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Conference on
Frontiers of Nuclear Structure

Clark Kerr Campus, UC Berkeley, CA
July 29th-August 2nd, 2002

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Oral Presentations

Poster Presentations

Oral Presentations

PROBING THE GATEWAY TO SUPERHEAVY NUCLEI IN CRANKED RELATIVISTIC HARTREE-BOGOLIUBOV THEORY*

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The cranked relativistic Hartree+Bogoliubov theory [1] (including approximate particle number projection through the Lipkin-Nogami method and the Gogny force in the particle-particle (pairing) channel) has been applied for a systematic study of the nuclei around ^{254}No [2]. These are the heaviest elements with a large body of spectroscopic data for testing the reliability of mean-field theory predictions for superheavy nuclei. The deformation, rotational response, pair correlations, quasiparticle spectra, nucleon separation energies and shell structure of these nuclei have been extensively studied with different RMF forces.

While the deformation properties are well reproduced, the calculations reveal that an accurate description of other observables requires better effective forces both in the particle-hole and particle-particle channels. The calculated moments of inertia show only small sensitivity to the RMF force and thus to the details of the single-particle structure. In contrast to previous studies, where the moments of inertia in lighter systems [1,3] are well reproduced, good agreement in the heaviest nuclei can be obtained only with a decrease ($\approx 12\%$) of the strength of the D1S Gogny force in the pairing channel.

Analysis of quasi-particle spectra in odd nuclei with the NL1 and NL3 forces suggests that the energies of most of the spherical orbitals, from which active deformed states of these nuclei emerge, are described with an accuracy better than 0.5 MeV. However, for a few subshells the discrepancies reach 1.0 MeV. Considering that the RMF forces were fitted only to bulk properties of spherical nuclei without considering single-particle energies, this level of agreement is impressive. However, in very heavy systems, where the level density is high, the accuracy is not sufficient for reliable predictions of the location of deformed shell gaps, which are small (≈ 1 MeV).

The implication of these results for the study of superheavy nuclei, e. g. the possible uncertainties of predictions for magic gaps, will be discussed. In addition, the study of a number of effects in superheavy nuclei, such as pairing effects and the importance of self-consistency in shell structure, is presently in progress.

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1. A. V. Afanasjev, P. Ring and J. König, Nucl. Phys. **A 676** (2000) 196
2. P. Reiter et al, Phys. Rev. Lett **82** (1999) 509
3. A. V. Afanasjev et al, Phys. Rev. C **62** (2000) 054306

Gamma spectroscopy of C and O neutron drip-line nuclei

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In-beam γ-spectroscopy technique associated with fragmentation reactions of radioactive beams have been recently used at GANIL in order to study the last bound carbon and oxygen isotopes and neighboring nuclei. A secondary beam mainly composed from ^{26}Ne,^{29,30}Mg,^{27,28}Na obtained by the fragmentation of a ^{36}S beam on a thick ^{12}C target using SISSI device was send on a target made of plastic scintillator. The produced fragments from this secondary reaction were detected using SPEG spectrometer which was optimized for the transmission of ^{24}O. The target have been surrounded by 74 BaF_2 detectors and 4 Ge clover type detectors. γ spectra have been obtained in coincidence with a number of very neutron rich nuclei detected by SPEG. Results on γ-spectroscopy of very neutron rich carbon and oxygen nuclei, known as drip line nuclei with halo structures, will be presented and discussed.

RECENT RESULTS OF PROTON DRIP-LINE STUDIES AT THE HRIBF RECOIL MASS SPECTROMETER

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Observation of protons emitted from nuclei beyond the proton drip-line allows one not only to establish the limits of stability for a given element, but also gives information on the structure of the parent and daughter nuclei. In order to determine an accurate spectroscopic factor for the proton emission, a precise measurement of the energy and partial proton half-life must be made. For most of the known proton emitters with $Z < 72$, the ß -decay branching ratio is either unknown, or has very large error bars. As such, our experimental program has concentrated on those spherical proton emitters with very short half-lives (i.e. μsec).

In this talk, I will present recent results on the proton decay of short-lived proton-emitting nuclei, performed at the focal plane of the Recoil Mass Spectrometer (RMS) at the Holifield Radioactive Ion Beam Facility (HRIBF) using a Double-Sided Si Dectector. In order to observe short-lived activity, we have installed and commissioned a digital flash ADC electronics system for proton decay studies using the Double Sided Strip Detector (DSSD). This new system is based on the Digital Gamma Finder (DGF-4C) units produced by X-ray Instrumentation Associates (XIA).. This system involves fitting the preamp signals via the on-board processors. The signal from the high energy recoil takes several tens of □sec to fall to the baseline, fast decays will then appear as a small "pileup" signal on top of the larger signal. By fitting the two signals, we are able to observe decays within ~500 nsec of implantation with a low-energy threshold of less than 300 keV.

ON THE TWO-PROTON EMISSION OF ^{45}FE - A NEW TYPE OF RADIOACTIVITY

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In an experiment at the SISSI-LISE3 facility of GANIL, the decay of the proton drip-line nucleus ^{45}Fe has been studied after projectile fragmentation of a ^{58}Ni primary beam at 75 MeV/nucleon impinging on a natural nickel target. After an event-by-event identification of the fragments selected by LISE3, fragment-implantation events have been correlated with radioactive decay events in a 16×16 pixel silicon strip detector. The decay-energy spectrum of ^{45}Fe implants shows a distinct peak (12 correlated events) at (1.06±0.04) MeV with a half-life of $T_{1/2} = (4.7^{+3.4}_{-1.4})$ ms. None of these events is in coincidence with β particles which were searched for in a detector next to the implantation detector. For a longer correlation interval between ^{45}Fe implants and subsequent radioactive decays, daughter decays of the two-proton daughter ^{43}Cr can be observed by decay-energy and decay-time distributions in nice agreement with the known decay characteristics of this nucleus. The observed decay energy agrees nicely with several theoretical predictions for two-proton emission of ^{45}Fe. Barrier-penetration calculations clearly favour a di-proton emission picture over an emission of two individual protons with half the decay energy each and point thus to a ^{2}He emission mode, a new type of radioactivity.

