by other methods [1].

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Phonon interaction in hot nuclei

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It is well proved for cold heavy nuclei that the main part of a width of collective giant resonance states is due to coupling of the RPA-states with more complex ones like $2p-2h$ [1,2]. The same idea can be explored in studying of the formation and dependence on temperature of a width of a giant dipole resonance in a hot nucleus (see, e.g.[3]).

We formulate here an approach to the problem based on the extension of the quasiparticle phonon nuclear model (the QPM) [2] to $T \neq 0$ using the formalism of the thermo field dynamics [4,5]. Starting with the QPM Hamiltonian at $T = 0$ we derive the thermal Hamiltonian $\mathcal{H}$ of the QPM expressed in terms of thermal quasiparticles $\beta^+_{jm}, \tilde{\beta}^+_{jm}, \beta_{jm}, \tilde{\beta}_{jm}$ and thermal RPA-phonons $Q^+_{\lambda\mu i}, Q_{\lambda\mu i}$ which consist of forward going and backward going thermal quasiparticle components like $\beta^+_{jm}\beta^+_{j'm'}, \tilde{\beta}_{jm}\beta_{j'm'}$ etc.

$$\mathcal{H} = \sum_{\lambda\mu i} \omega_{\lambda i}(Q^+_{\lambda\mu i}Q_{\lambda\mu i} - \tilde{Q}^+_{\lambda\mu i}\tilde{Q}_{\lambda\mu i}) -$$

$$-\frac{1}{2\sqrt{2}} \sum_{\lambda\mu i} \sum_{\tau} \sum_{jj'}{}^{\tau} \frac{f^{(\lambda)}_{jj'}}{\sqrt{\mathcal{N}^{\lambda i}_{\tau}}} \left\{ ((-)^{\lambda-\mu}Q^+_{\lambda\mu i} + Q_{\lambda-\mu i})B_\beta(jj';\lambda-\mu) - \right.$$

$$\left. - ((-)^{\lambda-\mu}\tilde{Q}^+_{\lambda\mu i} + \tilde{Q}_{\lambda-\mu i})\tilde{B}_\beta(jj';\lambda-\mu) + h.c. \right\}$$

Here $\omega_{\lambda i}$ is the energy of the thermal phonon state $Q^+_{\lambda\mu i}|\Psi_0(\beta)\rangle$ and $|\Psi_0(\beta)\rangle$ is the thermal phonon vacuum, $B_\beta(jj';\lambda-\mu)$ is a linear combination of products of creation and annihilation operators of thermal quasiparticles ($\beta^+_{jm}\beta_{j'm'}, \tilde{\beta}^+_{jm}\beta_{j'm'}$ etc.). The second term of $\mathcal{H}$ mixes states with different numbers of phonons, and to diagonalize $\mathcal{H}$, one has to include both one- and two- thermal phonon components in the trial wave function. Then using the variational principle one can derive the following equation for the energies $\eta_{J\nu}$ of these complex states

$$det|(\omega_{Ji} - \eta_{J\nu})\delta_{ii'} - \frac{1}{2}\sum_{\lambda_1 i_1 \lambda_2 i_2} \frac{U^{\lambda_1 i_1}_{\lambda_2 i_2}(Ji)U^{\lambda_1 i_1}_{\lambda_2 i_2}(Ji')}{\omega_{\lambda_1 i_1} + \omega_{\lambda_2 i_2} - \eta_{J\nu}}| = 0$$

The quantity $U^{\lambda_1 i_1}_{\lambda_2 i_2}(Ji)$ stands for the coupling matrix element of one- and two- thermal phonon states. The above equation is very similar to that for $T = 0$ [2]. This is the main difference of the present approach to damping of nuclear excitations at a finite temperature from that of [3]. It follows from the above consideration that the phonon interaction in hot nuclei depends only on the phonon structure and Bose thermal occupation numbers can not appear in this formalism naturally. In other words, although our thermal phonons are built from "thermal" quasiparticles, the system of interacting phonons isn't heated itself.

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Excitation of the isovector GDR by inelastic α scattering and the neutron skin of nuclei

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Determining the shape of the nuclear matter density distribution has received continued interest throughout the history of nuclear physics [1]. In our previous work [2] we have demonstrated that the determination of the GDR excitation cross section in inelastic α-scattering by $\alpha' - \gamma_0$ coincidence measurements provides a novel method to determine the difference of the radii of the proton and neutron distributions in N≠Z nuclei. The experimental data presented for ^{116}Sn, ^{124}Sn, ^{150}Nd and ^{208}Pb [2,3] were analyzed assuming a mixture of the collective Goldhaber-Teller and Steinwedel-Jensen vibrational modes of the GDR. In case of the deformed ^{150}Nd, this technique provides values for the neutron-skin thickness separately along and perpendicular to the symmetry axis, yielding $\beta_2^n/\beta_2^p = 0.92 \pm 0.08$ for the ratio of the nuclear and charge quadrupole deformation parameters.

In order to study the above ratio by an independent method, ^{150}Nd(α, α′) excitation function and angular distribution measurements were performed in the energy range where the Coulomb nuclear interference takes place. The measured cross sections were compared to the calculated ones. The coupled channel calculations were performed as a function of the β_2^n using the measured B(E2,$0^+ \rightarrow 2^+$) and β_4 values. The optical model potentials were checked by comparing the measured and calculated elastic cross sections. As a result of a preliminary analysis, the ratio of the nuclear and charge quadrupole deformation parameters was found to be $\beta_2^n/\beta_2^p = 0.80 \pm 0.10$ in good agreement with our previous results.

To describe the intrinsic structure of ^{150}Nd a self-consistent mean-field method was used. In the Hartree-Fock + BCS calculations we applied a quadratic constraint to the mass quadrupole moment. At the minimum of the potential energy surface the proton and neutron densities as well as their deformation parameters were deduced. For the ratio $\beta_2^n/\beta_2^p = 0.94$ was obtained in the model in a good agreement with our experimental values.

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sdg BOSON MODEL CALCULATIONS OF E2/M1 MULTIPOLE MIXING RATIOS IN ^{152}Nd

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Abstract : The E2/M1 multipole mixing ratios of the electromagnetic transitions of ^{152}Nd are obtained by the use of the sdg boson model. The calculated values show that the transitions which connect the levels of the same parity are prodominantly E2 and the ones which connect the levels of the opposite parity are prodominantly E1. The results are compared with the experimental ones and previous calculations. Its is shown that there is a good agreement between the results and experiments.

The Half-life of Two-neutrino Double Beta Decay

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During the last few years measurement of the half-life for two-neutrino double beta decays ($2\beta_{2\nu}$) has reached a stage in which they can provide significant contribution to our knowledge of the corresponding nuclear matrix elements. But it is well known that precise calculation of the $2\beta_{2\nu}$-decay rate presents difficulties to get analytic expression for the $T_{1/2}$ because of the energy denominators of the transition amplitude depends on the energies of the intermediate nuclear states (ω_n), electrons(e) and neutrinos(ν). Therefore, in order to permit analytic evaluation of the $T_{1/2}$ traditionally in decay rate it is assumed that each electron-neutrino pair participating in the decay takes away the half energy of the decay (e+ν=w/2).

The above simple description of $T_{1/2}$ certainly fails when strong cancellation among terms in ε_{-1} occurs. Such an approximation produces in QRPA with charge exchange spin-spin interactions in the ph- and pp-channels an incorrect value for decay rate ($T_{1/2} \to \infty$) around $g_{pp} \approx g_{ph}$. Since the main terms in $T_{1/2}$ are canceled the transition is suppressed. We wonder the contribution of further terms in the expansion of the transition amplitude in powers of $(e_{1(2)}+\nu_{1(2)}-w/2)^2$ because of $w=e_1+e_2+\nu_1+\nu_2$ linear terms are not risen. In present work with this consideration the half-life for $2\beta_{2\nu}$-decay can be expressed as

$$T^{-1} = \varepsilon f \cdot \varepsilon \varepsilon f \cdot \varepsilon f \qquad (1)$$

where

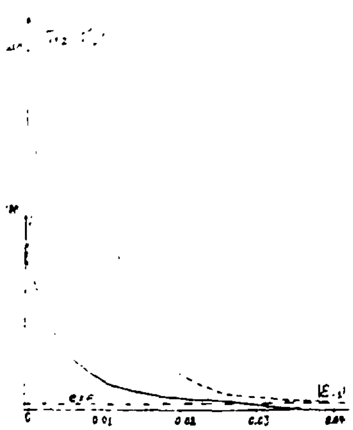
$$f = 2.84 \cdot 10 \; F_{PR} t (t^4 + 22t + 220t^2 + 990t + 1980) \quad MeV \; yr$$

$$f = 2.84 \cdot 10 \; F_{PR} t (t + 26t + 312t + 1430t + 2860) \quad MeV^4 \; yr$$

$$f = 1.30 \cdot 10 \; F_{PR} t (t + 30t + 420t^2 + 1994t + 4298) \quad MeV \; yr$$

$$\varepsilon = \sum \frac{4 \; Z \cdot 2 \; \sigma t \; n \; (n \; \sigma t \; 4 \; Z)}{(\omega_n - w/2)^k}$$

with m_e w/2 and F_{PR} is Primakoff-Rosen expression for non relativistic Coulomb correction. The first term in eq (1) corresponds to emission of the electron-neutrino pair with sum energy equal w/2 , if $\varepsilon_{-3}=0$.



The pp- interaction suppresses ε_{-1} around $g_{pp} \approx g_{ph}$ very rapidly [1,2] while g_{pp} dependence of ε_{-3} is expected weaker because of the sum in ε_{-1} and ε_{-3} contains different energy dependence. Therefore numerical calculations of $T_{1/2}$ for ^{130}Te were performed with the fixed ε_{-3}=0.033 MeV^{-3}. The figure shows the dependence of the $T_{1/2}$ on $|\varepsilon_{-1}|$ for $\varepsilon_{-1}\varepsilon_{-3}>0$ (solid line) and $\varepsilon_{-1}\varepsilon_{-3}<0$ (dashed line) with w=3.555 MeV. The long- dashed line indicates the lower limit $T_{1/2}^{exp}$. The contribution from last term in eq (1) is much smaller than first two terms for $\varepsilon_{-1} \approx \varepsilon_{-3}$ and gives finite value for $T_{1/2} \approx 10^{23}$ yr if $\varepsilon_{-1}=0$. The interference term in the case $\varepsilon_{-1}\varepsilon_{-3}<0$ gives strong suppression for decay rate $T_{1/2} > 10^{23}$ yr. We see that the experiment is described quite satisfactorily but direct comparison of the calculated and observed $T_{1/2}$ values might be achieved by using a large shell model basis.

