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Dedicated to the Institute of Nuclear Research of the Hungarian Academy of Sciences on the 30th anniversary of its foundation

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TO THE 30th ANNIVERSARY OF THE FOUNDATION OF ATOMKI

Three decades are a rather short period on a historical scale. For a research institute and thus for the Institute of Nuclear Research of the Hungarian Academy of Sciences (ATOMKI), however, it is a real epoch. It is especially a long period for us who have been working here since the foundation of this Institute.

As is well known, ATOMKI developed out of the Chair for Experimental Physics of the L. Kossuth University of Debrecen. The traditions of physics, however, are much older in Debrecen. The work in experimental physics was started in this city in the nearly four and a half centuries old Debrecen Calvinist (Reformed) College at the end of the 17th and in the first half of the 18th centuries. The names of Hatvani, Maróthy and Segner (the later professor at Jena University) characterize this period of physics education and research in Debrecen. The old experimental equipment can be seen even now in the present building of the College. Our Institute is a successor of these traditions, it continues the work started by our predecessors here.

In addition to the traditions of physics in Debrecen, there is another important factor which has a significant role in the life of the Institute. Namely, the founder of this institution, Professor Szalay worked for half a year at Rutherford in Cambridge in the mid-thirties, and this relatively short period was decisive for his scientific career and also for this Institute.

It is not the proper place to report on all the different scientific and applied results obtained in ATOMKI during the 30 years of its existence. It should be mentioned here only that the activity and results of the Institute are distributed in the field of fundamental nuclear and atomic physics; applied research in geology, biology, medicine, etc.; and in the field of real practical applications on the basis of research contracts with industrial enterprises and institutions in about equal percentage. The inter- and multidisciplinary interest in research is a special characteristic of this Institute as well as the development of research equipments and methods.

The institute is in very good connection not only with a number of institutes abroad, but also with the universities in Debrecen, as well as with many secondary school teachers, even with secondary school pupils, in many various ways. In general, ATOMKI has an important role in the cultural, scientific and technical life of the city and of this region of the country.

We strongly hope that the past thirty years mean only the beginning of the useful activity of ATOMKI in research for the good of our country and society.

The International Symposium on In-Beam Nuclear Spectroscopy is being organized on the occasion of the 30th anniversary of the Institute. We warmly greet the distinguished colleagues participating in this Symposium, and in this way taking part in our jubilee celebration. We wish all participants a very pleasant and successful time in Debrecen during the Symposium.

D. Berényi
Director of the Institute

I. STRUCTURE OF MEDIUM HEAVY NUCLEI : $Z < 50$

MEASUREMENT OF SHORT LIFETIMES IN SD SHELL NUCLEI

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The use of targets implanted into heavy backing material such as tantalum has an essential advantage in comparison with previous lifetime measurements, namely it has the high stopping power needed in the determination of short nuclear lifetimes with the Doppler shift attenuation method.

The use of experimentally known stopping power in the Monte Carlo analysis of the DSA measurements permits the determination of lifetimes to an accuracy which is sufficient to deduce nuclear parameters (like e.g. the isoscalar and isovector matrix elements of analogus levels).

The application of the above mentioned technique on some nuclei in the sd shell is discussed.

NUCLEAR LEVEL STRUCTURE IN THE A=54 TO 94 MASS REGION

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The low-lying states of ^{54}Mn, ^{64}Cu, ^{73,76}As, ^{77,80,82}Br and ^{94}Nb have been investigated by the (p,nγ) reaction with proton beam in the energy range from threshold energies to 3.0 MeV. The level schemes of the nuclei were determined from the measurements of γ-ray excitation functions, γ-γ and n-γ coincidence spectra. The angular distributions and linear polarization of the de-excitation γ-rays as well as the (p,n) cross sections corresponding to the individual residual states and n-γ angular correlations have been measured. Comparison of the data with the predictions of the compound nuclear statistical model yielded the following J^{π} for levels(level energies in keV) in ^{54}Mn:155.7,4^+;in ^{64}Cu:159.3,2^+;278.2,2^+;343.9, 1^+;in ^{73}As:254.0,$3/2^-$;393.3,$1/2^-$,($3/2^-$);427.9,$9/2^+$;577.5,5/2; 655.3,3/2;769.7,5/2;850.4,5/2;860.5,7/2;993.5,7/2,(5/2); 1037.0,7/2,(13/2);1078.5,3/2,(5/2);1087.1,5/2,(3/2);1178.1,7/2, (5/2);1221.3,5/2,7/2;1274.9,5/2,(7/2);1293.4,9/2-13/2;1302.4, (1/2),3/2;1324.3,1/2,3/2;1344.1,5/2,(7/2);1489.2,5/2;in ^{76}As: 121.1,$(1)^+$,2^+,3^+;165.0,3^-,$(4)^-$;264.6,3^+;300.7,(3,4);308.1, (3,4);321.5, $\geq$2;352.7,3^+,4^+;362.7,4^-,$(3)^-$;402.3,$(1-3)^+$;447.7, 3^+,$(4)^+$;471.9,4^-,$(3)^-$;499.9,3(2);517.5,1^+,2^+;544.3,3,3;550.5, 1-3;669.9,3;in ^{77}Br:105.8, $9/2^+$;129.7,$5/2^+$;162.1,$5/2^-$;167.0, 1/2;226.6,($3/2^-$,$5/2^-$);276.3,$5/2^+$;336.9,$3/2^-$;418.0,$7/2^+$;425.1, $5/2^-$;471.1,$3/2^-$,$5/2^-$;in ^{80}Br:256.4,3^-;in ^{82}Br:290.6,3^-;362.1, 1,2;419.1,1,2;475.0, $\geq$4;540.7, $\geq$4;640.4,3;763.0,1,2,(3);1022. 1,3,(4);1232.5,2,3,(4);1277.4,3,(4);in ^{94}Nb:140.4,2^-;301.8,2^-; 334.2,3^+;396.3,3^-;450.2,3^+;631.2,$(4)^+$;666.0(3^+);785.0,$3^{(+)}$; 792.7,3^+,4^+;817,4,(3^+),4^+;923.3,(2^+),3;972.8,3^+;979.3,2^+. Multipole mixing ratios and branching ratios for most of the transitions have also been determined. Systematics of the level structures of the nuclei,which belong to this mass region have been discussed in terms of shell model configurations and collective models.

ENERGY LEVELS OF NUCLEI VIA THE $(n,n'\gamma)$ REACTION

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In the course of the last years, our group has been involved in a nuclear spectroscopy research programme concerning the study of the $(n,n'\gamma)$ reaction on some medium-weight and heavy nuclei. That investigation, conducted with true-coaxial Ge(Li) detectors with good timing characteristics and pulsed-beam techniques, allowed us to obtain very detailed and precise information on the gamma decays from the excited levels of the nuclei under study. The comparison of the measured quantities (cross-sections for the gamma-ray excitation functions and angular distributions) with the statistical theory of the compound nucleus allowed us to determine the spin values of the investigated levels with a reasonable confidence.

All measurements were carried out using the 7 MV Van de Graaff accelerator of the Laboratori Nazionali di Legnaro (LNL, Padua, Italy). The neutrons were produced by means of the $^{3}H(p,n)^{3}He$ reaction on a Tritium-Titanium target. The measurements were performed at incident neutron energies ranging tipically from 1.3 MeV to 3.9 MeV, using the pulsed-beam time-of-flight technique for the neutron-gamma discrimination in the Ge(Li) detector.

The nuclei selected for the investigation were ^{75}As (1), ^{59}Co (2), ^{51}V (3). Some results were also obtained on the decay schemes of ^{93}Nb (4) and ^{164}Dy (5). In all those cases, an accurate determination of the decay schemes was achieved, improving the knowledge of branching ratios of the γ-decays and of the energies of the investigated levels, and obtaining also some new information on the spins of the studied levels.

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SHELL MODEL STATES IN THE ODD-ODD NUCLEUS ^{64}GA[+]

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As a part of our systematic studies of neutron deficient nuclei in the A = 60 - 80 mass region we investigated excited states in ^{64}Ga by the ^{54}Fe(^{12}C,pnγ) and the ^{64}Zn(p,nγ) reactions. The p-induced reaction was used to populate selectively low spin states in a γ-ray excitation function measurement. In the heavy ion induced reaction we measured excitation functions, γγ-coincidences, γ-angular distributions, conversion electrons and lifetimes in coincidence with the evaporated neutrons in order to suppress the competing reaction channels [1]. We found 17 previously unknown states above 1 MeV and made spin-parity assignments for most of the new and all lower lying states.

In order to understand the complicated structure of ^{64}Ga, we performed a shell-model calculation with the code RITSSHIL [2], using the 2p3/2, 1f5/2, 2p1/2 and 1g9/2 configuration space and the MSDI effective interaction for 3 active protons and 5 active neutrons outside the ^{56}Ni core. A comparison of the calculated positive parity states with the experiment is given in figure 1. The single particle energies are ε(p3/2)=0, ε(f5/2)=0.76, ε(p1/2)=1.1 and ε(g9/2)=1.6 MeV, where the fp values are ^{57}Ni data. All shell-model states below 1.5 MeV are shown and to each of them the experimental counterpart could be identified. The ordering of levels and the excitation energies are in excellent agreement. At higher spins we find some deviations, but the 9^+ 3.574 MeV state again fits very well.
The calculation shows, that this is the fully aligned πg9/2 x νg9/2 state, which is also known in the heavier odd-odd Ga isotopes.

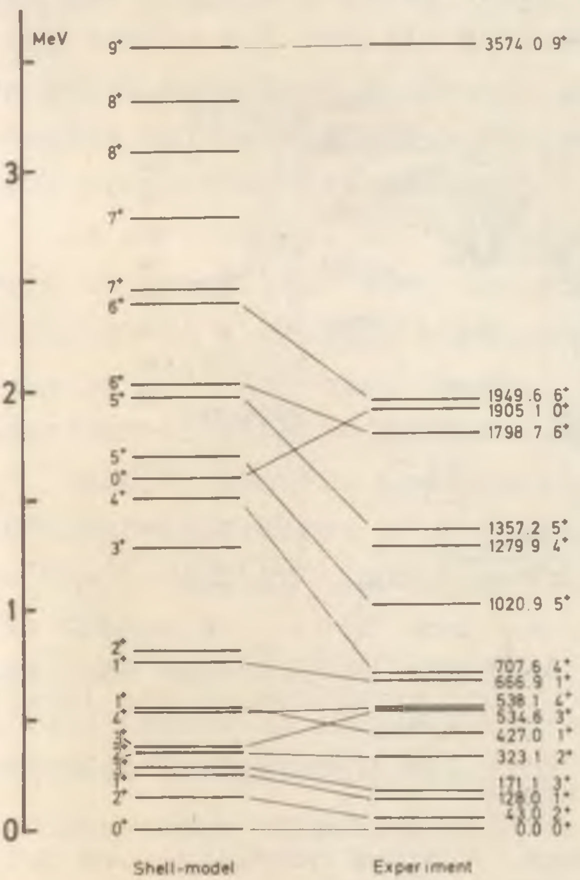

Fig.1 ^{64}Ga, partial level scheme of positive parity states.

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[+]work supported by BMFT

EXCITED STATES OF THE ^{70}Ga NUCLEUS

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The γ-spectrum of the $^{70}Zn(p,n\gamma)^{70}Ga$ reaction was measured with Ge(Li) spectrometers at 3, 3.5 and 4 MeV bombarding proton energies. 47 γ-rays were assigned to ^{70}Ga and the energies (E_γ) and relative intensities (I_γ) of γ-rays were determined. The electron spectrum of the reaction was measured with high transmission superconducting magnet transporter Si(Li) and mini-orange Si(Li) spectrometers. Internal conversion electron coefficients were determined for eight ^{70}Ga transitions. The level scheme of ^{70}Ga, γ-branching ratios, multipolarity of transitions, level spins and parities were deduced. The energies of low-lying ^{70}Ga levels were calculated on the basis of the parabolic rule derived from the cluster-vibration model. This calculation provided a simple classification of several multiplet states in ^{70}Ga for the first time (Fig. 1).

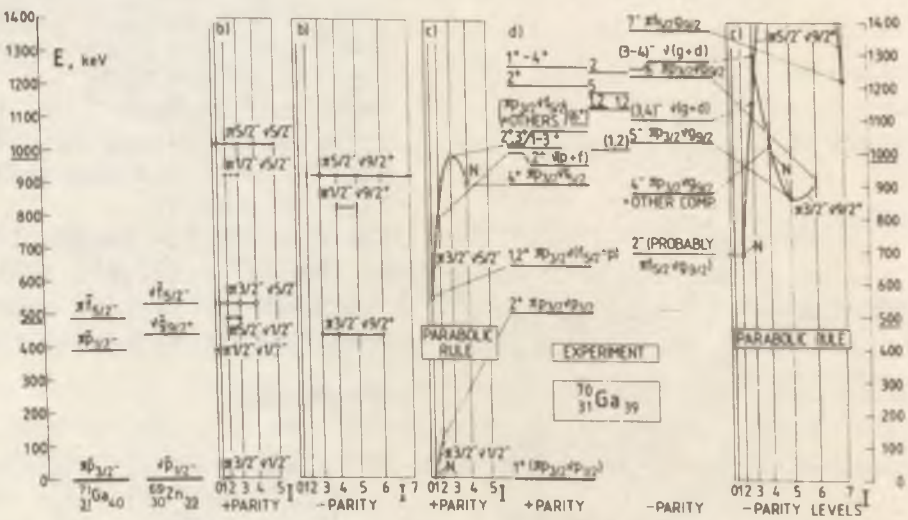

Fig. 1. Proton-neutron quasi-particle multiplet states in ^{70}Ga.
a/ Experimental level energies and configurations of the lowest three states of the ^{71}Ga and ^{69}Zn nuclei.
b/ The zeroth-order classification of the low-lying ^{70}Ga states. I is the spin of the nuclear state.
c/ The splitting of some states of Fig. 1b due to quadrupole and spin vibrational phonon exchange. N means normalization point.
d/ Experimental levels of ^{70}Ga below ~1300 keV.

QUASIPARTICLE AND COLLECTIVE EXCITATIONS IN NUCLEI OF THE MASS 80 REGION

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On the basis of extensive experimental results on several Kr and Br isotopes the collective and few-particle aspects of excitations in these transitional nuclei have been investigated. Similar to well-deformed nuclei band crossing phenomena, such as interaction matrix elements fluctuating with the nucleon numbers, fast $\Delta I=0$ M1 transitions between mixed states and reduced E2 transition rates near the crossing point have been observed. Due to softness of the core the γ degree of freedom plays obviously an important role in these transitional nuclei.

As an example, in $^{81-83}$Kr non-axial deformations were found in connection with the occupation of $g_{9/2}$ quasineutron orbitals. On the other hand, 3 quasiparticle (3qp) excitations in ^{81,83}Kr which contain $g_{9/2}$ quasiprotons indicate a behaviour similar to an axial-symmetric rotor.

Calculations in the cranked shell model show a very different dependence of the qp energy on the γ deformation for the lowest $g_{9/2}$ quasiproton and quasineutron orbitals with minima at $\gamma \approx +30^{\circ}$ and $\gamma \approx -30^{\circ}$, respectively. This behaviour may lead to configuration dependent polarization effects caused by the unpaired quasiparticles and explains the shape coexistence found in ^{81,83}Kr.

IN BEAM STUDY OF ^{78}SE

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Levels in ^{78}Se have been studied at the cyclotrons in Rossendorf and Leningrad using the ^{76}Ge(α,2nγ) reaction. High-resolution singles spectra, relative excitation functions, angular distributions, the linear polarization and coincidence relations of the γ-rays were measured at bombarding energies of 21-27 MeV. The lifetimes of 28 levels were determined using Doppler shift and pulsed beam timing methods.

As a result of these experiments the level scheme shown in fig.1 has been established. The spin and parity assignments of the 2742.4, 2949.3, 3306.7, 4047.9, 3013.8, 3550.0 and 4121.1 keV levels differ from those proposed in a recent (α,2n) study /1/ and are mainly based on our lifetime measurements. Moreover, several additional transitions were found. The three 8^+ and the two 10^+ states are suggested to involve collective and $g_{9/2}$ two proton and two neutron excitations. Their mixing reflected by the M1 transitions between the states with equal spin is treated in three band mixing calculations.

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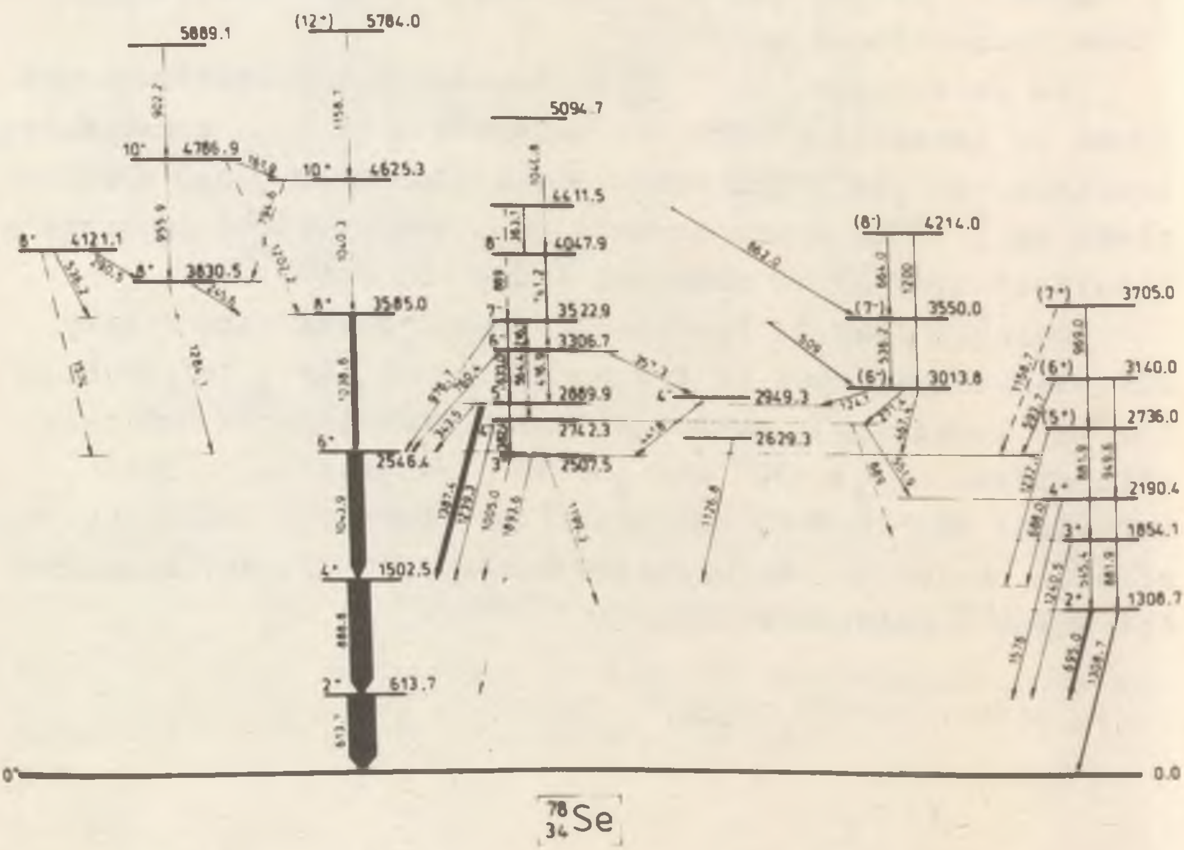

Fig.1: Preliminary level scheme of ^{78}Se.

EVIDENCE FOR SHAPE COEXISTENCE IN ^{83}Kr

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Excitations in ^{83}Kr were studied in-beam at the Stockholm and Rossendorf cyclotrons via the (α,3n) reaction. Coincidence relations, the polarization and angular distributions of the γ-rays were measured at E_α=42 MeV. Lifetime measurements (DSA method) were performed at E_α=42 and 27 MeV. The level scheme deduced from our experiments is shown in fig. 1. Its extension towards higher spins compared with recent (α,n) data [1] reveals 3 band like sequences. The spacings in the $\Delta I=2$ sequence on top of the $17/2^-$ yrast state and those of the ^{84}Kr yrast band are very similar. Low collectivity of the 1327.6 and 896.6 keV transitions, B(E2)=4(1) and $\leq$7.5 W.u., respectively, point also to properties of the heavier even-mass neighbour. In contrast the $\Delta I=1$ sequence, $I^\pi=21/2^+$ to $(29/2^+)$, resembles a 3qp band in ^{81}Kr [2]. The M1 intraband transitions are fast in both nuclides, for the 518.1 and 690 keV transitions we determined limits of B(M1)$\geq$0.4 W.u. Similarly as discussed for ^{81}Kr, the rather regular level separations are assumed to reflect a deformation stabilyzing effect of two rotation-aligned $g_{9/2}$ protons.

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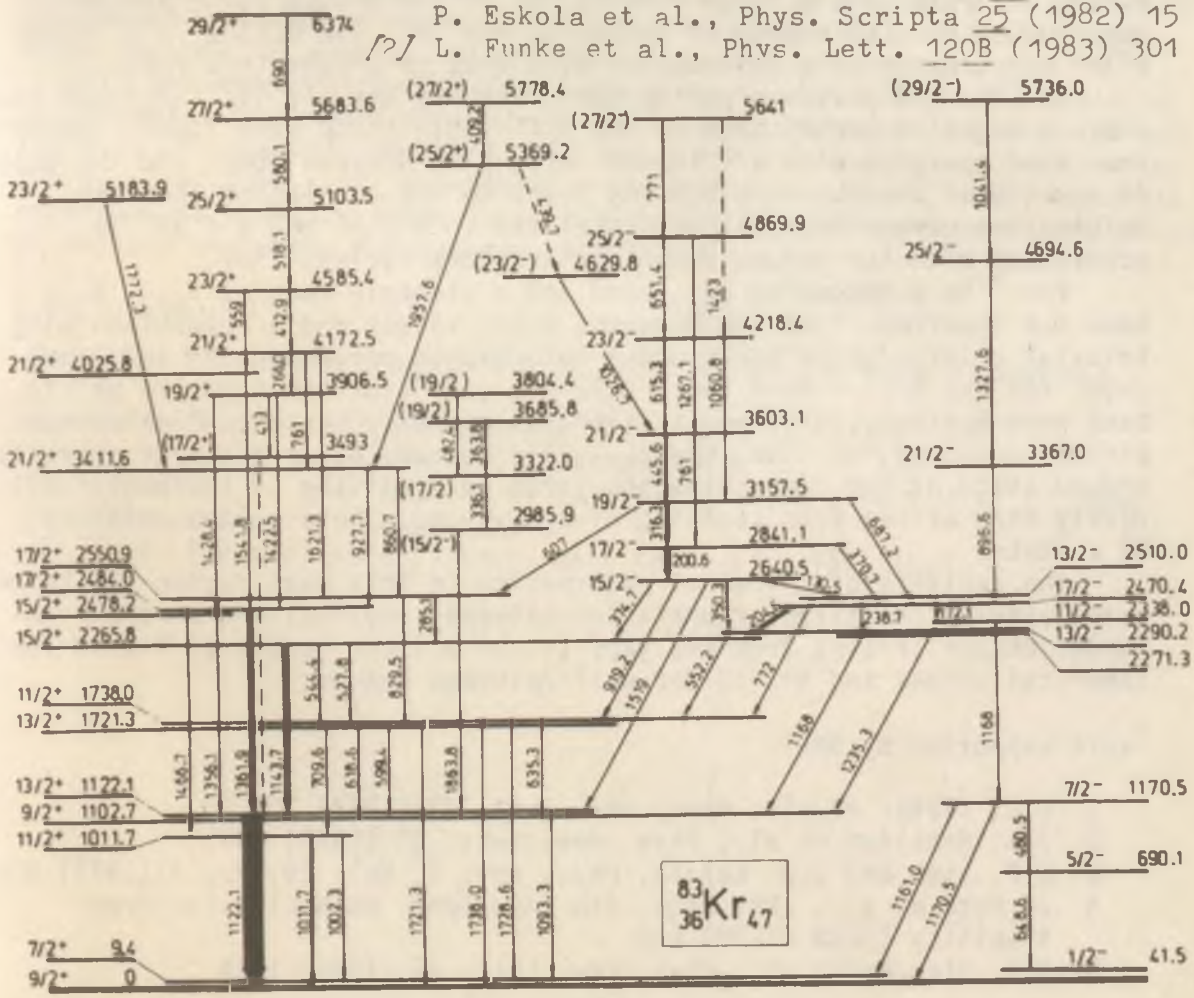

Fig. 1: Level scheme of ^{83}Kr

SHAPE COEXISTENCE IN SE AND KR ISOTOPES INVESTIGATED BY NEUTRON MULTIPLICITY GATED γ-SPECTROSCOPY+

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For nuclei with Z=38,40 (Sr,Zr) and N≈40 large quadrupole deformations were found experimentally |1|. First hints for strongly deformed shapes in this mass region were deduced from the anomalous behaviour of the yrast band in ^{72}Se |2,3|, which was interpreted as mixing of a band built on the near spherical ground state with a band based on the deformed 0_2^+ - state. To study the development and origin of deformation we investigated the isotone ^{74}Kr and the odd neighbouring nuclei ^{71}Se and ^{75}Kr as the odd neutron is expected to be a sensitive probe of the quadrupole field of the core nuclei. As these neutron deficient nuclei are only weakly populated by fusion-evaporation reactions - too low for standard in-beam γ-spectroscopy- informations were restricted so far to a few low-lying states. The recently developed neutron multiplicity - γ coincidence technique |4| allowed the observation of γ-transitions up to high spins. Using ^{19}F, ^{16}O, and ^{32}S beams of the FN Tandem at the University of Köln we measured n-gated $\gamma\gamma$-coincidences, yield functions, angular distributions, lifetimes with the Recoil-Distance method and conversion coefficients with a Mini-Orange spectrometer.

In ^{74}Kr the yrast band was established up to spin 20^+. A two band mixing analysis gave a large deformation of the ground state and an unperturbed 2^+ - 0^+ energy of about 200 keV |5|. The B(E2,2^+ - 0^+)=1400 $e^2 fm^4$ corresponds to a deformation of β~0.35 of a symmetric rotor.

In ^{75}Kr one positive parity band based on the $5/2^+$ |422| Nilsson state and one negative parity band on the $3/2^-$ |301| state were found. Comparing the level energies with a triaxial rotor plus Nilsson model and the absence of additional states below 500 keV leads to the conclusion that the deformation parameters must be restricted to β~0.36 and $\gamma \leq 15^0$ in accordance with the values found for the core nucleus ^{74}Kr.

For ^{71}Se a decoupled $g_{9/2}$ band and a strongly coupled $f_{5/2}$, $p_{3/2}$ - band was observed. From the measured B(E2) values and a comparison with the triaxial rotor plus particle model deformation parameters of β~0.2 and γ~30^0 for the $9/2^+$ - band and β~0.38 and γ~28^0 for the negative parity band were derived. This result strongly supports the shape coexistence picture proposed for ^{72}Se: the $g_{9/2}$ hole is coupled to the near spherical ground state of the core while the large collectivity of the negative parity band arises from coupling of a $f_{5/2}$, $p_{3/2}$ hole to the deformed 0_2^+ - state.