We will discuss the results obtained in the present experiment and discuss future work to be done on ^{45}Fe and other nuclei with the present technique as well as with a detection system adopted to experimentally visualize the two protons and to measure their individual energies and their relative angle.

HIGH ENERGY PHOTONS FROM VERY SYMMETRIC REACTIONS: THE GIANT DIPOLE RESONANCE IN THE HIGHLY ROTATING ^{179}AU NUCLEUS

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The high energy gamma-rays emitted by the symmetric reaction ^{90}Zr + ^{89}Y at a beam energy of 352 MeV have been measured at the Argonne National Laboratory using an experimental set up consisting of the Fragment Mass Analyser (FMA), a BGO multiplicity filter and 4 clusters of 37 BaF_2 detectors each.

Such symmetric fusion of two nearly closed shell medium heavy nuclei has the peculiar feature of leading to a warm compound nucleus that can deexcite to its ground state without the evaporation of nucleons (radiative fusion). There are two possible and different mechanisms leading to "radiative fusion". The direct process in which the emission of a single γ-ray populates "directly" the states around the Yrast line. The second mechanism consists of a two step process, namely the formation of the compound nucleus ^{179}Au by fusion reaction and the 0 nucleon channel is one of the possible decay mode together with particle evaporation with all the particle and γ-decay modes obeying statistical laws.

The first attempt to measure γ-rays from the symmetric reactions of medium mass nuclei have been performed at GSI over a decade ago. It was found that the relative population of the 0, 1 and 2 nucleon evaporation channels strongly depends on the E1 strength (measured with reasonable statistics only up to 4-5 MeV) but it was not possible to draw conclusions on the properties of the giant dipole resonance and on nuclear shapes involved in the reaction.

In the present experiment the high-energy γ-ray spectra associated with the evaporation of 0,1 and 2 nucleons have been measured up to 13 MeV with an increase of statistics of more of two orders of magnitude. The statistical model analysis indicates that the radiative-fusion process, namely the 0 particle emission channel can be described as statistical decay from the compound nucleus with shape and deformation similar to that deduced from the Yrast line. Similar shapes and deformations have been measured also for the 1n and 1p channels.

This suggests that shell effects are important also when the nucleus is excited at medium temperature. The same conclusion is supported by the fact that the width of the GDR has a value that is close to that predicted by the thermal fluctuation model including shell effects.

SHAPE CO-EXISTENCE AT THE OUTER EDGES OF STABILITY*

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Above N=82, the proton dripline follows closely the outer edges of the well deformed rare-earth region, and the ground states of nuclei which make up the dripline here are expected to have spherical or weakly deformed prolate shapes. Our recent experimental studies have concentrated in the upper portion of this region, namely the study of excited states in Os (Z=76) through Pb (Z=82) isotopes located in the vicinity of the proton dripline. One of our principle motivations has been to characterize the evolution of shape from the well studied deformed region to the near spherical ground states deduced for the proton emitters.

In-beam γ-ray studies of such heavy systems far from stability are hampered by the large fission cross sections associated with the heavy-ion fusion reactions which are used to produce these proton-rich nuclides. However, the use of recoil separators allows one to easily distinguish fusion-evaporation residues from fission products. In addition, all nuclides in this region which lie at the dripline or beyond, decay via charge particle radioactivity. As a result, the recoil decay tagging (RDT) technique can be utilized allowing for in-beam γ-ray studies of nuclides produced with sub-μb cross-sections. By coupling the Fragment Mass Analyzer (FMA) with Gammasphere, the high-spin structure of a number of nuclides in this Os-Pb region have been investigated. In addition, complimentary decay studies of these same nuclides has allowed, in several instances, spin/parity and excitation energy assignments for all observed states. Results to be discussed include: (1) the characterization of the ground state deformations in proton unbound Ir and Au nuclei, and (2) the identification of two isotopes, ^{175}Au and ^{179}Hg, where structures built on three distinct shapes at low excitation energy have been observed.

*This work was supported in part by the U.S. DOE, under Contract No. W-31-109-ENG-38.
[1] F.G. Kondev *et al.* Phys. Lett. B **512** (2001) 268.
[2] F.G. Kondev *at al.* Phys. Lett. B **528** (2002) 221.

CRITICAL POINT SYMMETRIES AND PHASE TRANSITIONS IN FINITE NUCLEI

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Recent experiments and interpretation of existing data suggest that nuclei in shape changing regions can exhibit behavior at low energies, as a function of nucleon number, that resembles the phase transitions seen in macroscopic systems. (Of course, their behavior is muted due to the finite nature of nuclei.) These observations inspired the development, testing, and confirmation of new structural symmetries for nuclei at the "critical points" of these phase transitional regions. These critical point symmetries, in particular those denoted by the labels X(5) and E(5), provide new, analytic, parameter-free paradigms for nuclear structure, expanding considerably the number of such paradigms beyond the traditional vibrator, rotor and asymmetric rotor standards that have existed for decades.

These new developments will be discussed, along with a few comments on the origins of deformation in nuclei, and on how the addition of a few nucleons in heavy nuclei can so drastically change their structure.

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THE MASSES OF A ≈ 60 – 70 NUCLEI CLOSE TO THE N = Z LINE

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Neutron-deficient nuclei close to the N = Z line provide astrophysical input for the modeling of the rapid proton-capture (rp-)process as well as information relevant to nuclear structure in a region of high deformation. The ground-state masses of these nuclei constitute crucial data on which the understanding of the nucleosynthesis of the heavy elements and energy generation in the rp-process depend. In particular masses of nuclei close to the N = Z line above ^{56}Ni are used to determine the path and waiting points of the rp-process. The masses in this region close to the proton drip-line are, however, very scarcely and poorly known experimentally.