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Probability of ^{178}Hf*(16$^+$)(p,t)^{176}Hf*(16$^+$) transition in the framework of the pairing correlation theory with exact particle number

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Recently the unique experiment on the measurement of ^{178}Hf*(16$^+$) (p,t) ^{176}Hf*(16$^+$) cross section has been performed [1] where $I^\pi = K^\pi = 16^+$ states in Hf are four quasiparticle states (π[404]7/2, π[514]9/2, ν[514]7/2, ν[624]9/2). The reduction of the cross section in this transition in comparison with the one between ground states of the same nuclei $R = \sigma(16^+ \to 16^+)[\sigma(0^+ \to 0^+)]^{-1}$ =0.27(5) or 0.39(8) is connected with the blocking effect caused by two neutron quasiparticles.

We have carried out an estimation of R in the framework of the pairing correlation theory taking into account the exact conservation of particle number by the method described in [2]. We have calculated nuclear structure factors

$$S(i \to f) = \langle \Psi_f(N-2)| \sum_k a_{\bar{k}} a_k |\Psi_i(N)\rangle$$

($a_{\bar{k}}$ being an annihilation operator of a particle in state k) and supposed that $R \simeq |S(16^+ \to 16^+)/S(0^+ \to 0^+)|^2$. As $|\Psi_i(N)\rangle$, $|\Psi_f(N)\rangle$ we use quasiparticle functions projected onto states with fixed particle numbers. Bogolubov parameters are found for each state involved by variation after projection (FBCS) taking into account the blocking effect. Computations include Woods–Saxon potential single–particle energies for each nucleus and pairing strengths determined on pairing energies. Energies (ω in MeV) isomer states 16^+ in Hf calculated by our method are in a good agreement with experiment $\omega_{th}(16^+, {}^{176}\mathrm{Hf})=3.32$ ($\omega_{exp}=3.27$); $\omega_{th}(16^+, {}^{178}\mathrm{Hf})=2.41$ ($\omega_{exp}=2.45$). It should be mentioned that ω in ^{178}Hf can not be calculated by using BCS–theory with blocking as in this case the pairing strength is less than its critical value. Our calculations give for R the value equal to 0.38 that corresponds to the experiment and a qualitative estimation given in [1]. Besides we have calculated nuclear structure factors and $(R_A)_{th}$ for the (p,t) reactions in neighbour odd hafnium isotopes $(R_A)_{th}=|S(A \to A-2$, ground states)/ $S(178 \to 176$, ground states)$|^2$; $(R_A)_{exp}=\sigma(A \to A-2$, ground states)/ $\sigma(178 \to 176$, ground states): $(R_{177})_{th}=0.50$; $(R_{177})_{exp} \le 0.73$; $(R_{179})_{th}=0.37$; $(R_{179})_{exp}=0.49$. Thus, our calculations give values that are a little less than experimental rates.

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HIGH-LYING GAMOW-TELLER STATES IN THE SPHERICAL NUCLEI

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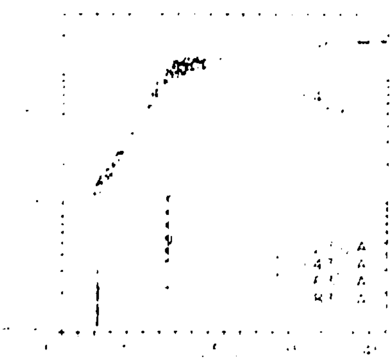
The results of calculation of the Gamow-Teller (GT) $\sigma t^{(-)}$- strength distribution in the RPA are presented. Unlike previous calculations [1-4] we use the strongly non-local separable residual interaction:

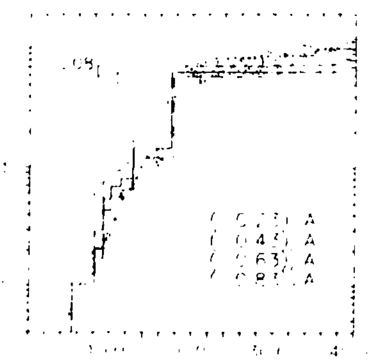
$$H_{res} = -2\kappa_1^{01} \sum_\mu Q^\dagger_{1,\mu} Q_{1,\mu},$$

$$Q_{1,\mu} = \sum_{j_p, m_p, j_n, m_n} < j_p, m_p | U'(r) \sigma_\mu t^{(-)} | j_n, m_n > a^\dagger_{j_p, m_p} a_{j_n, m_n},$$

here κ_1^{01} is the effective constant of the residual interaction, $U'(r)$ is the radial form factor chosen to be equal to the derivative with respect to the radii of the central part of the shell potential. This interaction leads to the excitation of two-quasiparticle states in which the proton- and neutron quasiparticles occupy the single-particle states with the same angular momentum and the different number of nodes in the radial part of the wave function. As a result, additional collective GT states placed considerably higher than the usual giant GT resonance can be formed. These states can absorb a considerable part of the strength of the $\sigma t^{(-)}$ transitions.

On the pictures the summed GT strength functions $S(E) = \frac{1}{3(N-Z)} \sum_{i, E_i < E} B^-(GT, i)$ for ^{54}Fe and ^{208}Pb are shown. The calculations performed for different values of κ_1^{01}. The experimental results are taken from Tables I of [5] and Tables I and II of [6].





All energies are reckoned from the ground state of the parent nuclei.

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EXPLORING NUCLEAR STABILITY NEAR N=162 AND Z=108

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Recent experiments [1] performed in the framework of the Dubna-Livermore collaboration have led us to the discovery of the three new heaviest nuclides, $^{266}106$, $^{265}106$, and $^{262}104$, that were produced in the $^{248}Cm+^{22}Ne$ reaction by employing the Dubna gas-filled recoil separator [2]. The identification of the new species was based on establishing genetic links between α decays of the mother nuclides and subsequent α or spontaneous-fission (SF) decays of their descendants.

Nuclide	Principal decay mode	Alpha-particle energy MeV	Half-life s
$^{266}106$	α	8.63±0.05	10 30
$^{265}106$	α	8.71 to 8.91	2-30
$^{262}104$	SF		$1.2^{+1.0}_{-0.5}$

The ground-state decay properties that we established for the new nuclides (see the Table and Ref.[1]) indicate a large enhancement in their SF stability and thus confirm the existence of the predicted deformed shells N=162 and Z=108 [3,4]. Our data clearly show that the SF stability at Z=106 and N=160 is not reduced by the destabilizing effect of the new fission valley which was predicted by theory to develop close to the fragment magic numbers N=2×82 and Z=2×50, to present up to Z=110, and to lead, with a low collective inertia, to very compact scission shapes and very short SF half-lives in the sub-*ms* range [5]. The discovery of the significant nuclear stability near N=162 and Z=108 creates new opportunities for many further explorations at the edge of the nuclear domain.

During February, March, and April of 1994 we are performing further experiments to explore properties of unusually stable nuclei near N=162 and Z=108. In this series of experiments, targets of ^{238}U are bombarded with high-intensity beams of ^{34}S accelerated by the Dubna U400 cyclotron. The aim of these long-term bombardments is to produce $^{267}108$ and $^{268}108$. The experiments will be finished by April 30 with an expected total beam dose of about 2×10^{19} particles ^{34}S. Findings of these experiments will be presented.

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THE STATUS OF THEORETICAL MASS VALUES OF NUCLEI WITH Z>N

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There are large discrepancies between mass values of nuclei with $Z > N$ calculated in different approaches /1/. An analysis of these discrepancies in the case of nuclei whose masses are known from experiment and in the case of nuclei far from stability makes possible to select the group of approaches best suited to predict M(Z,N) values. The common property of these selected approaches is that they employ one or another relation linking masses of mirror nuclei.

Further decrease in the scatter of mass predictions given by different approaches was attained by substitution of theoretical mass values for initial nuclei by more accurate experimental ones in relations linking masses of mirror nuclei.

There are different ways to parameterise Coulomb displacement energies (CDE) in approaches which take into cosideration nuclear shell structure. Nevertheless for 186 nuclei with $Z > N$ and $18 < A < 60$, whose masses are presented in /1/ the mean square deviations between mass predictions given in various approaches do not exceed 0.26 MeV.

Another situation holds for nuclei with $A \geq 60$. Reported in /2/ diagonal and global systems of parameters defining CDE lead to drastic difference between calculated mass values. We get the conclusion that the diagonal system of parameters is more preferable. Its use diminish significantly the scatter in mass values calculated in various works. Of special note is a good agreement of M(Z,N) values calculated in our approach /3/ and in other selected approaches. In our approach contrary to remaining ones Coulomb energy and various corrections to it are calculated directly without any additional parameters and the parameterisation of CDE is not employed.

Mean square deviations (δ) between mass predictions given in our approach and in other selected ones were calculated over 266 nuclei with $Z > N$ and $A \geq 60$. Values of δ lie in the range $0.13 \div 0.29$ MeV.

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SCISSORS MODES: FROM SEMICLASSICAL TO MICROSCOPIC DESCRIPTIONS

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ABSTRACT

The semiclassical description of the scissors mode[1] based on the two-rotor model (TRM)[2] is shown to lead to a quantum mechanical definition of the mode. It represents also the common classical limit of many unrelated phenomenological as well as microscopic models. This can be shown once the TRM Hamiltonian is expressed in terms of the quadrupole shape variable α rather than the angle variable ϑ as in the original formulation.

The shape variable can be indeed related by the use of coherent states to the quadrupole bosons adopted in the proton-neutron interacting boson approximation (IBA-2). In this limit the general IBA-2 M1 scissors summed strength[3] assumes the TRM form.

If on the other hand the strength of α is equated to that of the fermionic quadrupole operator in the particle-hole or two quasi-particle space[4] a complete quantitative equivalence with schematic RPA is reached. Like schematic RPA, the semiclassical approach predicts a low and a high energy scissors mode in deformed as well as superdeformed nuclei.

An adequate and complete description of the low lying mode can be made however only in realistic rather than schematic RPA. This approach being formulated in the intrinsic frame, suffers from some limitations which can be overcome only by the use of sophisticated techniques. A QRPA approach formulated in the laboratory frame is proposed as a way of avoiding the mentioned difficulties[5]. This is achieved by adopting a projected spherical single particle basis which reproduces the Nilsson level scheme[6]. The approach describes satisfactorily the observed deformation properties[7] and distribution of the scissors M1 strength. It is also successful in describing the fragmentation of the M1 spin strength induced by deformation as observed in ^{154}Sm[8]

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ON THE STRUCTURE OF EXCITED STATES AT INTERMEDIATE ENERGIES OF DEFORMED NUCLEI

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Detailed information on the internal quasiparticle structure of excited states of atomic nuclei and its complication with increasing excitation energy can be gained from comparison of theoretical and experimental nuclear spectra, transition probabilities and nuclear reaction cross sections. Until recently this information was mainly restricted by data on simplest few quasiparticle components of the wave functions of low-lying states. Studies of states at intermediate excitation energies (of an order of the nucleon binding energy and lower) are of great interest since they allow one to determine the role of more complex many-quasiparticle components.

For the deformed nuclei, similar researches encounter additional difficulties caused, essentially, by the high density of states and mixing of different multipolarities. In recent years, with the development of new experimental methods very interesting and important experimental results have been obtained in studying the above mentioned energy region of spectra of deformed nuclei [1-4]. The authors of these papers observed isomerical states and structural specific properties in the spectra of some nuclei which cannot be explained theoretically within the limits of a statistical approach.