The rapidity of change of deformation in this mass region has to be correlated to the strong competition between spherical and strongly deformed shapes arising from the gaps in the Nilsson levels at N=Z=40 for spherical shapes and N=Z=38 for well deformed shapes.

+work supported by BMFT

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SUBSHELL GAPS AT N = 40 AND Z = 40 AND SHAPE COEXISTENCE IN THE fpg SHELL

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Deformation in nuclei is approached from the viewpoint of the number of protons and neutrons in the active or valence space and their interaction through a proton-neutron force [1]. In certain situations the number of active protons and/or neutrons can be increased by their promotion across shell or subshell gaps. The resulting configurations, called (shell model) intruder states, generally give rise to shape coexistence phenomena [2]. The occurrence of these configurations is especially dramatic at and near closed shells, where well-defined rotational bands are sometimes found in regions of low level density (below the pairing gap).

The occurrence of these intruding configurations and the associated shape coexistence can be understood simply as the interplay of two energy factors: (a) the cost in energy of promoting nucleons across shell and subshell gaps and, (b) the "return" in energy gained due to the residual pairing force between like nucleons and a residual quadrupole force between protons and neutrons. This picture suggests that shape coexistence inevitably occurs, provided that the intruder configurations are not severely fragmented. Further, the proton-neutron residual force will favor mid-shell regions for unusually low-lying coexisting shapes.

In the present investigation, shape coexistence in the fpg shell is considered. The empirical evidence for shape coexistence is reviewed and the role of subshell gaps at Z = 40 and N = 40, in producing this coexistence, is studied. It is especially important to subject this picture to experimental scrutiny since, e.g., "deformed shells" have been invoked also to explain the shape coexistence in ^{74}Kr [3].

*Work supported in part by U. S. DOE Contract No. DE-AS05-80ER10599.

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EXCITED STATES OF ^{96}Nb FROM ^{96}Zr(p,nγ)^{96}Nb REACTION

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The γ-ray spectra of the ^{96}Zr(p,nγ)^{96}Nb reaction have been measured with Ge(Li) detectors at different bombarding proton energies between 1.3 and 5.1 MeV. γγ-coincidences were observed at E_p=4.7 and 5.0 MeV. On the basis of experimental results a level scheme of ^{96}Nb was deduced (see fig.), γ-threshold energies and γ-branching ratios were determined. Computed Hauser-Feshbach (p,n') cross sections have been compared with experimental data obtained from the γ-ray measurements, and level spins and parities have been determined. The energies of ^{96}Nb levels were calculated on the basis of the parabolic rule, derived from the cluster-vibration model. The Racah multipole decomposition method was used also for the theoretical interpretation of several ^{96}Nb multiplet states.

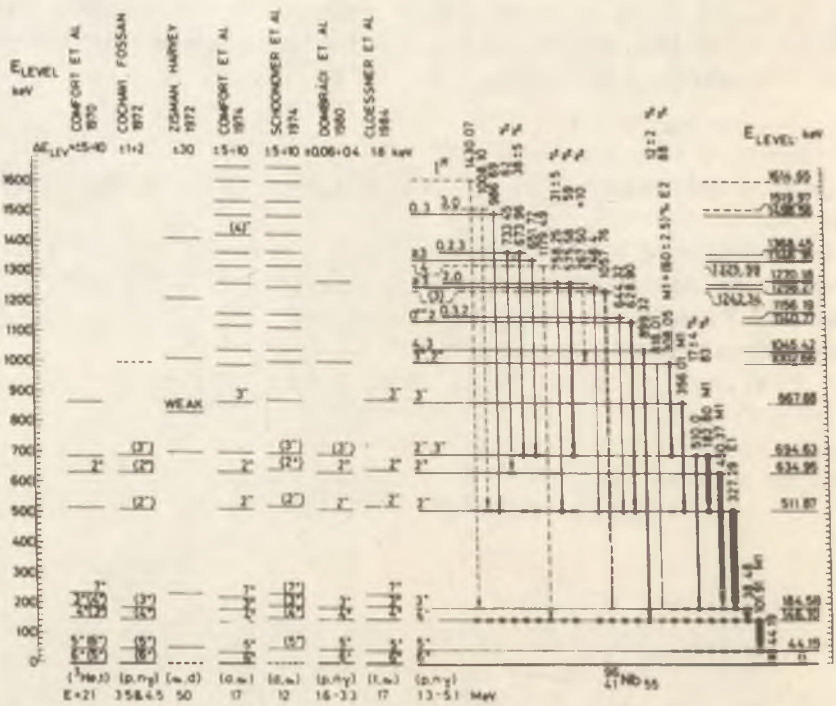

Fig. The energy level diagram of ^{96}Nb

STUDY OF QUASI-MAGIC ^{96}Zr

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The ^{96}Zr nucleus, suspected of being magic, has been studied in the (n,n'γ) reaction of reactor fast neutrons. Spins and decay properties of most of the twelve lowest levels are obtained for the first time.

Early shell model calculations for the Zr isotopes were restricted to the $d_{5/2}$ neutron shell which is closed at N=56. Hence a simple spectrum, reminiscent of that of magic ^{90}Zr, has been predicted - in clear disagreement with present experimental knowledge. Even so the influence of the subshell closure is obvious and more detailed theoretical analysis is called for.

THE ^{94}Mo VIBRATIONAL NUCLEUS

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The ^{94}Mo nucleus is adjacent to the N=50 closed neutron shell. It has a vibrational spectrum with the remarkable feature that the energy of the two-phonon 0^+ state is exactly twice the energy of the one-phonon 2^+ state.

The level and decay schemes of ^{94}Mo were studied using the $(n,n'\gamma)$ reaction induced by reactor fast neutrons. The obtained spins, branchings and mixing ratios have increased considerably the experimental knowledge of this nucleus.

In order to see whether shell model calculations can account for the experimental data entirely or coupling of vibrational and particle degrees of freedom is necessary, more extended calculations are required.

$(n,n'\gamma)$ SPECTROSCOPY OF TRANSITIONAL $A \simeq 100$ NUCLEI

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The region of deformation around $A \simeq 100$ has been an exciting subject since the discovery of neutron-rich deformed Zr, Mo and Ru isotopes off the stability line. The $(n,n'\gamma)$ reaction, induced by reactor fast neutrons, was used to obtain new levels, spins and B(E2) ratios in vibrational ^{94}Mo and in ^{98}Mo and ^{100}Mo transitional nuclei.

Although both shell model and cluster vibrational model calculations were available for ^{94}Mo, only recently has a description of the transitional Mo nuclei become possible in the framework of the proton-neutron interacting boson model with configuration mixing [1]. The mixing between vibrational and γ-unstable features, the latter being typical for the heavy isotopes, accounts well for the observed level structures.

The $(n,n'\gamma)$ method has also been applied to Zr isotopes. Spins, branching and mixing ratios for most of the twelve lowest states of ^{96}Zr were obtained. In order to understand to what extent this nucleus is magic a comparison is drawn between ^{96}Zr, the isotone of transitional ^{98}Mo, and truly magic ^{90}Zr.

General conclusions are made with respect to experimental knowledge and theoretical interpretations in the Zr-Mo region.

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ROTATIONAL STRUCTURES AT A = 100

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In 1970 it has been shown [1] that neutron-rich even-even nuclei with masses around 100 have rotational level patterns with strongly enhanced $B(E2: 2^+ \rightarrow 0^+)$ values. Since then intensive investigations have been performed on the detailed nuclear structures in this new region of deformations. The studies were based on the spectroscopy of fission products and on reactions in which neutron-rich nuclei are produced as (n,γ) or (t,p). Theoretical studies were performed in the frame of the shell model [2] or of the IBA (e.g. ref. [3]).

The results for the even-even nuclei indicate that the isotones ^{100}Sr and ^{102}Zr are symmetric rotators while more complex shapes exist for $N < 62$ and $Z \geq 42$.

Very recently rotational behaviour has also been observed in odd-mass nuclei at $A \sim 100$ which provides interesting insight into the individual Nilsson configurations of the levels of isotopes of Sr through Mo. Well developed rotational bands have been found here already at $N = 60$ (for example in ^{99}Y [4]).

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BETA-STRENGTH FUNCTION PHENOMENA OF EXOTIC NUCLEI IN THE A = 100 MASS REGION

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In recent years, the investigation of the ß-strength function, $S_\beta(E)$, of nuclei far away from the line of ß-stability has received considerable attention because the knowledge of $S_\beta(E)$ is of importance for various problems in nuclear physics, astrophysics and for nuclear reactor applications [1,2].

With regard to nuclear physics, $S_\beta(E)$ of far-unstable nuclei can provide new insight into nuclear structure since such nuclides have exotic neutron-to-proton combinations which consequently have symmetries different from those found in near-stable systems. With this, nuclei far off stability may have ß-decay modes and quantum numbers different from those occuring near stability; e.g. ß-delayed particle emission and anomalies in the ß-strength function behaviour related to the interplay between new shells and deformations.

By comparison of experimental $S_\beta(E)$of neutron-rich Br to Sr isotopes in the transitional region around A=100 with theoretical GT strength functions from recent shell model calculations in the RPA [3], nuclear structure effects related to deformation and to the subshell closures at N=56, 60 and Z=38 are examined. With the presently existing systematics of $S_\beta(E)$ of neutron-rich isotopes in the A=80-110 mass range, the reliability of nuclear models to predict global ß-decay properties (e.g. $T_{1/2}$, P_n) and spectral distributions (e.g. the antineutrino spectra) of unknown nuclei will be discussed. First results on the "quenching" of the low-lying GT strength accessible to ß-decay of exotic nuclei will be presented.

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CONVERSION ELECTRON MEASUREMENTS IN ^{100}Rh AND ^{102}Rh

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In a recent research on ^{100}Rh and ^{102}Rh performed with the ^{100,102}Ru(p,nγ)^{100,102}Rh reactions, the level scheme of these two nuclei and the γ-decay of their levels up to about 600 keV have been reported (1,2) .

In both cases the level scheme can be divided in two parts with weak or no γ-transitions between them; only for very few levels the assignement to one of the two classes is uncertain. In analogy to previously investigated odd-odd Tc isotopes, the two groups of levels have been assumed to have opposite parity.

In order to test the above assumption, and to resolve residual ambiguities (concerning a few low-lying levels of ^{102}Rh) electron conversion coefficients have been measured. Measurements have been performed at the CN Van de Graaff of Laboratori Nazionali di Legnaro, with the reactions ^{100,102}Ru(p,nγ)^{100,102}Rh at E_p=6MeV and E_p=4.5 MeV. Spectra of prompt γ-rays and conversion electrons have been recorded with a Ge hyperpure counter and a small electron spectrometer. The latter (3) consists of a broad acceptance magnetic analyzer followed by a Si detector cooled to liquid nitrogen temperature. Preliminary measurements cover the region 120keV$\leq E_e \leq$350 keV for ^{100}Rh and 100keV $\leq E_e \leq$ 200 keV for ^{102}Rh. Since in this region, conversion coefficients for E1 and M1 transitions differ by about a factor 2, it is possible to distinguish between the two multipolarities also with moderate statistical accuracy. Due to the low energy and short lifetimes of the transitions considered, higher multipolarities can in fact be neglected (apart, perhaps, from some very weak E2 branches).

Measurements in ^{100}Rh confirm up to now, the parity attributions assumed on the only base of the decay scheme. Also in ^{102}Rh all parity attributions which could be tested until now, have been confirmed and, in addition, definite evidence of positive parity of the level at 178 keV has been obtained due to the E1 character of the 178.6 $\rightarrow$41.9 keV transition. The parity attribution to these two levels can be extended (with the decay-scheme criterion) to higher levels decaying predominantly to them, as the 206.9,263.8 302.2, 431.5, 545.9 and 645.8 keV states.

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MULTIPOLARITY OF SOME ^{102}Rh TRANSITIONS

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In our earlier work [1] we have measured the gamma and gamma-gamma coincidence spectra of the ^{102}Ru(p,nγ)^{102}Rh reaction and a level scheme has been proposed for the ^{102}Rh nucleus. The aim of the present work was the measurement of the conversion electron spectra of the ^{102}Ru(p,nγ) reaction and the determination of the multipolarity of the ^{102}Rh transitions in order to obtain information on spins and parities of the levels of the ^{102}Rh nucleus.

Isotopically enriched (to 98.7 %), 1 mg/cm^2 thick ^{102}Ru powder target prepared on a 200 μg/cm^2 Al foil was used for the experiments. The measurements were performed at the Van de Graaff accelerator of our institute with a proton beam of 4.0 MeV energy and 10-20 nA intensity. The spectrum of the conversion electrons was studied with a superconducting magnet transporter Si(Li) spectrometer.
The conversion electron line intensities were normalized so that the internal conversion coefficient of the 475 keV transition from the ^{102}Ru(p,p') reaction should correspond to the theoretical E2 value. Using this procedure the multipolarity of 12 ^{102}Rh transitions has been determined. Preliminary results are shown in Table 1.

[1] Zs. Dombrádi, A. Krasznahorkay and J. Gulyás, Z. Phys. A 313 (1983) 207

Table 1. Multipolarity of ^{102}Rh transitions

γ-ray energy [keV]	Multipolarity*	γ-ray energy [keV]	Multipolarity*
123.78	M1	259.69	E1
136.72	E1	270.52	E1
146.01	M1	291.57	E1
167.14	E1	304.50	E1
182.10	E1	338.91	M1
243.53	M1	343.78	M1

*Small admixtures of E2 radiation are not indicated.

PROTON-NEUTRON MULTIPLET STATES IN ^{114}In

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The γ-spectrum of the ^{114}Cd(p,nγ)^{114}In reaction was measured with Ge(Li) and hyperpure Ge spectrometers at 4.8, 5.3 and 7 MeV bombarding proton energies. The energies (E_γ) and relative intensities (I_γ) of ≈170 γ-rays assigned to ^{114}In were determined. The electron spectrum of the reaction was measured with a combined magnetic plus Si(Li) spectrometer. Internal conversion electron coefficients were determined for about 20 ^{114}In transitions. The level scheme of ^{114}In, γ-branching ratios, multipolarity of transitions, level spins and parities were deduced.

The energies of several ^{114}In proton-neutron multiplets were calculated on the basis of the parabolic rule derived from the cluster-vibration model. This calculation provided a simple classification of various multiplet states in ^{114}In.

PROTON - NEUTRON MULTIPLET STATES IN MEDIUM HEAVY ODD-ODD TRANSITIONAL NUCLEI

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I. Introduction

II. Experimental technique. Van de Graaff and isochronous cyclotron accelerators. (p,nγ) reactions.
In-beam hard and soft γ-spectrum, excitation function, γ-angular anisotropy, internal conversion electron, internal e^-e^+-pair, and scattered proton spectrum measurements. γγ-, e^+e^--, and beam pulse-γ-coincidence spectra. Ge(Li), and hyperpure Ge γ-spectrometers, superconducting transporter Si(Li), mini-orange Si(Li) and combined magnetic plus Si(Li) electron spectrometers, surface barrier Si proton spectrometer. Different reaction chambers. Enriched targets

III. Survey of experimental results on ^{114}In, ^{102}Rh, ^{100}Tc, ^{98}Tc, ^{96}Nb, ^{94}Nb, ^{82}Br, ^{76}As, and ^{70}Ga nuclei

IV. Theoretical interpretation of the level schemes.
Shell model, parabolic rule (derived from the cluster-vibration model), and Racah multipole decomposition calculations

V. p-n multiplet states in odd-odd nuclei. Examples: ^{114}In, ^{96}Nb, ^{82}Br, and ^{70}Ga

VI. Conclusions

II. STRUCTURE OF MEDIUM HEAVY NUCLEI: $50 \leq Z \leq 82$

UNIFIED DESCRIPTION OF INTRUDER STATES IN EVEN-EVEN NUCLEI

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We give a unified description of low-lying "intruder" states in even-even nuclei.It is shown that the proton-neutron quadrupole-quadrupole interaction which is causing deformed shapes when many valence protons and neutrons outside closed shells are present,also causes particle-hole "intruder" states to occur at very low excitation energy.Results for such "intruder"states ,especially around the single-closed shell at Z=50 are shown.

NUCLEAR STRUCTURE STUDIES THROUGH THE COMBINED USE OF THE (n,n') AND (n,n'γ) REACTIONS

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Studies of the nuclear structure of medium-mass and heavy nuclei have been conducted with excited states being produced by incident neutrons in the energy range from 0.5 to 4.0 MeV. Both neutron and γ-ray detection have been employed in many experiments to exploit the separate advantages of observing these reaction products. The incident neutrons were produced at the University of Kentucky 6.5-MV electrostatic accelerator.

Certain refinements in technique and recent experimental results will be described:

A. Improved shielding of large Ge detectors, utilizing a massive copper collimator and a boron-loaded polyethylene shield.

B. The use of accurately measured thresholds for γ-ray production in the placing of γ-rays into complex decay schemes. The use of the curvature of γ-ray excitation functions near threshold to limit spin assignments in nuclei with A>150.

C. Complementary use of (n,n') and (n,n'γ) cross sections to confirm the placement of γ rays and alternatively to enable the extraction of (n,n') individual level cross sections from unresolved neutron multiplets.

D. The sensitivity of neutron angular distributions to spin 0 and spin 1 levels, which has enabled otherwise difficult spin 0 assignments to be made in ^{94,100}Mo, and ^{198}Pt, for example. Neutron angular distributions are sharply anisotropic for low-spin final states. On the other hand, γ-ray angular distributions have large anisotropies for higher-spin final states.

E. Recent results which were obtained through use of these methods in the study of spherical, deformed, and transitional nuclei will be discussed, including those on ^{124}Sn, ^{168}Er, and ^{198}Pt.

HALF-LIVES OF ^{109}Sn AND SHELL-MODEL CALCULATIONS

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In a recent comparison of experimental data with shell-model predictions for ^{111}Sn a remarkable agreement could be stated [1] . An extension of this investigation to further tin nuclei enables us to test the validity of the shell-model Hamiltonian used [2] .

Half-lives of positive-parity states in ^{109}Sn have been determined by means of the γ-RF method using the $^{106}Cd(\alpha, n)$ reaction (E_α = 20 MeV). The half-lives summarized in Fig. 1 have been deduced from the slopes or centroid shifts of the measured time distributions.

In the shell-model predictions presented in Fig. 1 the higher lying states are quite well reproduced. The calculated half-lives are in rather good agreement with the experimental values.

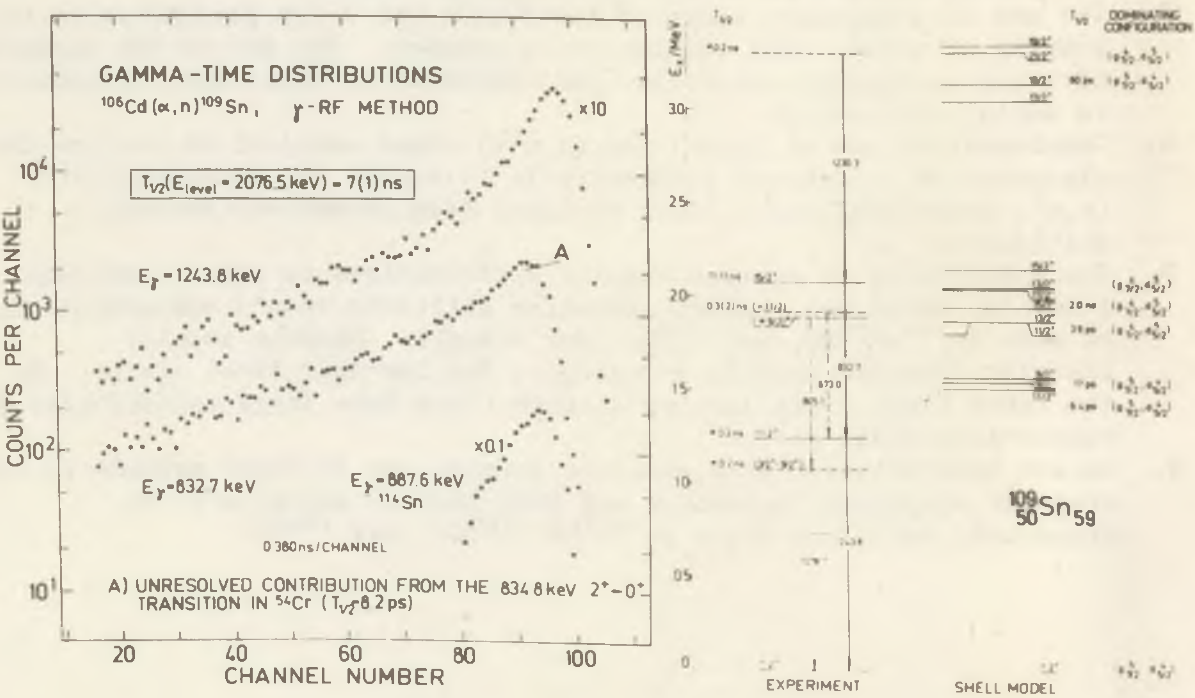

Fig. 1: Time distributions for transitions deexciting the 15/2$^+$ isomer as well as a comparison of experimental [3, 4] and theoretical (π = +1) energy spectra and half-lives in ^{109}Sn. For each spin value only the two lowest calculated states are shown. The Hamiltonian applied is identical with that of Refs. [1, 2] . The half-lives have been calculated with experimental transition energies.

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COMPARISON OF LOW LYING LEVELS IN ^{128}XE WITH IBM-2^{+}

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Using an extensive set of data of energies and branching ratios obtained for the nucleus ^{128}Xe in a ^{125}Te(α,n) ^{128}Xe experiment, we have done an IBM-2 calculation. As a starting point we used the parameters of the systematic fit of Xe, Ba and Ce isotopes by Puddu and Scholten. Two essential changes had to be made: 1) A relatively large C_4 coefficient was introduced to reproduce the excited 0^+ states. 2) The M(1) transitions and a g-factor were reproduced using the M(1) operator of the form

$$T(M1) = \sqrt{\tfrac{3}{4\pi}}\ \left(0.8\cdot\sqrt{10}\ (d^+\,\tilde{d})_\pi^{(1)} + 0.15\cdot\sqrt{10}\ (d^+\,\tilde{d})_\nu^{(1)}\right)$$

Reasonable fits of branching ratios and $g(2_1^+)$ were obtained by use of different energies for proton and neutron bosons. The obtained fit is satisfactory although the B(E2) values from the γ-band to the g-band are too weak and the number of parameters is rather high.

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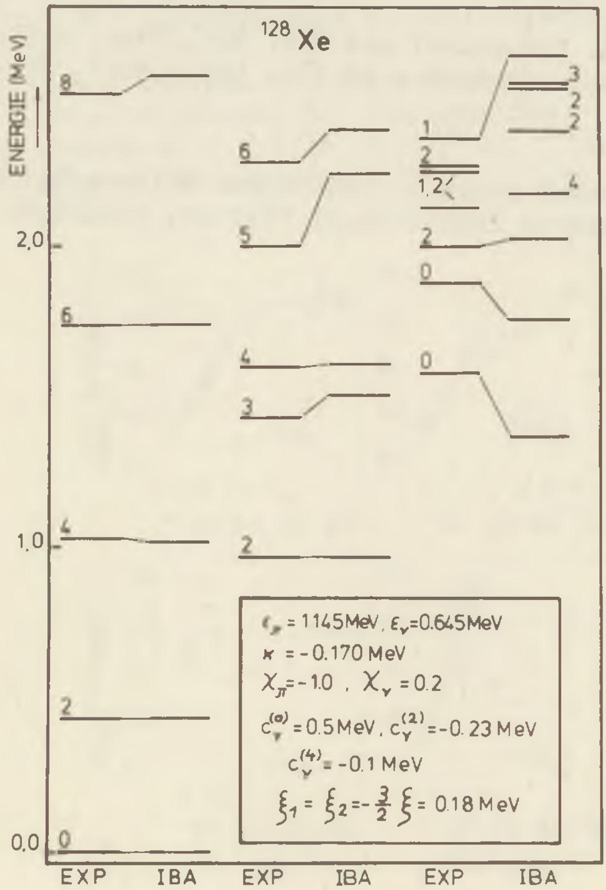
$^{+}$supported by BMFT

$g(2_1^+) = 0.30$ exp: 0.32 ± 0.01

Transitions	Branching / B(E2)-ratio EXP	IBA
2(2)→0(1) / 2(2)→2(1)	0.261 / 0.0125	0.247 / 0.0122
3(1)→2(1) / 3(1)→2(2)	1.083 / 0.010 v 0.06	0.491 / 0.012
3(1)→4(1) / 3(1)→2(1)	0.198 / —	0.284 / 29.40
5(1)→4(2) / 5(1)→3(1)	0.145(7) / —	0.221 / 0.49
0(2)→2(1) / 0(2)→2(2)	3.17 / 0.150(5)	6.51 / 0.294
0(3)→2(1) / 0(3)→2(2)	4.67 / 0.48(4)	6.53 / 0.70
4(2)→4(1) / 4(2)→2(1)	2.29 / —	97.94 / 2963.



STUDY OF BAND CROSSINGS IN ^{130}Xe

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Excited states in ^{130}Xe were populated in the reaction $^{130}Te(\alpha,4n)$ and the subsequent γ-radiation was studied with in-beam spectroscopic methods. High-spin bands were observed to a spin of 19 and an excitation energy of 7 MeV. The ground-state band was followed up to spin (14^+). A sharp backbend at $J^\pi = 10^+$ gives rise to the yrast positive-parity band and it was followed up to spin (18^+). A complex negative-parity band structure, which ultimately merges into the ground-state band mostly via a $5^- \rightarrow 4^+$ E1 transition, was observed up to spin (19). The negative-parity bands backbend at spins 12^- and 13^-.

The backbends are treated as band crossings within the framework of the triaxial Cranked Shell Model [1,2]. The first crossing is correctly (the g-factor is known [3]) reproduced as an AB_n neutron crossing of the $h_{11/2}$ quasiparticles, whereas the second crossing in the ground band is attributed to the AB_p $h_{11/2}$ configuration. The crossings in the negative-parity bands are interpreted to be BF_nAD_n and BE_nAD_n for the signatures $\alpha = -1$ and 0, respectively. The E and F orbitals refer to the $d_{3/2}$ orbitals. The calculated crossing frequencies and the gains in aligned angular momenta agree well with the experimental values.