A direct mass measurement of neutron-deficient nuclei with A ≈ 60 – 70 was performed at GANIL [1,2]. The direct time-of-flight technique using the SPEG magnetic spectrometer was for the first time extended to the neutron-deficient side of the nuclear chart. Secondary radioactive ion beams were produced via the fragmentation of a 73 MeV/nucleon high-intensity ^{78}Kr beam on a ^{nat}Ni target located between the two superconducting solenoids of the SISSI device. The method consists in measuring event by event the magnetic rigidity of the ions and their time-of-flight over a known flight path, using a position-sensitive microchannel-plate detector and fast microchannel-plate and silicon detectors, respectively. Particle identification (Z and A) is obtained using a cooled silicon-detector telescope, surrounded by high-efficiency germanium detectors to correct for the presence of isomers in this region of nuclei. The unknown masses are determined relative to the known masses of less exotic ions, produced and transmitted simultaneously, which are taken as references. This very sensitive direct mass-measurement method achieves a mass resolution of 2-3 $\times 10^{-4}$ for a time-of-flight of the order of 1 μs over a linear flight path of about 80 m.

The masses of very neutron-deficient ^{66}As, ^{68,70,71}Se and ^{71}Br were measured for the first time and those of ^{64,65}Ge and ^{67}As remeasured, with total uncertainties ranging from 200 to 1000 keV, including systematic, extrapolation and statistical errors. These new results will be discussed and compared to other recent experimental data and mass predictions.

1. M. Chartier *et al.*, Nucl. Phys. **A637** (1998) 3.
2. G. F. Lima *et al.*, accepted in Phys. Rev. **C** (2002).

NUCLEAR STRUCTURE OF NEUTRON-RICH NUCLEI IN THE SD-SHELL

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The fragment separator FRS(GSI) was used as an energy-loss spectrometer to measure momentum distributions of relativistic fragments after one-nucleon removal for different secondary beams in coincidence with gamma rays from the de-excitation of those fragments. One-nucleon removal cross-sections were also measured with the same experimental setup. The combination of those measurements has been used to extract information about the nuclear structure (assignment of spins and parities of the ground states) in a wide range of species in the sd-shell and has allowed to test theoretical predictions for the nuclear structure of halo nuclei.
The systematic study and comparison of longitudinal and parallel components of the momentum distributions has been used to learn about the influence of the reaction mechanism in the process. Those reaction effects have been studied as well measuring on different targets (C and Pb), and from them we could learn about the difference between nuclear and Coulomb breakup.
The proton-rich isotope ^{8}B is presented as a test case to show the power of the experimental technique that combines in-beam gamma spectroscopy at relativistic energies with secondary nuclear reactions. New and very interesting experimental results on momentum distributions(parallel and longitudinal) and one-nucleon removal cross-sections in coincidence with gamma ray detection for neutron-rich N, O and F isotopes at relativistic energies will also be presented and discussed in detail.

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NUCLEAR STRUCTURE NEAR THE DRIP LINE USING LARGE GAMMA-RAY DETECTOR ARRAYS

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Big Ge-arrays like Euroball or Gasp have been built with the main purpose of studying high angular momentum phenomena in nuclei. When coupled with powerful ancillary detectors they became also excellent instruments to explore the properties of very exotic nuclei far from Beta-stability. A large fraction of the experiments has been therefore devoted to study both proton-rich and neutron rich nuclei populated using stable beams provided by the Legnaro and Strasbourg accelerators. In the talk the main emphasis will be on nuclei lying close to the N=Z line where fundamental properties of the nuclear force can be tested, like isospin symmetry and isospin breaking terms, proton neutron pairing, dripline effects.

We have investigated the high spin structure of even-even and odd-odd N=Z nuclei in the A~70 mass region. New results on ^{62}Ga, ^{66}As, ^{70}Br will be reported.
The recent observation of the excited states of ^{67}Se has also allowed to extract the Coulomb energy differences (CEDs) between isobaric analog states in the A=67 mirror pair. Here the peculiar behavior of the CEDs can possibly be related to the contribution of the isospin breaking electromagnetic spin orbit term of the nuclear Hamiltonian.

TOWARDS THE SOLUTION OF COUPLED CLUSTER EQUATIONS*

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One of the frontiers we face in nuclear science today is the discovery, description, and understanding of exotic nuclei. These systems offer a number of challenges: they will often be far from closed core configurations and will therefore be difficult to describe with conventional shell-model methods. While experimental techniques and the promise of RIA are indeed pushing us into new regions of the nuclear many-body problem, various alternative *ab initio* methods must also be investigated that will allow for a theoretical description of the nuclear many-body problem.

I will discuss the application of coupled cluster theory to the nuclear many-body problem. Coester and Kummel developed coupled cluster theory in the late 1950's, but surprisingly few researchers pursued applications of coupled cluster theory in nuclear physics since initial investigations by Zabolitsky *et al* in the early 1970's. While the nuclear physics community did not pursue these approaches beyond the early initial studies (and some recent work by Heisenberg *et al*) they were pursued with vigor in computational quantum chemistry and have become *the* method of choice for precise calculations of both ground and excited state properties of both atoms and molecules, and for chemical reaction studies.

Coupled cluster methods (CCM) have been applied in chemistry up to the S_4 and S_5 levels. As a first step of application in modern nuclear many-body problem, I will apply the CCM at the one- and two-body (single and double correlations, or S_1 and S_2) levels. This is known as the CCSD method. Instead of directly applying this technique to the bare nucleon-nucleon interaction, I will use instead a *G*-matrix as the starting point to describe several systems in a very large model space. During the talk, I will also assess the applicability of the CCM approach to the nuclear many-body problem especially in the context of RIA physics.

*Oak Ridge National Laboratory is managed by UT-Battelle for the US Department of Energy under Contract Number DE-AC05-00OR22725.

GROSS SHELL STRUCTURE OF MOMENTS OF INERTIA IN THE ABSENCE OF PAIR CORRELATIONS

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We present a systematic study of the deviation of the moment of inertia from the rigid-body value in nuclei at high spins where the pairing correlations are expected to be negligeable. In that case, the deviation from the rigid-body moment of inertia is a manifestation of shell effects in a finite quantal system.