The Quasiparticle Phonon Nuclear Model, developed in Bogoliubov Laboratory of Theoretical Physics, JINR [5], provides a qualitative description of similar structures. This model with the use of the strength function method suggests describing fragmentation of many-quasiparticle components and probabilities of electromagnetic transitions between nuclear states at intermediate energies. The approach proposed enables one to simplify the calculation of probabilities of electromagnetic transitions between complex states of the deformed nuclei and the analysis of their structure.

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Anharmonic Vibrations and Cranking Model

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The self consistent cranking model (SCCM) is the main theoretical approach which has been applied successfully to the analysis of the properties of the yrast line states as well as the excited two-quasiparticle states of even-even deformed nuclei and one quasiparticle states of odd mass nuclei at nonzero value of the angular momentum. In this model the collective states are formed due to the change of the angular frequency when the angular momentum vector lies along the direction of an axis which is perpendicular to the symmetry axis. Combining the SCCM with a random-phase approximation (RPA) it becomes possible to investigate the properties of one-phonon vibrational states at different value of the angular momenta. However, it is a well known that RPA is a good approximation for the description of motion with small amplitude. Thus, one could not expect to obtain a good description of anharmonic effects which show up, for example, in direct experimental measurement of the electromagnetic transitions for the decay of two- or one- phonon states of the deformed nuclei.

In [1, 2], the fruitfulness of the idea of using the SCCM in describing vibrational states was demonstrated for two simple models: a phenomenological IBM and the anisotropic harmonic oscillator model (AHO). Our analysis allows to formulate the following statement:

If a system has an equilibrium axis of symmetry, then self consistent cranking about this axis yields families of solutions that bifurcate from the trivial solution at the critical rotational frequencies $\Omega_c = \omega_\mu / K_\mu$, where ω_μ is the RPA frequency of each mode with nonzero spin K_μ.

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COLLECTIVE DYNAMICS OF NUCLEAR FUSION

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Starting with the kinetic equation for the distribution function, a closed set of equations is obtained describing in a classical way the process of fusion [1],[2]. This is achieved by making the following simplifying assumptions :

- restrictions are imposed on the shapes of composite systems; their surfaces are approximated by the equation [3]

$$R(\theta) = R(a)\sqrt{1 + a\left(\frac{3}{2}\cos^2\theta - 1\right)}$$

- the nuclear mean field is approximated by the sum of the Coulomb and surface potentials;
- the energy dissipation is described through a collision term issuing from a mean-relaxation-time approximation.

The numerical analysis is performed for the head-on collisions of identical nuclei. The mutual excitations of approaching ions before the contact is ignored.

The shape evolution of colliding ions shows a quite particular behaviour during the reaction. They resemble elastic bodies at the beginning of the process. The sudden shock produced by the collision is either followed by a quick rebound or by fusion. The fusion takes place when the projectile energy lies in a certain interval, the fusion window being strongly dependent on the value of the mean-relaxation time parameter $\tau = 2.97 \cdot 10^{-23} A^{1/2}\gamma^{-1}$ sec. (see upper part of the figure).

In the case of fusion the shock creates dampened oscillations with a frequency typical for the GQR excitations. In the next phase of the fusion, the nuclei behave as droplets of a liquid with a great viscosity. During this phase, the deformation of the composite system with A nucleons and Z protons decreases exponentially with the characteristic time

$$t_0 = \frac{2.5 \cdot 10^{-22} A^{2/3}}{\left(1 - \frac{Z^2}{49A}\right)} \text{ sec.}$$

The typical evolution pattern is shown in the middle part of the figure for the central collision of two ^{100}Mo nuclei . Here the dimensionless quadrupole moment $Q(t)$, representing the shape, is shown as a function of time. The quantity $Q(t)$ is defined as follows : $Q = 1.26$ for two touching spheres (beginning of the fusion); $Q = 0$ for one sphere (the fusion accomplished). The theory describes qualitatively the new experimental findings concerning fusion in symmetric systems [4] and confirms the "long" duration of fusion in heavy symmetrical systems.

The non trivial shape evolution leads to a characteristic distribution of gamma-rays emitted during the fusion. In the bottom part of the figure the prompt quadrupole radiation from the fusing system (solid line) is shown in comparison with bremsstrahlung of two pointlike nuclei with the same charges (dashed line).

The restrictions used when performing the calculations hinder much the quantitative comparison of the theory with the experimental data. However, the theoretical approach chosen for studying the fusion process seems to be adequate for the necessary generalizations. More work on the subject is in progress.

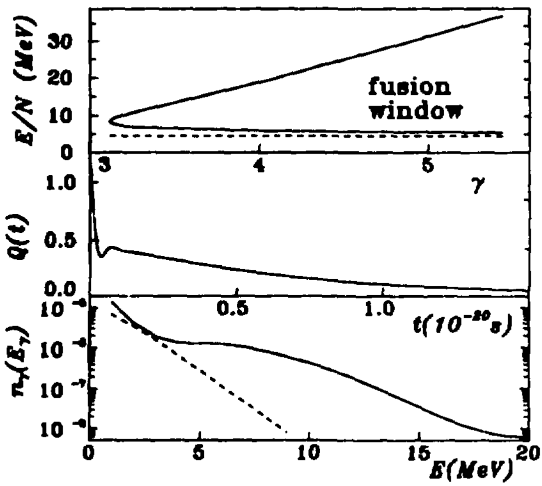

Fig. 1 *Fusion in the central collision of two ^{100}Mo nuclei as predicted by the model.*
Above: fusion window as a function of parameter γ (the inverse of the relaxation time). Broken line marks the barrier energy.
Middle part: evolution of the quadrupole moment $Q(t)$, time is given in 10^{-20} sec., here and below projectile energy $E = 7MeV/N$, $\gamma = 4$.
Below: intensity of quadrupole radiation $n_\gamma(E_\gamma)$ from the fusing system in comparison with bremsstrahlung; the gamma-ray energy is given in MeV.

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TOROIDAL QUADRUPOLE TRANSITIONS IN ELECTRO-EXCITATION OF ATOMIC NUCLEI

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Longtime before, Dubovik *et al* showed the transverse electric multipole $t_{E\lambda}(q)$ can be splitted as follows

$$t_{E\lambda}(q) = -\frac{\omega}{q}\sqrt{\frac{\lambda+1}{\lambda}}t_{C\lambda}(0) + q^2 t_{T\lambda}(q) \tag{1}$$

where $t_{C\lambda}(0)$ is the Coulomb multipole in the low-q limit and $t_{T\lambda}(q)$ is the toroidal multipole. In the first approximation beyond the long-wavelength limit $t_{E\lambda}(q)$ can be expressed in terms of the charge Q_λ and toroidal T_λ multipole moments

$$t_{E\lambda}(q) \simeq \frac{iq^{\lambda-1}}{(2\lambda+1)!!}\sqrt{\frac{\lambda+1}{\lambda}}(Q_\lambda + q^2 T_\lambda) \tag{2}$$

We consider the case of exciting the ground-state rotational band of an even-even nucleus $(0^+, 2^+, 4^+, \ldots)$ by real-photon electron scattering, in the framework of oscillating incompressible liquid-drop model. For transition to the one-surfon 2^+ state, the transverse electric quadrupole $t_{E2}(q)$ is related to $t_{C2}(q)$ through the relation

$$t_{E2}(q) = -\frac{\omega_2}{q}\sqrt{\frac{3}{2}}t_{C2}(q) \tag{3}$$

with $\omega_2 = [C_2/B_2]^{1/2}$, the energy of the $\lambda^\pi = 2^+$ one-surfon state. Since $t_{C2}(q)$ can be expanded in terms of the 2-n power mean-square charge quadrupole radii $\bar{r}_Q^{2n}$ we have in the second order in q

$$t_{C2}(q) = \frac{q^\lambda}{(2\lambda+1)!!}(Q_\lambda + \bar{r}_Q^{2n}) \tag{4}$$

Comparing term by term (2) and (4) we arrive at

$$T_2 = \frac{1}{10c}\,\bar{r}_Q^{2n} \tag{5}$$

Therefore, in order to measure the toroidal quadrupole transitions in spherical vibrational nuclei it is necessary to know the 2-n power mean-square charge quadrupole radius, a quantity which can be measured in (e,e') and (α,α') reactions. This will hold also for the higher terms in the expansion of $t_{C2}(q)$ and of $t_{E2}(q)$ i.e. the 2-n power charge quadrupole and toroidal quadrupole mean-square radii.

This very special result is obtained only for the collective vibrational model when the velocity of the nuclear fluid is supposed to be irrotational for any value of the excitation energy. Obviously this hypothesis is not satisfactory since the inelastically scattered electrons induce vortical components in the field velocity, and the Coulomb and electric transverse multipoles are no longer proportional to each other, except in the low-q limit when the Siegert theorem recovered. The vortical components of the fluid velocity will enter only in the high-q terms of the electric transverse multipoles, i.e. the toroidal multipoles. We finally conclude by substantiating the relative importance of toroidal transitions at high momentum transfer and the possibility of investigating the nuclear dynamics for various nuclear structure models by making use of the inelastic electron scattering.

PARTIAL PROTON ESCAPE WIDTHS AND CONFIGURATIONAL SPLITTING OF THE GAMOW-TELLER RESONANCE IN SN ISOTOPES

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The theoretical prediction that the main component of the Gamow-Teller resonance in the ^{118}Sn parent nucleus is splitted into two components with comparable strengths [1] (the configurational splitting of the GTR) and the lack of an uniquely interpretation of experimental data [2,3], which could be evidence in favour of existence of the configurational splitting effect, induce us to perform a quantitative analysis of partial proton escape widths of the GTR in a number of Sn isotopes near ^{118}Sn. In this analysis we used a method [4] based on the continuum-RPA.

In this work a satisfactory quantitative interpretation of the experimental data on the resonance $^{117}Sn(p,n)^{117}Sb$ reaction [2] was given under assumption that the GTR built on the $\{2d^n_{3/2},[3s^n_{1/2}]^{-1}\}$ excited state of the parent nucleus ^{118}Sn is excited together with "normal" GTR by means of this reaction (both these resonances are splitted). This fact is a certain experimental corroboration of the configurational splitting effect.

Calculations of partial proton escape widths of the GTR in the $^{112,114,122,124}Sn$ isotopes show that because of nonmonotonic dependence of the GTR energy on $N-Z$ (due to the configurational splitting effect), these widths in the $^{122,124}Sn$ isotopes are several times larger than those in $^{112,114}Sn$. Thus, experimental investigations of the direct proton decay of the GTR in Sn isotopes could clarify the question of existence of the configurational splitting effect.