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COLLECTIVE MOMENT OF INERTIA OF ^{118,122}Xe AND ^{128,130}Ba

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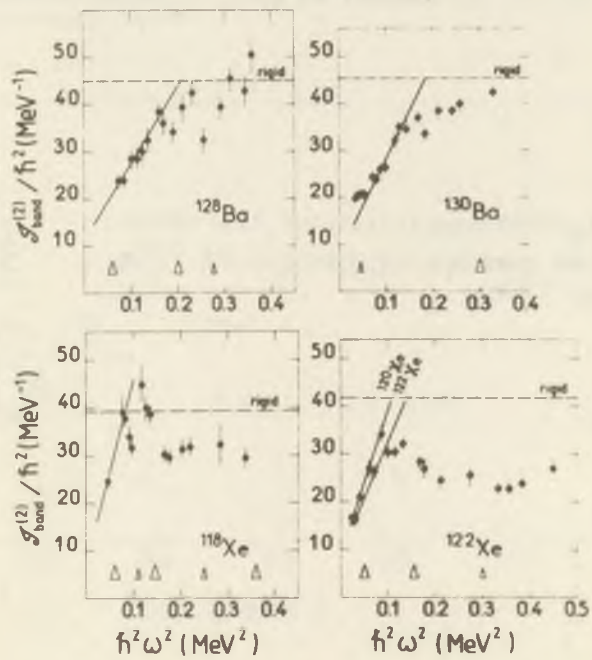
In order to study collective properties of transitional nuclei, the dynamic moment of inertia $\mathcal{J}^{(2)}_{band}$ of ^{118,122}Xe and ^{128,130}Ba has been investigated by measuring γ-γ energy correlations. These nuclei were produced by bombardment of ^{112,117}Sn, ^{123}Sb and ^{122}Sn enriched targets, respectively, with ^{12}C ions from the Grenoble variable energy cyclotron. The γ-γ coincidence events were obtained by means of six 8" x 6" hexagonal NaI(Tl) detectors which were strongly collimated.

The results extracted from the width of the valley in the correlation matrices are presented below. They indicate a major difference between the Xe and the Ba : $\mathcal{J}^{(2)}_{band}$ of the former decreases after the first band-crossing and remains small and almost constant while it increases in the latter with the frequency.

Such a qualitative difference could reflect changes in the high-spin collective properties. Calculations made using the method of ref[1] show, for example, that bands built with $h_{11/2}$ protons ($\pi h^{1,2}_{11/2}$ $\nu h^{6}_{11/2}$) in ^{122}Xe can have $\gamma \simeq 33°$ corresponding to only moderately collective rotation and $\mathcal{J}^{(2)}_{band}$ smaller than 30 $\hbar^2$/MeV whereas the $h_{11/2}$ bands [($\pi h^{2}_{11/2}$ $\nu h^{8}_{11/2}$) and ($\pi h^{3}_{11/2}$ $\nu h^{2}_{9/2}$)] in ^{128}Ba exhibit γ-values ($\gamma \simeq 0°$) corresponding to collective rotation and $\mathcal{J}^{(2)}_{band} \simeq 35$ $\hbar^2$/MeV.

The possible existence of a secondary minimum at larger deformation in the potential-energy surfaces [2] could also account for the continued increase of $\mathcal{J}^{(2)}_{band}$ in ^{128,130}Ba. This minimum at $\varepsilon \simeq 0.34$, $\gamma \simeq 0°$ in ^{128}Ba corresponds to bands with a pair of aligned $h_{9/2}$ neutrons. In the ^{122}Xe data there is no evidence of influence of ($\pi h^{1,2}_{11/2}$, $\nu h^{6}_{11/2}$) bands at $\varepsilon \simeq 0.28$, $\gamma \simeq 0°$.



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MEASUREMENT OF $\mathcal{J}^{(2)}_{band}$ IN ^{123}Cs

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$\mathcal{J}^{(2)}_{band}$ As shown in a preceding paper [1] the collective moments of inertia of Xe and Ba nuclei behave differently. This can be interpreted considering the collectivity (Ba) or non-collectivity (Xe) of these nuclei and/or the existence of a strongly deformed secondary minimum in the potential-energy surfaces of the bariums. Experimental data were collected on ^{123}Cs in order to bring some insight on the behaviour of nuclei in this transitional region.

An experiment was performed with the Grenoble cyclotron by bombarding a ^{115}In target with 80 MeV ^{12}C ions. The γ-γ energy correlations were measured using six 8"x6" hexagonal NaI(Tl) detectors. At this beam energy, the correlation matrix is mainly generated by ^{123}Cs since the 4n channel represents more than 60 % of the total cross-section.

It appears in fig. 1 that, up to $\hbar^2\omega^2$ = 0.16 MeV^2, the moment of inertia of ^{123}Cs increases and follows the $\mathcal{J}_0+3\omega^2\mathcal{J}_1$ relation where $\mathcal{J}_0$ and $\mathcal{J}_1$ are deduced from the discrete lines. ^{123}Cs and ^{122}Xe behave similarly up to 0.30 MeV^2 and then the moment of inertia increases rapidly in ^{123}Cs while it stays almost constant in the xenon. This effect observed in the cesium is directly related to the addition of a proton to the ^{122}Xe core.

Indeed, calculations as in ref.[1] show that the $(\pi h^2_{11/2}\ \nu h^6_{11/2})$ band with a prolate deformation ($\mathcal{J}^{(2)}_{band}$ = 35 - 40 $\hbar^2$ MeV^{-1}) is lower than the band with the same configuration at $\gamma \simeq 30°$ above spin 20 for ^{123}Cs, whereas for ^{122}Xe, they are calculated to have almost the same energy. The experimental results of ref.[1] indicate that ^{122}Xe tends to favour the triaxial bands. It is thus tempting to interpret the rise of $\mathcal{J}^{(2)}_{band}$ in ^{123}Cs as a change of deformation from $\gamma \simeq 30°$ to $\gamma \simeq 0°$.

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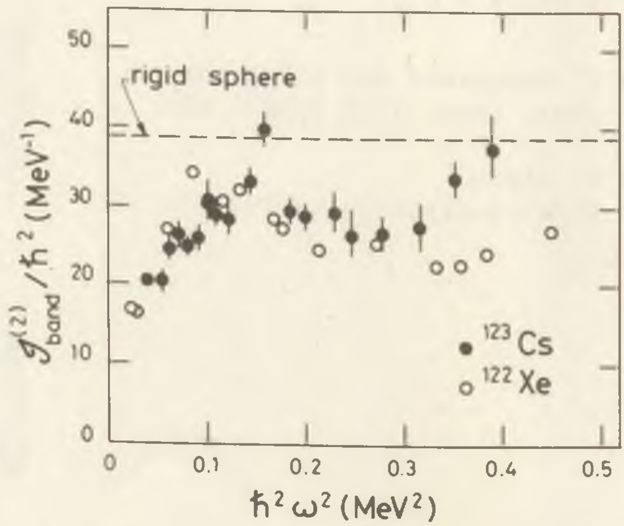

Fig.1 : Comparison of the collective moments of inertia of ^{122}Xe and ^{123}Cs.

THE EFFECTIVE MOMENT OF INERTIA OF ^{118}Xe AND ^{130}Ba

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Experiments were performed with the Grenoble cyclotron accelerating 112 and 80 MeV ^{12}C ions on ^{112}Sn and ^{122}Sn enriched targets, respectively. The total γ energy was recorded in a sum-spectrometer made of 12 hexagonal cross-section (20 cm long, 15 cm outer diameter) NaI(Tl) detectors arranged in a cylinder along the beam axis. The γ-ray spectra were obtained by means of another hexagonal crystal which was placed at 55° to the beam, strongly collimated and in coincidence with the sum-spectrometer. The raw γ-spectra were unfolded and normalized to the multiplicity extracted from the fold distribution in the 12 pieces sum-spectrometer. The subtraction of the statistical component $E_\gamma^3 \exp(-E_\gamma/T)$ was made using a nuclear temperature of 0.50 MeV for both cases presented here. A correction for feeding was applied following the method employed by Deleplanque et al. [1]. The final nuclei produced in the reactions were identified by a Ge detector in coincidence with the sum-crystal.

Results relative to the moment of inertia of ^{118}Xe are shown in fig. 1. $\mathcal{J}^{(2)}_{eff}$ increases rapidly with the frequency up to the first band crossing ($h_{11/2}$ neutrons and/or protons) at $\hbar\omega$ = 0.39 MeV and has approximately the same amplitude as $\mathcal{J}^{(2)}_{band}$. Two bumps show up at 0.53 and 0.62 MeV. They appear at the same frequencies as bridges in the γ-γ energy correlation matrix [2] and are very likely due to particle alignments. Then $\mathcal{J}^{(2)}_{eff}$ continues to increase while $\mathcal{J}^{(2)}_{band}$ remains constant. This is not in favor of a good collective behavior and suggests a triaxial shape with large γ values (γ ∿ 30°).

In the case of ^{130}Ba, the data indicate that $\mathcal{J}^{(2)}_{eff}$ behaves similarly with a peak at $\hbar\omega$ = 0.55 MeV which corresponds to a strong bridge in the correlation matrix [2]. Taking into account the variations of $\mathcal{J}^{(2)}_{band}$ and $\mathcal{J}^{(2)}_{eff}$, it appears that the collectivity is larger in ^{130}Ba than in ^{118}Xe.

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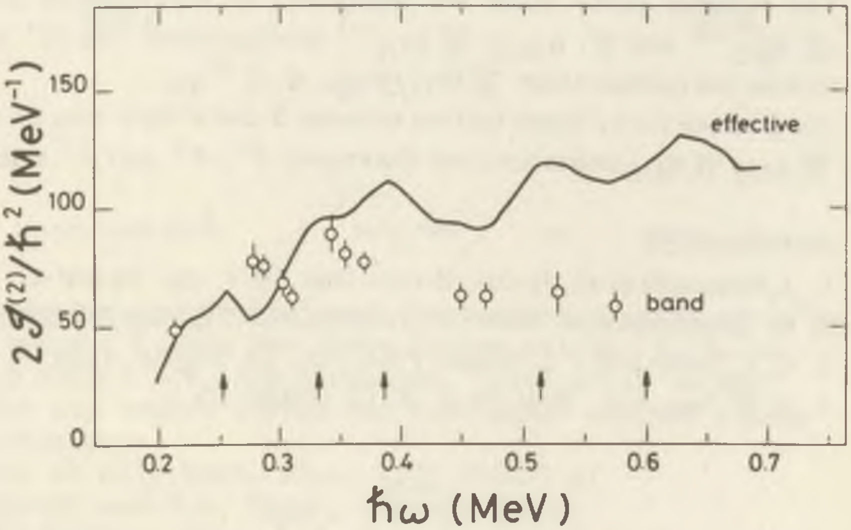

MULTIPARTICLE EXCITATIONS IN THE SINGLE CLOSED SHELL NUCLEUS $^{140}_{58}Ce_{82}$

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The $^{138}Ba(\alpha, 2n)$ reactions have been used to study the level structure in the semi–magic $^{140}Ce_{82}$ nucleus with filled $1g_{7/2}$ proton orbit. The experiments [1/] included measurements of γ–ray angular distributions, excitation functions, and γ–γ–t–coincidences as well as two–parameter timing measurements (γ–t_{RF}) and (e^- –t_{RF}).
Conversion electron data obtained at the Jyväskylä University with combined intermediate–image magnetic plus Si(Li) electron spectrometer [2/] provided α_K values for the strong transitions from 130 up to 1900 keV. Supplementary lifetime and three–parameter γ–γ –coincidence experiments with higher energy α –particles have been performed at the Stockholm and Krakow cyclotrons.

The results establish the ^{140}Ce partial level scheme; giving spin and in most cases parity assignments for the levels up to about 4 MeV. Our experiment confirms and gives the location of the earlier proposed [3/] isomer at 3716 keV. The present measurement gave its half–life as $T_{1/2}$ = 26±2 ns. The observed levels are in agreement in relevant parts with decay data [4/].
Two–particle (hole) excitations within the $\pi d_{5/2}$ and $\pi g_{7/2}$ shells provide spins up to 6. The negative parity states are interpreted as particle–hole excitations of the $\pi h_{11/2} \pi d_{5/2}^{-1}$ and $\pi h_{11/2} \pi g_{7/2}^{-1}$ configurations. The 10^+ isomer at 3716 keV is expected to have the configuration $\pi(h_{11/2})_{10+}\, \nu\, (j^{-2})_{0+}$.
The positive parity levels located between 3 and 4 MeV may be ascribed to the coupling of the $\pi g_{7/2} \pi d_{5/2}$ excitations and the known 2^+, 4^+ and 6^+ states in ^{138}Ba.

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EVIDENCE FOR CORE COUPLED STATES OF NEGATIVE PARITY IN ^{138}Ba AND ^{140}Ce

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Negative-parity states in an odd-mass N = 82 nucleus ($137 \lesssim A \lesssim 145$) can be assumed to arise from coupling a proton occupying the $1h_{11/2}$ intruder orbit to low-lying $\pi = +1$ states of the (A - 1) even-mass isotone, which is considered as the core [1].

In order to test the validity of this coupling scheme for negative-parity states of ^{138}Ba and ^{140}Ce observed in γ-spectroscopic experiments at the Rossendorf cyclotron using the reactions ^{136}Xe (α, 2n) and ^{138}Ba (α, 2n), we applied a particle-core coupling picture [2] to these states. The ^{137}Cs and the ^{139}La cores have been described by 30 and 35 low-lying $\pi = +1$ states, respectively, which were obtained from a shell-model description using Wildenthal's approach [3]. Fig. 1 shows a rather good theoretical reproduction for all $\pi = -1$ levels by such a description as well as for $\pi = +1$ states by our shell model calculations for $J \geq 6$ based on the Hamiltonian given in ref. [3].

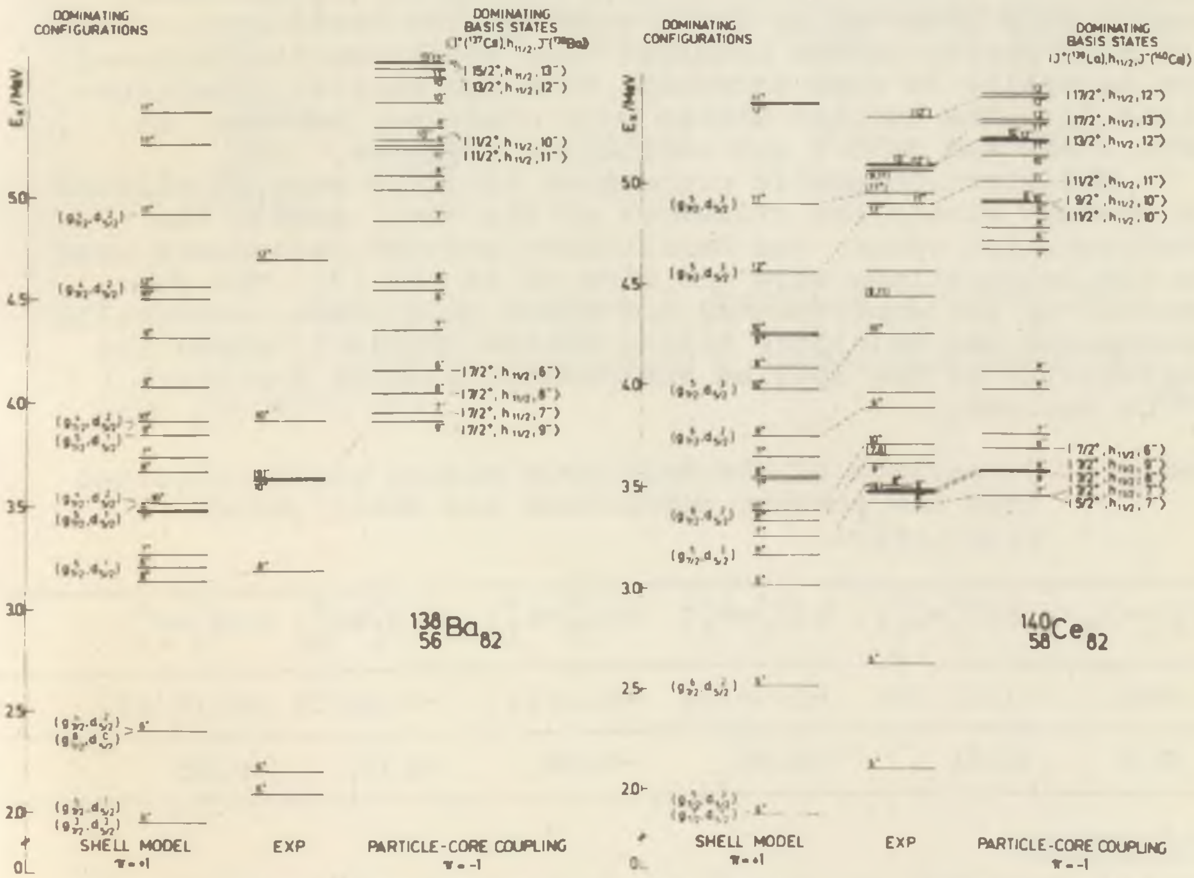

Fig. 1: Comparison between experimental and theoretical spectra of ^{138}Ba and ^{140}Ce. For each value J^{π} only the three lowest states [E_x(Ba) < 5.7 MeV, E_x(Ce) < 5.5 MeV, $J \geq 6$] are displayed. Information on the structure is given for the lowest levels and for higher excited states observed in the experiment.

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(n,n'γ) REACTION AND SHELL MODEL STUDY OF ^{140}Ce

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Continuing the systematic study of the stable N=82 nuclei [1] the ^{140}Ce (n,n'γ)reaction was investigated using the fast neutron beam of the WWR-SM reactor in Budapest.

From the measured singles γ-spectra and γ-ray angular distributions precise γ-ray transition energy and intensity values, furthermore branching and E2/M1 multipole mixing ratios were extracted. Excited levels up to 3.5 MeV level energy were observed by their γ-decay. The level structure and spin-parity values obtained from the present experiment are generally in good agreement with the earlier investigations [2]. New excited states were observed, however, at 3001.3 keV and 3473.9 keV excitation energies.

The electromagnetic properties of ^{140}Ce were calculated in Dresden within the framework of the shell model. The configuration space, the Hamiltonian and the parameters used in the calculations were the same as in ref.[3]. The comparison of the experimental and shell model data, especially concerning the multipole mixing ratios (Table 1) shows the reliability of the applied shell model picture for the ^{140}Ce nucleus.

Table 1 Comparison of the multipole mixing ratios obtained from the present experiment and shell model calculation

$\delta(J_i \to J_f)$	$\delta(2_2^+ \to 2_1^+)$	$\delta(5_1^+ \to 4_1^+)$	$\delta(5_1^+ \to 6_1^+)$	$\delta(3_1^+ \to 2_1^+)$	$\delta(4_3^+ \to 4_1^+)$
Exp.	0.31(34)	-0.04(4)	-0.04(6)	-0.06(3)	-0.18(6)
S M	0.31	-0.04	-0.08	-0.02	-0.05

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DECAY OF 0_2^+ STATES IN EVEN-EVEN N=82 NUCLEI

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Decay properties of the 0_2^+ state and the proton E0 effective charge in the doubly closed shell $^{146}_{64}Gd_{82}$ nucleus has been discussed in ref. 1. As a continuation of this work we have carried out a comprehensive study of 0_2^+ states in $^{144}_{62}Sm_{82}$, $^{142}_{60}Nd_{82}$ and $^{140}_{58}Ce_{82}$. The E0/E2 branching ratios were obtained from the singles conversion-electron and γ-ray spectra following the β^+ decay of the 1^+ ground states of ^{144}Eu, ^{142}Pm and ^{140}Pr. In lifetime measurements a centroid-shift method with the JYFL conversion-electron spectrometer (2) was used and the 0_2^+ states were populated in the $^{144}Sm(p,p')$, $^{140}Ce(\alpha,2n)$ and $^{138}Ba(\alpha,2n)$ reactions. Preliminary results summarized in Table 1 will be discussed.

Nucleus	$E(0_2^+)$ keV	$T_{1/2}(0_2^+)$ ps	$\rho^2(0_2^+-0_1^+)$ 10^{-3}	$B(E2,0_2^+-2_1^+)$ W.u.
$^{146}_{64}Gd$	2165	375±40	11±2	20±10
$^{144}_{62}Sm$	2478	<50	>3	>0.7
$^{142}_{60}Nd$	2217	80±30	17±6	1.2±0.5
$^{140}_{58}Ce$	1903	400±30	14±4	6.3±1.7

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LOW AND MEDIUM SPIN STATES IN ^{143}ND FROM THE $(\alpha,n\gamma)$ REACTION NEAR THE COULOMB BARRIER [+]

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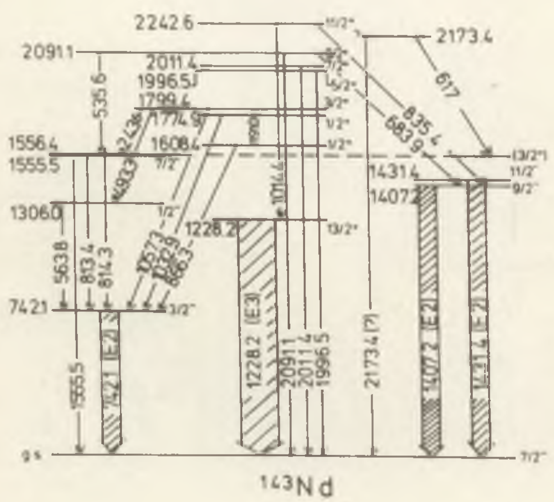
Low and medium spin states in ^{143}Nd were populated via the ^{140}Ce $(\alpha,n\gamma)$ reaction at energies near the coulomb barrier. This reaction is a useful tool for the detailed study of low lying configurations as for example multiplets arising from particle core coupling. Standard γ-ray spectroscopy methods have been used, that is $\gamma\gamma$ - coincidences, γ - excitation functions ($E\alpha$ = 14 - 20 MeV) and γ - angular distributions. Core coupled configurations $(3^- \times f_{7/2})$, $(2^+ \times f_{7/2})$, and $(4^+ \times f_{7/2})$ are observed around $E^* \approx 2$ MeV, where a high level density is expected for a nucleus with a semi-magic core. The complete particle-octupole $(3^- \times f_{7/2})$ multiplet (Fig. 1) recently identified in a (p,p') experiment (1) is populated. The angular distributions of its members (Tab. 1) show that they decay mainly through fast E1 transitions: the 5/2+, $7/2^+$ and the $9/2^+$ directly to the groundstate, the others to π = -1 levels with known $(2^+ \times f_{7/2})$ - components. In addition two M1 intramultiplet transitions ($11/2^+ \rightarrow 13/2^+$ $E\gamma$ = 1014.4 KeV and $3/2^+ \rightarrow 1/2^+$ $E\gamma$ = 191.0 KeV) are observed. All spins of the multiplet are uniquely determined.

Tab. 1 :

E (KeV)	Angular distribution A_2 / A_0	A_4 / A_0	Assignment
191.0	-0.107		1799.4 $3/2^+$ - 1608.4 $1/2^+$
243.6	+0.201		1799.4 $3/2^+$ - 1555.5 $7/2^+$
493.3			1608.4 $1/2^+$ - 1306.0 $1/2^-$
535.0	-0.273		2091.1 $9/2^+$ - 1555.5 $7/2^-$
683.9	-0.203	-0.06	2091.1 $9/2^+$ - 1407.2 $9/2^-$
835.4			2242.6 $11/2^+$ - 1407.2 $9/2^-$
866.3	-0.128	+0.01	1608.4 $1/2^+$ - 742.1 $3/2^-$
1014.4	contaminated with ^{27}Al		2242.6 $11/2^+$ - 1228.2 $13/2^+$
1228.2	+0.505	+0.043	1228.2 $13/2^+$ - g.s. $7/2^-$
1555.5	+0.035		1555.5 $7/2^-$ - g.s. $7/2^-$
1996.4			1996.4 $5/2^+$ - g.s. $7/2^-$
2011.4	-0.163	-0.025	2011.4 $7/2^+$ - g.s. $7/2^-$
2091.1			2091.1 $9/2^-$ - g.s. $7/2^-$



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STRUCTURE OF EVEN-EVEN AND ODD-ODD TRANSITIONAL NUCLIDES WITH 50<Z<64 AND 82<N<92*

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The gradual transition from the closed shell structure at N=82 to the deformed structure beyond N=90 may be contrasted with the much sharper transition that is observed for deformed nuclides near A=100. The source of these differences can be attributed to the effects of the Z=64 subshell [1] as well as the strength of the interaction between neutrons and protons in spin-orbit partner orbitals [2]. The character of the neutron-proton interaction can be observed in the splitting of p-n multiplets in odd-odd nuclides. In light nuclides where neutrons and protons are filling the same orbitals a strong short-range interaction, often approximated by a δ function, can be used to describe this splitting [3]. In contrast, the splitting of low-lying proton neutron multiplets in odd-odd N=83 nuclides can be described almost completely by a quadrupole p-n interation [4,5]. Another feature of the proton-neutron interaction is the 1^+ state formed from the spin orbit partner orbitals. Recent studies in odd-odd La nuclides indicate the presence of significant $\nu h_{9/2}\pi h_{11/2}$ character in three low-lying 1^+ levels. The positions of these 1^+ levels are found to drop as N increases from N=82 to N=90 in parallel with the drop in position of the collective states in the adjacent even-even nuclides [6].

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STUDY OF NEUTRON-POOR NUCLEI IN THE SM-GD REGION

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An experimental study of nuclei far from stability in the proximity of the proton number Z=64 has been undertaken at the Tandem XTU accelerator in Legnaro. A new region of strong nuclear deformation is expected for Z=64 centered around mass 130, well far away from current experimental accessibility. Recent calculations |1|, however, predict the existence of a promontory of very deformed nuclei with quadrupole deformation $\varepsilon_2 > 0.3$, which extends into the region where nuclei can be populated following H.I. compound nucleus reactions. Nothing is presently known about excited states for $Z \sim 64$, $A \leq 138$ nuclei; therefore we have started our study from the less neutron deficient N = 78 and N = 76 nuclei, with 4 and 6 neutrons less than the N=82 closed shell respectively.

Targets of ^{108}Pd, ^{109}Ag, ^{108,110,112}Cd were bombarded with a ^{32}S beam in the energy range 126÷170 Mev. Excitation function, γ-ray angular distribution and γ-γ-t coincidence measurements were performed. In ^{140}Sm the previous level scheme known up to a 10^+ isomer |2| has been extended up to spin 14^+ and a new long-lived state has been identified. From the angular distribution results and from the transition probabilities involved, a 10^+ value is proposed for the new isomer, which lies only 39 kev above the known 10^+ level. A 10^+ state is observed in all N=78 isotones with smaller proton number,at an excitation energy almost constant in all those nuclei, suggesting a $(\nu h_{11/2})^{-2}$ structure. In the Z=62 nucleus ^{140}Sm the existence of a second 10^+ isomer at approximately the same energy can only be explained with the promotion of two protons into the $h_{11/2}$ shell.

The N=76 nuclei ^{138}Sm and ^{139}Eu were also strongly populated in the reactions mentioned above and their high spin states identified up to spin 14^+ and $31/2^-$, respectively. In ^{138}Sm a number of states based on the 2^+ γ vibration was also observed. In this nucleus the yrast band shows an irregularity at spin 10^+, due to the alignement of two nucleons in the $h_{11/2}$ shell. Responsible of this behaviour can be either protons or neutrons since we see from the ^{140}Sm level scheme that the 10^+ excitation of $(\nu h_{11/2})^{-2}$ and $(\pi h_{11/2})^2$ character occur at about the same energy. The observation of a similar irregularity also in ^{139}Eu (one proton more) where the band built on the $h_{11/2}$ proton state is observed, indicates that two $h_{11/2}$ neutrons are the cause of the irregularity of the ground state band in the case of ^{138}Sm.