Average kinematic moments of inertia are derived from the experimental energies of positive and negative parity yrast levels for cascades reaching spins greater than $17\hbar$ for lower masses and $22\hbar$ for higher masses. Substantial deviations (called $\mathcal{J}_{sh}$) from the rigid-body values are found (see Fig.1), reaching ~100% near the N=126 spherical closed shell. The moments of inertia calculated by means of the cranked Woods-Saxon shell model without pairing show deviations similar to those found in experiment. We discuss the gross dependence of moments of inertia and ground state shell energies on the neutron number in terms of the semiclassical periodic orbit theory (POT). Consideration of the simplest orbits (triangle, square, and five-point star) allows us to understand several features from a common point of view. The fact that near the closed shells the moments of inertia are much smaller than the rigid body value, that they overshoot the rigid body value around N=90, but that in most of the open shell they stay below it reflects the shell structure caused by the orbits in the meridian planes. The appearance of high-K isomers around N=100 and of high spin isomers near the closed shells is explained as a preference for rotation about the symmetry axis that is due to orbits in the equatorial plane. It also becomes evident why the moments of inertia in superdeformed bands are close to the rigid body value. We shall point out new relations between the shell effects in the ground state binding energies, the nuclear deformations and the deviations of the moments of inertia from the rigid body value, which are all due to the same periodic orbits.

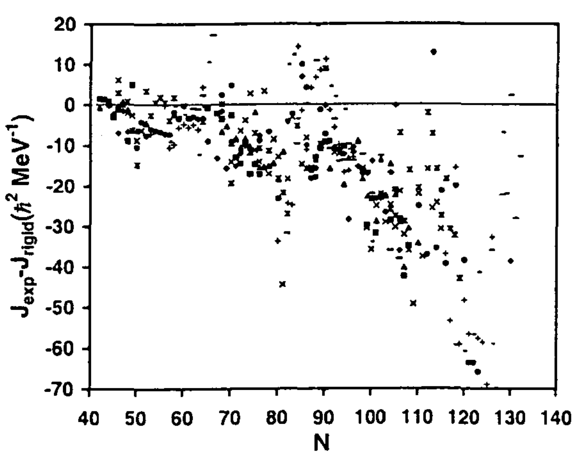

Figure 1: Experimental deviations from the rigid-body moments of inertia as a function of neutron number.

ISOMERS AS A PROBE OF TRIPLE SHAPE CO-EXISTENCE IN ^{188}PB

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Nuclei have a surprising ability to exhibit distinct co-existing shapes, controlled by non-uniformities in the single-particle level densities near the Fermi surface and through the population of specific orbitals by valence protons and neutrons. Although lead nuclei are generally spherical because of the closed proton shell at Z=82, the coexistence of three shapes at low energy, spherical, oblate-deformed and prolate-deformed, is predicted to occur near neutron number N=106. Distinguishing between such shapes through level structures is generally ambiguous at low angular momentum but the presence of metastable states with different spins and parities and decay properties may provide a means of characterisation [1]. We have offered such evidence recently for the case of ^{188}Pb [2] and have now carried out an extensive measurement using time correlated gamma-gamma coincidence techniques with GAMMASPHERE at the 88-inch cyclotron, LBNL. Collective structures above the isomers have been observed allowing the conjectures to be tested. Additionally, the fragmented decay of the proposed ($K^{\pi}=8^-$) prolate isomer has provided a means of identifying non-yrast states which were previously inaccessible. This includes the yrare positive parity sequence arising from the excited 0^+ states. The implication of the new results, including analysis of the properties of the observed bands illustrated in figure 1, and features such as electric monopole transitions between the low-spin states of the yrast and yrare bands, will be discussed in the context of band-mixing and shape co-existence, as well as the related structures in neighbouring nuclei and systematics in the region.

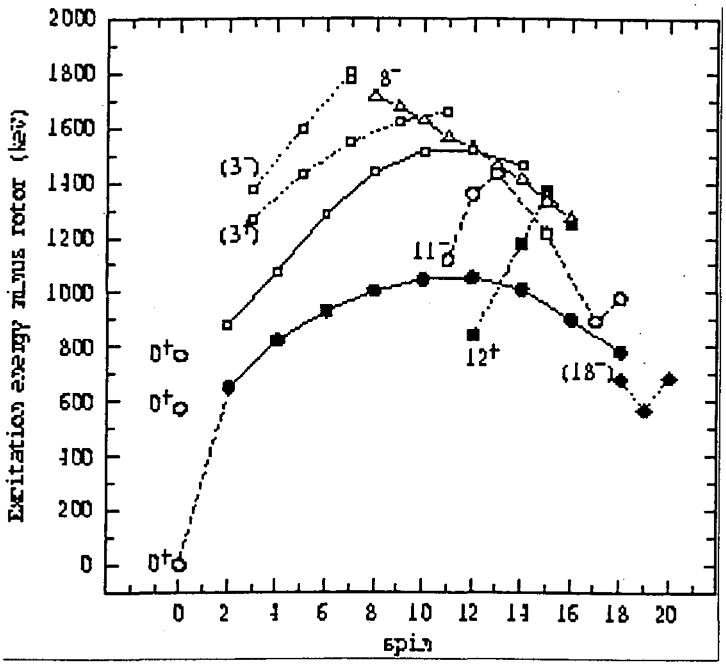

Figure 1. Energies relative to an arbitrary rotor.

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MINIBALL
A GE DETECTOR ARRAY FOR EXPERIMENTS AT THE NEW RADIOACTIVE BEAM FACILITY REX-ISOLDE*

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and the MINIBALL collaboration

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A new generation of position-sensitive Ge detector arrays is being developed for the investigation of rare γ decays at the upcoming radioactive ion beam facilities. These arrays are optimised for high full-energy peak efficiency and angular resolution of the γ-ray detection needed for a proper Doppler correction of the γ-rays emitted by fast recoiling nuclei. MINIBALL consists of 40 six-fold segmented, encapsulated Ge detectors which are clustered in eight cryostats with three detectors each and four cryostats with four detectors. The individual components – the six-fold segmented Ge detector, the cryostats, the fast preamplifier, the digital pulse-processing electronics and the flexible mechanical frame – and their properties are described. It is shown that from pulse-shape analysis of the events within a detector segment the effective granularity of the MINIBALL array can be enhanced from 240 to ~ 4000 [1].