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GENERALIZED VIBRATING POTENTIAL MODEL FOR COLLECTIVE EXCITATIONS IN DEFORMED AND SUPERDEFORMED NUCLEI

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The vibrating potential model (VPM) [1-3] has recently been generalized [4,5] to the description of $E\lambda$ collective excitations in atomic nuclei with practically any kind of deformation (spherical, deformed and superdeformed forms). Nuclei with two and more deformations, e.g., quadrupole together with hexadecapole or octupole, are also covered. The model provides the RPA accuracy of numerical calculations (the dispersion equation of the model is of the same form as in the case of the RPA with schematic separable forces). Expressions for the residual interaction and strength constant are derived in a self-consistent way. Any single-particle potentials and ground state densities, for which the coefficients of the multipole expansion are known, can be used within this model. As a result, the model has a much wider range of applicability as compared to the (double) "stretched" coordinate method (see, for example, [6]) derived only for oscillator potential with quadrupole deformation.

In the contribution the main points of the model as well as the results of numerical calculations for collective states with $\lambda = 2,3,4$ in deformed ($\beta \sim 0.2 - 0.3$) and superdeformed ($\beta \sim 0.6$) nuclei are presented. The self-consistent VPM [4,5] turns out to be quite useful for studying superdeformed nuclei (where the common schematic RPA cannot be used because of the absence of any experimental data for fitting the strength constant) since it provides both the form of the residual interaction and the value of the strength constant. Our calculations confirm the conclusion [7] that the deformation mixing of nuclear shells in superdeformed nuclei can lead to noticeable enhancement of collectivity of low-frequency octupole states .

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Test for the $^{178}Hf^{m2}(\gamma,n)^{177}Hf^{m2}$ reaction yield.

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Photonuclear reactions with a high-spin isomeric nucleus is a real challenge in the study of giant resonances built on high-K states as well as of K-mixing at high excitations. The $^{178}Hf^{m2}(\gamma,n)^{177}Hf^{m2}$ reaction is of special interest because it is a unique case when the reaction on the four-quasiparticle K^{π} 16^{+} isomeric target leading to another exotic five-quasiparticle $K^{\pi} = 37/2^{-}$ isomer could be detected experimentally.

The $^{178}Hf^{m2}$ material was produced in extensive irradiations of the ^{176}Yb target by the ^{4}He-ion beam on the U-200 cyclotron of FLNR JINR. In the framework of the international Hafnium Collaboration a microweight quantity of the $^{178}Hf^{m2}$ was produced and isolated within the last few years. Using precision radiochemical methods a special target for bremsstrahlung irradiations was prepared from this material. A lot of care was taken to find the purest Be foil for the target backing and to purify the Hafnium fraction from both ballast activities and weight contaminants. All contaminants generate the background after a bremsstrahlung induced activation.

In order to detect the $^{178}Hf^{m2}(\gamma,n)$ reaction the induced 51.4-minute-lived activity of the $^{177}Hf^{m2}$ isomer was searched for. The $^{178}Hf^{m2}$ sample of $3\cdot10^{13}$ atoms on a Be substrate was exposed to the bremsstrahlung with maximum energy of 24 MeV on the electron beam of the MT-25 microtron at FLNR. Before the irradiation the target was covered with a Be catcher to collect the $^{177}Hf^{m2}$ atoms recoiled eventually from the thin target layer. After the irradiation the activities of both the target and the catcher were measured on high-resolution "Ortec" and "Canberra" HP Ge detectors as well as on a Si spectrometer of conversion electrons with a magnetic guide line at LNP JINR. The experimental conditions such as the geometry and time intervals of the irradiation and measurement were optimised in order to achieve maximum sensitivity.

After a series of experiments the upper limit for the $^{178}Hf^{m2}(\gamma,n)$ - reaction yield was determined to be 5 times lower than that of the monitoring reaction $^{181}Ta(\gamma,n)^{180}Ta^{g}$ measured simultaneously. It is a somewhat unexpectedly low yield for the population of the $^{177}Hf^{m2}$ isomeric state in the evaporation residue of the (γ,n)-reaction. Proceeding from the earlier observed [1,2] high probability of the $^{177}Hf^{m}(n,\gamma)^{178}Hf^{m2}$ and $^{180m}Ta^{m}(\gamma,2n)^{178}Ta^{m}$ reactions, one can predict for the $^{177}Hf^{m2}$ in the (γ,n) reaction on $^{178}Hf^{m2}$ feeding intensity no lower than 50% of the total reaction yield. The experimental result for the $^{177}Hf^{m2}$ can be interpreted by efficient trapping of the deexcitation cascade intensity by some special levels placed at higher excitation and connected with the ground state band by enhanced transitions. Another approach is to assume the total K-mixing at energies higher than 3 MeV and random statistical character of the deexcitation γ-cascade.However, the feeding intensity for the 37/2 trap again will not be low when the mean initial spin is as high as 33/2. So the studies should be continued both by experimental and theoretical methods.

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CALCULATIONS OF E2/M1 MULTIPOLE MIXING RATIOS IN SOME EVEN-EVEN NUCLEI ON THE 150≤A≤190 DEFORMED REGION

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Abstract : The E2/M1 multipole mixing ratios that the electromagnetic transitions between the levels of even-even Sm, Gd, Dy, Yb, Hf, W, Os and Pt nuclei are calculated by the use of the interacting Boson Model. B(E2;L+2→L) transition probabilities between the members of ground state band and the B(E2)$\uparrow$ values and the Q(2^+) quadrupole moment are also calculated.The calculated mixing ratios show that,the transitions that connect the levels of the same parity are predominantly E2 and the ones that connect the levels of opposite parity are predominantly E1. The our results are compared with the experimental data and the former values of the theoretical works.It's found that there is a good agreement with the results found and the others.

Deuteron and nuclei structure

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From the experimental data it follows that the deuteron in many respects can be considered as a simple object. That is why it is possible to describe this nucleus as a whole by the wave function and corresponding wave equation. This equation was proposed in [1]. In particular, from this equation it follows that the deuteron cannot exist in the singlet state. Besides, one can show that considered equation is invariant with respect to the gauge group $SU(2) \times U(1)$. Thus, there should be additional interactions between the deuterons. In principles, such interactions can explain the existence of the region of stability of nuclei on the plane (p,n) which goes along the straight line defined by the nuclei with equal numbers of the protons and neutrons. Really, the existence of the deuteron clusters in nuclei means that there are new forces in nuclei in accord with the model represented above. The existence of a new type of interactions can be verified from the experiments on scattering of deuterons by nuclei. In the first series of experiments one should investigate the elastic scattering of deuterons on the nuclei with equal numbers of protons and neutrons; and in the second one, do this for stable nuclei which are taken away as far as possible from the line of stability.

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Search for the Orbital M1 Mode in Deformed Odd Mass Nuclei

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Numerous electron and photon scattering experiments provided detailed information on the distribution of low-lying magnetic dipole strength in heavy deformed even-even nuclei (*"Scissors Mode"*). On the other hand, up to now there is no evidence for a concentrated M1 strength in odd deformed nuclei.

For first nuclear resonance fluorescence experiment (NRF), performed at the Stuttgart facility, the isotope ^{163}Dy was chosen as a first candidate for an odd nucleus, since the neighbouring even-even nuclei ^{162}Dy and ^{164}Dy are well investigated. In both isotopes the orbital M1 strength is concentrated within two or three strong transitions. In ^{164}Dy the largest M1 strength in all rare earth nuclei was observed. Furthermore, detailed spectroscopic information from (n,γ), $(n,n'\gamma)$, (d,p), and (d,t) reaction studies is available for the isotope ^{163}Dy. In addition, orbital M1 excitations should be more pronounced in neutron-odd isotopes following theoretical considerations.

The observed concentration of dipole strength in ^{163}Dy around 3 MeV fits very well in the sytematics of the scissors mode in the even Dy isotpes. Both, the excitation energy as well as the summed strength follow the trends expected for the orbital $M1$ mode. The strength distribution is in good agreement with recent calculations performed in the framework of the IBFM approach (Interactin-Boson-Fermion-Model). The different decay branchings predicted by the IBFM-calculations for several states can be used for tentative spin assignments. To establish a systematics the isotopes ^{161}Dy and ^{157}Gd were investigated recently at the Stuttgart photon scattering facility. Preliminary results are presented and discussed.

LOOKING INSIDE GIANT RESONANCE FINE STRUCTURE

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Microscopic calculations of the fine structure of giant resonances for spherical nuclei will be presented. Excited states are treated by wave function which takes into account coupling of simple one-phonon configurations with more complex ones [1]. Nuclear structure calculations are applied to description of the γ-decay of resonances into low-lying states and relativistic excitation of the double resonances.

As an example, we consider γ-decay properties of the High Energy Octupole Resonance (HEOR) in ^{90}Zr [2]. In our calculation, the HEOR has the energy centroid E_x = 22.4 MeV and the total width Γ = 4.4 MeV. The total width $\Gamma_{HEOR \rightarrow 2^+_{1,4}, 4^+_{1,2}}$ is equal to 3 keV or about 10% of the GDR γ-decay width into the ground state. It opens a new possibility to investigate the HEOR.

For the first time the relativistic excitation of the double giant resonance in ^{136}Xe is calculated based on the microscopic structure of the GDR [3]. Second order perturbation theory is used to describe the excitation process. It is found that the two-phonon cross section is essentially equal to that of the non-interacting phonon model and that the associated width is 1.5 times the width of the one-phonon resonance. Calculated and experimental [4] cross section (in mb) for the excitation of the single GDR, GQR_{is} and GQR_{iv} and the double $[GDR \otimes GDR]_{0^+,2^+}$ resonances are presented in table. The results of calculations are strongly dependent on the minimal value of the impact parameter $R_{min} = r_o(A_t^{1/3} + A_p^{1/3})$ used and the ones in table are obtained with $r_o = 1.5 fm$. While the predictions associated with the one-phonon states provide an overall account of the experimental findings, the calculated cross section for the two-phonon states is much smaller than that extracted by the involved analysis of the data.

GDR	GQR_{is}	GQR_{iv}	$GDR+GQR_{is}+GQR_{iv}$	$[GDR \otimes GDR]_{0^+ + 2^+}$
1480	110	60	1650	50
1024 ± 100	–	–	1485 ± 100	215 ± 50

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SEMICLASSICAL METHODS IN THE STRUCTURE OF HOT NUCLEI

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A semiclassical formalism which is based on an energy functional and generalizes the fluid dynamical model (first sound) of Eckart *et al* has recently been developed and extended to a finite temperature. The model accounts for important transverse components in the current of low lying modes with $\ell > 1$. It is shown that new eigenmodes appear when the temperature does not vanish. In the limit of $T \rightarrow 0$ the strength of the new eigenmodes goes to 0 proportionally to T^2 and the currents and transition densities are proportional to T. The inclusion of tensor fields in the action integral of the model leads to important changes as compared with the results of the simpler model based on first sound dynamics.