Lifetimes measurements are in progress to test the degree of collectivity in these nuclei as a function of spin and of neutron number.

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MEDIUM AND LOW-SPIN STATES IN N = 82 ± 1 NUCLEI NEAR ^{146}Gd

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The ^{146}Gd nucleus has many properties characteristic of doubly closed nuclei and therefore the neighbouring nuclei are of special interest. We have studied the N = 81 nuclei ^{143}Sm and ^{145}Gd and the N = 83 nucleus ^{147}Gd using (^{3}He,xn) and (α,n) reactions. In-beam γ-ray and conversion electron spectroscopic methods were employed in these investigations. About 15 new medium-spin states were observed in every nucleus studied.

The N = 81 nuclei ^{143}Sm and ^{145}Gd have very similar level structures below 2 MeV. In addition to neutron $d_{3/2}$, $s_{1/2}$, $h_{11/2}$, $d_{5/2}$ (and possibly $g_{7/2}$) hole states and a group of hole $\otimes$(3^- or 2^+) levels, an interesting one-particle, two-hole $\nu f_{7/2} j_0^{-2}$ $7/2^-$ state was identified at low energy in both nuclei (at 1310 keV in ^{143}Sm and 1273 keV in ^{145}Gd). An octupole excitation of this state was observed in ^{145}Gd, the $13/2^+$ level at 2200 keV being isomeric with $T_{1/2}$ = 20.4 ns [1]. A corresponding isomer was not found in ^{143}Sm; probably because some $h_{11/2}^{-1} \otimes$ (3^- od 2^+) states with J = 13/2, 15/2 can be below the $\nu f_{7/2} j_0^{-2} \otimes 3^-$ level. The decay of the $23/2^-$ 30-ms isomer in ^{143}Sm was observed to be more complex than proposed earlier [2].

Low-lying excitations in the N = 83 nucleus ^{147}Gd can be classified in to four groups: single-neutron states, hole-j_0^2 states, a neutron coupled to a ^{146}Gd excitation, and a hole coupled to a ^{148}Gd excitation. Although the neutron single-particle gap is large (3-4 MeV), the $\nu s_{1/2}^{-1} j_0^2$ and $\nu d_{3/2}^{-1} j_0^2$ states were observed at low energy, 1292 and 1412 keV, respectively [3]. The $f_{7/2}$ neutron coupled to the 1579 keV octupole excitation of ^{146}Gd gives a septuplet of states with I^π from $1/2^+$ to $13/2^+$. The $13/2^+$ member at 997 keV was known earlier and we found five new members: $11/2^+$ at 1702 keV, $9/2^+$ at 1643 keV, $7/2^+$ at 1628 keV, $3/2^+$ at 1699 keV and ($1/2^+$) at 1759 keV. About 20 levels were observed between 2.3 and 3.6 MeV and many of them can be interpreted in terms of an $f_{7/2}$ neutron coupled to ^{146}Gd core excitations. These higher-spin J =17/2-25/2 states are discussed on the basis of the spherical shell model.

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SPECTROSCOPY OF N=81,82,83 NUCLEI NEAR THE PROTON DRIP LINE*

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The Z=64, N=82 nucleus ^{146}Gd has many properties of a doubly closed shell system [1], and the yrast states of neighboring nuclei are well described [2] as shell model configurations involving a few valence nucleons outside the ^{146}Gd core. Since $s_{1/2}$, $d_{3/2}$, and $h_{11/2}$ are the proton orbitals between Z=64 and Z=82, rather pure $(\pi h_{11/2})^n$ excitations are found [3] to figure prominently in the yrast spectroscopy of N=82 nuclei with n valence protons. We are investigating the structure of very proton rich nuclei above ^{146}Gd using heavy-ion beams from the Argonne superconducting Linac. Thin targets located within a large NaI sum-spectrometer are bombarded with 220-260 MeV ^{58,60}Ni beams to form compound nuclei at low excitation energy, favoring the production of the nuclei of interest by two or three nucleon evaporation. Recoiling residual nuclei are stopped in a Pb catcher downstream, where comprehensive γ-ray measurements are performed. Isotopic assignments are based on separate Z and A identification for the observed γ-ray families.

In this talk, we present detailed spectroscopic results for some ten previously unstudied nuclei with Z>64 and N=81,82,83, and discuss their interpretation mainly in terms of seniority 2, 3, and 4 shell model configurations.

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ANOMALOUS SIGNATURE SPLITTING IN THE $[i\ 13/2]_n\ [h\ 11/2]_p$ BAND OF THE ODD-ODD NUCLEI

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We have experimentally studied the high spin states in ten odd-odd nuclei at the beginning of the deformed rare earth region : $^{150,152}Eu$, $^{152,154,156}Tb$, ^{160}Ho and $^{158,160,162,164}Tm$. The common feature in all this nuclei is the presence of the decoupled $[i\ 13/2]_n\ [h\ 11/2]_p$ band always strongly fed in the heavy ion reactions. We have shown that the considered configuration carries an aligned angular momentum comparable with the values measured in the S-band of the neighbouring even-even nuclei which fully explains the strong feeding of this band and the simplicity of the level schemes of these odd-odd nuclei. But the most striking feature of $[i\ 13/2]_n\ [h\ 11/2]_p$ band is that the experimental Routhians, corresponding to the two signatures observed ($\alpha = 0$ and $\alpha = 1$), are crossing each other at a rotational frequency, $\hbar\omega_c$, characteristic of the considered nucleus. This anomalous signature splitting, present in all the studied nuclei, can be reproduced theoretically if we assume a positive triaxial deformation of the core. By fitting the theoretical Routhians to the experimentally observed signature splitting for $N \geq 89$ γ values in the range $5° < \gamma < 25°$ were found (ref.[1] and fig.1).

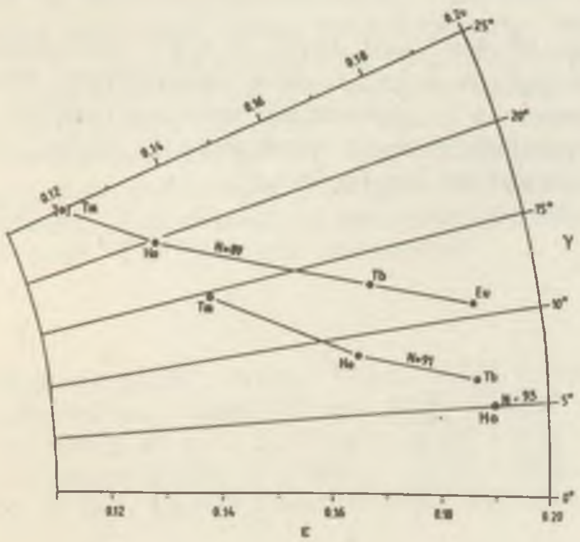

Fig.1 - Deformations of the $[i\ 13/2]_n\ [h\ 11/2]_p$ bands.

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NUCLEI FAR FROM β-STABILITY LINE. SOME RESULTS OF THE IRIS-YASNAPP COLLABORATION

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Spectra of γ-rays, positrons, X-rays and conversion electrons at the decay of neutron deficient isotopes of rare earth elements was investigated at the ISOL-facility IRIS. In course of measuring and making more precise the energies of α-decays in long α-decay chains, using our values of β^+-decay energies of nuclei in the ends of these chains and the results of previous papers, masses of about 40 nuclides were determined.

Analysis of the obtained data on nuclear masses allowed us to draw the following conclusions:

- earlier known α-decay nuclei ^{175,176,177}Au, ^{169,170}Ir, ^{165,166}Re and probably ^{178}Au, ^{172}Ir, ^{161}Ta, ^{155}Lu and ^{151}Tm must be also proton emitters;
- location of an extent part of the proton drip line was established for the first time. It goes through ^{178}Au, ^{172}Ir, ^{167}Re, ^{161}Ta, ^{156}Lu and ^{151}Tm in this region of nuclei;
- values of proton pairing energy for isotones with N=92,90,88,86,84 near proton drip line are ~50% larger than those in the region of β-stability line;
- residual (n,p)-interaction increases by more than two times for isotones with N=87,85 as compared with nuclei near stability;
- from the data on two neutron separation energy it follows that ^{154}Er, ^{156,158}Yb, ^{162,160}Hf and probably ^{164}W belongs to the transition region of nuclei.

Some pure Gamov-Teller $0^+ \rightarrow 1^+$ and $11/2^- \rightarrow 9/2^-$ β-transitions with unusually small values of lgft = 4.2÷3.6 were identified. Precise experimental values of lgft allowed us to determine renormalisation of ratio of the weak axial-vector and vector current constants - $|g_A/g_V|_{eff}$ in heavy nuclei. The mean value is equal to $|g_A/g_V|$=0.63.

PROPERTIES OF HEAVY-ION PRODUCED NUCLEI FAR FROM STABILITY

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At the GSI On-line Mass Separator, nuclei far from stability are produced using heavy-ion beams from the UNILAC between ^{16}O and ^{238}U with energies between 4 and 12 MeV/u. The reaction products are caught in an ion source and, after re-ionization and mass separation, investigated on-line by decay spectroscopy. The advantages and limitations of this technique, and examples of complementary in-beam experiments, are discussed.

Neutron-rich isotopes are reached through multi-nucleon transfer reactions: The new isotopes ^{179}Yb and $^{181-183}Lu$ were identified [1] using 9 MeV/u ^{136}Xe induced break-up reactions of tantalum/tungsten targets; projectile break-up reactions between a 9 MeV/u ^{76}Ge-beam and such a target yielded the new isotopes ^{62}Mn and $^{71-73}Cu$ [2] around the semimagic nucleus ^{68}Ni. Recent results obtained for beta-decay half-lives and partial level schemes will be discussed. Of astrophysical interest is the β^- decay of 5.7 min ^{180}Lu: Due to the β^- branch of its decay into $^{180}Hf^m$ measured to be 0.4(2) %, only a fraction of the very small solar abundance of $^{180}Ta^m$ is due to r-process formation.

Neutron-deficient isotopes from fusion-evaporation reactions were investigated in the regions around ^{100}Sn and ^{146}Gd, extending systematic proton, alpha and beta decay measurements towards and across the proton drip line [3,4]. In reviewing the resulting nuclear structure information, particular emphasis will be put on this borderline of nuclear stability and the proton-radioactive nucleus ^{147}Tm.

As a novel application for heavy-ion produced nuclei, collinear laser spectroscopy was performed in a pilot experiment [5] for neutron-deficient indium isotopes. The resulting magnetic moments, quadrupole moments and isotope shifts of $^{107-111}In$ are presented.

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PROTON ALIGNMENTS AT HIGH SPINS IN RARE EARTH NUCLEI

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The cranking model calculations predict that, as the nucleus rotates, single-particle high-j orbitals align and come down in energy. Fig. 1 shows the behavior of proton orbitals in the rare-earth region, for the deformation parameters $\beta = 0.2$, $\gamma = -4^\circ$, calculated with a Wood-Saxon potential by Dudek. The aligned h 9/2 and i 13/2 orbitals, coming down from the empty N = 5 shell, will be populated as they reach the Fermi level. This will happen at different frequencies in Er(o), Yb(□), Hf(●) and W(◇) nuclei. At that "crossing" frequency a lot of angular momentum is generated and the dynamic effective moment of inertia $\mathfrak{J}^{(2)}_{eff} = dI/d\omega$ increases. The γ-ray spectra are unresolved in that frequency region ($\hbar\omega = \simeq 0.5$ MeV), but since the nuclei are rotational, the height of the spectra is proportional to $\mathfrak{J}^{(2)}_{eff}$ once they are normalized to the γ-ray multiplicity, and properly corrected for incomplete feeding. Bumps, which could be due to the above orbitals, are indeed observed at high frequencies, and experimental results for nuclei of the region mentioned above will be discussed.

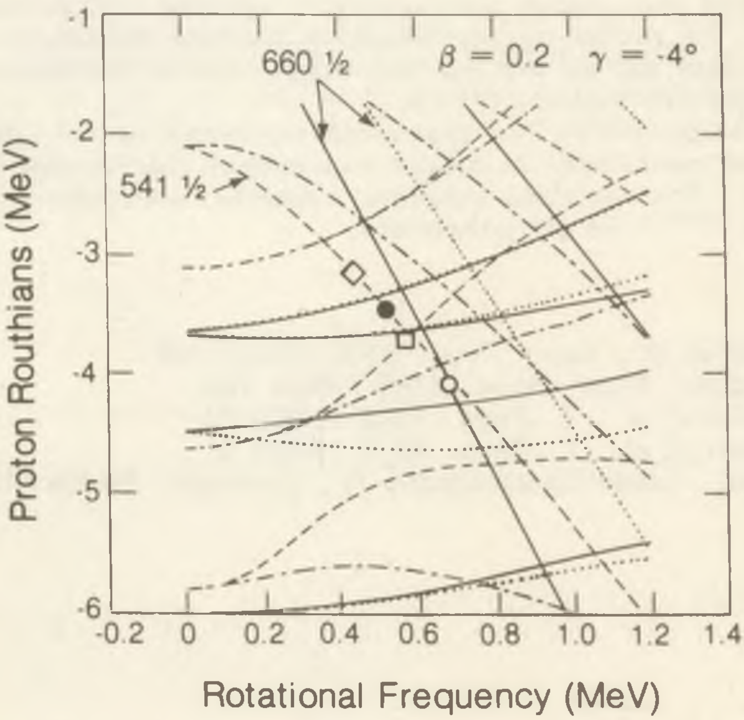

Fig. 1

IN BEAM GAMMA-RAY SPECTROSCOPY ON Re ISOTOPES

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N.J.Stene

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The recent develepment of interacting bason medels and the idea af dynamical supersymmetries in nuclei [1] give a great suppert for an extensive study af transitienal even-even and odd heavy nuclei in W-Os-Pt region, very suitable fer the testing of various nuclear models. Great interest is dedicated not only to precise knowledge of spins and parities of nuclear excited states but also to branching and mixing ratios of gamma-transitions. A combined method of gamma-ray angular distribution and linear polarization measurements [2] reported recently in low temperature nuclear orientation experiments, can yield information comparable with a theoretical calculation also for in-beam experiments.

The experiment has been performed on natural Ta target using (alpha, 2n gamma) reaction induced by 30 MeV alphas from 120-M cyclotran at Rez near Prague. A precise analysis of very complex gamma-ray spectra gives angular distribution anisotropies for many transitiens below 600 keV in 183Re.

The results confirm and extend the previous data [3] and are discussed in terms of IBFA model together with the known data on excited states of 181,185 Re.

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STUDY OF SIDE BANDS AND BAND CROSSINGS IN THE Os REGION

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The field of high-spin states is in a phase of rapid progress related to the development of advanced experimental equipment. A state-of-the-art γ-γ coincidence spectrometer consists of a large number of anti-Compton spectrometers and a γ-ray calorimeter. In this way the detection efficiency is considerably increased and the background in the γ-ray spectra is strongly reduced. The reinvestigation of deformed rare earth nuclei allowed to extend previously known bands to angular momenta of about 40 $\hbar$ and to establish a large number of additional side bands. The features of these bands and their crossings contain information about (i) their configurations, (ii) residual interactions, and (iii) the shape of the excited nuclei. The experimental data are generally interpreted in terms of the cranked shell model.

The nuclei $^{179-184}$Os and $^{179-181}$Re have been investigated in Jülich, Copenhagen and Daresbury using α-, ^{18}O- and ^{34}S-induced reactions, respectively. The following features have been established: (i) three crossings, due to the rotation-alignment of a pair of $i_{13/2}$ quasineutrons, $h_{9/2}$ quasiprotons and probably $h_{11/2}$ quasiprotons, respectively, (ii) a shift in frequency of the second crossing between certain bands caused by residual interactions related to the $7/2^-|514|$ quasineutron configuration, (iii) a signature splitting caused by γ deformation, (iv) a change of parity of the yrast states at spin I=19 related to different gains in aligned angular momentum of the involved bands.

The subject will be introduced generally and the results for the Os and Re nuclei will be discussed in detail.

PERTURBED SUPERSYMMETRY IN IRIDIUM AND GOLD NUCLEI*

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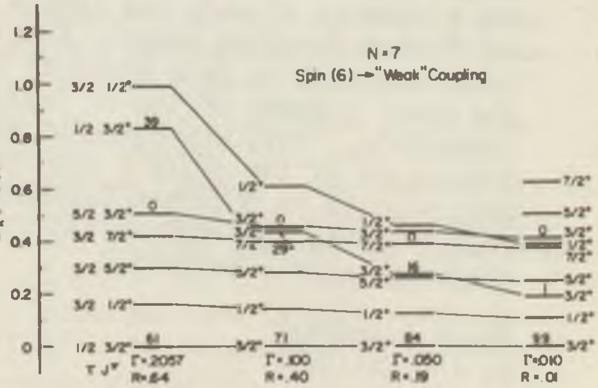
The dynamical U(6/4) supersymmetry[1] in the Interacting Boson-Fermion model arises from the coupling of a j=3/2 fermion to the O(6) boson core which characterizes the even Os and Pt nuclei. The ground states of the Ir and Au nuclei are $3/2^+$. The possibility of a supersymmetry in the A=190 region has motivated the study of the $(\vec{t},\alpha)$ reactions[2] on the even $^{194-198}$Pt and $^{196-204}$Hg nuclei.

In ^{193}Ir the $d_{3/2}$ transfer strength is a fragmented strength into two components; this fragmentation and the ratio R of excited to ground state strengths is well-reproduced by the supersymmetry predictions. However, the distribution of $d_{3/2}$ strength in the other Ir and Au isotopes is markedly different from the predictions of the U(6/4) scheme. In addition, the $s_{1/2}$ strength is also relatively strong.



The U(6/4) supersymmetry requires a good O(6) boson core, a single j=3/2 fermion and a particular strength, Γ, of a quadrupole type boson-fermion interaction. The figure presents results of schematic IBFA calculations in which the magnitude of Γ was changed. As a function of decreasing Γ values, the j=3/2 strength appears lower in the spectrum, reproducing the trends in j=3/2 strength observed in ^{195}Ir, corresponding to $\Gamma\sim0.09$, and ^{197}Ir, corresponding to $\Gamma\sim0$.

In contrast to the rapid variation in the Ir nuclei, the structure of the odd-mass $^{195-203}$Au nuclei is relatively constant with the $d_{3/2}$ and $s_{1/2}$ strengths concentrated in the ground and first excited states, respectively. This structure is similar to that observed in ^{197}Ir, that is, characteristic of a weak coupling between the particle and core. The structure of the Au nuclei may also be an example of a pseudo-spin symmetry[3] which reproduces the observed doublet structure of the Au isotopes and the absence of excited $s_{1/2}$ or $d_{3/2}$ strength.

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SUPERSYMMETRIC MULTIPLETS IN TRANSITIONAL NUCLEI
FROM (n,n'γ) REACTION STUDIES*

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Dynamical symmetries, such as those of the IBA, have proven effective in describing complex transitional nuclei. Success in interpreting the structure of even-mass Os and Pt nuclei as displaying deviations from an O(6) limiting symmetry is well-documented [1] and has stimulated experimental and theoretical studies of odd-mass nuclei in an interacting boson-fermion (IBFA) formalism, with the odd-A nuclei characterized by coupling a fermion to the O(6) core. Nuclei near the end of major shells, particularly those in the Os-Ir-Pt region, have been grouped into supersymmetric multiplets which include both even-A and odd-A nuclei described within a single framework [2]. Experimental evidence for supersymmetry has been obtained for several odd-Z nuclei in this region. The nuclei ^{191}Ir and ^{193}Ir belong to supermultiplets which also include ^{190}Os & ^{192}Pt and ^{192}Os & ^{194}Pt, respectively, and provide a prime testing ground for supersymmetric representations.

Using the (n,n'γ) reaction, we have studied five of these six nuclei; only ^{192}Pt was unavailable for study. Excitation functions have permitted the placement of many new levels (e.g. 17 in ^{192}Os and 33 in ^{193}Ir), while excitation function shapes, angular distribution measurements, and γ-ray decay systematics have aided in spin-parity assignments. As shown in Fig. 1, the level schemes of the Ir isotopes studied are quite complex yet very comparable. This abundance of new spectroscopic data permits meaningful evaluation of the j=3/2 X O(6) or U(6/4) supersymmetry scheme, and reasonable success is obtained for both supermultiplets. Interestingly enough, each of these supermultiplets spans a nuclear shape transition, with ^{193}Ir appearing nearly triaxial.

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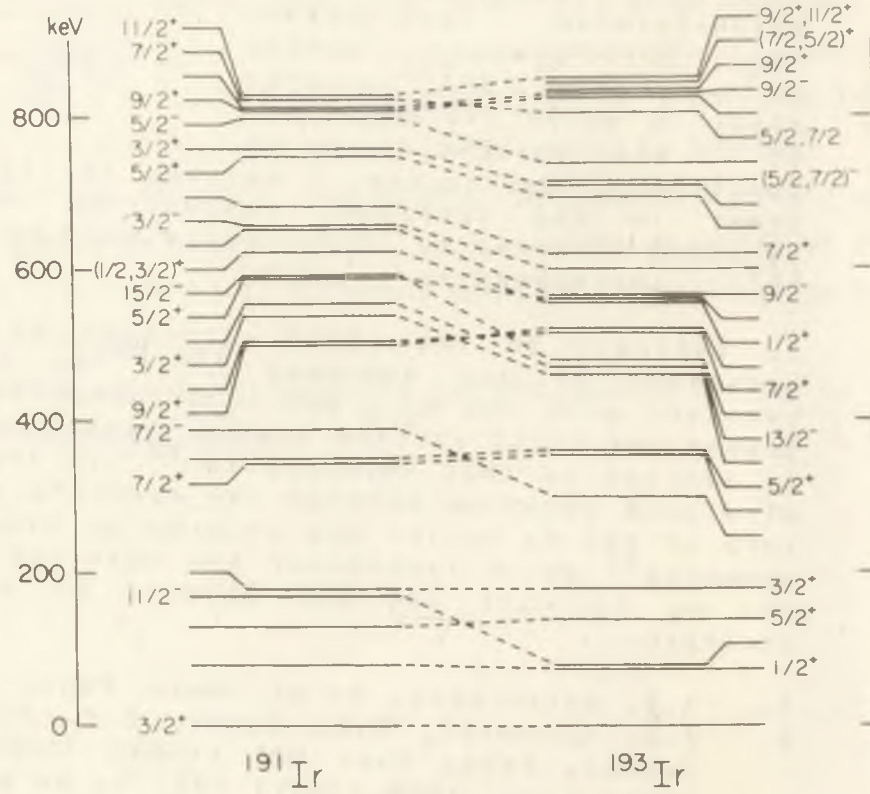

Fig. 1 Comparison of levels in ^{191}Ir and ^{193}Ir.

LOW-SPIN STATES OF ^{185}Pt

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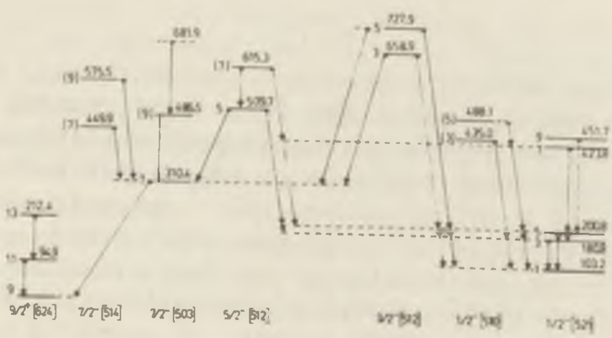
The platinum nuclei are good tools to test the nuclear models since their level schemes show great differences when the mass number decreases. In this way, the ^{185}Pt nucleus is the first odd - A platinum isotope which is prolate-shaped in its high spin states[1)]. In order to find the shape of the nucleus in its low spin states, we have studied the $^{185}Au \xrightarrow{\beta^+/CE} {}^{185}Pt$ decay on line from mass-separated sources, with the Isocele facility. To produce gold nuclei, a Pt - B alloy target placed inside the ion source of the separator was irradiated by the 200 MeV proton beam from the Orsay synchrocyclotron. Classical measurements of γ-spectroscopy were performed and conversion electron lines were detected precisely by means of a semi-circular magnetic spectrograph. The ^{185}Pt level scheme has been built ; it exhibits several states deexciting both to the states built on the ground state and on the isomeric state, which have allowed us to locate firmly at 103.2 keV the isomeric state with respect to the ground state, contrary to the first position previously proposed[2)] from preliminary results. Most of states can be interpreted as rotational states built on the Nilsson states (Fig. 1), which indicates a prolate shape for the ^{185}Pt nucleus in its low-spin states. Yet, some levels located up to 700 keV could not be identified : among them, the two states deexciting by abnormally converted transition. Such conversion anomalies have already been pointed out in the ^{187}Pt nucleus and are not understood up to now. Two questions remain to be solved : the first one is to determine the nature of these peculiar states and to know if they correspond to a different deformation of the nucleus ; the second one is to explain the presence of the abnormally converted transitions.

Fig. 1 : Experimental levels of ^{185}Pt as quasi-rotational bands built on Nilsson states.



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THEORETICAL DESCRIPTION OF ^{185}Pt

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Recently, an "*axial rotor + qp*" model has been applied with success to transitional nuclei, to deformed nuclei and even to fission isomers[1,2]. The typical features of this model developed by M. Meyer et al[2] are : i) the core is approximated by using an axial-symetric rotor, ii) the wave-functions of the quasi-particles are determined from HF + BCS calculations with the SIII Skyrme effective force in a self consistent way, iii) the deformation of the odd nucleus is settled by the minimum of the deformation energy curve calculated for the core, and iv) the Coriolis interaction between the quasi-particles and the core is exactly solved. In this model, no projection onto a good number of particles is worked out, which means that the A-1 and A+1 odd nuclei are simultaneously described with the even-even core A. The ^{185}Pt nucleus has been calculated with ^{186}Pt and ^{184}Pt prolate cores : the experimental 9/2 + |624|, 5/2 - |512| and 7/2 - |514| bandheads lie between the theoretical location found with the two cores. We present here the results obtained using the ^{184}Pt prolate core (Fig. 1). Although the relative location of the bandheads

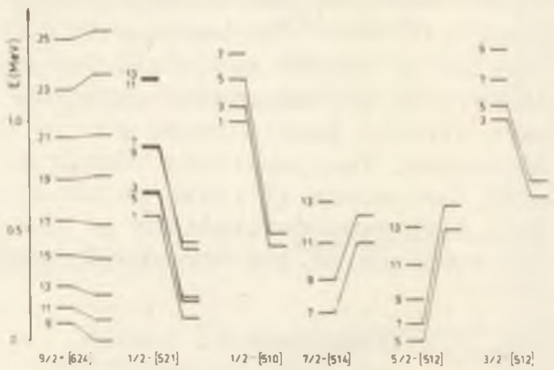

Fig. 1 : Comparison between experimental quasi rotational bands of ^{185}Pt and theoretical results obtained from the coupling of one neutron quasiparticle with the ^{184}Pt prolate core (β_2=0.27). The main component of the wave function has been used to label the theoretical band. Spin values have been multiplied by 2.

are not exactly reproduced theoretically, we can notice that, especially for the 9/2 + |624| and 1/2 - |521| bands, the energy differences between the states are in good agreement with those found experimentally. One has to remark that there is no adjustable parameter in this model. However, other I^π = 3/2 -, 5/2 -, 7/2 - experimental states have not been found in these calculations. They could correspond to states with a different deformation or to vibration-coupled states. Nevertheless, the deexcitation modes of these levels seem to infirm an oblate shape of the nucleus in these states. It would be fruitful to calculate the ^{185}Pt levels in the frame of the IBFM model[3] which takes into account vibrational excitations of the core. But two conditions have to be fulfilled to allow these calculations : first, to calculate the boson matrix element of the boson fermion interaction with a large number of bosons (2 proton bosons + 9 neutron bosons), second to take into account five single-particle orbits to describe the negative parity states.