MINIBALL Phase I (eight three-way cryostats) was commissioned in autumn 2001 at the FN tandem accelerator of the University of Cologne and subsequently operated in experiments for two months. The experimental programme included the investigation of nuclear symmetries at the critical point in ^{122}Ba, ^{160}Dy and ^{152}Sm, the study of T=0 pairing in the N=Z nuclei ^{48}Cr and ^{62}Ga and the spectroscopy of ^{196}Au. In March 2002 MINIBALL will be installed at CERN at the new radioactive beam facility REX-ISOLDE. The first experimental programme at REX-ISOLDE which is planned to commence in late April will concentrate on Coulomb excitation of proton-rich nuclei near the N=Z line at A=50-70 and on the study of neutron-rich light nuclei by neutron and proton pickup reactions. Preliminary experimental results will be presented as well as the performance of MINIBALL deduced from the experiments.

The position-sensitive MINIBALL Ge detector is an intermediate step on the way from 4π arrays like EUROBALL towards the γ-ray tracking arrays AGATA and GRETA. Our development is based on the encapsulation technology which has proven to facilitate the maintenance and enhance the reliability of composite Ge detector systems. With the first 12-fold segmented, encapsulated detectors the technology has been extended for the encapsulation of multi-segmented Ge detectors. The layout of the prototype of a 36-fold segmented, encapsulated AGATA detector and a three-way cryostat is being prepared at the moment.

*This work is supported by the German BMBF, the Flemish Fund for Scientific Research and by the European Community under contract No. TMR ERBFMRX CT97-0123.

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LEFT-HANDED NUCLEAR ROTORS

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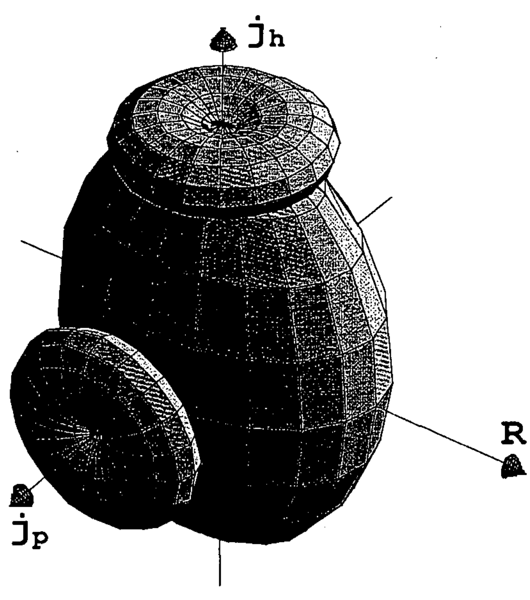
The rotational motion in triaxial nuclei may attain a chiral character. If the rotational axis does not lie in one of the planes spanned by the three different principal axes of the triaxial density distribution, these axes form either a left- or a right-handed system with respect to the rotational axis. The two chiralities manifest their existence as two $\Delta I=1$ rotational bands of the same parity and (nearly) the same energies. Tunneling between the left- and right-handed configurations causes a splitting of the doublets. The available experimental evidence for chirality will be critically reviewed.



The angular moments of a particle j_p, of a hole j_h, and of the remaining nucleons R may arrange into a left-handed system, as shown, or into a right-handed system, by reversing the orientation of R.

INTRUDER AND MULTI-PHONON STATES IN ^{108}Cd*

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^{108}Cd was investigated using the powerful combination of two complementary experimental techniques: $\gamma\gamma$-spectroscopy following the β-decay of ^{108}In and the non-selective (α, n) fusion evaporation reaction. This resulted in the observation of 120 new states and more than 580 new transitions. 30 new spin assignments and more than 80 multipole mixing ratios were derived from $\gamma\gamma$-angular correlation analyses and eight effective lifetimes stem from a Doppler Shift Attenuation (DSA) analysis following the fusion evaporation reaction.
The proton $2p - 2h$ excited intruder band, that is typical for near proton-magic nuclei, was established up to the 4^+ member including lower limits for the absolute $E2$ transition strengths of interband and intraband decays. The heavily suppressed absolute $E2$ transition strength out of the proposed intruder band indicates pure bands with little mixing. These findings are compared to neighboring Cd isotopes and related six quasi-proton structures.
An analysis of the multi-phonon structures observed in ^{108}Cd and heavier Cd isotopes shows that the chain of even mass cadmium isotopes may form a transitional path between the vibrational U(5) and gamma-unstable O(6) dynamical symmetry with ^{108}Cd closer to the gamma-soft case.

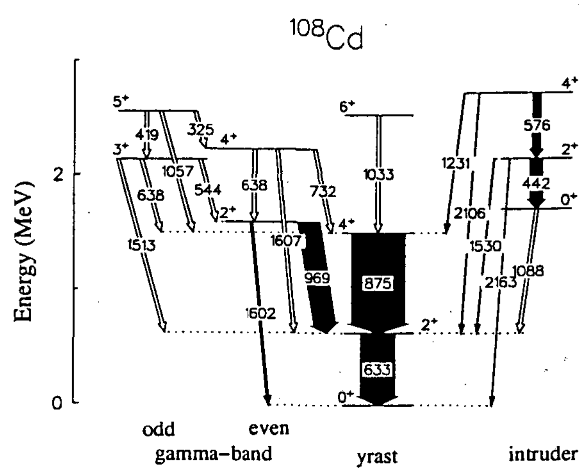

Figure 1: Prominent positive parity band structures in ^{108}Cd [1]. The width of the black arrows is proportional to the absolute $B(E2)$ transition strength. For the newly established intruder band we give only lower limits. The results for the ground band and the 2_2^+ state were taken from literature.

* This work was partly supported by the Deutsche Forschungsgemeinschaft under Contract No. Br799/10-2.

1. A. Gade et al., Phys. Rev. Rapid Comm., in press.

STUDY OF EXCITED STATES IN ^{12}N WITH RADIOACTIVE BEAMS FROM BEARS.