CURRENTS AND GENERALIZED INERTIA PARAMETERS IN LARGE AMPLITUDE COLLECTIVE MOTIONS(*)

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A microscopic description of large-scale collective motions in finite quantal many-body systems (as in atomic nuclei) is approached upon incorporating into the quantal theory, classical concepts concerning matter and current distributions in liquid droplets as well as using analogies between the formalisms of canonical transformations in classical mechanics and of unitary transformations in quantum mechanics. We then derive a generalization to a large class of collective modes of the semi-quantal routhian approach currently used for rotations. The stationary solutions so obtained satisfy cranking-like equations with a time-odd (cranking) constraint of the form $\alpha.\mathbf{p}$ where α is a vector field (function of the position $\mathbf{r}$) unequivocally associated to the corresponding classical motion velocity field and $\mathbf{p}$ is the momentum operator.

The solutions of such generalized cranking equations are then searched within the Hartree-Fock approximation using a Skyrme effective nucleon-nucleon interaction. We will present here the corresponding results within a semiclassical approximation (specifically in the Extended Thomas-Fermi framework[1]) up to $\hbar^2$ terms) similar to the one used recently for the routhian case[2]). Explicit expressions are obtained for the current density whose Thomas-Fermi approximation is exactly found to be the classical one whereas the semiclassical corrections are surface-peaked and similar to Landau diamagnetic corrections for a confined electron gas (at least for rotational modes). Upon extracting the collective velocity-dependent part of the lab energy we have also obtained generalized inertia parameters and the corresponding coupling terms whenever more than a mode is present.

The domain of applications of the present formalism is rather extended: from giant resonances and high spin modes (together with their coupling) to genuine large amplitude collective motions like fission or fusion (under the lines for instance of a recent microscopic description[3])). Explicit results will be presented for the coupling between a rigid body rotation and a specific vortical motion (namely the motion of an ellipsoid having a finite uniform vorticity in the body-fixed frame[4])) together with its possible consequence on the yrast line relation between energy and angular momentum.

(*)This work has been made possible by a grant received through a collaboration agreement between JINR (Russia) and IN2P3 (France)

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$2\nu\beta\beta$ decay and $SU(4)$ symmetry violation in nuclei

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To the present time the calculations of $2\nu\beta\beta$ decay rates have been performed by different authors for a great many of nuclei [1]. The main shortcomings of mentioned calculations are: (i) essential dependence of calculated values on model parameters and, as the consequence, significant distinction of results obtained by different authors [1]; (ii) the use in calculations a large basis of states and complex residual interaction, that needlessly hinders the calculations and limits the area of application of the method only by rather light nuclei [2].

In this connection the approaches based on the use of approximate conservation of the spin isospin symmetry at an analysis Gamow-Teller excitations [3] and free from the mentioned shortcomings are of interest. The work [4] seems to be more realistic as compared with ref.[3]. In this work the $2\nu\beta\beta$ decay rate of the ^{48}Ca agreeing with experimental data and conclusions of other works is evaluated.

In presented work the approach is extended to the case of nuclei having strong nucleon paring. The precomputations performed for the ^{150}Nd nucleus lead to value of half-live 4×10^{20} years, that on order exceeds the relevant experimental value. Besides, for the check of the method the β^- decay rates for some nuclei were calculated. The results qualitatively agreeing with known experimental data are obtained.

The analysis performed within the framework of the presented approach allows us to make the conclusion that the degree of the $SU(4)$ symmetry violation and, hence, nuclear part of $2\nu\beta\beta$ decay amplitude are approximately identical for medium and heavy nuclei. Therefore, the difference of the decay rate for different nuclei is mainly determined by the volume of the relevant lepton phase space.

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BAND CROSSINGS WITHIN THE FRAMEWORK OF THE PHENOMENOLOGICAL MODEL

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We developed a variance of the rotation model /1/ to describe energy levels of rotation states from lower spins to the highest observed ones. It is based on the high spin approximation of Coriolis mixing of positive parity states. The basis of eigenfunctions is restricted by low-lying rotational bands, and consists of ground (gr), vibrational (β,γ) and a certain number of aligned ($s(n)$) bands required for the description of experimentally observed cases of alignment. Calculations for energy levels of ^{158}Er have been done within the framework of this model /1/. Its spectrum has been observed experimentally up to spin $I^{\pi}=46^{+}$.To describe all alignment processes in this nuclei spectrum it is necessary to include 3 aligned bands. But to describe successive alignments we should as well consider anomalous $a(n)$ – bands of antialigned nature, which are considered as a continuation of the $s(n)$– band. Thus its crossing with the following $s(n+1)$ – band is provided. A good agreement has been reached for calculated and experimental energy values (the average deviation from experiment is less than 20 KeV at the energy level $E_I^{exp} \approx 10 \quad 17$ MeV). The alignment process of the angular momentum is demonstrated clearly, if the energy of rotational bands E^I_ν is presented as a diagram $E^I_\nu(\omega_{rot}) = E^I_\nu - E^I_{rot}(\omega_{rot})$, where ω_{rot} and $E^I_{rot}(\omega_{rot})$ – is the angular velocity and level energy of Harris parametrization. Here the angular velocity of rotational core ω_{rot} is the independent variable quantity, characterized by a monotonous change with a spin unlike the effective angular velocity of nuclei rotation $\omega^I_{ef} = (E^{I+1} - E^{I-1})/ 2$. This diagram shows the dynamics of alignment processes of angular momentum in rotational bands. With the increase of nuclei rotation velocity the $s1$– band at first crosses vibrational bands, and then – the ground band. According to it the alignment of angular momentum begins in the energetically high lying states of vibrational nature. After the alignment reaches its maximum value, it decreases in vibrational states and increases in the ground band. That proves that one and the same pair of nucleons takes part in the formation of the alignment in different bands.

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Self-Consistent Description of the Elastic Magnetic Electron Scattering by Nuclei

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Magnetic scattering of electrons by odd nuclei is known as a tool for measurement of the single-particle orbit radius for the odd nucleon. More precisely, the coordinate form of the single-particle wave function is tested by this probe. Usually calculations with the Saxon-Woods potential well with parameters fitted to the magnetic scattering data are used. It is much more informative to use wave functions generated by a self-consistent nuclear potential well calculated within a self-consistent approach which contains no parameters adjusted for the nucleus under consideration. We have carried such an analysis within the framework of the self-consistent Finite Fermi System (FFS) theory for ^{41}Ca, ^{17}O, ^{117}Sn and ^{89}Y nuclei for which high precision measurements of elastic magnetic form factors were recently made. The single particle model for the magnetic elastic form-factor provides a reasonable description of positions of the minima and maxima but in many cases overestimates the absolute values.

The main reason is the core polarization effects which are governed by the spin dependent components of the effective NN-interaction in nuclei. It proved out that the use of the usual FFS interaction with the q-independent local spin-isospin amplitude g' (Migdal force) leads to a dramatic suppression of the single-particle form factors which contradicts to the experimental data. In order to save the situation, one should suppose that the g' - amplitude is a q dependent function falling at high q. There is some interplay between this q independence and the strength of the ρ - meson exchange term $\mathcal{F}_\rho$ of the effective interaction, but some diminishing of the g' strength in this region should exist in any case.

We have used the simplest form for it as follows:

$$g'(q) = \frac{g'}{1 + r_0^2 q^2},$$

considering r_0^2 as a new FFS theory parameter. It was estimated from the analysis as $r_0 = 0.40$ fm. It should be mentioned that in the case of the ^{89}Y nucleus the accuracy of measurements as well as the interval of the momentum transfer q proved to be sufficient for the first model-independent extracting of the magnetization current density distribution from the data. It is concentrated in the inner region of the nucleus showing that we deal with a volume effect and really examine in-volume properties of the g' -interaction.

IV INTERNATIONAL CONFERENCE on SELECTED TOPICS in NUCLEAR STRUCTURE, DUBNA 5-9 July, 1994

NUCLEAR FUSION FOR THE REACTION 3He+3He AT VERY LOW ENERGY

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The fusion process between charged particles was investigated by using the shadow model 1). In this model the fusion process is considered as the shadow of the Rutherford scattering so that the particles which fuse are those that in Rutherford scattering are detected in the shadow region. By using this point of view a regularity was found by analysing fusion data relative to systems with 24<A1+A2<194 and a new expression for the fusion cross section was suggested 1). The shadow model is based on this observed regularity and it is able to reproduce the experimental values of fusion cross section for about 100 reactions at energies below the Coulomb barrier. For light systems 3≤A1+A2≤8 and at energies not far below the Coulomb barrier the observed regularity is found, but at very low energy this regularity disappears and the shadow point of view is not able to describe the fusion process. However it is possible to generalize the shadow model so that it is able to reproduce the fusion process for light systems at very low energy 2). To judge the success of the shadow model approach in reproducing the data we used 1,2) a logarithmic scale to plot the rapidly varying cross sections, but it is more easily to judge the success of the model if we transform the fusion cross section as calculated from the shadow model equations into the astrophysical S factor

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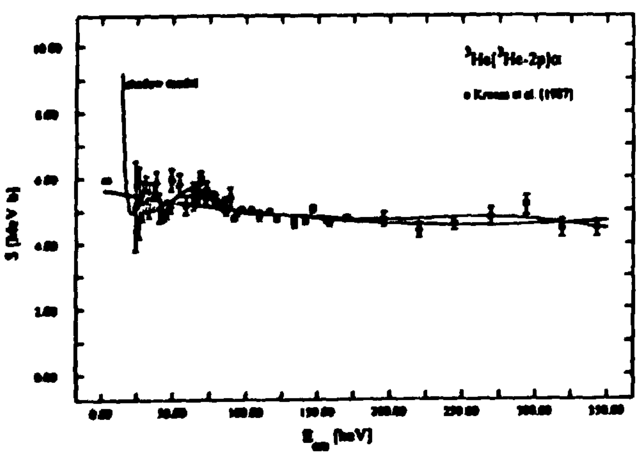

COMPLETE FUSION AND BINARY REACTIONS IN HEAVY-ION COLLISIONS AT THE COULOMB BARRIER

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Complete fusion, deep inelastic, quasielastic and total cross sections[1] in the reactions $^{58}Ni + ^{124}Sn$ at near-barrier energies are compared with the results of the quasi-classical critical distance model[2]. The nuclear ion-ion potential is taken in the form.

$$V(r) = V_{ad}(r)\,F(r) + V_s(r)\,(1 - F(r))$$

Here $V_{ad}(r)$ is the "adiabatic" potential, $V_s(r)$ is the potential, obtained in the "sadden approximation" and the form-factor $F(r)$ is the Fermi-type function. For heavy nuclei there are two barriers in the potential: the Coulomb barrier V_b and the inner barrier V_c, situated at $r_0 \approx 1.0\ fm$

Following Stelson[3] we take a flat distribution of the Coulomb barriers. The width of the distribution is $2(V_b - V_f)$. Cross sections of fusion, deep inelastic and quasielastic collisions have been defined by the ingoing wave boundary conditions at different parts of the potential: $r \le R_c$, $r = R_b$ and $r = R_f$, respectively.

The result of the fitting procedure is shown in Figure 1 and Table 1.

Table 1. Parameters of the potential.