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1/2-|521| QUASIROTATIONAL BAND IN NEUTRON DEFICIENT PLATINUM ISOTOPES

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The $^{177-181}$Pt nuclei are accounted to be well deformed prolate nuclei since E. Hagberg et al[1)] have studied them from α-decay and identified the 1/2 - |521| state and the 3/2 - and 5/2 - rotational levels built on it. Recently, we have studied the ^{181,183,185}Pt isotopes from the β^+/EC decay of gold nuclei, using the Isocele facility. The band built on the 1/2 - |521| state has been observed in these three isotopes of platinum. For ^{181}Pt , the results obtained support the previous attribution of the 1/2 -, 3/2 - and 5/2 - states and allow us to locate the 7/2 - 1/2 - |521| level. The rotational 1/2 - |521| band has been found to be built on the groundstate in ^{183}Pt and on the isomeric state in ^{185}Pt. Figure 1 shows the

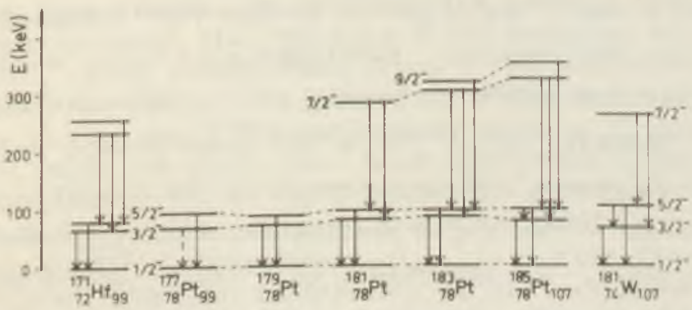

Fig. 1 : Quasi-rotational band built on the 1/2 - |521| state.

systematic of the 1/2-|521| band through the platinum isotopes. We also drew on this figure the states of the same band for $^{181}_{74}$W and $^{171}_{72}$Hf, which are the nearest isotones of ^{185}Pt and ^{177}Pt where the 1/2 - |521| band is known. We can notice the anology between the deexcitation mode of the 5/2 - state in ^{185}Pt and ^{181}W : particularly, we have observed a 20 keV M1 transition (5/2 - → 3/2 -) in ^{185}Pt analogous to the 38.1 keV M1 line in ^{181}W. The systematic through the platinum isotopes shows clearly that all $^{177-185}$Pt nuclei correspond to prolate shaped nuclei. It indicates also that the decoupling parameter, accountable for the relative location of the 3/2 - and 5/2 - states, is maximum for ^{183}Pt the neutron number of which corresponds to the middle of the shell.

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ON LINE NUCLEAR ORIENTATION OF AU ISOTOPES

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Since 1981 research with the KOOL facility demonstrates that the on-line nuclear orientation technique [1] is a reliable method for determining nuclear moments and decay scheme parameters [2,3]. Moreover, important information on low temperature implantation behaviour has been published [4].

Making use of this method we started a systematical study of the nuclear moments of ground- and isomeric states of Au isotopes, as well as of their decay properties to the Pt daughter nuclei. On-line production, separation and orientation of the very neutron-deficient Au isotopes are compulsory due to the short lifetimes involved.

The chain of Au isotopes, situated in a region of shape transition, is an attractive probe to study shape coexistence and phase transitions. Spectroscopic studies revealed that the isomeric $11/2^-$ states in the odd-mass isotopes $^{185-197}Au$ have a small variation in energy with changing neutron number and have an oblate deformation. Experimentally this 'stability' of the $11/2^-$ states is reflected in the constancy of the magnetic moments of $^{197m,195m,193m}Au$ [5]. However, for ^{191m}Au a 30% lower moment value was deduced [6]. Here we report the measurement of the magnetic moment of the 4.6 min $11/2^-$isomer in ^{189m}Au and a preliminary result on the same state in ^{191m}Au ($t_{1/2}$=.9sec). An experiment on ^{185}Au($t_{1/2}$=4.3 min) has been carried out as well. In the odd-odd Au nuclei we measured the moment of the ^{186}Au groundstate ($t_{1/2}$=10.7 min). This gives an important test for the supposed $3^-\{(\pi \frac{3^-}{2}[532] \quad \nu \frac{9^+}{2}[624])\}$ configuration [7].

Our data lead, simultaneously, to spin (parity) assignments and allow to extract δ values of transitions in the excited states of the Pt daughters. This information gives indications of the shape of the Pt nuclei.

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Anomalous low lying 0^+ state in the $^{198-192}$Pb isotopes

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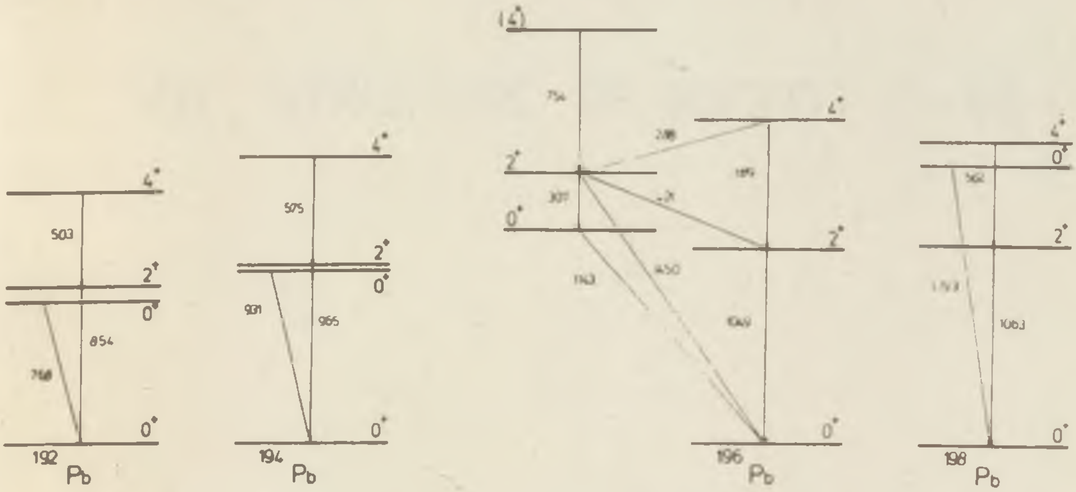
In a recent article K. Heyde et al. [1] gave an overview of the experimental and theoretical work concerning intruder states and shape coexistence. A great variety of experimental data, proving the existence of these intruder states, is already available. However, in the even-even Pb nuclei no evidence was found for these states although they were clearly observed in the neighbouring odd Bi and odd Tl isotopes.
We started at the LISOL-facility [2] a systematic study (e^-, γ, x singles and γ-γ, x-γ coincidences) on the β^+/EC decay of the neutron-deficient $^{198-192}$Bi isotopes, produced in the ^{16}O (^{nat}Re,xn) fusion reaction. Although in a heavy ion reaction the high spin states are favoured, we found evidence for a strong feeding, by means of internal transitions, of a low spin β^+/EC decaying state in ^{196}Bi. This made it possible to detect an E0 transition occuring in ^{196}Pb. On the basis of e^--γ and γ-γ coincidences, this transition gives evidence for an exited 0^+ state at 1143.4(2)keV above the ground state. Due to the fact that this 0^+ state deexites almost completely to the ground state, giving a strong e^- signal in an almost background free region, we searched for similar states in the neighbouring Pb isotopes although the low spin β^+/EC decaying state in Bi was poorly fed. Indeed, these states were found at an exitation energy of 1392.0(2)keV in ^{198}Pb, 930.1(2)keV in ^{194}Pb and 768.5(2)keV in ^{192}Pb (see fig. 1). In the ^{196}Pb nucleus we found a 2^+_2 and 4^+_2 state (besides the normal ones) of which the $B(E2:2^+_2 \to 0^+_2)/B(E2:2^+_2 \to 0^+_1)=377$ ratio and the absence of competing transitions with the $4^+_2 \to 2^+_2$ transition, shows the strong enhancement of these transitions (fig. 1). These two states are probably two members of a collective band built on top of this $J^\pi = 0^+_2$ state. Further experiments on the neighbouring Pb nuclei are planned in the near future to reveal the nature of the other 0+ states and to search for analogue enhanced interband transitions.



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III. STRUCTURE OF NUCLEI : Z > 82

The β^+/EC decay of ^{197,195,193}Bi isotopes

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The light odd Pb isotopes are characterised by the coupling of single neutron states (p3/2, f5/2, i13/2, p1/2, f7/2) to an even even Pb core. In beam studies [1-2] on the $^{201-193}$Pb isotopes show bandstructures resulting from the coupling of the i13/2 single neutron states to excitations of the even-even Pb core. From our experiments, in which we feed the Pb isotopes via the β^+/EC decay of the Bi isotopes, complementary information on the low spin part of the level schemes is expected. Untill now the decay of the light odd ^{197,195,193}Bi isotopes was only studied by their α-emission [3]. Except for the ^{197}Bi isotope, for which only one lifetime was observed, two half lifes were found in the other Bi isotopes, probably belonging to a $9/2^-$ proton particle state and to a $1/2^+$ proton hole intruder state. The Bi isotopes were produced in the reactions 170 MeV ^{16}O on (14,7 mg/cm^2)^{nat}Re and 137 MeV ^{20}Ne on (4,15 mg/cm^2) ^{181}Ta at the Cyclone cyclotron at Louvain-La-Neuve. After mass separation, production rates of 10^3 nuclei/sec were obtained. For each isotope x and γ ray singles and a total of 2×10^6(γ,γ,t) and (x,γ,t) coincidence events were collected. Very recently e^- singles are (e^-,γ,t) coincidence measurements were performed on the ^{197}Bi β^+/EC decay. Similar experiments are planned for ^{195,193}Bi.
On the basis of lifetimes and x-γ coincidence measurements about 60 γ-rays could be assigned to the ^{197}Bi decay. A half life of 539 ± 9 sec was found which agrees well with the ~10 min. of Y. Le Beyec et al. [3]. In the mass chain 195 a total of 73 γ-rays exhibit a 187 ± 4 sec lifetime, corresponding with the 170 ± 20 sec half life of the ^{195}Bi ground state [3]. No evidence however was found for the feeding of the 90 ± 5 sec isomeric state in ^{195}Bi. We assigned the 134.1 keV to the $5/2^- \rightarrow 3/2^-$ or $3/2^- \rightarrow 5/2^-$ groundstate transition. To determine whether the groundstate spin of ^{195}Pb is a $5/2^-$ or $3/2^-$ state, we studied the α-decay of ^{199}Po by the reaction 170 MeV ^{14}N on ^{nat}Ir. Due to the fact that the α-decay proceeds most likely between states in which the odd nucleon wave function remains unchanged, the ^{199}Po($3/2^-$) $\rightarrow$ ^{195}Pb($3/2^-$) transition will be favoured. By comparing the intensity of the β^+/EC decay of ^{199}Po $\rightarrow$ ^{199}Bi (88%) with the 134.1 keV intensity, we could conclude that the groundstate spin of ^{195}Pb is most likely $3/2^-$. Preliminary decay schemes which are constructed for ^{197}Bi and ^{195}Bi show that about 60% of the total γ-intensity comes down to the low spin groundstate and 30% to the $13/2^+$ β+ decaying ^{195}Pb state, indicating that the β+/EC decaying Bi states fed in our reactions are most probably the $9/2^-$ states. The half lifes of ^{193}Bi and ^{193m}Bi are 64 ± 4 sec and 3.5 ± .2 sec respectively [3]. From a first analysis we can identify 21 γ-rays with a 65 ± 4 sec lifetime. The analysis of the data is in progress.

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THE LEVEL STRUCTURE OF ^{215}Fr*

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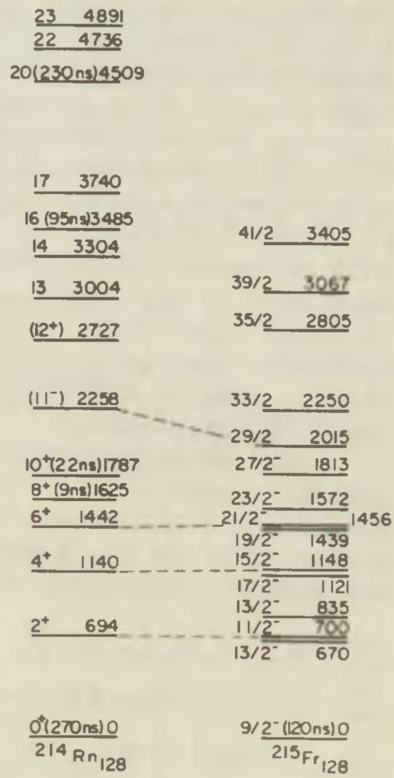
One of the most exciting recent developments in nuclear structure studies has been the investigation of the interplay between single particle and collective degrees of freedom near the doubly magic ^{146}Gd nucleus. A similar competition between the single particle and collective degrees of freedom is expected to occur in the region above ^{208}Pb.

To further probe the structure as a function of angular momentum in this region, we have studied ^{215}Fr using the Yale MP Tandem Van de Graaff accelerator via the ^{208}Pb(^{11}B,4nγ) reaction at 61 MeV with standard γ-ray techniques. Our level scheme for ^{215}Fr for spin up to J=41/2 is shown in the figure. Concurrently, this system is also being studied[1] at the Hahn-Meitner Institute and a similar decay scheme has been obtained. The results of ref. 1 indicate isomers at 1573, 2016, 2251 and 3068 keV.



In ^{215}Fr the valence nucleons include five protons in the $h_{9/2}$ subshell and a $g_{9/2}$ neutron pair. Recently, the ^{214}Rn core has been studied[2]; the level schemes of the isotones are compared in the figure. The low-lying states of ^{215}Fr are well-described by coupling the $h_{9/2}$ proton to the 0^+, 2^+, 4^+ states of ^{214}Rn, which are mainly[2] $\nu(g_{9/2})^2_{0,2,4}$ configurations with $\pi(h_{9/2})^4_0$. The 6^+ state and 8^+ isomer of the core also have a sizeable proton component[2], which is confirmed in the odd-Z isotone where the maximally aligned state is no longer the lowest-lying state in the multiplet, and the $23/2^-$ state becomes the isomer. The 11^- state in ^{214}Rn is proposed[2] to arise from the $\pi(h_{9/2}i_{11/2})_{11^-}$ configuration. If the additional $h_{9/2}$ proton is then coupled to this configuration, the maximum angular momentum is $29/2^+$ suggesting positive parity for the 29/2 state in ^{215}Fr. We are in the process of doing shell model calculations to test these qualitative conclusions.

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GAMMA-RAY SPECTROSCOPY IN THE REGION OF OCTUPOLE DEFORMATION NEAR Z = 90

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We have carried out an experimental programme to study the structure of nuclei with Z ∿ 90 and N ∿ 132. These nuclei are of theoretical interest in that their ground states are predicted to have stable octupole deformation [1]. One consequence of such a shape is that the ground state band should have the spin parity sequence 0^+, 1^-, 2^+, 3^- ... with stopover E1's competing strongly with the crossover E2's. Such a sequence has been observed recently in ^{218}Ra [2] and the more deformed ^{222}Th [3]. In addition, it is expected that the odd mass nuclei should have degenerate bands with sequences K^+, $(K+1)^-$, $(K+2)^+$, ... and K^-, $(K+1)^+$, $(K+2)^-$, ... as observed recently in ^{227}Ac [4]. In this work we report the results of γ-γ measurements on ^{220}Ra and ^{223}Th, populated by the reactions ^{208}Pb(^{18}O,α2n) and ^{208}Pb(^{18}O,3n) respectively. In these experiments evaporation residues were selected using a fast avalanche counter system, in order to suppress the strong fission background. The 83 MeV ^{18}O beam was supplied by The Nuclear Structure Facility, Daresbury.

Preliminary analysis of the data indicates that ^{220}Ra has a structure similar to ^{218}Ra and ^{222}Th, with enhanced E1 transitions connecting a sequence of negative parity states to the positive parity states built on the ground state. The structure of ^{223}Th is more complex, but appears consistent with picture of degenerate $K^{\pm}$ bands.

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GAMMA BRANCH FROM THE ^{238}U SHAPE ISOMER

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The γ-ray decay of the ^{238}U shape isomer has been reinvestigated using the ^{238}U(d,pn)^{238}U^{m} reaction with a new two-detector technique. The new technique is especially designed for in-beam studies of actinide nuclei involving radiations from several different origins. One of the detectors is shielded against direct target radiations, so that the other one offers a particularly sensitive means of the identification of lines due to nuclei in the actinide region. A number of transitions were found to belong to ^{238}U; a line at 2512.7(5) and another possible one at 1877.6 keV are attributed to the isomer. The cross section for production of the 2512.7-keV γ ray by 18-MeV deuteron bombardment of ^{238}U is 42(12) μb, consistent with our earlier conversion-electron work[1)] on ^{238}U^{m}.

1) J. Kantele *et al.*, Phys. Rev. Lett. 51, 91 (1983)

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GYROMAGNETIC RATIOS AND MODIFIED SCHMIDT'S FORMULA

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The report presents some experimental regularities and an empirical formula for the description of gyromagnetic ratios.

Some of the main regularities are:

1. Experimental g-factors (g^{exp}) are split into groups. For even-even nuclei this is $Z=Z_{mag}$; $N=N_{mag}$; $Z, N \neq Z_{mag}, N_{mag}$. For odd-A nuclei such splitting is the function of nucleon number in the last shell (either less or more than half-filled).

2. g^{exp} values are independent of sphericity or deformation for the majority of nuclei. As a rule, they are not dependent on level parity.

3. The orbital g-factors for coupled protons, g_l^{eff}, may be equal to unity or zero.

4. Gyromagnetic ratios of nuclear levels (g^{calc}) may be described by using modified Schmidt's formula and such effective g-factors as: $g_{p(n)}^{eff}$ - the sum of calculated by classical Schmidt's formula g-factors of protons (neutrons) in (i) or (j) subshell and

$$g_d^{eff} = \frac{\sum_{ij} g_p^{(i,j)} K_p^{(i,j)} + \sum_{ij} g_n^{(i,j)} K_n^{(i,j)}}{A}.$$

Here i-subshell has $I_{p(n)}^{(i)} = l + 1/2$; j-subshell has $I_{p(n)}^{(j)} = l - 1/2$; $g_{p(n)}^{(i,j)}$ -g-factor of nucleons. The sign of their sum in the formula for $g_{p(n)}^{eff}$ depends on sign of $I_{p(n)}^{(i)} = (l+1/2)$ or $I_{p(n)}^{(j)} = (l-1/2)$; $K_{p(n)}^{(i,j)}$ is number of nucleons on the subshell; $g_{p(n)}^{eff} = g_{p(n)}^{free}$, if $J^{lev} = 1/2$. $g_{p(n)}^{free}$ g-factors of free protons (neutrons), J^{lev} is spin of levels.

g^{calc} fit well with g^{exp} for several hundreds nuclear levels (A= 3 - 254).

THE PROSPECTS TO PRODUCE THE SUPERHEAVY ELEMENTS IN HEAVY-ION ACCELERATORS BASED ON THE SECONDARY REACTION EXPERIMENTS IN CERN W TARGETS.

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Previously some evidences were presented(1-6) for the possible production of superheavy elements(SHE) in W targets that were irradiated with 24 GeV protons. These results can consistently be interpreted if one assumes that, like in the actinide region(7,8), the production of neutron-deficient superheavy nuclei is not impossible. The measured energy spectra (2,6) of the fission fragments can be interpreted in terms of fission to four fragments with a total kinetic energy of about 320 MeV. The position of the fission fragments as observed in the focal plane of a mass seperator(3,9) are given in the figure for two ploycarbonate exposures. (The points on the left hand side are due to edge effect). In the table the observed masses (from all the exposures) were arranged according to various possible molecules of element 112. (Number of fission tracks are given in parentheses). Five different molecules, with 11 events total,can be related to element 112 with 160-161 neutrons. Under these conditions quite a unique situation, namely the radiative capture process of for instance $^{86}Sr + ^{186}W \rightarrow ^{272}_{112}X$ or $^{88}Sr + ^{184}W \rightarrow ^{272}_{112}X$, is possible. According to this interpretation there is no contradiction with any other data. It will be argued that, based on these results, the prospects to produce SHE using such reactions are reasonable.

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A^+	$A^{16}O^+$	$A^{35}Cl^+$	$A^{12}C^{14}N^{16}O^+$ / $A^{14}N_3^+$	$A^{14}N^{16}O_2^+$	N
269(1)					157
272(1)	288(1)	308(3)[a]	315(2)	317-318(4)	160-161
276(1)	292(1)	311(1)[b]			164

[a] Mass 308 may also be interpreted as $^{276}AO_2^+$.

[b] Mass 311 may also be interpreted as $^{269}AN_3^+$ or $^{269}A^{12}C^{14}N^{16}O^+$.

IV. NUCLEAR STRUCTURE RESEARCH WITH LIGHT AND HEAVY ION REACTIONS

ON THE EXCITATION OF RESONANCES IN THE LIGHT ATOMIC NUCLEI INTERACTION

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To determine the resonance states and their nature in light atomic nuclei a microscopic model is proposed in which collective and cluster degrees of freedom are considered simultaneouly. This model is based on the assumption that the energy of colliding nuclei at the moment of their interaction is transferred on one or several collective modes of a compound nucleus and, consequently, is uniformly distributed in all nucleons. Thus in a compound nucleus collective resonances characterised by a large amplitude of collective motion are excited. The greater is the lifetime of such resonances, the less is the connection between collective and cluster modes.

These assumptions are confirmed by the calculations of the resonance states in nuclei ^{5}He (^{5}Li), ^{6}Li, ^{7}Li (^{7}Be), ^{8}Be which are formed when nucleons, deuterons, ^{3}H (^{3}He) and ^{4}He collide with α- particles. The wave function of resonance states Ψ is represented by a sum of two sets of oscillator functions. The first set is suitable to the description of collective (quadrupole) excitations of compound nuclei, the second describes the motion of colliding nuclei. The expansion coefficients of Ψ in oscillator functions as well as the energy E and widths Γ of these states are obtained when solving the set of algebraic equations.NN - interaction is simulated by the Brink-Boeker potential. The calculated values of E and Γ are given in the table.

A	^{6}Li			^{7}Li, ^{7}Be				
I^π	2^+	0^+	2^+	3^-	1^-	3^-	1^-	3^-
E,MeV	3.62	22.24	24.94	5.27	26.15	29.80	35.33	38.15
Γ,MeV	0.92	0.28	0.52	2.36	0.58	0.73	0.51	0.84

INVESTIGATION OF RESONANCE STATES IN ELASTIC SCATTERING AND RADIATIVE CAPTURE PROCESSES

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The possibilities of getting resonance data from simultaneously measured α-particle elastic scattering and radiative capture processes ($E_{\alpha} \leq 5$ MeV) are discussed.

In general, resonance strengths, decay schemes and angular distributions are determined from studying the (α,γ) process on one hand and on the other hand spin values, total and partial α-widths of resonance levels can be deduced from the R-matrix analysis of the elastic scattering cross sections measured at several angles [1,2]. However, additional results can be deduced from the combination of the (α,γ) and (α,α) data of some resonances, namely it was possible to resolve ambiguities regarding spin values and to determine radiative partial widths.

For the usefulness of the above mentioned simultaneous measurements, examples are given for the ^{28}Si and ^{23}Na nuclei.

In addition, the applicability of the vibron model for the description of resonance level scheme is shown for the ^{24}Mg+α system [3,4].

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INTERMEDIATE STRUCTURE OF RESONANCES IN (p,γ) REACTIONS ON NICKEL ISOTOPES

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A new method of determination of intermediate structures based on the analysis of δ - multipoles mixtures value signs for the γ -decay resonances is proposed [1].

The value and sign of δ are determined from the analysis of angular distributions of γ -transitions in (p,γ) reactions of a compound nucleus resonance, the spin of which is known at the level of given spins.

In nuclear (p,γ) reactions on ^{58,60,62}Ni-isotopes an intermediate structure of proton resonances is discovered experimentally, relative signs of the multipoles mixture are equal.

The intermediate structure is interpreted as a distribution of the strength of the giant Gamov-Teller resonance over the resonance states of a more complicated form.

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TRANSFER REACTION SPECTROSCOPY REVISITED

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The object of the spectroscopy of transfer reactions is to determine to what extent nuclei tend to behave like compositions of a single particle (or cluster) and an inert core. The conventional technique relies on the validity of a direct reaction approach that excludes antisymmetrization between the reaction partners. In this picture the transition amplitude of the $A+a \rightarrow B+b$ ($a=b+x$, $B=A+x$) transfer contains a product of the overlaps [1]

$$\mathcal{U}_B(\vec{r}) = \binom{B}{x}^{\frac{1}{2}} \langle \Phi_x \Phi_A \delta(\vec{r}-\vec{r}_{xA}) | \Phi_B \rangle, \qquad \mathcal{W}_a(\vec{r}') = \binom{a}{x}^{\frac{1}{2}} \langle \Phi_b \Phi_x \delta(\vec{r}'-\vec{r}_{bx}) | V_{bx} | \Phi_a \rangle,$$

where Φ are wave functions in the centre-of-mass frames, $\vec{r}_{ij}$ are relative coordinates and V_{bx} is the interaction between the constituents of b and x. When x is a nucleon transferred between large nuclei, it is convenient to apply the shell model to nuclei a and B, whereby Φ are approximated by wave functions that are given in the external frame. Then it is still not a gross error to regard $\mathcal{U}_B$ as a relative orbit and its norm square, the so-called spectroscopic factor, as a measure of its being occupied in nucleus B. For a single particle outside a closed shell the spectroscopic factor is just an occupation probability in this picture.