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A group of researchers from HRIBF have been developing efficient techniques to do detailed studies of nuclei that can not be produced otherwise with stable beams. A program to study resonant states in light nuclei with inverse kinematics and using thick targets together with double-sided silicon strip (high granularity) detectors has led to the discovery of the simultaneous two-proton emission from excited states in ^{18}Ne formed with the use of the exotic radioactive beam ^{17}F [1]. Furthermore, important information such as determining the quantum numbers of resonant states in nuclei of astrophysical interest is been obtained. Recently, radioactive ion beams of 55 MeV ^{11}C from the BEARS project at LBNL were used to study several resonance states in ^{12}N. An excitation function of elastic scattering cross section was measured in a single exposure covering the center of mass energy range between 300 keV to 1200 keV. We compare the excitation functions of ^{11}C + ^{1}H with the ^{11}B + ^{1}H obtained at HRIBF using the same technique. The data was analyzed using the R-matrix code MULTI.

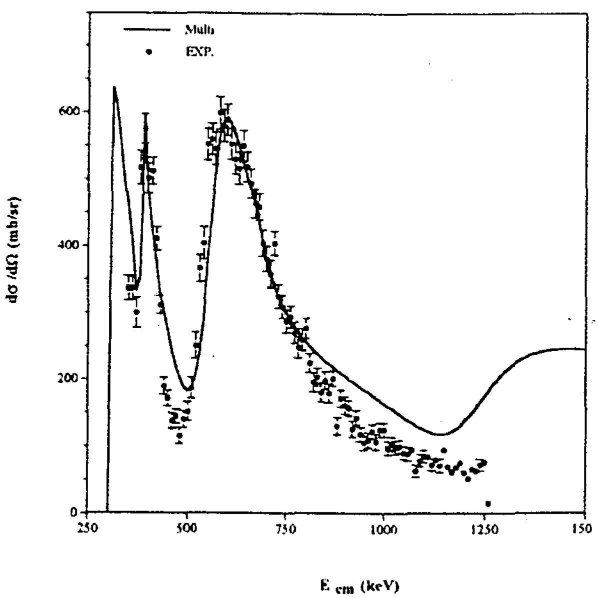

Figure 1. Experimental excitation function obtained from the recoil proton spectra for the reaction ^{1}H(^{11}C, p). The solid curve is an R-matrix fit.

*This research is supported by the the U.S. Department of Energy under Contract No. DE-AC05-76OR000333 with UT-Battelle, LLC.

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G FACTOR MEASUREMENTS OF ISOMERIC STATES IN NEUTRON RICH NUCLEI

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Here we report on the first application of the TDPAD method to measure the g factor of neutron-rich isomeric states, produced and aligned in projectile fragmentation reaction. The feasibility of similar measurement opens up a new, unexplored part of the nuclear chart for studies of the magnetic moments of microseconds isomers.

Nuclei around ^{68}Ni were produced following the fragmentation of 61.6 MeV/u ^{76}Ge on a 145 mg/cm^2 Be target. The isotopes of interest were selected using the LISE spectrometer at GANIL, Caen, France, and were implanted in a high purity Cu foil fixed between the poles of an electromagnet. Two Ge Clover detectors, positioned in a plane perpendicular to the holding magnetic field, were used to observe the rotation of the nuclear spins ensemble and to derive the experimental R(t) function.

In the same setting we could select two different isomeric states, which properties were suitable for a TDPAD measurement. The g factors of ^{69m}Cu ($J^\pi = 13/2^+$, $T_{1/2}$ = 354 ns, E_x = 2741 keV) and ^{67m}Ni ($J^\pi = 9/2^+$, $T_{1/2}$ = 13.3 μs, E_x = 1007 keV) were determined experimentally and were compared with shell model calculations. The theoretical estimations are in good agreement with the experimental g factor for $|g|(^{69m}Cu) = 0.213(25)$. However, $|g|(^{67m}Ni) = 0.125(6)$ cannot be reproduced in the $\nu(fp+g_{9/2})$ model space and points towards possible excitation across the Z=28 shell gap. More experimental data is necessary for the better understanding of the structure of the states in the neutron-rich N=40 region.

VERY EXTENDED SHAPES IN ^{108}Cd*

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Cranked Strutinsky calculations [1] predict very extended shape minima in ^{108}Cd with deformations larger than the superdeformed shapes observed in other mass regions. An experiment to search for such structures was performed with the Gammasphere spectrometer. High-spin states in ^{108}Cd were populated in the reaction ^{64}Ni(^{48}Ca,4n) at a beam energy of 207 MeV with the beam provided by the ATLAS accelerator at Argonne National Laboratory.

A band associated with a very deformed shape was found in this experiment [2]. A lifetime analysis of this band resulted in a lower limit for the deformation corresponding to an axis ratio of $c/a > 1.8$, compared to the theoretical prediction of $c/a \simeq 2.3$. Since only a lower limit for the deformation could be given, the possibility that the band is associated with the predicted larger deformation cannot be ruled out.

The data also revealed a second, excited band in ^{108}Cd [3]. The dynamic moments of inertia for both bands show a very similar behavior. However, the decay paths to normal deformed states could not be established, so that the spins of both bands remain unknown. The lifetime analysis for the excited band using the method of residual fractional Doppler shifts resulted in a quadrupole moment of $Q_0 = 8.5$ eb, which corresponds to an axis ratio of $c/a = 1.72$. The χ^2 fit to the data is very shallow for large quadrupole moments, so that no meaningful upper limit can be given. The lower limit compatible with a 1σ error is $Q_0 = 6.2$ eb.

New calculations using the projected shell model [4] describe the dynamic moment of inertia very well. These calculations suggest a spin of 36 $\hbar$ for the lowest observed state in band 1, and assign this band as a proton $i_{13/2}$ two-quasiparticle structure coupled to $i_{13/2}$ neutrons. The $i_{13/2}$ proton intruder orbital is responsible for the superdeformed shapes in the $A \simeq 150$ region and in the $A \simeq 110$ region it may be classified as a "hyperintruder" level which is expected to be occupied at hyperdeformation.