Reaction	V_b, MeV	R_b, fm	V_c, MeV	R_c, fm	V_f, MeV	$\hbar\omega_b$, MeV	$\hbar\omega_c$, MeV
$^{58}Ni + ^{124}Sn$	158.3	11.8	155.1	8.8	152.0	6.1	34.4

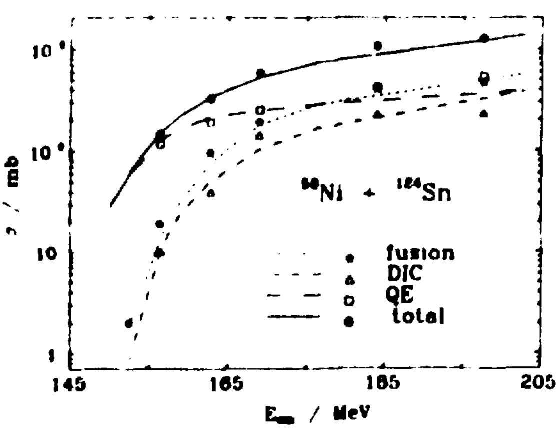

Fig.1. Fusion, deep inelastic, quasielastic and total cross sections vs bombarding energy. Experimental data are taken from Ref.[1].

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The Isoscalar Giant Monopole Resonance and Nuclear Matter Incompressibility

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The nuclear matter incompressibility coefficient, K, is an important quantity characterizing the nuclear matter equation of state. An accurate determination of K is very important for the study of properties of nuclei, supernova collapses, neutron stars and heavy ion collisions. We will review the current status of the experimental and theoretical methods used to determine the value of K. We will discuss, in particular, the most sensitive method which is based on experimental data on the strength function distribution of the isoscalar giant monopole resonance in nuclei. We will review the present status of the entire data set, accumulated from measurements carried out in several laboratories, and the theoretical methods used to determine K, which are based on microscopic self-consistent Hartree-Fock with random phase approximation and semi-classical approaches.

What is the dominant mechanism of two neutrino double beta decay?

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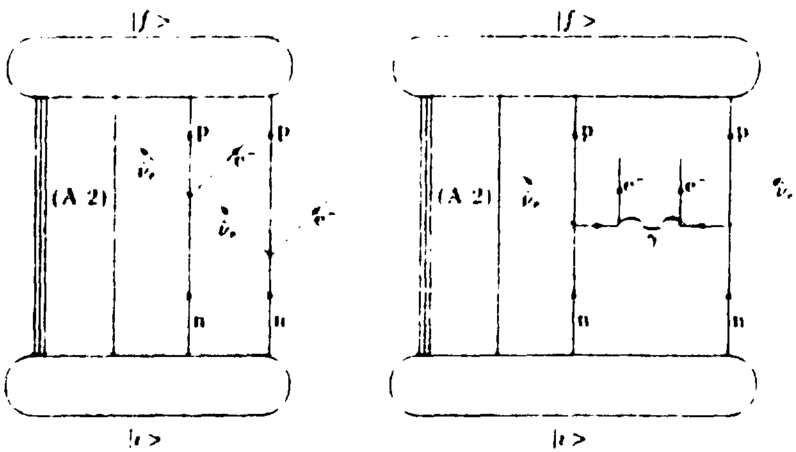
The two neutrino mode of nuclear double beta decay ($2\beta2\nu$-decay) has two electrons and two antineutrinos in the final state and occurs in the standard theory in the second order. This mode being independent of neutrino properties offers a sensitive test of nuclear structure calculations.

The results obtained in the framework of Quasiparticle Random Phase Approximation approach (QRPA) have been found extremely sensitive to the residual interaction of nuclear Hamiltonian. It is the difficulty of making definite rate predictions. A possible strong suppression of two neutrino double beta decay half time indicates that the considered mechanism has not to be the dominant one for $2\beta2\nu$-decay.

We have performed a detailed analysis of $2\beta2\nu$-decay amplitude in the framework of S matrix approach. We have shown that the diagram in Fig. 1a, which is supposed to be the main mechanism, does not contribute to $2\beta2\nu$-decay process. We explain that in QRPA calculations including the construction of the intermediate nucleus it is effectively sum the contribution from a definite class of strong interaction exchange diagrams. It clarifies the sensitivity of QRPA results to the residual interaction.

We first consider the electrons-gamma exchange mechanism for $2\beta2\nu$-decay in Fig. 1b. This diagram is favored in comparison with strong exchange diagrams, because the exchange electrons and gamma are closed on shell. The calculated half times for $2\nu2\beta$ decay of ^{128,130}Te, ^{150}Nd and ^{238}U have been found close to experimental half times.



a)　　　Fig. 1　　　b)

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Vibrational states in doubly even well-deformed nuclei

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The energies and wave functions of non-rotational states below 2.3 MeV in doubly even well-deformed nuclei of the rare earth region have been calculated within the Quasiparticle-Phonon Nuclear Model [1]. General properties of vibrational states are formulated. The wave function of excited states below 2.3 MeV is dominated by the one-phonon term. The contributions of the two-phonon configurations to the wave functions of the $K^\pi \neq 0^+$ and 4^+ states are smaller than 10%. The $K^\pi = 4_1^+$ state in ^{168}Er contains the double-gamma vibrational term equal to 30%. The existence of the double-gamma vibrational state with $K^\pi = 4^+$ at (2.1–2.3) MeV in ^{166}Er is predicted. The $K_\nu^\pi = 4_1^+$ and 4_2^+ states in ^{156,158,160}Gd and ^{162}Dy are hexadecapole ones. High intensities of the one-nucleon transfer reactions are explained by the relevant large two-quasiparticle components of the one-phonon terms of the wave functions. The origin of the E1 strength in the low-energy region is explained as an effect of the quadrupole equilibrium deformation and isoscalar octupole and isovector dipole particle-hole interactions. The calculated $B(E1;0^+0_{g.s.} \rightarrow 1^-K_\nu)$values for the $K^\pi = 0^-$ and 1^- states are 3–5 times larger than the experimental ones. The fragmentation of the one-phonon $K^\pi = 0^-$ and 1^- states in the energy range 2.3–4.0 MeV is not so strong. The concentration of the E1 strength in $K^\pi = 0^-$ states at energies 2.6–3.5 MeV in ^{168}Er and 3.6–3.9 MeV in ^{164}Dy and in $K^\pi = 1^-$ states at energies 3.2–3.4 MeV in ^{160}Gd is predicted.

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Nonstatistical effects in nuclei with Z up to 20-28

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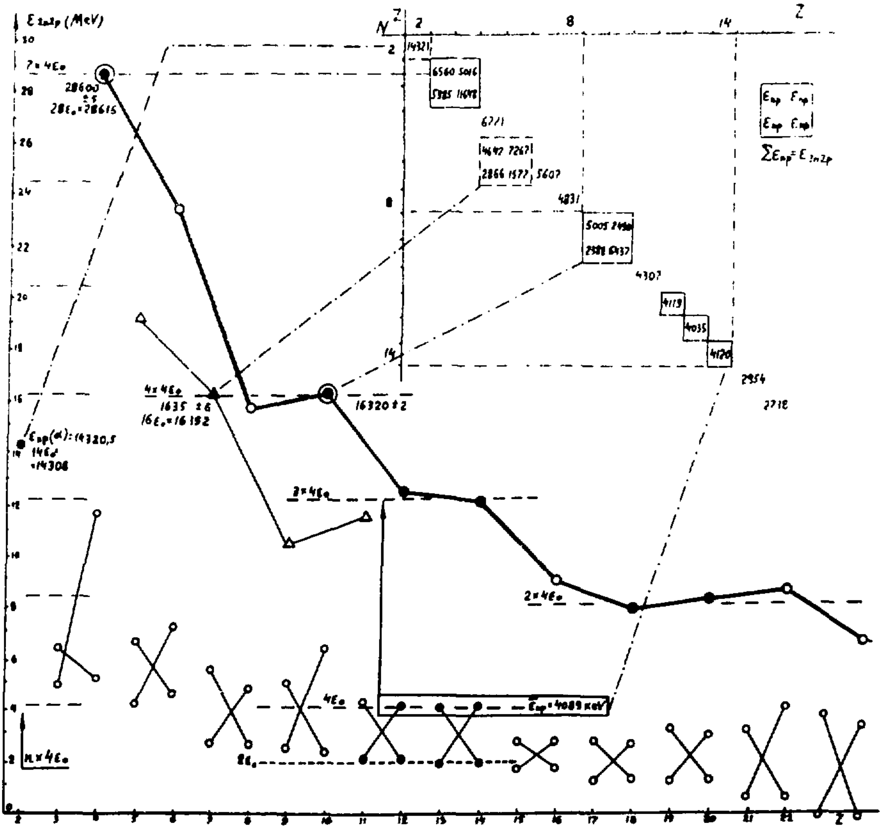
The presence of distinguished neclear excitations with multiple values of the parameter very close to the rest mass of electron m_e as well as presence of intervals multiple to $9m_e \approx 16$ MeV in the binding energies of nuclei (E_B) was considered earlier as the manifestation of the common properties of mass/energy spectrum of hadron system. In this work the parameters of the residual interactions in light nuclei were analysed by the standard procedure of subtracting E_B in nuclei differing by one or two nucleons (ε_{np} or $\varepsilon_{2n2p} = \Delta S_{2p}, \Delta N = 2$). Figure shows the dependence of ε_{2p2n} on Z and discrete character of it as well as proximity of the values for valence nucleons (two pairs of nucleons above well known shells ^4He and ^{16}O) 28600(5) keV and 16320(2) keV to $28\varepsilon_o = 28616$ keV and $16\varepsilon_o = 16352$ keV where parameter $\varepsilon_o = 1021,8(2)$ keV $\approx 2m_e$ is taken from real spin-flip splitting of ^{10}B levels .