For cluster transfer or when the transferred particle is not much smaller than the other participants, the internal wave functions must not be substituted by external ones. Therefore, $\mathcal{U}_B$ cannot be interpreted as a probability amplitude. Indeed, in a normalized two-cluster state $\langle \mathcal{U}_B | \mathcal{U}_B \rangle \neq 1$; instead, the normalization

$$\langle \mathcal{U}_B(\vec{r}) | A^{-1}(\vec{r},\vec{r}') | \mathcal{U}_B(\vec{r}') \rangle = 1 \qquad (1)$$

holds, where

$$A(\vec{r},\vec{r}') = \langle \mathcal{A}\{\Phi_A \Phi_x \delta(\vec{r}-\vec{r}_{xA})\} | \mathcal{A}\{\Phi_A \Phi_x \delta(\vec{r}'-\vec{r}_{xA})\} \rangle$$

with $\mathcal{A}$ being the intercluster antisymmetrizer.

Recently, however, the reaction theory has been reformulated with the application of an apparently fully antisymmetrized treatment [2]. This non-conventional theory involves $A^{-1/2}\mathcal{U}_B$ in place of $\mathcal{U}_B$, and a similar quantity to replace $\mathcal{W}_a$. As eq. (1) shows, $A^{-1/2}\mathcal{U}_B$ is normalized in the ordinary sense, and hence may be viewed as a probability amplitude.

In this contribution we give a critical comparison of the non-conventional model with the conventional one both in theoretical terms and by means of numerical examples. We use the orthogonality-condition model (OCM) to describe both the $a=b+x$ and $B=A+x$ subsystems. We have shown that the version of the OCM we use [3] gives an excellent approximation to the overlaps produced by the microscopic cluster models. As a specific example, we consider the $^{16}O(^7Li,t)^{20}Ne$ process.

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EMISSION OF PROMPT X-RAYS FOLLOWING THE FUSION OF ^{35}CL AND ^{59}CO NUCLEI

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In heavy-ion reactions the fusion-evaporation process is usually dominant but the identification of the residues, emerging near 0° from the target, is particularly difficult. Even their direct observation - after a long flight time and in hindrance with the slightly diffused beam - offers no information on the first nanoseconds. The prompt γ-rays from highly excited residues are mainly statistical and structureless, thus providing information only on their multiplicity. As a result, the prompt X-rays - partly from vacancy production during the fusion process and partly from internal conversion of prompt γ-rays - represent a valuable information: the production yield of residual elements.

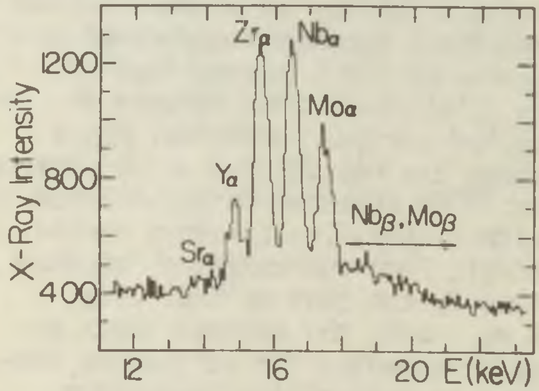

Figure 1. Prompt X-rays.

Figure 1 illustrates prompt X-rays following the fusion of ^{35}Cl and ^{59}Co nuclei at 100 MeV c.m. energy and the subsequent evaporation of particles from ^{94}Ru. The X-ray spectrum was collected by a 5mm thick Si(Li) detector in coincidence with statistical γ-rays from a 50ccm Ge(Li) detector. The various elements reached by particle evaporation and their relative intensities are represented in the figure by the corresponding monoenergetic Kα-rays. The unusual broadening of the Kβ lines indicates that the X-rays were emitted from highly disturbed atoms less than 1ns after fusion.

Figure 2 permits to compare the above Kα-ray yields with the theoretical cross sections which were calculated by the ALICE fusion-evaporation code using standard parameters. The yield and the cross section for molybdenum are normalized to unity. At this energy, there is a good agreement between expected and measured values.

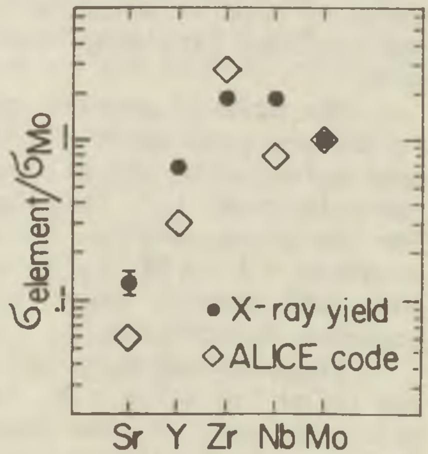

Figure 2. Relative yields.

The target has to be sufficiently thin (~1mg/cm^2) to permit the escape of the residues. In a (Li,xn) reaction with A~200 nuclei, Karwowski *et al.* used much thicker targets resulting in monoenergetic Kβ lines. Their high KX-ray multiplicities are thus partly due to radioactive atoms embedded in the target.

The observation of prompt X-rays and their distinction from radiogenic ones - due to the onset of fast beta decay - is discussed in detail. To be useful, the X-ray yield has to vary smoothly with excitation energy and mass of the reaction products. In this respect, the trend of KX-ray yields from primary fission products is most supportive.

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ANGULAR MOMENTUM TRANSFER IN PARTIAL FUSION REACTIONS INDUCED BY ^{14}N ON ^{154}Sm

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^{14}N + ^{154}Sm collisions at 154 MeV bombarding energy have been studied at the Stockholm cyclotron. The angular momentum input in collisions leading to partial fusion reactions has been determined by measuring the γ-ray multiplicity in coincidence with forward directed charged particles. Fig.1 shows the results for γ-transitions in ^{158}Er detected in coincidence with H-ejectiles (protons dominating). From the observed approximately constant multiplicity, $\langle M_\gamma \rangle \approx 18$, the average input angular momentum for collisions leading to H-ejectiles in massive transfer reactions can be deduced to be $\langle \ell \rangle \approx 38\ \hbar$. This value is determined by assuming that γ-emission removes $2(\langle M_\gamma \rangle - 4)$ units of angular momentum and that the neutrons take away one unit each.

The deduced angular momentum is in very good agreement with predictions from the Wilczyński sum-rule model [1]. See fig.2. For the proton channel the model predicts $\langle \ell \rangle \approx 41\ \hbar$. (Note the long tail towards lower angular momentum for protons.)

The measured multiplicity is far below the value $\langle M_\gamma \rangle \approx 31$, which has earlier been reported [2] for a bombarding energy of 167 MeV.

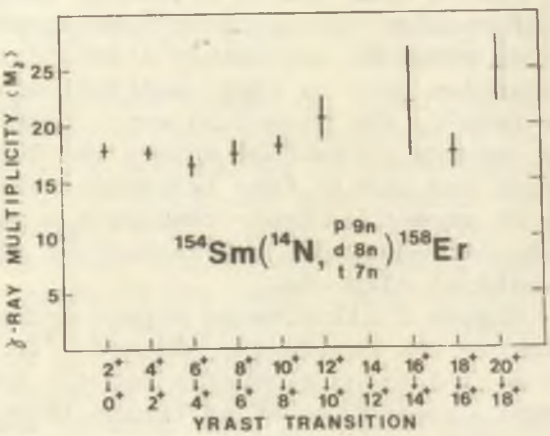

Fig.1. Average γ-ray multiplicity for yrast transitions in ^{158}Er.

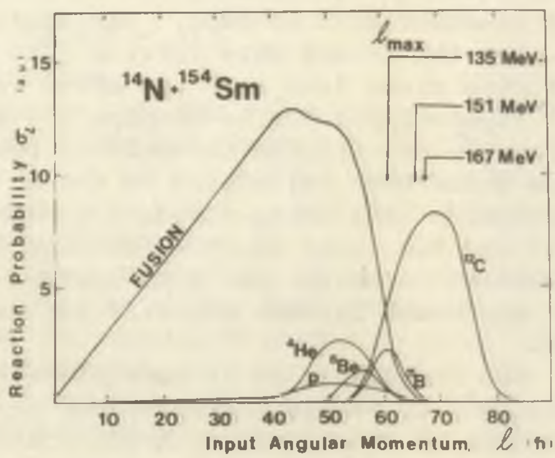

Fig.2. Predictions from the sum-rule model.

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DYNAMICAL DEFORMATIONS AND CORIOLIS COUPLING EFFECTS ON GIANT DIPOLE RESONANCES

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In this contribution we are able to show the effects of dynamical deformations and Coriolis coupling on the frequencies and strengths of Giant Dipole resonances, built on high spin states. In particular we obtain two main features that have been observed in the first available experimental data[1]: a shift of the centroid of the resonances to lower energies with higher angular momenta and a larger overall width. The key point of our fluid-dynamical approach is to assume that for a giant collective state all the strength is concentrated on only one level. This ansatz, largely justified from RPA calculations, corresponds to take into account only the lowest multipole distorsions of the momentum distribution during the vibration, which is described as a scaling mode .

The dynamical equations are derived from the Vlasov equation in a rotating frame

$$\frac{\partial f_q(\bar{r},\bar{p},t)}{\partial t} = \left\{h_q(\bar{r},\bar{p},t)-\bar{\omega}\cdot\bar{L},f_q(\bar{r},\bar{p},t)\right\} \tag{1}$$

which can be obtained as a semiclassical limit of the cranked TDHF equation for the Wigner transform $f(\bar{r},\bar{p},t)$ of the one-body density matrix[2].

Isovector dipole resonances are described as out of phase small amplitude oscillations $\delta f_q(\bar{r},\bar{p},t)$ of the neutron/proton distribution function around the stationary value f_q^{st} which is solution of the cranked equation $\{h_q^{st}-\bar{\omega}\cdot\bar{L},f_q^{st}\}=0$. Assuming the nucleus to undergo rigid rotations, for an irrotational scaling mode we can exactly close the fluid-dynamical chain of equations derived from eq.(1) at the lowest two $\bar{v}$-moments, continuity and Euler equation[3]. Choosing as real scaling fields

$$\phi_o = r\,Y_{10} \quad , \quad \phi_1 = \sqrt{2}\, r\mathrm{Re}Y_{11} \quad , \quad \phi_{\bar{1}} = -\sqrt{2}\, r\mathrm{Im}\, Y_{11},$$

the Euler eq. becomes a set of equations with the modes $1,\bar{1}$ coupled through the Coriolis term. We get three frequencies in the intrinsic frame (axially symmetric nucleus along the z-axis).

$$\Omega_o = \sqrt{\frac{d_o+f_o}{M}}\ ,\ \Omega_{\pm} = \sqrt{\frac{d_1+f_1+c}{M} + \left(\frac{b}{M}\right)^2} \pm \frac{b}{M}$$

where $M=m\int d^3\bar{r}\,\frac{\rho_q^{st}}{1+\frac{m}{2\hbar^2}t_+\rho^{st}}$, collective mass, $b=m\omega Z_q$ and $c=-m\omega^2 Z_q$ Coriolis and centrifugal terms, $d_{o,1}=\frac{t_+}{2}\int d^3\bar{r}\tau\partial^2_{z,x}\rho_q^{st}$ kinetic energy contribution and

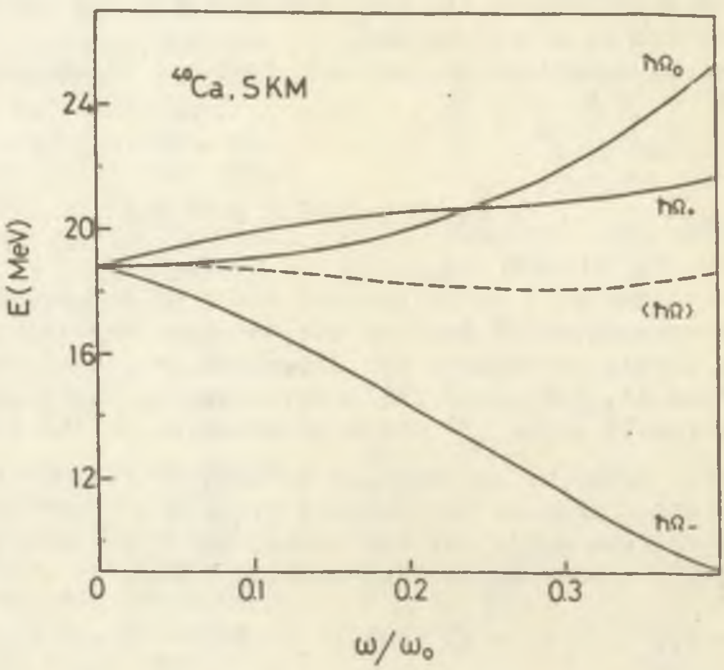
$$f_{o,1} = \int d^3\bar{r}\ \{(\alpha-\alpha')\rho_q^{st}+(\beta-\beta')\nabla^2\rho_q^{st}+(\gamma-\frac{\gamma'}{\sigma+1})(\rho_q^{st})^{\sigma+1}\}\partial^2_{z,x}\rho_q^{st}$$

interaction contribution with $t_+,\alpha,\alpha',\beta,\beta',\gamma,\gamma',\sigma$ directly related to the used Skyrme force.

In this contribution we show some preliminary, not fully self-consistent, results obtained from a stationary cranked density constructed with the Virial tensor method[4] and by imposing an oblate Wood-Saxon shape and with a SKM force. The exp-ected effects are shown in the figure for ^{40}Ca. We predict a clear increasing of the width mainly due to a splitting of the giant level. The reduced e.m. transition strengths, easily computed in our approach, are used as weights in order to get the average dipole energy.

We obtain a small shift of the centroid of the resonance to lower energies. This effect is enhanced in the laboratory frame, but still the maximum shift is of the order of 1.5 MeV for $I \sim 20\hbar$.

These results with a classically rotating nucleus correspond to a maximum collectivity condition for the rotation. We are improving our approach using fully self-consistent calculations with a finite temperature cranked HF code to get the stationary solution[5].



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V. TECHNIQUE OF IN-BEAM NUCLEAR SPECTROSCOPY

METHODS OF EXPERIMENTAL INVESTIGATION OF NUCLEAR HIGH-SPIN STATES WITH HEAVY IONS

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For the last 10-15 years fast development of investigations on heavy ion beams /HI/ has been taking place in nuclear physics. Nowadays, the must promising investigations are those of nuclear high-spin states /HSS/. The report contains a number of trends of experimental investigations of HSS:

1/ The traditional γ- /and conversional/ in-beam spectroscopy. In so doing, γ-deexcitation of the high-excited residual nucleus is investigated after particle emission, i.e., beginning from some "entry line" by γγ-angular correlation methods, "particle-γ-quantum" correlations, by various polarization measurements. As a rule, /HI,xnγ/,/HI,xpγ/, /HI,xαγ/ reactions; more seldom /HI,HIγ/ reaction and radiative capture are used. It is important, that in some experimental situations predominant is the excitation of HSS/1/ /f.i., at small overlap of the projectile angular momentum distribution with the yrastline of the compound nucleus/, that allows to obtain more reliable information about their spectroscopic characteristics.

2/ The levels with I 20ħ usually lay in the γ-ray continuum, while the largest spin value is expected to be possible here, and now methods, allowing to obtain spectroscopic data from several averaged measured values /f.i., mean γ-multiplicity Mγ, mean energy of γ-transition E_γ etc./ are being developed. The measurement methods separately for light and heavy fragment of two-body reactions /2/ are also developed. The basical methodics of measurements are "particle-γ-quantum" manyfold coincidences. The most powerful instruments in such investigation are multidetector sets of "crystal ball" type with geometry, close to 4π in combination with high resolvent detectors of γ and x-irradiations and identification of charged particles /3/.

3/ In the light nucleus region in continuum, separated HSS of "doorway states" may be found, in the decay of which "aligned configuration" component dominates. For determinations of their spin the alignement measurements of concrete states of the residual nucleus, which are realized by study of γ-quantum correlation asymmetry /4/ are carried out. α-cluster and quasimolecular HSS, investigated via "particle-particle" correlation and excitation function measurements are also of great interest. The advantages and handicaps of each of the considered trends are demonstrated in the report through the examples of original works.

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A method to study neutron-deficient nuclei produced in HI reactions.

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As one departs to the left from the line of stability in compound nuclear reactions, the yield of channels emitting solely neutrons rapidly becomes very small. In order to emphasize this narrow channel with respect to the immense background of reactions which also emit charged particles, a 4 π charged particle anticoincidence system has been developed at the 225 cm Stockholm cyclotron.

The device consists of a 45 cm long, 40 mm diam. and 3 mm thick NE 102 plastic scintillator tube, into which the target is inserted through a narrow slit. The scintillator covers 96 % of 4 π solid angle and its signals, originating from charged particles (i.e. p,d,t,α, etc.) are used to veto out the gamma pulses recorded in four germanium detectors arranged in a coincidence set-up. The background radiation from activities, unrelated in time to the charged particles, tends to dominate the remaining spectrum although a coincidence is required with the RF-signal. This is especially serious in the region far from the line of stability. Therefore the radioactivity is further suppressed and neutron channels further enhanced by introducing large neutron detectors in coincidence with the germanium detectors.

The final set-up is displayed in fig. 1. The method is limited by the extremely high count rate in the scintillator tube from elastically scattered beam-particles. This count-rate has to be kept well below the rate of the beam pulses from the cyclotron, usually 7-8 MHz; we have found 2 million counts per sec to be a suitable limit.

In fig. 2 the effect of the method is illustrated for the $^{118}Sn(^{12}C,6n)^{124}Ba$ reaction. The 6n channel, which constitutes less than 10 % of the total cross-section, is here enhanced by a factor of 20 relative to the channels involving charged particles.

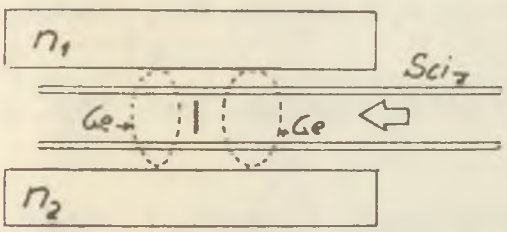

Fig. 1. Set-up for suppression of charged outgoing particles and induced activities.

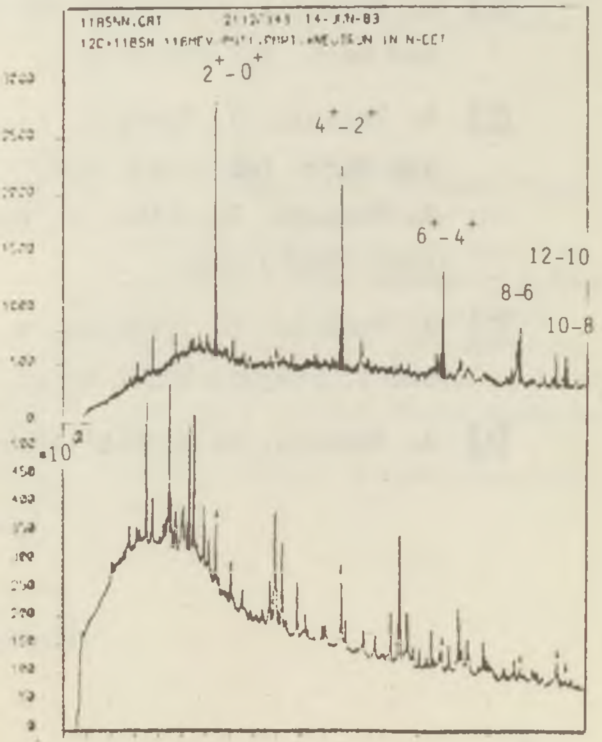

Fig. 2. Bottom: singles gamma ray spectrum; Top: coinc. with n and RF, anticoinc. with charged particles.

RECENT PROGRESS OF IN-BEAM INTERNAL-PAIR SPECTROSCOPY IN CONNECTION WITH LIGHT-ION ACCELERATORS

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I Introduction

II A method for high-resolution in-beam studies of internal-pair transitions [1]

III A combination magnetic plus Si(Li)-Si(Li) sum-coincidence technique [2]

IV A superconducting-solenoid-transporter Si(Li)-Si(Li) spectrometer [3]

V Proposal for a new method for multipolarity determinations: an application of the electron-positron angular correlation in internal-pair transitions [4]

VI Concluding remarks

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ADAPTATION OF A SUPERCONDUCTING SOLENOID TRANSPORTER Si(Li)-Si(Li) SPECTROMETER FOR IN-BEAM STUDIES OF INTERNAL-PAIR TRANSITIONS

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The Debrecen superconducting magnetic spectrometer (SMS) has been adapted for in-beam internal-pair studies. Test measurements have been carried out using a ^{207}Bi radioactive source and the ^{19}F(p,αγ)^{16}O, ^{23}Na(p,αγ)^{20}Ne, ^{27}Al(p,p'γ)^{27}Al, and ^{42}Ca(p,p'γ)^{42}Ca reactions (at bombarding energies E_p=3.5-4.0 MeV). Convenient spectrometer parameters and back-scattering of electrons and positrons from one detector to the other have been investigated. Experimental values of (14±3)%, (12±3)%, and (14±2)% for the one detector pair-line efficiences were determined for the ^{20}Ne(E2; 1634 keV), ^{42}Ca(E0; 1836 keV), and ^{27}Al(M1+E2; 2211 keV) transitions, respectively. The observed pair-line detection efficiences for two detectors operated in sum-coincidence mode were (35±7)% and (34±6)% for the ^{42}Ca(E0; 1836 keV) and ^{27}Al(M1+E2; 2211 keV) transitions, respectively. The energy resolution of the sepctrometer was ~0.5% in singles and ~0.6% in sum-coincidence measurements for the 2211 keV M1+E2 pair line of ^{27}Al. Effective pair-formation coefficients for one-detector and opposite two-detector geometries have been calculated theoretically for various multipoles.
Different methods for the determination of the multipolarity of internal-pair transitions have been investigated. Optimum multipole discrimination effects have been discussed. The experiments show that a good multipole discriminating power can be achieved with the SMS. See fig.

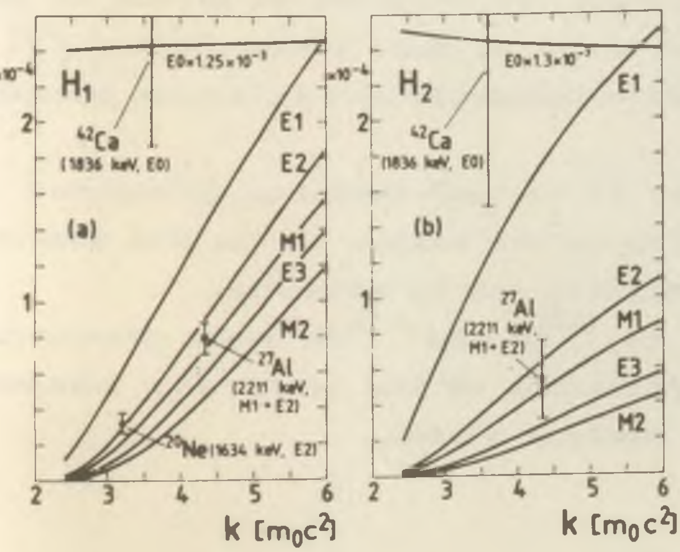

Fig. The transition energy dependence of effective pair formation coefficients in one-detector (H_1) and opposite-detector (H_2) geometries. Curves: results calculated in zero order Born approximation. Poins with error bars: experimental data.

A SIMPLE METHOD FOR TIME ANALYSIS BASED ON COMMERCIAL MCA

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INRNE - BAS

The large application of multichannel analyzer (MCA) in nuclear spectroscopy research stimulated our efforts to find a compromise solution for time analysis.

The memory of MCA, with $(4-16).10^3$ channels and capacity up to 10^6 counts per channel, has a considerable volume and can be divided by sectors with an external device. This idea is very attractive especially for life-time measurements, considering that only 100-200 channels are needed to store one time distribution.

This method was realized with a device in standard CAMAC, which operates with commercial MCA (ICA-70, CANBERRA-40) and single channel analyzers or digital windows. All spectra in memory of MCA can be controled during the experiment. With the constructed device it is possible to make all sorts of time measurements, $\gamma\gamma$-coincedence, delayed coincedence and life-time measurements.

The supplement of the μP-technics offers new possibility depending on the volume of the MCA memory and over 100 time-spectra can be measured.

Measurements in ^{140}La and ^{214}Pb decay demonstrate the possible application of the system for investigation of isomeric nuclear states.

LINE-SHAPE ANALYSIS OF DOPPLER-BROADENED γ-LINES FOR DERIVING THE ANGULAR DISTRIBUTION OF THE LIGHT REACTION PRODUCT

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A method of determining the angular distribution of particles b from the reaction A(a,bγ)B by studying the shape of the Doppler-broadened γ-ray line was proposed by Tryti et al. [1].

According to the procedure the energy distribution of γ-rays in a spectrum observed with a Ge(Li) detector at 0° relative to the beam direction is given by an integral formula $N(E_\gamma)$ which contains the angular distribution of particles b preceding the observed γ in terms of the Legendre polynomials. The experimentally measured γ-ray line shape has to be fitted by the distribution $N(E_\gamma)$ applying the method of least squares with adjustable parameters A_L. The A_L values belonging to the best fit give the Legendre coefficients of the derived angular distribution.

This line-shape method offers the possibility to deduce the b angular distribution in such cases where the direct observation of the b particles is difficult or impossible because of the disturbing effect of background peaks appearing in the particle spectra.

The A_L values with their errors determined by the above procedure from a series of measurements as a function of bombarding energy are regarded as experimental data for a multi-level R-matrix code which is used for the analysis to extract resonance parameters [2] [3].

The possible applicability and practical limits of the line-shape method for determining nuclear resonance parameters will be given.

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NEW DEVELOPMENTS IN COULOMB EXCITATION

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The use of heavy-ion beams and newly developed computer codes [1] in Coulomb excitation makes it possible to extend considerably the available information on E2 matrix elements in stable nuclei. Large solid angle gas-counters allow measurements of gamma-ray yields as a function of the projectile scattering angle with a good efficiency. The experimental techniques will be discussed and results from "transitional" nuclei in the region around A=100 will be shown.

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CHARGED PARTICLE SPECTROSCOPY WITH SOLID STATE NUCLEAR TRACK DETECTORS

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For studies in nuclear spectroscopy it is required to detect the particles and to determine their energy and type simultaneously, frequently in the presence of high background due to various radiations. In addition, especially in studying low-yield nuclear processes, high efficiency and long-term stability of the spectroscopical method is highly desired. In such situations various nuclear track methods may be used very advantageously and successfully.

The purpose of our paper is to overlook some of earlier and recent methods for differentiation of charged particles according to their energy and charge, based on the use of polymeric etch-track detectors (namelly CN, CA, PC and CR-39). The principle of three track methods suitable for nuclear spectroscopy is discussed in some detail. These are based on the analysis of the diameter, surface size or shape of etch--track "cones" produced by charged particles in polymers after shorter or longer chemical etching processes.

Examples will be presented from our results had been achieved in the last decade in ATOMKI, concerning the application of nuclear track spectroscopy to different low-energy nuclear reaction studies, angular distribution and excitation function measurements. These involve the investigation of (d,α) reactions on ^{14}N, ^{19}F and ^{27}Al nuclei, (^{3}He,α) reactions on ^{15}N and ^{14}N nuclei, (p,α) reaction on ^{27}Al and the study of the process $^{12}C(^{12}C,^{8}Be)^{16}O$. Finally, the possibility of the use of track method for spectroscopy related to naturally occurring α-emitters in environmental samples and for proton-spectroscopy with high-sensitivity CR-39 track detectors will be discussed.