* This work was supported by the U.S. DOE under Contract Nos. DE-AC03-76SF00098 (LBNL) and W-31-109-ENG-38 (ANL).

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BETA DECAY OF ^{72}Co AND EXCITED LEVELS IN ^{72}Ni

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for Warsaw-Caen-Bucarest-Paris-Darmstadt-Oak Ridge-Knoxville collaboration

Nuclear structure studies of neutron rich nickel isotopes will be presented, resulting from the data obtained during a recent experiment [1] at GANIL.

In December 2001, an experiment aiming at isomer and beta-delayed gamma spectroscopy of the very neutron rich nuclei around ^{74}Ni was performed. The experiment was done using fragmentation of the ^{86}Kr beam at 60 AMeV and new devices: LISE 2000 spectrometer and EXOGAM germanium array.

We have successfully measured beta delayed gammas from the decay of ^{72}Co. Excitation energies of the lowest excited states in ^{72}Ni were determined. This finding seems to solve the problem of disappearance of the 8^+ isomer in ^{72}Ni [2,3]. We also measured beta decay of other Co isotopes and found evidence for new short lived isomers in other exotic neutron rich nuclei. Search for an 8^+ isomer in ^{76}Ni was attempted.

The most interesting results of this experiment will be discussed.

ORNL is managed by UT-Battelle, LLC for the U.S. DOE under contract DE-AC05-00OR22725

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TRIAXIALITY AND THE WOBBLING MODE OF STRONGLY DEFORMED NUCLEI*

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Triaxiality in nuclei influences many spectroscopic quantities related to rotational band structure in deformed nuclei. Signature effects are expected in energies as well as in electromagnetic properties. Yet such effects may also arize as a result of the interplay of mechanisms not related to triaxiality.

In the region around Lu - Hf, nuclei with strongly deformed stable triaxial shape ($\varepsilon_2, \gamma \sim 0.4, \pm 20°$) are expected. Several bands have been identified in these nuclei with characteristic features similar to those of the first observed case in ^{163}Lu [1], suggested to be built on an $i_{13/2}$ proton [2]. The region is now broadened with new bands found in lighter and heavier Lu-isotopes, as well as in heavier even-even Hf isotopes. Only a few of these bands have identified connections to known structures. Therefore, for most of the bands excitation energy, spin and parity are unknown.

The wobbling mode which is uniquely related to triaxiality has been predicted more than 25 years ago [3]. Wobbling introduces a series of bands with increasing wobbling phonon number, n_W. The pattern of γ-transitions between the wobbling excitations will be influenced by the presence of an aligned particle [4]. Recently evidence for the wobbling mode was obtained in ^{163}Lu [5,6]. The wobbling interpretation is based on comparison to particle-rotor calculations in which an $i_{13/2}$ proton is coupled to a triaxial core [4]. The similarity between the data in ^{163}Lu and newly established bands and connecting transitions in ^{167}Lu [7] indicates that wobbling may be a more general phenomenon in this region.

In an experiment with the Euroball detector array in Strasbourg, July 2001, the wobbling picture in ^{163}Lu was further developed, and even a second phonon wobbling excitation could be identified [8]. The higher phonon wobbling description shows some anharmonicity, but the characteristic large $\Delta n_W = 1$ E2 strength is observed.

* This work supported by the EU TMR project No. ERBFMGECT980145 and the Danish Science Foundation.

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SINGLE-PARTICLE STRUCTURE OBSERVED IN RADIOACTIVE-BEAM EXPERIMENTS *

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Michigan State University, East Lansing 48824

In a series of investigations, see [1] and also the review [2], we have demonstrated that single-nucleon knockout reactions in inverse kinematics at energies above 50 MeV/nucleon offer a powerful spectroscopic tool for identifying single-particle structure of nuclei near the drip lines. Partial and differential cross sections to individual final levels are obtained by measuring the momentum of the projectile residue in coincidence with gamma rays. The shape of the longitudinal momentum spectra identifies the orbital angular momentum *l*, while the absolute cross sections determine single-nucleon spectroscopic factors. The example in Fig. 1 shows that the $3/2^+$ ground state of ^{17}C has a structure based on the 2^+ level of ^{16}C coupled to l=0,2 single-particle components. The method has an extremely high sensitivity, and experiments have been carried out with incident beams of less than one atom/second.

The accuracy of this technique has been assessed [3] in an analysis of neutron and proton knockout from ^{16}O and ^{12}C on a target of ^{12}C. From precisely known experimental cross sections obtained at high energies at the Bevalac, we obtain quenching factors from 0.49 to 0.68. These numbers are essentially identical to those found in the (e,e'p) reaction, normally considered the benchmark for absolute spectroscopic factors. GSI data for the halo proton of radioactive ^8B, which evidently has not been studied in reactions of electrons, show less quenching, 0.88(4), suggesting that the physical occupancy of shell-model orbitals may not be describable in terms of a single quenching parameter. We strongly suspect that the nuclear knockout method, in addition to being a tool for structure studies, has great potential for exploring the fundamentals of the shell model.

* This work was supported by the National Science Foundation, Grant No. PHY 9528844.

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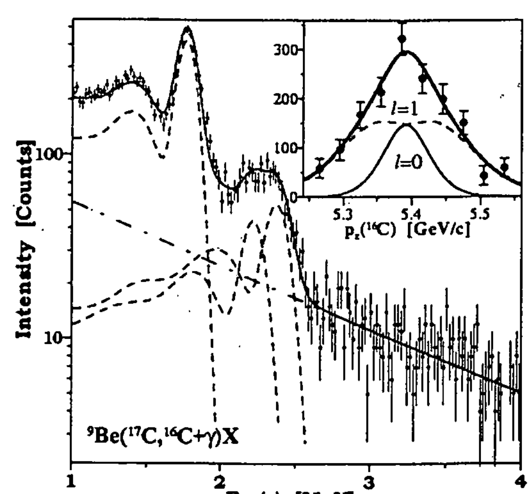

Figure 1. Gamma rays in coincidence with ^{16}C residues from the reaction $^9Be(^{17}C,^{16}C^*)X$ at 62 MeV/nucleon. The strong 1.77 MeV ray signals that approximately one half of the cross section goes to the 2^+ first-excited level of ^{16}C. The corresponding momentum spectrum (inset), selected by coincidence requirements, demonstrates that this partial cross section has two components, l=0 and l=2, with cross sections of 16 and 44 mb, respectively, in good agreement with theory [1].