Distinguished intervals in spacings of highly excited nuclear levels (4)

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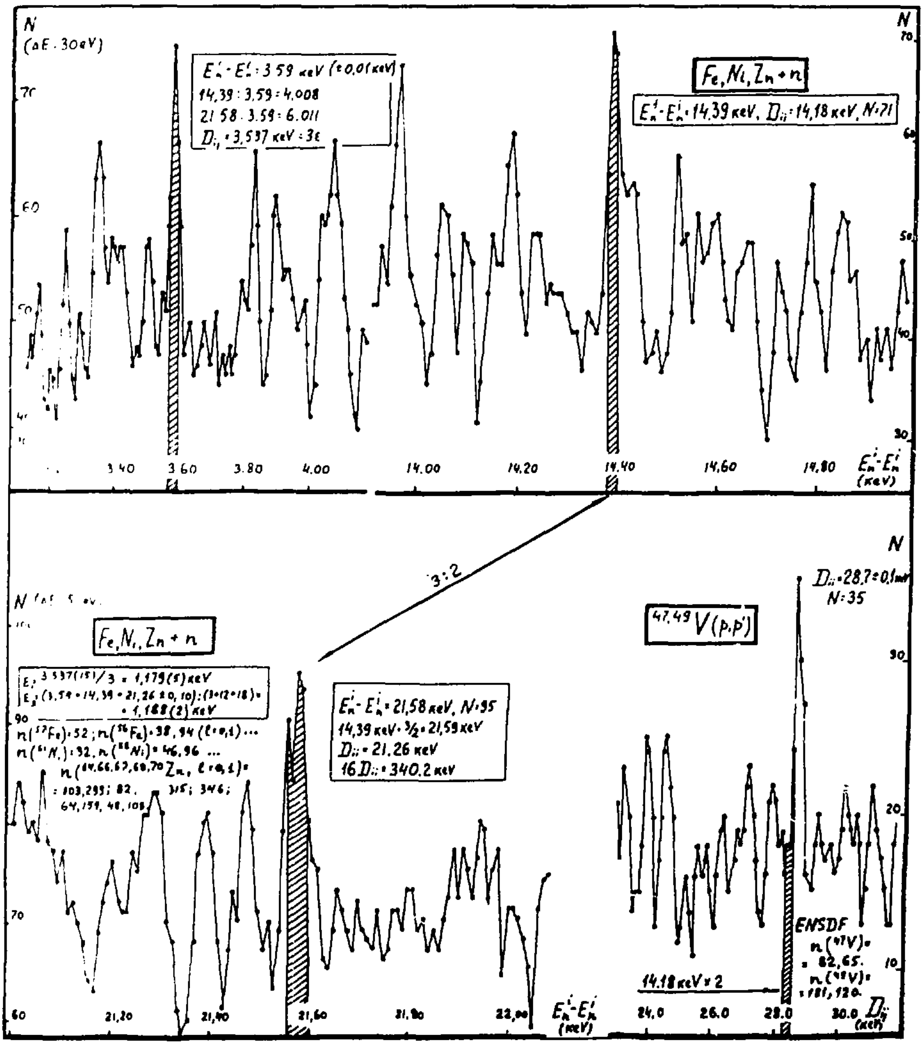
In PNPI Data Center analysis of nonstatistical effects in neutron level spacing distribution was continued and Figure show the discret character of this distribution for nuclei with Z=26,28,30. Marked regions are located at rational values of single interval with the value 1,18 keV found independetly in proton resonances of light nuclei and in neutron resonances of more heavy isotopes.



FROM THE "ORDER" OF LOW-LYING LEVELS TO THE "CHAOS" OF NEUTRON RESONANCES: EXPERIMENT

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The main results of an analysis of the average parameters for γ-decay cascades of compound states in complex nuclei are presented. The experimental data of nuclear level densities, for certain J^π, at excitation energies above 2 MeV are compared with that predicted by two different theoretical models. Cascade intensities measured over the entire excitation energy range, from the ground state up to the neutron binding energy, are compared with different model predictions. Conclusions about the radiative partial width enhancements for transitions between the compound state and high-lying excited states are given. The problems of estimating the actual temperature of excited nuclei, and of the experimental possibilities to observe phase transitions, their influence on γ-decay modes, and possible equidistance between intermediate levels of intense cascades are discussed.

New Method for the Fragment Mass Measurements on the Storage Ring

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Abstract

Nuclear mass measurements are the fundamental base for the construction of different nuclear models. The mass measurements of nuclear reaction fragments far from the valley of beta-stability where the divergence of the results of the different nuclear-models takes place are of great importance.

The mass measurements of short-lived recoil fragments are carried out on the storage rings. In these cases the storage ring is used as a multi-turn time of flight mass spectrometer or as a high frequency mass spectrometer [1].

In the last case the response function of the storage ring is

$$\frac{\Delta f}{f} \pm \frac{\delta f}{f} = -\frac{1}{\gamma_{tr}^2} \cdot \frac{\Delta m}{m} \pm \left[1 - \left(\frac{\gamma}{\gamma_{tr}}\right)^2\right] \frac{\delta v}{v} \pm \frac{\delta B}{B}, \tag{1}$$

where f is the revolution frequency of the ions circulating in the storage ring, m,v,γ are the rest mass, the velocity and the relativistic factor of the ions, γ_{tr} is the transition γ-value of the ring, B is the magnetic induction of the ring. The symbol δ means the chaostic spreadings of the reference values, the symbol Δ denotes the systematic differences of the reference ones.

One known method to achieve small value $\delta f/f$ is the minimization of $\delta v/v$ by means of the electron cooling up to the $\delta v/v \approx 10^{-5}$. The other method is the realization of the γ_{tr}-value equal to the γ-value of the ions (isochronous ion revolution).

The third method to improve the mass resolution which is proposed here is the momentum selection of the circulating ions by means of the superconducting solenoid located along the rectilinear optical axis of the storage ring. With special parameters of the solenoid the ions of determined momentum continue to circulate in the storage ring. At the same time all other the ions are lost due to increasing the amplitude of the betatron oscillations.

In this case the response function of the storage ring is

$$\frac{\Delta f}{f} \pm \frac{\delta f}{f} = -\frac{1}{\gamma^2} \cdot \frac{\Delta m}{m} \pm \frac{1}{\gamma^2} \left[1 - \left(\frac{\gamma}{\gamma_{tr}}\right)^2\right] \frac{\delta p}{p} \pm \frac{\delta B}{B}, \tag{2}$$

where p is the ion momentum selected by the superconducting solenoid, $\delta p/p \approx 10^{-8}$.

From the formula (2) mass resolution $\delta m/m$ is more better than from the formula (1) because $\delta p/p \ll \delta v/v$ and $\gamma < \gamma_{tr}$.

The final result of the solenoid action in the storage ring is the splitting of the wide unresolved peak in the spectrum of the frequences of the Schottky noise in two narrow peaks corresponding to small difference masses of the ion doublet. From the known practice of the using superconducting magnetic field and ion cyclotron resonance (Penning trap) it follows that the mass resolution of about 10^{-8} may be obtained by the proposed method.

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Study of the Giant Dipole Resonance Built on Highly-Excited States via Inelastic Alpha-Scattering

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The high energy region beyond the giant resonances in inelastic scattering is not fully understood. This continuum may correspond to high energy target excitations, or could be predominantly due to other kinematic processes. If the target is indeed highly excited by inelastic scattering, the high energy γ-ray spectrum from a coincidence measurement should exhibit the γ-ray decay of the giant dipole resonance (GDR) built on these excited states.

In order to better understand the continuum and to search for high target excitations, we measured inelastic α scattering at 40 MeV/A and 50 MeV/A on ^{208}Pb and ^{120}Sn targets. The inelastically scattered α-particles and other light charged particles were detected using the *Dwarf Ball/Wall* 4π CsI array. High energy γ rays were measured in coincidence using 95 BaF_2 detectors arranged in five close-packed arrays.

A simple analysis of the γ-ray multiplicity as a function of the energy of the α particles shows clear evidence for multi-neutron evaporation thresholds in the target up to 60 MeV. The high energy γ spectra are enhanced in the region of the GDR (13.5 MeV in ^{208}Pb and 15.4 MeV in ^{120}Sn). These enhancements due to the GDR become more pronounced with increasing apparent excitation energy, thus indicating target excitations to even higher energies.

Since in inelastic α scattering only small angular momenta are transferred to the target, it is possible to study the evolution of the GDR as a function of excitation energy only. This is an advantage compared to heavy-ion fusion evaporation reactions where the angular momentum increases with excitation energy.

A preliminary analysis with the statistical model code CASCADE shows an increase of the GDR width with excitation energy similar to the increase observed in fusion evaporation reactions. This seems to indicate that the broadening of the GDR is dominated by the energy and not the angular momentum increase. However, detailed potential energy surface calculations of the two measured systems have to be performed in order to explain the effect.

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SEARCH FOR TOROIDAL CONTRIBUTIONS TO THE DIPOLE ELECTRIC TRANSITIONS

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Recent experimental results [1] on the spectrum and matrix elements of E1, E2 and E3 transitions in ^{226}Ra are analysed within a model taking into account the Coriolis coupling of bands and the interference of the dipole ($\hat{d}$) and toroidal ($\hat{t}$) moments in the matrix elements of E1-transitions. The intrinsic part of the operator responsibie for E1 transitions is taken as $\hat{m}_K = \hat{d}_K + E_\gamma \cdot \hat{t}_K$. The theoretical description of all measured quantities is quite reasonable. The introduction into the matrix elements of E1-transitions of the toroidal (γ-ray energy dependent) contribution improves the description of these transitions. The figure shows the comparison of the "effective" dipole moments

$$Q_1^{(\mp)} = \sqrt{\frac{4\pi}{3}\frac{(2I+1)}{(I+1/2\mp 1/2)}B(E1; I^- \to (I\mp 1)gr)}$$

found in the experiment and calculated within the model. In the figure the solid line represents the calculation in which the toroidal contribution is admitted (d_0=-0.049 fm; d_1=0.313 fm; t_0=-0.214 fm/MeV; t_1=0.063 fm/MeV), the broken line corresponds to the usual description in terms of dipole electric moments (d_0=0.003 fm; d_1=-0.15 fm; $t_0 = t_1$=0). These values of the toroidal moment matrix elements correspond to the exhaustion of about 10% of the energy weighted sum rule. The latter was calculated in a usual way as a double commutator involving the toroidal moment operator and the shell-model Hamiltonian.

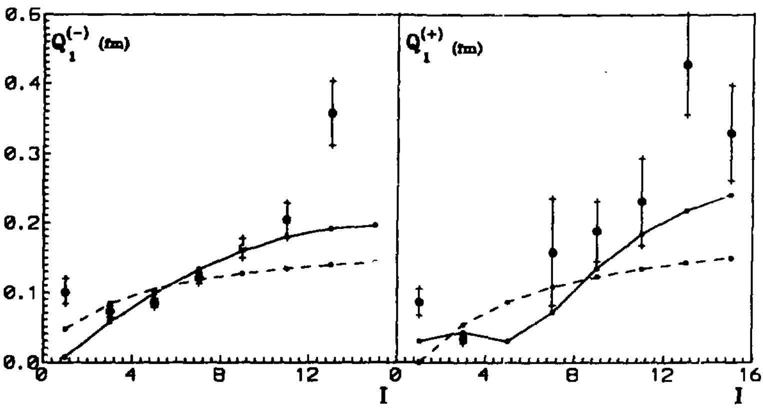

Fig. 1 Comparison of the experimental and calculated "effective" dipole moments $Q_1^{(\mp)}$:
solid line with toroidal moment contribution,
dashed line without such contribution

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Collective states in even Sn isotopes

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Even isotopes of tin are of a special interest due to the filled proton shell Z=50. One can expect different simple pictures of quasi-particle and vibration states at these nuclei excitation. For low excitations energies this is really observed. However, at higher excitation energies the form of a nucleus core may change because of refilling proton and neutron quasi-particle level and this may lead to appearance of characteristic bands. For the first time such bands were discovered in ^{112,114,116,118}Sn [1] and ^{108}Sn [2].