ATOMIC AND TARGET EFFECTS ON THE IN-BEAM CONVERSION LINES DUE TO THE RECOIL IONISATION

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In in-beam experiments the investigated nuclei are produced in violent nuclear collisions where they can obtain quite large kinetic energies. For the majority of the interesting reactions we can assume that the momentum of the projectile is transferred completely to the residual nucleus. Due to the large recoil of the nucleus the atom becomes strongly ionised [1]. If the projectile velocity is comparable to that of the inner shell electrons the recoil is the main source of ionisation of the outer shell electrons.

The values of the conversion electron energies and conversion coefficients depend on the atomic state. If τ_a, which is the time needed to reach the ground state of the neutral atom, is comparable to the life-time τ_N of the investigated nuclear level we can observe the effect of the atomic deexcitations and electron captures from the target.

The effect on the K or L shell conversion coefficients can be studied if $\tau_N \lesssim \tau_K$ or $\tau_N \lesssim \tau_L$ where τ_K and τ_L are the life times of the K-shell and L-shell vacancies, respectively [2]. Since the conversion coefficient is proportional to the number of electrons in the given shell, the conversion coefficient for a shell with hole has a decreased value. For τ_K and τ_L we have to use the values which correspond to multiple ionised outer shells. The life-time of an inner-shell vacancy in a multiple charged ion is much higher than that of in an atom with intact shells [3]. The effect is stronger for the L-shell then for the K-shell since the recoil ionisation probability strongly increases with the decrease of the binding energy.

The energy of the conversion line decreases with the increase of the ionic charge since the binding energy of the K- and L-shell electrons increase with the increasing number of vacancies in the atomic shells. For the case of strong multiple ionisation of an atom with medium Z the shift of the K-shell binding energy can reach a few KeV. The probability of the nuclear decay at a given ionic charge depends on the initial recoil ionisation and on the time scale of the decrease of the ionic charge due to the subsequent electron capture from the material of the target. If the neutralisation time τ_a of the atom is comparable to τ_N then the conversion line, independently from the experimental resolution, shows an asymmetrical line shape. The line-width is determined by the degree of the recoil ionisation which we can give in a good approximation. The line shape depends on the electron capture cross sections from the target atom. This dependence gives an interesting possibility to study the electron capture process at projectile and target atoms with nearly equal mass.

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SEARCH FOR ANOMALOUS INTERNAL CONVERSION COEFFICIENT OF ^{18}F IN $^{16}O(^{3}He,p)^{18}F$ REACTION

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The electron shells of the ^{18}F atom produced in the $^{16}O(^{3}He,p)^{18}F$ ($E[^{3}He] \approx 3$ MeV) reaction are heavily ionized. The ionization probability (P_K) for the K shell can reach 20 %. Using the SCA model calculation [1] we can have an estimation for the direct ionization probability $P_K \approx 15$ %, and the contribution of the recoil ionization according to the model [2] is about 5 %. Since the life-time of the 1041 keV excited state of the ^{18}F is shorter than the life-time of the atomic K shell vacancy, the internal conversion of the 1041 keV E1 transition takes place before the complete filling of the K electron shell by atomic transitions.

As the internal conversion coefficient (ICC) is proportional to the number of electrons in the given shell, the ICC will be reduced with about 10 % in this case according to the above values of the ionization probabilities.

The existence of this small deviation can be demonstrated studying the $^{18}O(^{3}He,p)^{18}F$ reaction. There is a group of resonances in the excitation function of the 1041 keV level of the ^{18}F at $E[^{3}He] \approx 2.95$ MeV. At this bombarding energy the feeding of the 1041 keV level by γ radiations is small, so one can measure the reduced ICC of the transition. There is an another way of excitation of the 1041 keV level. At ≈ 3.1 MeV ^{3}He energy this level is fed mainly by a γ transition from the 1701 keV state. The life-time of this state is so long that the 1041 keV transition occurs in the ground state of the neutral ^{18}F atom. Therefore one can measure the normal ICC in this case. The effect can be investigated by measuring the deviation of the two ICC-s at the two bombarding energies, given above.

Up to now we have recorded γ and conversion electron spectra from the $^{16}O(^{3}He,p)^{18}F$ reaction, but the background was rather high in the electron spectra due to ^{20}F β^- activity. In order to reduce the background we are going to repeat the experiments using pulsed beam.

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WHAT A PHYSICIST SHOULD KNOW ABOUT NUCLEAR SPECTRUM DECOMPOSITION

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Let y_i be the number of counts in the i-th channel of the total spectrum of a nuclear measurement /having Poisson distribution/. The activity at the background in each channel is B_i. Let $A_{i\ell}$ be the net activity in the i-th channel of ℓ-th radiation source /standard, also result of measurement/. Let us consider

$$^{o}f_i = [\sum_{\ell=1}^{s} (^{o}C_\ell \times A_{i\ell}) + B_i] \times T$$

as a model function to the maximum likelihood or least squares method, where T is the counting time, $^{o}c_\ell$ is the ratio of the activity of the standard to that of the sample. It will be proved by theoretical approximation that when introducing and considering two functions to be optimized /where $Z_i = y_i + 1$/

$$1. \quad \sum_{i=1}^{n} (Z_i - {}^{1}f_i)^2 / Z_i \Rightarrow \min \qquad 2. \quad \sum_{i=1}^{n} (y_i - {}^{2}f_i)^2 / y_i \Rightarrow \min$$

the first is almost unbiased /about 0.1/ whereas the bias of the second /that is widely used/ is one count in each channel. An example is shown where a Gaussian curve, a horizontal straight line and a sloping straight line were fitted by Monte Carlo method with the following results: $\langle y_i - {}^{1}f_i \rangle = -0.1127 \pm 0.0135$ and $\langle y_i - {}^{2}f_i \rangle = 0.977 \pm 0.012$.

/An average of 2025 simulated spectra and thus an average of 40 channels./

By theoretical proof $\langle y_i - {}^{1}f_i \rangle = 0$ and $\langle y_i - {}^{2}f_i \rangle = 1$. The proof is based on the approximation $1/\langle y_i + 1 \rangle \approx 1/\langle y_i \rangle$ /introduced by L. Jánossy/. As a verification we could prove by Monte Carlo method the null hypothesis: $\langle f_i - {}^{o}f_i \rangle \approx 0.00 \pm 0.01$.

Of the five different methods mentioned for linear equations the above suggested first method has the smallest bias. If the model function itself is not linear the maximum likelihood method is proposed using the first of the two above functions as the first step.

PROJECT OF THE BULGARIAN ACCELERATOR

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This report considers some problems that have emerged in connection with the forthcoming establishment of a National Accelerator Laboratory in Bulgaria the basic equipment of which will be a multi-purpose isochronous cyclotron U-250. Some project parameters of this cyclotron intended for accelerating ions to maximum energy $W = 204 \frac{Z^2}{A}$ are given. The programme which is to be accomplished by means of particle beams accelerated by the cyclotron is stated. This programme includes the fundamental researches as well as the operation for practical purposes. A scheme is suggested for disposing the equipment and distributing the beams in the experimental room. Some assessments are summarized concerning the parameters of the devices used in the accelerator beam deviation systems when using extraction by deflection and extraction through recharging which show that in case of extraction through recharging the deviation systems will be realized easier. The necessity for the establishment of a modern system for acceleration control is shown making use of modern computers as well as the basic problems that must be solved. The configuration of a computers control system is given. The report also states the prospects for U-250 operation by its improvement.

CYCLOTRON LABORATORY IN THE INSTITUTE OF NUCLEAR RESEARCH, DEBRECEN

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A new cyclotron laboratory is under construction at the Institute of Nuclear Research of the Hungarian Academy of Sciences, Debrecen. The laboratory will be equipped with a small size compact isochronous cyclotron type MGC, designed and manufactured by the D.Jefremov Scientific Research Institute of Electrophysical Apparatures, Leningrad. The project of the laboratory initiated in 1978, the construction work of the building began in 1982 and the first beam is expected in summer 1985.

The cyclotron MGC has been designed for the acceleration of protons, deuterons, ^{3}He and ^{4}He 2+ ions in the energy range $E=(5\div20)Z^2/A$ MeV [1]. The intensities of the extracted beam at the maximum energies are 50 μA for protons and deuterons and 25 μA for ^{3}He- and ^{4}He-ions. The planned beam transport system transmits the accelerated particles to five target rooms.

Data acquisition and analysis will be based on a computer network system with a host computer TPA 11440. The satellite stations consist of a small number of components: LSI-11/23 computer including processor and memory, CAMAC crate controller, terminal, display board, network interface.

Basic researches in nuclear and atomic physics, interdisciplinary researches, industrial and medical applications are programmed at the cyclotron. Researchers from other institutions collaborate in these activities, too. The realisation of these programmes also started and designing and manufacturing of experimental appartures are in progress.

The cyclotron project of the Institute is partly supported by the International Atomic Energy Agency in Vienna.

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VI. NUCLEAR MODELS AND MODEL CALCULATIONS

SHELL MODEL CALCULATIONS OF ^{90}Zr AND ^{88}Zr*

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Conventional spherical shell model calculations have been undertaken to describe ^{90}Zr and ^{88}Zr. This work was motivated by recent experimental results on these nuclei [1], extending the nuclear spectroscopy to $E_x \sim 11$ MeV and $J \sim 20$. Valence orbitals included the $1f_{5/2}$, $2p_{3/2}$, $2p_{1/2}$, and $1g_{9/2}$. For ^{90}Zr, the number of $1g_{9/2}$ protons was ≤ 2; for high-spin positive parity states, however, excitation to the $2d_{5/2}$ orbital of ≤ 2 $1g_{9/2}$ neutrons was also allowed. For ^{88}Zr states, the number of $g_{9/2}$ protons was ≤ 2, except that for high spin states the number of $g_{9/2}$ protons was ≤ 3. A realistic two-body interaction [2] and single particle energies which account for the properties of single particle states in this mass region were employed in this calculation. As one illustration of results, the calculation predicts (in Weisskopf units) $B(E2; 10_1^+ \rightarrow 8_1^+) = 0.03$ and $B(E2; 10_1^+ \rightarrow 8_1^+) = 4.56$, in accord with the observed experimental branching ratio. Effective charges $e_n = 0.5e$ and $e_p = 1.5e$ were used to calculate E2 transition rates.

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MULTISTEP SHELL-MODEL METHOD

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The many-body shell-model equations are solved in several steps. First one chooses a single-particle representation which defines the shell-model space. Then one proceeds to calculate the two-particle system. In this step, one assumes that the two-body interaction is well known or, alternatively, the interaction matrix elements are taken from experiment. These two first steps are actually the way in which standard shell-model calculations are performed [1] . In later steps one calculates a system σ (with s particles) in terms of a correlated basis consisting of the tensorial product of two subsystems μ and ν (with m and n particles, respectively, such that s=m+n). Such a basis usually violates the Pauli principle. As a result the number of basis elements is larger than the number of physical states, i. e. the basis becomes overcomplete. To overcome this problem one has to evaluate the overlap matrix among the basis vectors also. Within the multistep shell-model method (MSM) [2] the overlap and dynamic matrices resulting from the correlated MSM basis can be written in terms of quantities related to the subsystems that form this basis. This property greatly simplifies the formalism, since all the recoupling coefficients contained in the equations of a given step are not passed to later steps.

One important feature of the MSM basis is that it allows drastic truncations of the original shell-model basis. As an example, let us consider the ground states of spherical nuclei. Written the s-particle wave function in terms of the two- and n-particle wave functions (s=2+n) as

$$|g.s.;\ s\rangle = NP^{+}(g.s.;2)P^{+}(g.s.;n)|0\rangle \qquad (1)$$

where N is a normalization constant, the MSM gives for the ground state energy of the s-particle system the value

$$W(s)=2W(n)-W(n-2)+W(4)-2W(2) \qquad (2)$$

where W(p) is the p-particle energy. For neutron holes in ^{208}Pb one obtains (energies in MeV) the values shown in Table 1

s	202	200	198	196	194	192	190
W(s,exp.)	44.25	60.17	76.57	93.47	110.95	128.61	146.82
W(s,the.)	44.46	60.28	76.81	93.68	111.08	129.14	146.98

Table 1

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α-CLUSTERING AND ABSOLUTE α-DECAY WIDTHS IN ^{212}Po

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High lying configurations are important to describe processes (such as α-decay) that take place in the nuclear surface region. The α-decays widths are also strongly enhanced by the same effect [1]. Moreover, the inclusion of high lying configurations gives the proper tail of the α-cluster wave-function and the α-width may be written in the classical form

$$\lambda_L = 2P_L(r_c)\gamma_L^2(r_c) \qquad (1)$$

where γ_L is the α-particle formation amplitude and P_L is the Coulomb penetration factor.

A proper description of the α-cluster would require either the inclusion of all ^{210}Pb and ^{210}Po states or the inclusion of correlated states in ^{210}Bi. If there is a state in ^{210}Bi which shows to be clustered in the nuclear surface then one would expect that neutrons and protons in the α-particle may also be clustered through the same mechanism. In this case

$$|^{212}\mathrm{Po(gs)}\rangle = A|^{210}\mathrm{Po(gs)}\,^{210}\mathrm{Pb(gs)} + B|^{210}\mathrm{Bi}(\lambda)\,^{210}\mathrm{Bi}(\lambda)\rangle . \qquad (2)$$

In general, the wavefunction amplitudes A and B can be calculated using e.g. the multi-step shell-model [2].Since the state $^{210}\mathrm{Bi}(0_1^+)$ has a strong clustering feature and assigning to it the excitation energy of 5 MeV we obtain, using MSM A=0.98,B=0.1. In Fig.1 we show, that the α-particle is indeed clustered in the nuclear surface.

The calculation of the α-width for ^{212}Po requires the computation of a 9-dimensional integral which was done using the code D01FCF [3].The calculated widths are practically independent upon the distance between the daughter nucleus and the α-particle around the nuclear surface as shown in Tab.1. The calculated halflife for ^{212}Po at r=8.7fm for B=0.1 is $R=T_{1/2}(th)/T_{1/2}(exp)=31$.It is worthwhile to note that the value B can be much more important in our case and that the value of R is quite sensitive with respect to B as seen from Tab.2.

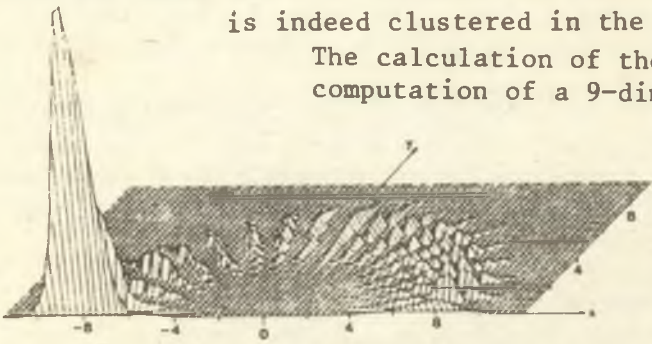

Fig.1.
Square of α-wavefunction moving around the ^{208}Pb core.The clustering effect is clearly seen around x=8fm.

r(fm)	7.5	8.0	8.5	8.6	8.7	8.8	8.9	9.0	9.5
R	94	39	29	31	31	35	36	39	70

Tab.1.

B	0.0	0.1	0.2	0.4	0.6	1.0
R	76	31	20	8	5	3

Tab.2.

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ODD-J — EVEN-J STRAGGLING OR SMOOTH PARABOLAS?

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The structure of odd-odd nuclei adjacent to a double-magic one is well described using a δ force, which causes a strong odd-J — even-J straggling. At the same time, the splitting of p-n multipletts e.g. in ^{100}Tc or ^{146}Eu are nicely fitted with help of a dipole plus quadrupole interaction, from which a smooth parabolic dependence of E(J) on J(J+1) arises [1].

To search for the limits of validity of the two approximations and to understand the transition between them the splitting of the $\pi\tilde{g}_{9/2}\ \nu\tilde{d}_{5/2}$ multiplet has been calculated using an effective interaction built up from a δ force with a spin exchange term and a core polarization interaction. The strength of the short range component was taken from the systematics of Daehnick [2], and the strength of the long range part was calculated according to Bohr and Mottelson [3].

It can be shown that the straggling is smoothed out when the quadrupole core polarization component becomes the dominant one.

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DESCRIPTION OF THE LOW-LYING STATES IN DEFORMED NUCLEI WITHIN THE QUASIPARTICLE-PHONON NUCLEAR MODEL

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Electrical transitions between low-lying states of odd-mass nuclei are considered within the quasiparticle-phonon model [1-2]. The Hamiltonian contains the average Saxon-Woods field, pairing and multipole interactions, the last one includes the quasiparticle-phonon interaction. The wave function consists of one-quasiparticle and quasiparticle-plus-phonon components. Using the exact commutation relations between quasiparticle and phonon operators the Pauli principle is taken into account[3].

Reduced probabilities B(E2,ΔK=2) are calculated for nuclei of the rare-earth region with $155 \leq A \leq 175$. Single-particle levels are taken from the bottom of the potential well up to 5 MeV. Neutron and proton effective charges equal 0.1 and 1.1, respectively. Our results are compared with the Coriolis coupling calculations and experimental data. Some of our results are presented in the table(hindrance factors).

We have shown that except for the region A~173 the γ-vibrational components of the wave function are not less important for the description of B(E2,ΔK=2) than the Coriolis interaction. In N-odd nuclei even very small vibrational components (~1%), as a rule, give a larger contribution to B(E2, ΔK=2) than the single-particle transition. The reason for this is the large collectivity of 2^+-phonon in the even-even core and the values of the effective charges. In Z-odd nuclei the situation is more tangled. When the Pauli principle is taken into account the wave function structure may change due to the quenching of its components forbidden by the Pauli principle.

Nucl.	Initial st.		Final st.		
	$I^{\pi}K$	Structure	$I^{\pi}K$	Structure	F
^{163}Dy	$1/2^-1/2$	521↓88% 523↓-Q_{221}10%	$5/2^-5/2$	523↓96%	1.2
^{165}Ho	$3/2^-3/2$	541↑ 4% 523↑-Q_{221}95%	$7/2^-7/2$	523↑98%	2.0
	$11/2^-11/2$	523↑+Q_{221}100%	$7/2^-7/2$	523↑98%	1.7

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MICROSCOPIC CALCULATIONS OF IBM PARAMETERS

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The Interacting Boson Model (IBM) of Arima and Iachello [1] has been quite successful in correlating and describing a wide variety of experimental data regarding the collective properties of medium-to-heavy mass nuclei. The development of the proton-neutron IBM (the so-called IBM-2) has allowed a connection to be established with the microscopic nuclear Shell Model [2]. We use the generalized seniority scheme of Talmi [3] to truncate the fermion Shell Model space to configurations made up of pair states of identical nucleons coupled to angular momentum 0^+ or 2^+. Configurations with generalized seniority $\nu \leq 2$ are mapped into the boson space. We are then able to calculate the parameters of the IBM-2 Hamiltonian by equating equivalent matrix elements in the fermion and boson spaces. Our calculations are carried out for non-degenerate single-particle orbits in the fermion space and also include the renormalization effects due to the excluded g bosons (i.e. the $J = 4^+$ pair)[4]. Our results for the IBM-2 parameters show a definite relationship to the underlying subshell structure of each major shell, in agreement with the phenomenological results. However, only part of the observed renormalization is obtained. Possible sources of further renormalizations are discussed.

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LIGHT ION RESONANCES AND THE VIBRON MODEL

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The vibron model [1] was suggested to describe the nuclear quasimolecules on the basis of their dipole type collectivity. At present there are two kinds of its applications in nuclear physics. i) Low-lying levels of some nuclei show evidence of the dipole collectivity [2]. Their interpretation is given by the hybrid model, in which the dipole degrees of freedom of the vibron model are combined with the quadrupole degrees of freedom of the IBM. ii) Some high-lying resonance levels of light nuclei are known, for a long time, as examples of quasimolecular states. The vibron model has been used for their description, too [3-5]. In this contribution this latter kind of application is discussed briefly.

In the vibron model the collective excitations of a nuclear molecule are generated by a fixed number of bosons which are in two-body interaction with each other. The Hamiltonian has U(4) group structure, and the model has two dynamical symmetries labeled by O(4) and U(3).

The O(4) limit has been applied in Ref. [3] for the description of the $^{12}C+^{12}C$ system, and in Ref. [4] to the case of some core+α-particle states. These letter ones are compared with the spectra of both dynamical symmetries in Ref. [5]. Obviously, however, analyses based on the general case of the model are also needed in order to explore its applicability. Using the ROTVIB code [6] in a parameter searching mode, we performed calculations on the data of Ref. [3], and on some core+α-particle states, recently.

The analyses, performed till now, are far from being complete. Only energies have been calculated, and no partial widths, for instance. Yet the vibron model seems to be a useful tool of the analysis. It may be applied more generally than most of the previous models of the quasimolecular states; and on this way a great number of states can be simply parametrized.

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IBA CALCULATIONS OF MULTIPOLE MIXING RATIOS

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The interacting-boson approximation (IBA) can be used to calculate multipole mixing ratios in terms of a number of parameters. Of notable practical interest are the E2/M1 mixing ratio δ, or the corresponding reduced quantity Δ, and the E0/E2 ratio X.

The IBA version not distinguishing between proton and neutron bosons (IBA-1) gives M1 transitions only in second order of the operator since the first-order M1 operator is proportional to the angular momentum. There are three second-order terms, each with a free parameter [1,2]. For a given nucleus, an IBA-1 calculation of Δ(E2/M1), which is the ratio of the reduced matrix elements, proceeds as follows. First the six Hamiltonian parameters are determined by a fit to all well-established levels encompassed by the model. With the wave functions thus obtained, the two E2 parameters are fixed by fitting two experimental B(E2) values, usually those for $2_1^+ \rightarrow 0_1^+$ and $2_2^+ \rightarrow 0_1^+$. Then finally the three M1 parameters are fitted to the best three experimental Δ(E2/M1) values. All other Δ values are then predicted and may be compared with the experimental ones.

The nuclei $^{146-152}$Sm, ^{154}Gd, ^{162}Dy, $^{162-168}$Er and ^{172}Yb have been calculated according to the above prescription. They are about the only ones with enough data [3,4] to warrant such calculations. The calculated Δ values generally agree in sign and rough magnitude with the experimental ones. However, the fitted M1 parameters fail to conform to smooth systematic trends. It should be noted that all three M1 parameters are needed when both signs are found among the $\Delta(J \rightarrow J\pm1)$. Nevertheless, Warner's simple two-parameter model [5] for deformed nuclei is quite successful. It is compared in ref. [6] with the complete IBA-1 calculation for ^{154}Gd. Ref. [6] also discusses the one-parameter Δ formula resulting from any of the IBA-1 dynamic symmetries [1] or from the geometric model.

The quantity X(E0/E2) is readily obtained within IBA-1 once the energy and E2 parameters have been fixed. The E0 operator contains only a normalization parameter, which can be fitted to one transition. Beyond that, the predictions are rigid. Agreement with experiment is generally poor [4], and an improvement constitutes a theoretical challenge.

The neutron-proton IBA (IBA-2) contains little freedom of adjustment for the E2/M1 mixing ratios because its first-order M1 operator does give transitions [7]. The parameters of the Majorana operator embodied in the model, however, allow some leeway worth exploring. Such studies are under way, with a view to comparison with IBA-1.

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AN ANALYSIS OF MAGNETIC DIPOLE PROPERTIES IN IBA-2

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Stimulated by recent accurate measurements,we have analyzed magnetic dipole properties of even-even nuclei with $54 \leq Z \leq 78$ within the framework of the Neutron-Proton Interacting Boson Model(IBA-2).

At a first stage,a phenomenological analysis of the g-factors of the first excited 2^+ states has been performed.The magnetic dipole operator used has the form[1]

$$\vec{\mu} = g_p L_p^{(1)} + g_n L_n^{(1)}$$

The parameters g_p and g_n have been allowed to vary smoothly as functions of the number of protons and neutrons,respectively.Where available,IBA-2 wave functions for the 2_1^+ states have been used.In the other cases,the approximate expression

$$g(2_1^+) = g_p \frac{N_p}{N_p + N_n} + g_n \frac{N_n}{N_p + N_n}$$

has been emploied,where N_p and N_n are the numbers of proton and neutron bosons.

Values of g_p and g_n close to unity and zero,respectively,have provided a good fit to the experimental data.In terms of these values,g-factors are predicted to decrease(increase) in the first half of a major shell with N_n(N_p) while the opposite happens in the upper half of the shell.Deviations from this average behaviour are observed only in the lighter isotopes of $_{60}$Nd, $_{62}$Sm and $_{64}$Gd and they seem related to a subshell closure at Z=64.

At a second stage,the microscopic theory of the IBA-2 has been applied to calculate g_p and g_n on a shell model basis.These have been derived by equating boson and fermion M1 matrix elements in the case of generalized seniority v=2,for protons and neutrons separately.These calculations have provided a qualitative understanding of the values g_p and g_n used in the phenomenological analysis.

Finally,some E2/M1 mixing ratios have been analyzed together with the M1 excitation of the $K^{\pi}=1^+$ band in deformed nuclei.A calculation of the B(M1) value and of the collective form factor for the transition $0^+ \rightarrow 1^+$ in $_{64}Gd_{92}$ is presented.

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DESCRIPTION OF GD ISOTOPES IN IBA

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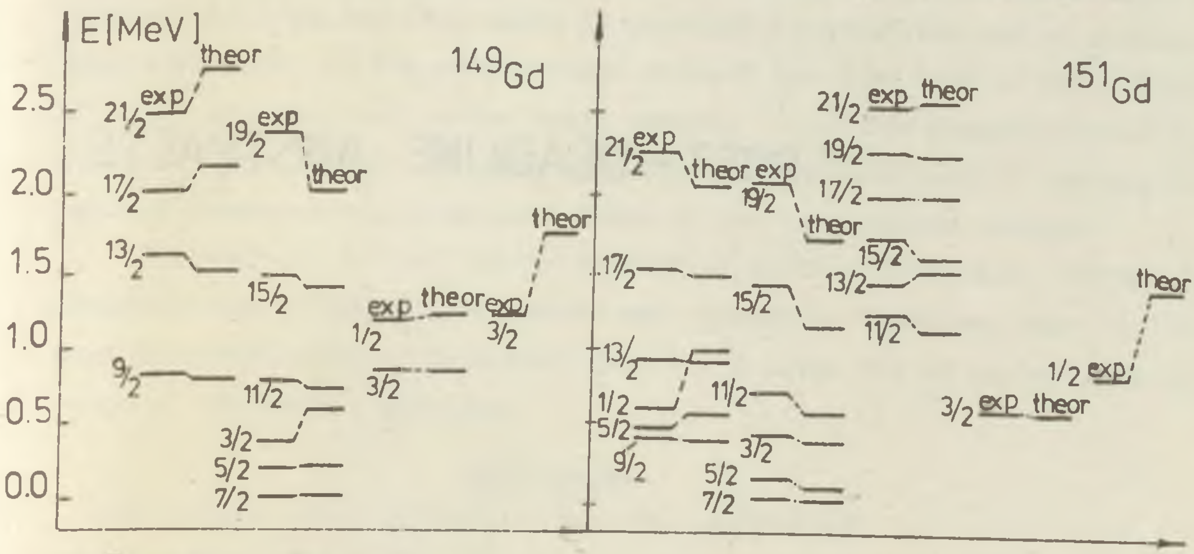
Energy levels of odd parity and reduced probabilities of E2- and M1-transitions in ^{149,151}Gd have been determined by means of IBFM[1]. The optimal parameters of cores of both nuclei have been calculated using program PHINT[2]:HBAR=854keV,C_0= 67.92 keV,C_2=409.44 keV,C_4=-27.14 keV,F=446.83 keV,G=83.43keV, N=8 for ^{149}Gd;HBAR=738 keV,C_0=-355 keV,C_2=409.448 keV,C_4=39.52 keV,F=446.83 keV,G=73.43 keV,N=9 for ^{151}Gd. The parameters of boson-fermion interaction are/assignment as in 3)/: N=8, Γ_0= 0.358MeV, $\chi=-\sqrt{7}/2$, Λ_0=2.4 MeV,A_0=0, $\varepsilon_{7/2^-}$=0 MeV,$V_{7/2^-}$=0.38, $V_{9/2^-}$= 0.39 for ^{149}Gd; N=9, Γ_0=0.403 MeV, $\chi=-\sqrt{7}/2$, Λ_0=2.2MeV,A_0= 0.1 MeV, $\varepsilon_{7/2^-}$=0 MeV, $\varepsilon_{9/2^-}$=0.38 MeV, $V_{7/2^-}$=0.39, $V_{9/2^-}$=0.39 for ^{151}Gd. Effective charges for E2-transitions are e_B=0.36, e_F=0.4/for ^{149}Gd/ and e_B=0.15, e_F=0 /for ^{151}Gd/. Gyromagnetic ratioes for M1-transitions are g_B=0.5, g_ℓ=0.0, g_s=-3.8256. Results are summarised in tab. and fig.:

	^{149}Gd		^{151}Gd	
	$B(X\lambda)_{exp}$ [$e^2\cdot barn^2$ or μ^2]	$B(X\lambda)_{theor}$ [$e^2\cdot barn^2$ or μ^2]	$B(X\lambda)_{exp}$ [$e^2\cdot barn^2$ or μ^2]	$B(X\lambda)_{theor}$ [$e^2\cdot barn^2$ or μ^2]
E2: $5/2^- \to 7/2^-$	$7.1\ 10^{-2}$	$4.3\ 10^{-2}$	$1.8\ 10^{-1}$	$1.22\ 10^{-1}$
E2: $3/2^- \to 5/2^-$	$5.4\ 10^{-3}$	$2.23\ 10^{-1}$	$2.8\ 10^{-3}$	1.03
E2: $3/2^- \to 7/2^-$	$1.9\ 10^{-2}$	$2.1\ 10^{-2}$	$5.3\ 10^{-3}$	$2.0\ 10^{-3}$
M1: $5/2^- \to 7/2^-$	$2.2\ 10^{-3}$	$2.0\ 10^{-3}$	$2.2\ 10^{-3}$	$2.0\ 10^{-3}$
M1: $3/2^- \to 5/2^-$	$1.5\ 10^{-3}$	$5.6\ 10^{-2}$	$3.3\ 10^{-3}$	$4.0\ 10^{-3}$



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POST - DEADLINE ABSTRACTS

STATISTICAL MODEL FOR CALCULATING THE CHARACTERISTICS OF HEAVY ION NUCLEAR REACTIONS BASED ON THE MONTE-CARLO METHOD

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The statistical theory of nuclear reactions is used to describe the decay of an excited compound nucleus with large angular momentum, produced by a heavy ion-induced reaction. In describing such reactions we used an approach [1] which allows one to take into account fairly correctly the large angular momentum effect at each stage of the sequential particle emission by the nucleus. The probability of particle emission from a compound nucleus with an energy E, orbital angular momentum $\vec{\ell}$ in the direction $\vec{n}$ was calculated according to the Ericson-Strutinsky quasiclassical approximation [2]. For calculating the evaporation cascade a Monte-Carlo method was used, the mathematical nature of which exactly reflects the stochastic character of the process of particle evaporation from a "heated" nucleus,and this makes it possible to avoid the use of common approximations. In the calculations account has been made of the effect of shell smearing out in the level density [3], of the competition of n, p, d, t, ^{3}He, α and γ -ray emission with fission, and of changes in nuclear characteristics at each stage of the evaporation cascade.

The analysis of the energy spectra of emitted particles, the angular distributions of reaction products and excitation functions show a fairly good agreement with experimental data for a large set of nuclei in a wide range of excitation energies.

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DETERMINATION OF ANGULAR MOMENTA IN INCOMPLETE-FUSION REACTIONS

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At present a large amount of experimental data have been accumulated on the inclusive spectra of light charged particles, e.g. hydrogen, helium, lithium and other isotopes produced by heavy ion reactions. We have established that the end-point energies of these particles are close to the kinematic limit equal to the energy release in a given reaction under the assumption of the two-body character of the interaction process [1]. The understanding of the mechanism of fast particle formation is substantially connected with the determination of the input angular momenta of their formation reaction. Such studies have been carried out using the technique of gamma-ray multiplicity measurements in reactions involving light charged particle emission for nuclei with $A \sim 70$ and $A \sim 160$ (ref.[2]). However these data are not related to particle energies. In the present paper the average values of the input angular momenta were determined for the channels of alpha-particle and Li-particle emission in the reaction Ta +Ne and alpha-particle emission in the reaction Ir +C, which, in the case of an incomplete fusion reaction with alpha-particle emission, was expected to lead to the same residual nuclei (Tl). The angular momenta were determined as a function of the energy of the emitted particles in both reactions. The incomplete fusion channel was identified by means of the characteristic KX-ray emission of the residual nuclei, which were registered in coincidence with charged particle and gamma-ray folding distributions.

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GAMMA-GAMMA ENERGY CORRELATION STUDY OF ^{158,160}Er NUCLEI

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Gamma-gamma energy correlation technique became widely used in studying nuclear motion at very high spins. The presence of ridges in the correlation spectrum indicates collective rotation. From the distance of the ridges the characteristics of the rotational bands can be deduced.

The gamma-gamma energy correlation study of ^{158,160}Er nuclei is a part of the systematic investigation on very high spin states of Er-isotopes. High statistic E_γ-E_γ correlation spectra for ^{158,160}Er nuclei were generated with high energy resolution, using the γ-γ coincidence events from the escape supressed Ge detectors of the sum energy array TESSA2 at the Nuclear Structure Facility, Daresbury. The reactions used were ^{114,116}Cd(^{48}Ca,4n)^{158,160}Er at bombarding energies of 205 and 210 MeV, respectively. The selection of these reaction channels from the other open ones was done by requiring high multiplicity and high sum energy events in the BGO detectors of the array. A simple method has been developed to unfold the uncorrelated events related to coincidences with Compton scattered γ-rays. The 2-dimensional spectra of real correlated events were corrected for the efficency of the Ge detectors. The ridge structure has been observed for both nuclei up to the highest spins, and dynamical moments of inertia $\mathcal{J}^{(2)}_{band}$ vs. E_γ have been determined from the distances of the ridges on perpendicular cuts to the equal energy diagonal of the spectra. Deformation parameters have been deduced with the assumption of rigidity. A comparison with the predictions of the cranked shell model is in progress.

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ALPHA DECAY OF FISSION ISOMERS

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The theory of α-decay in the first order of perturbation is presented. It is designed for nucleus in an isomeric state which is strongly deformed and which changes its deformation dynamicaly through decay from the very deformed to an almost spherical shape. It is shown that other channels are not coupled to the α-channel in the first order of perturbation. The collective degrees of freedom of the daughter nucleus are described by the shape vibrational states, eigen states of the Hamiltonian whose potential has two minima. The parent nucleus is described by dynamically coupling the vibrational degrees of freedom to the α - particle motion and also taking into account the rotations.

The theory is applied to the α- decay of the isomeric state of $^{242}_{95}$Am.

RELATIONS BETWEEN COLLECTIVE AND MICROSCOPIC PROPERTIES

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There are experimental indications that nuclei around A = 56 may exhibit collective properties. The doubly magic $^{56}_{28}Ni_{28}$ core makes it feasible to study these nuclei also microscopically since not too many active particles are involved. In this way one can investigate the interesting relation between a largely independent-particle behaviour and collective properties of nucleons. Therefore, an extensive shell-model study of the A = 52–60 nuclei has been undertaken. It was found that the experimental data could be very well reproduced by the shell model [1].

With the shell model the excitation energies, electromagnetic moments and transition rates are calculated for all lower-lying states with $J < 16$. These observable quantities are considered to be the 'experimental' data for an interpretation in terms of an axially symmetric rotor. In this way about twenty good rotor bands could be localized in the A = 52–60 nuclei.

In order to illustrate the close relationship between the shell-model and rotor description, we compare the observables of a 'shell-model' band in ^{53}Fe with the corresponding rotor values for a K = 1/2 band. It is seen from fig. 1 that both models produce almost identical results. One should realize that for a rotor only one single parameter, i.e. the value of the intrinsic quadrupole moment Q_o is needed to reproduce all quadrupole moments and E2 transition rates derived from the shell model. Various microscopic aspects of these rotor bands will be discussed.

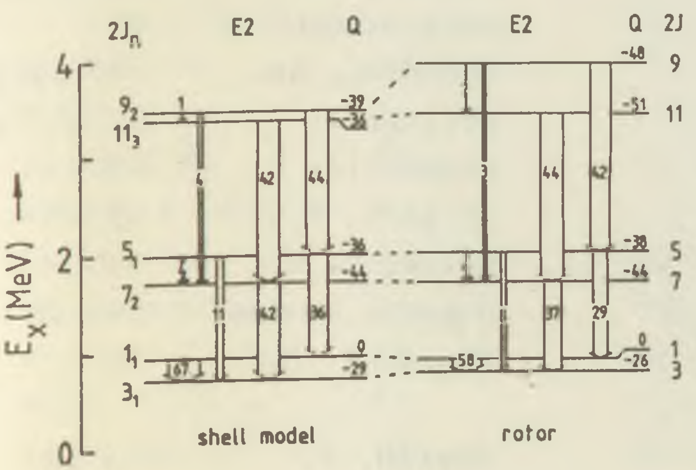

Fig. 1. Comparison between the shell model and rotor model for a K = 1/2 band in ^{53}Fe. Presented are energies, E2 strengths in W.u. and Q-pole moments ($e.fm^2$).

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Principles for New Uses of Fast (MeV) Molecular Ions*

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Abstract
Molecular ions and cluster ions become available in many accelerator systems. The principles of demonstrated and of possible uses of these ions are discussed. Applications in diverse fields of science are indicated.

Introduction

Most particle accelerators have been and are used with mono-atomic particles such as e.g. e^-, H^+ or U^{+44}. Ion sources, however, provide molecular ions in large quantities and with a large variety of species [1] e.g. H_3^+, NeH^+ or CH_4^+. Studies and results with energetic (MeV) molecular ions up to now have been published in recent conference proceedings [1, 2, 3].
It is the aim of the present communication to point out principles of new uses of molecular ions. For simplicity these principles will be discussed with diatomic molecular ions predominantly; however, most phenomena can be studied with much more complex systems as well.

Molecular Ion sources and beam preparation

Standard high - frequency or Penning ion sources produce molecular ions of many types and of many internal excitation stages [4]. Recently, also cluster ions have been generated e.g. by inert gas condensation of metal vapors; thus, clusters of Sb_1 through Sb_{500} or Pb_1 through Pb_{400} have been used to test the transition of typical properties of the atom to typical properties of the solid as e.g. magnetism [5].
It should be noted that also ion-induced desorption of macro-molecules from solid surfaces, first studied by Macfarlane [6], could serve as a source of more exotic molecular ions such as involatile, thermally unstable biomolecules (e.g. palytoxin = $C_{129}H_{223}N_3O_{54}^+$).
Generally, molecular ions are only single charged particles; consequently, their mass times-energy over charge -square-values (M_pE_p/q^2) are unusually high. Bending, analysing, steering, and focusing requires extremely high magnetic -or electric- fields or bending radii which can cause technological and financial problems. Also, the separation of molecular ions from particles with other isotopes or other molecular ions but the same M_pE_p/q^2-value (e.g. H_3^+ versus HD^+ or CO^+ versus N_2^+)

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must be carefully controlled [7,8]. For many classes of experiments it is desirable to have molecular ions with their internuclear axis aligned in a chosen direction; so far, no studies of this type have become known, except by cumbersome indirect postcollision coincidence techniques [1,4].
Care must be taken to provide molecular ion beams at the target location with adequate incident energy spread and adequate incident divergence [1].

Kinematics
The collision -induced dissociation- (or Coulombexplosion-) energy E_{Cb} of molecular ions with kinetic energy E_{kin} is transformed from the projectile frame of reference (E_{Cb}) into the laboratory frame of reference by

$$\Delta E = \sqrt{cE_{Cb}\ E_{kin}}$$

Here c containes essentially the masses of the molecular fragments and the molecular ion [9]. If, e.g., the molecular ion has a fixed kinetic energy of $E_{kin}=10^6$ eV and a dissociation energy of typically $E_{Cb}=1$ eV, then the dissociation energy observed in the laboratory system is in the order of $\Delta E=1$ keV: The accelerator acts like an amplifier which transforms small E_{Cb}-energies into large ΔE-energies which are measurable with high precision with accelerator-based detection techniques. Thus, an E_{Cb} - resolution of <20 meV could be achieved and allows one to study physicochemical reaction processes of molecular ions (e.g. Franck-Condon factors) [10].
The large energy separation of the dissociating molecular fragments in the laboratory frame of reference and, consequently, also their large spatial separation provides new techniques to study bond lengths and stereo structures of molecular ions not easily accessible by other means [2,4]. Thus, only recently the stereo structure of such a simple molecular ion as H_3^+ could be determined experimentally by these techniques [11].
Furthermore, Auger electrons and characteristic X-rays suffer a Doppler shift or Doppler broadening [12] when emitted from coulombexploding molecular ions. The same kinematic transformation makes accessible also Auger electrons from beamfoil- or beam-gas excited extremely low energy electronic transitions including transitions in highly excited Rydberg states or "cusp electrons" [14,15].

Penetration of correlated particles through solids
After interaction with matter single charged particles of typical specific energy E_{kin}/M=1MeV/n generally have a much higher electron loss than electron capture probability. Highly excited and highly ionized, positively charged (q_1 q_2...) molecular fragments are generated in the collision [12]. After the molecular ion break-up in the entrance layer of the solid, the molecular fragments move under their mutual Coulomb force or under other forces associated with the process. The motion is not the one of independent fragments but of particles correlated in space and time. In addition to their mutual correlation they also modify the medium they penetrate: a non-spherical distribution of the target electrons around each fast

moving ion is created. The cylindrical symmetric potential the "wake" potential [13], associated with this non-equilibrium charge distribution oscillates along the ion trajectory. Its amplitude ϕ_w and wave length λ_w depend on the ionic carge q, the ion velocity v_p, on the dielectric response of the solid with plasmon frequency ω_p and on the damping of the plasmon oscillations. Under typical experimental conditions (E_p/M_p=0.1 MeV/n) with plasmon energy $h\omega_p$=20 eV one finds λ_w in the order of several 10A and ϕ_w in the order of several 10V. The wake potentials of each of the correlated fragments penetrating the solid are superimposed, they can modify dramatically many observable quantities such as the transmission and reconstitution probabilities of molecular ions through solids [7], the electron loss or capture in continuum states [15,16,17], the stopping power [18], the joint centre of mass, angular and energy distribution of fragments [4,19], quantum beat amplitudes of beam foil excited molecular ions [20], nuclear track formation and radiation - (here: heavy ion) damage of biological samples [21].
The penetration of positively charged, correlated ions is associated with the penetration of correlated electrons [16]. Their transmission probability depends strongly on the correlation and spatial orientation of the penetrating, clustered particles. In this context it is of interest to study the interaction and penetration of neutral beams such as H^0. The production probability of neutral beams at MeV energies is extremely low because of the high electron loss cross sections. The dissociation of molecular ions

($H_2^+ \longrightarrow H^0 + H^+$ or $H_2^+ \longrightarrow 2\,H^+ + e^-$) in soft collisions,

however, present a good possibility to produce neutral beams with reasonable intensity [7].

The double collision

The bond lenght or internuclear separation of molecular ions is in the order of $r=10^{-8}$ cm; particles of E/M=1MeV/n specific energy have velocities in the order of $v=10^9$ cm/s. The time of flight t of such a particle through a thin solid target (thickness, say, $x=10^{-6}$ cm), i.e., its transient - or dwell - time, is in the order of $t=x/v=10^{-15}$s. This transient time t is around typical inner shell vacancy life times of low-Z elements and makes possible life time measurements in the 10^{-15}s - time regime with the beam - in-foil - technique [12]. Suppose now, the internuclear axis of the molecular ion is oriented in the beam direction. The time interval between the first and the second collision of the constituents of a diatomic molecular ion with a target atom or nucleus is in the order of $t=r/v=10^{-17}$s. This time is short compared to many atomic or nuclear life times. A comparison of signals (e.g. X-rays, ionisation electrons, y-rays, nuclear reaction products...) generated by a diatomic projectile ion with signals produced by an isotachic monoatomic projectile would give access to the study of atomic or nuclear reactions with short life time ($t=10^{-17}$s) targets. Extrapolating the term coincidence one deals here with a "physical coincidence" resolution in the

order of 10^{-17}s.
The above arguments use an atomistic concept of two sequential single collisions with a defined and controlled spatial or temporal separation. As in the times of Thales of Milete, Leukippos, Newton or Goethe the dualistic approach calls for a continuum concept as well. These two concepts are physically manifest e.g. in the mechanisms of bremsstrahlung production and Cerenkov radiation production. In the present context the atom can be treated in a Thomas-Fermi-like approach [22], or the target as whole be described by its dielectric function; the excitation of the target medium is here represented statically by the excitation of plasmons, dynamically by the wake potential trailing the projectile [13, 22, 23]. This type of collective excitation of a solid has been studied with diatomic molecular ions [24]: The damped periodic fluctuations of the wake potential ϕ_1 created by the leading ionic fragment of coulombexploding molecular ions penetrating a solid effects the trailing fragment and its wake potential ϕ_2. Interference effects of the superimposed wake potentials ϕ_1 and ϕ_2 of the two fragments at the surface can lead to a pronounced change of the total electron yield if the internuclear separation r of the two fragments at the surface is controlled [24]. The molecular ion serves here as a new tool to probe dynamic properties of the solid with a 10^{-8} cm spatial resolution of a fraction of an Angström. Experiments should be performed to show whether or not such electron density interference effects can also influence other phenomena. Such phenomena may be: convoy electrons [15, 16], charge distribution [8], ion induced molecular desorption from solid surfaces [6], energy loss [18], nuclear track formation and radiation damage of molecules, macromolecules, in particular biological objects [21], channeling, sandwich target - or tilted foil-arrangements shock electron production [22, 23], sputtering [25].

Charge density
The double collision time interval mentioned in the preceeding chapter was typically in the order of 10^{-17} s. The charge of a single proton is in the order of 10^{-19} Cb. Extrapolating the term "current" to a single event, we can formally calculate the current of a, say, H_2^+ (E_p/M_p=1 MeV/n) to be $i=q/t=10^{-19}\text{Cb}/10^{-17}\text{s}=10^{-2}\text{A}$ [26]. The cross section of a molecular ion is in the order of $F=(10^{-8})^2$ cm^2 which leads to an extrapolated "current density" of $j=i/F=10^{16}$ A/cm^2, a truely exorbitant value. It signalizes, however, that locally, quite unusual, probably non-linear, non-equilibrium phenomena occur. Areas, where these arguments apply have been mentioned in the preceeding chapters already. One can speculate on other areas such as ion implantation, ion beam materials modification, fusion etc. The application of cluster ions or channeling conditions may further intensify these exotic effects.

Conclusions
It has been argued that fast molecular ions are a new and, up to now, only partially explored tool for experiments. The consequences of their kinematic properties, the motion of correlated particles through matter, the consequences of the

short but experimentally well controlled time interval between successive collisions of molecular fragments, and the consequences of the extrapolated current density are essential ingrediences. Experiments relate to such diverse fields as physical chemistry, stereo chemistry, solid state physics, surface physics, atomic physics and more. If cluster ions become available in accelerators [7] the principles compiled in this communication can open up new frontiers in basic and in applied research.

D. Hofmann's and H.J. Frischkorn's critical comments to the manuscript are much appreciated.

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DECAY OF HIGH-SPIN YRAST-ISOMERS AND DELAYED AUTOIONIZATION OF HI FUSION RECOIL IONS

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When heavy-ion fusion recoil atoms leave the target and move into the vacuum, their ionization degree with high probability may sufficiently exceed the value of equilibrium ionic charge distribution [1] . The dominant mechanism of heavy nuclear reaction products enhanced ionization is considered as inner-shell electron vacancy creation due to internal conversion of nuclear transitions followed by Auger-cascades. In free recoil atoms this process may result in loss up to the half of orbital electron number [2] .

The direct experimental evidence for existence of such mechanism was achieved in our experiments on ionization time measurement of fusion products from reaction $^{138}Ba(^{22}Ne,xn)$ [3]. Experiment shows the prominent isotopic dependence of the ionization time of $^{151-153}Dy$ recoil ions (these nuclei belong to the high-spin yrast-isomers island near the quasi-doble-magic nucleus ^{146}Gd). Time intervals in which enhanced ionization occures are correspond to the life-times of high-spin isomeric states of these nuclei.

Observed in this way delayed nuclear-induced autoionization as a result of the influence of isomeric state decay on the free recoil atomic electron cloud may be a good tool for:

1) nuclear influence on atomic electron cloud and inverse influence of electron shell structure on nuclear processes study;

2) nuclear features study from electron shell perturbation;

3) spectroscopy of highly-ionized atoms with inner-shell vacancy;

4) the nature of hiperfine interaction study in free recoil atoms.

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LEVEL MIXING RESONANCES ON ORIENTED NUCLEI

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In atomic spectroscopy crossings and anticrossings of electronic levels are well studied, and have been a source of a considerable amount of information. Also, in the hyperfine splitting of nuclear levels, such crossings and anticrossings can occur. Until recently, these fenomena have been used for hyperfine investigations only in a few cases.

We study anticrossings (we call them level mixings) which occur in the hyperfine energy level scheme of nuclei experiencing an axially symmetric quadrupole interaction and a magnetic dipole interaction, the axes of which are slightly misaligned by an angle β. In an angular distribution experiment, in which the initial orientation can be produced by any means (very low temperature, in beam nuclear reactions, beam-foil interaction, ...) the angular distribution of radiation emitted by such nuclei shows resonances under influence of these mixings.

The observation of these resonances allows very accurate measurements of hyperfine parameters, especially of the quadrupole frequency. Furthermore, by this method hyperfine parameters of nuclei with lifetimes shorter than the spin-lattice relaxation time can be studied. The less accessible lifetime range between microseconds and minutes is covered by this method.

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HIGH-SPIN STATES IN THE ODD-EVEN $^{135,137}Pr$ AND ODD-ODD ^{136}Pr NUCLEI

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The transitional nuclei with 50 < Z, N < 82 exhibit collective structure ($h_{11/2}$ proton) having a similar behaviour to the one already observed ($h_{11/2}$ and $h_{9/2}$ proton) in heavier transitional nuclei with proton number below and close to Z = 82 magic number (1-3).

The neutron deficient praseodyum nuclei have been studied using in-beam gamma-ray spectroscopic methods by means of the $^{125,126}Te$ (^{14}N, xnγ) and $^{122,124}Sn$ (^{19}F, xnγ) reactions at energies of 45-72 MeV obtained from FN Bucharest Tandem.

The building of level schemes was carried out from γ - γ coincidences, excitation functions, intensity balance arguments and populations in different reactions. The spins of the levels are based on the gamma-ray angular distributions.

One observes that the lighter odd-A praseodyum nuclei presents the negative-parity decoupled bands based on the coupling of $h_{11/2}$ proton orbital. The coupling of $d_{5/2}$ and $g_{7/2}$ proton orbital with even core produces the positive-parity states. Also the states in odd-odd ^{136}Pr nucleus can be explained within the shell-model.

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THERMAL NEUTRON CAPTURE IN sd-SHELL NUCLEI*

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We have used the curved crystal Bragg, Ge(Li) and pair spectrometers at the high flux reactor of ILL for a systematic study of the (n,γ) reaction on odd-A nuclei in the sd-shell |1-7|. In each of the final nuclei ^{20}F, ^{24}Na, ^{28}Al, ^{36}Cl and ^{40,41,42}K, some 30 - 130 levels have been identified, many with spin-parity assignments, and some 150 - 500 γ-ray transitions have been located, by the Ritz combination principle. Level and neutron binding energies have been determined with a precision better than 10 ppm relative to the ^{198}Au standard |8| (see Table I).

A survey will be given on the deduced level densities, γ-ray multiplicities and distributions of E1 and M1 primary transitions. Non statistical effects in the population of particle-hole states near the ^{40}Ca shell closure and in the distribution of the M1 strength will be discussed.

Table I: Survey on (n,γ) reactions in the sd-shell

Nucleus	Capture state I^π	B_n(keV)	Final states observed	Number of primary transitions total	E1	M1	Ref.
^{20}F	1^+	6601.33(4)	26	20	6	11	|1|
^{24}Na	$1^+,2^+$	6959.73(7)	45	42	15	18	|2|
^{28}Al	$2^+,3^+$	7725.18(9)	50	46	8	31	|3|
^{36}Cl	2^+	8579.68(9)	75	67	26	26	|4|
^{40}K	$1^+,2^+$	7799.55(8)	53	50	23	9	|5|
^{42}K	$1^+,2^+$	7533.82(8)	132	108	?	?	|6|
^{41}K	$7/2^-$	10095.25(10)	107	95	25	7	|7|

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Extended parabolic rules for odd-odd nuclei

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Content:

1. Parabolic rule for proton-neutron and proton-neutron-phonon multiplets. Illustrations.

2. Extension of the parabolic rules for cluster states

3. Extension of the parabolic rules with inclusion of surface-delta, surface-spin and tensor interactions

4. Computer code OTQM for odd-odd nuclei with inclusion of particle-phonon interaction, particle-phonon exchange (Pauli principle), surface delta interaction, surface spin interaction and tensor interaction.
Illustrations.

5. New SU(3) limit for odd-odd nuclei-analytic solution for the supersymmetric $J = j_p + j_n$ band

- computed supersymmetric - and signature-bands
- illustrative calculations in SU(3) limit for configurations $\pi g_{9/2} \nu d_{5/2}$ and $\nu i_{13/2} \pi d_{5/2}$.

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