No bands were observed in ^{106}Sn [2], and no data are available for more neutron-deficient tin isotopes [3]. Classification of excited states of Sn nuclei based only on their energy [1,2] makes difficult the interpretation of these states nature. More complete data including probabilities of transition between the level appeared recently [4,5]. The totality of available data permits to outline a comprehensive interpretation of even tin nuclei excited states.

Firstly, states of vibration nature can be indicated: one-phonon, two-phonon and some non-collective ones. However, we concentrate attention on the bands of states connected by strong E2-transitions. In frames of traditional ideas about the co-existence of spherical and deformed forms, these bands of states could be interpreted as a fragment of normal rotating bands based on a 4-quasi-particle (2p-2h) or on 8-quasi-particle (4p-4h) 0^+-excitations in Sn isotopes should be located in more high-energy region, and not near 2 MeV, as it is observed experimentally.

This circumstance give us a chance to consider another hypothesis, namely to suggest that the observable bands of states are standard vibration bands, but distorted by the connection of collective and no-collective degrees of freedom. Such an idea is used in this work in frames of dynamic collective model [6]. it was shown that the experimental spectrum of excited states can be explained without using the "inculcated states" hypothesis.

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Excitation and Decay of Giant Resonances in the ^{40}Ca(e,e'x) and ^{40}Ca(p,p'x) Reactions*

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The population and decay of electric multipole strength in ^{40}Ca for excitation energies $E_x = 8 - 25$ MeV was investigated in (e,e'x) and (p,p'x) reactions with x = p, α. The (e,e'x) data measured at the MAMI-A accelerator in Mainz and at the S-DALINAXC accelerator in Darmstadt were taken at four different momentum transfers in the range $q = 0.26 - 0.66$ fm^{-1}. First results are presented in ref. [1]. A decomposition of isoscalar E2/E0 (GQR/GMR) and isovector E1 (GDR) contributions following the method of ref. [2] was performed. The resulting GDR strength distribution is in good correspondence with photonuclear data. The GQR shows strong fragmentation over the whole investigated excitation energy range with maxima at 12, 14 and 18 MeV. The fine structure shows very good agreement with RPA calculations including the continuum and more complex 1p1h⊗phonon configurations [3] which relate the unexpectedly large amount of E2 strength at lower excitation energies to 2p2h ground state correlations.

The (p,p'x) experiment [4] was performed at the National Accelerator Centre in Faure, South Africa using a recently installed $K = 600$ magnetic spectrometer. Scattered protons were measured at angles $\Theta_p = 17°$, $23°$ and $27°$ and excitation energies 10 – 25 MeV. Angular correlations were detected in plane for angles $\Theta_x = 0° - 200°$ relative to the recoil axis. A multipole decomposition using DWBA angular distributions is presented. Good agreement with the (e,e'x) results is found for the GQR strength distribution. A fine structure decomposition is possible for the decays to the ^{39}K and ^{36}Ar ground states by comparison of the two experiments.

Decay branching ratios and spectra of both experiments are compared to statistical and direct decay model calculations. A predominantly statistical decay of the GQR strength is indicated. A fluctuation analysis demonstrates the direct character of proton decay from the GDR excitation region into low-lying states of ^{39}K.

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THE ROLE OF DIPOLE TRANSITIONS IN DETERMINING THE COLLECTIVITY OF NUCLEAR EXCITATIONS

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While the degree of nuclear collectivity is frequently assessed by examining the quadrupole characteristics of nuclei, the use of dipole transitions in determining collectivity is considerably more ambiguous. However, a wealth of new information about E1 and M1 transition rates has become available in recent years, and with these data has come new information about collective structures. At the University of Kentucky, we have employed the inelastic neutron scattering (INS) or $(n,n'\gamma)$ reaction with accelerator-produced monoenergetic neutrons, coupled with the Doppler-shift attenuation method (DSAM), to measure a large number of nuclear lifetimes.[1]

Low-energy, collective excitations in nuclei have been predicted by a variety of models when the effects of separate proton and neutron degrees of freedom are included. The geometrical interpretation of these isovector excitations as out-of-phase angular oscillations of the protons against the neutrons about the common rotation axis has led to the designation of these levels as "scissors mode" states. Scissors mode states have been observed in nuclei ranging from ^{46}Ti to ^{238}U, and theoretical approaches have included various collective models as well as a variety of microscopic techniques. In well-deformed nuclei, these states appear with $J^{\pi} = 1^{+}$ at $E_x \sim 3$ MeV and have a B(M1) strength of ~ 2-3 μ_N^2; considerable amounts of data has been collected on nuclei in the rare earth region, primarily through (e,e') and (γ,γ') measurements.[2] A particularly interesting case is ^{164}Dy, since this nucleus exhibits substantially more fragmentation and possibly a larger total B(M1) than that seen in similar nuclei or predicted by model calculations.[3] In DSAM-INS measurements, the lifetimes of these states in ^{162,164}Dy have been measured, and the M1 strengths have been determined. Measurements of similar excitations in transitional nuclei have also been performed.

The interesting behavior of electric dipole transition rates observed in the N = 82 nuclei has been reported by Gatenby et al.[4] who observed a large number of fast E1 transitions and suggested candidates for two-phonon octupole and quadrupole-octupole vibrational multiplets. These measurements have inspired additional measurements in this mass region to understand the possible source of these enhancements. Specifically, we have chosen to study ^{146}Nd and thus move away from the closed shell, where shell effects may be important, but not into a region of large quadrupole deformation.

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A test QPM and IBM models by inelastic excitations and transfer reactions

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The stable neodymium isotopes provide a sensitive testing ground for nuclear models since many properties are expected to change at the onset of their deformation. Inelastic cross sections have been measured for proton and deuteron scattering on ^{142,144,146,148,150}Nd. The phenomenological information obtained has been compared to the predictions of different theories, with a special emphasis on the IBM and Quasipartile-Phonon Model (QPM). This latter model gives a very satisfactory description, in terms of one and two-phonon configurations to the E2, E3, E4, E5 and E6 excitations.

The collective states are strongly excited by inelastic scattering processes and give information on particle-hole *(p-h)* correlations. To implement this information with that on quasi-particle excitations, the ^{142,144,146,148}Nd(p,t) reactions have been studied. About 360 transitions have been measured and several final levels, not reported in literature, have been detected. It can be stressed here that with the (p,t) reaction, studied with a high resolving power, *complete* sets of levels in certain spin and excitation-energy regions can be populated.

The (p,t) reaction should give information on the other effect which determines the nuclear structure: the particle-particle *(p-p)* correlations. In a superfluid description *p-h* and *p-p* correlations should affect the same states. In this case it is necessary to analyze simultaneously inelastic scattering and two-neutron transfer reactions. The data from the above experiments have been comparated with QPM predictions. Calculations have been done with a *p-h* interaction fixed by inelastic scattering data and using different values of the quadrupole pairing force (G_2). The B(E2) value and the (p,t) cross section for the excitation of the first 2^+ state give a G_2 value of about 0.009. However the ratio between (p,p') and (p,t) cross sections for higher lying 2^+ states seem to indicate a lower G_2 value. ^{144,146}Nd data are reasonably reproduced. The calculated cross sections in the ^{142}Nd(p,t) reaction are much larger than in other Nd targets. Unfortunately QPM in the present form seems to overestimate the contribution of levels near the Fermi surface to the lowest phonons. The resulting effect is particularly evident in nuclei filling hole levels. Further calculations are in progess.

INVESTIGATION OF THE ^{124}Te (n,2γ)-REACTION DECAY

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The coincidence pulse amplitude sum method is applied to investigate the nuclear structure characteristics of the spherical ^{124}Te compound- nucleus. Its 52 protons and 72 neutrons make it interesting for investigation. The main γ-transition features between the compound-state and the low lying pre-compound and simple states are available for investigation with this simple technique [1].

The two γ-transition decays were measured with the help of the Ge(Li)-detectors during 400 hours. The resolution of the detectors was about 5 keV at the γ-ray energy of 1332 keV and the efficiency was ≈10%. Three summarized peaks from the sum amplitude spectrum with $E = E_1 + E_2$ were available for examination, namely: 9424.9 keV, 8820.9 keV and 6676.8 keV. They present decays from the compound-state to the low excited state levels with energies of: 0 keV, 558 keV and 2747.3 keV, and with $J^\pi = 0^+, 2^+, 1^-$ respectively. Ninety-four two-quanta cascades were obtained and 17 of them were placed in the decay scheme.

The cascade intensities were measured and their absolute values calculated, using the literature values [2] of the absolute intensities of some primary transitions. The experimental absolute intensity sum for each final level was calculated and compared with the model calculations [3, 4, 5, 6]. A comparison of the sum intensity values, as well as their dependence on the prime transition energy, with the model calculations shows a great discrepency. A deviation from the statistical model in the attitude of the function of cascade intensity from the primary γ-ray intensity for the cascade, ending at the first excited level 2^+ is observed. No model exactly describes the experimental situation, but one can see that the model [3] which assumes a giant resonance temperature dependance [6] gives the best fit. A further theoretical explanation is necessary.

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THE TWO-GAMMA QUANTA CASCADE OF THE ^{114}Cd COMPOUND-STATE DECAY

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The coincidence pulse amplitude sum method is applied for the investigation of the spherical ^{114}Cd nucleus. The $^{113}Cd\,(n,2\gamma)^{113}Cd$ thermal neutron capture reaction was used. The high $\sigma \approx 20000$ barn cross section of this reaction makes this nucleus convenient for measurements. $^{114}_{48}Cd_{66}$ is interesting to examine, with its almost full proton shell (the number of protons is 48).

The measurements were carried out by two Ge(Li) γ-detectors with a resolution ≈ 5 keV at the 1332 keV line of ^{60}Co and an efficiency about 10%. The data processing is described in [1, 2].

The ^{114}Cd compound-state has a spin and pairity of $J^{\pi} = 1^{+}$. The five two-quanta cascades with energy sums of: 9040.8 keV, 8482.3 keV, 7831.1 keV, 7735.8 keV and 7676.4 keV, going to: 0 keV, 558 keV, 1209 keV, 1305 keV, 1364 keV levels respectively with their respective spins and pairity: $0^{+}, 2^{+}, 2^{+}, 0^{+}$ and 2^{+} were measured. We obtained 192 γ-cascades, 43 of them were placed in the decay scheme according to the criteria, described in [2]. No literature data are known for the other 25 excited levels with an energy above 3500 keV .

The relative γ-transition cascade intensities were measured and their absolute values were calculated, using the literature data in [3]. A comparison of the former with the model calculations shows a presence of nonstatistical effects in the case of the $1^{+} \rightarrow J^{+} \rightarrow 2^{+}$ cascade. The attitude of the $I_{\gamma\gamma}(I_1)$ function is like the fragmentation pecularities of the one quasiparticle state, described detail in [4] for the case of deformed nuclei. Final conclusions of the mentioned effect may be made after a detailed theoretical analysis of the ^{114}Cd level structure at the excited energies above 4 MeV.

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