FIRST LOW TEMPERATURE MEASUREMENT OF THE GDR WIDTH*

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Theoretical calculations predict differences between Sn and Pb due to the presence of shell effects in Pb. In Pb, the increase of the Giant Dipole Resonance (GDR) width as a function of temperature is predicted to be suppressed at low temperatures due to shell effects [1–3]. In Sn, where no shell effects are present, this initial suppression of the increase should be absent.

The width of the GDR built on excited states in ^{120}Sn was studied by means of inelastically scattered ^{17}O particles. This technique allowed for the first measurement of the GDR width at a temperature below 1 MeV. A GDR width of 4 ± 1 MeV consistent with the GDR width of the ground state [4] was extracted. This result does not confirm the adiabatic coupling calculations [3] of the evolution of the width as a function of temperature and indicates an overestimation of the influence of thermal fluctuations. A self-consistent description of the width was built up by examining the higher temperature data along with this low temperature measurement.

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DEVELOPMENTS IN TRANSFERMIUM SPECTROSCOPY

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Nuclei far from stability are an important testing ground for the understanding and the predictive power of nuclear models. The heaviest nuclei can today be produced and detected at production cross sections as low as 1 pb, corresponding to a rate of a few nuclei per month. The experimental observables yield nuclear masses, alpha decay half-lives, energies hindrance factors and branching ratios, fission characteristics, and production cross sections.

However, studies carried out using the conversion electron spectrometer SACRED and the gamma ray spectrometer JUROSPHERE II together with the gas-filled recoil separator RITU of the University of Jyväskylä demonstrated that *in-beam* spectroscopic experiments on reaction channels as weak as a few hundred nanobarn are possible today. Several experiments have already been carried out on the $Z = 102$ nuclei ^{252,253,254}No [1-3].

The latest experiments on ^{250}Fm and ^{254}No using SACRED will be presented. The comparison of the spectra indicates that the population of high K bands is stronger in ^{254}No than in ^{250}Fm. A comparison with the new in-beam gamma ray data on ^{250}Fm will be made.

Decay data following the ground state alpha decay from ^{253}No into excited states of ^{249}Fm expands the available information in this region. The new GREAT spectrometer [4] will provide the needed sensitivity for studies on weakly populated channels, exotic decays and studies of isomeric transitions. It consists of a combination of highly segmented silicon and germanium detectors and a new triggerless data acquisition system (TDR). Decay data following the ground state alpha decay from ^{253}No into excited states of ^{249}Fm illustrates the power of such a setup. First impressions of the working spectrometer will be presented.
format

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MAGNETIC ROTATION IN ^{196}Pb*

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Magnetic rotation (MR) was first discovered in Pb isotopes and is now a well established mode of nuclear excitation. In many near-spherical nuclei rotational-like cascades of strongly enhanced magnetic dipole (M1) transitions have been observed. Similar to the long-known rotation of a deformed charge distribution which we might call 'electric rotation', magnetic rotation occurs when the symmetry is broken by the current distributions of a few high-spin particles and holes outside a spherical core [1]. These currents lead to a large component of the magnetic dipole moment perpendicular to the total angular momentum and generate the enhanced M1 radiation.

In this work, we report on the results of two experiments, carried out with the EUROBALL γ-ray spectrometer array, to investigate high-spin states in ^{196}Pb. In addition to the previously established four MR bands [2], we have identified five new M1 sequences. In the previous work, only one of the bands was linked to lower-lying levels. In our work, we have established these connections for all but one of the bands. In addition, the previously known bands have been extended to higher spins and some of their levels have been reordered. Furthermore, the normal scheme of irregularly spaced energy levels has been substantially extended. From the systematic properties of the bands and from comparison to tilted-axis cranking calculations arguments for configuration assignments to the bands are derived. It is suggested that the bands are based on proton 11^- and 8^+ particle states coupled to various neutron-hole excitations.

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PERIPHERAL NEUTRON DISTRIBUTION DEDUCED FROM THE ANTIPROTONIC ATOMS

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Large differences between neutron and proton radii are expected to characterize the nuclei at the border of stability line, the future domain of the nuclear structure studies. Therefore the information on these quantities for stable nuclei is a convenient starting point for studies of more exotic nuclei. However, whereas the peripheral proton distributions are precisely known for stable nuclei from electromagnetically interacting probes, the situation is much more unclear for neutron distributions, where 20–40% errors of their mean square radii are a rule rather than an exception. Therefore, all new experimental information on these distributions is of a great interest.

In this contribution a ten years effort of the Warsaw–Munich collaboration aiming at the determination of the extent and composition of the nuclear periphery using antiprotons from the LEAR facility at CERN will be summarized. The differences between the root mean square radii of neutron and proton distributions Δr_{np} were determined for more than 20 nuclei, spanning the mass range from 40 to 238. Two experimental methods were applied: nuclear spectroscopy analysis of the antiproton annihilation residues one mass unit lighter than the target mass and the measurements of strong interaction effects in the antiprotonic X-rays. The conclusion is that under the assumption of two-parameter Fermi neutron and proton distributions only the neutron diffuseness is increasing in neutron rich nuclei and not the half-density radius. The differences between neutron and proton rms radii calculated under these assumptions are in agreement within the errors with measurements employing other methods.

A linear relationship between the Δr_{np} and asymmetry parameter $\delta = (N - Z)/A$ was established. The experimentally determined Δr_{np} value of ^{208}Pb is excellent agreement with the expectation of the neutron Equation of State.

The possibilities of formation of the antiprotonic atoms with radioactive beams will be also shortly discussed.

INSIGHTS INTO THE ORIGIN OF NUCLEAR MOLECULES FROM STUDIES OF THE HEAVY ION RADIATIVE CAPTURE REACTION

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Radiative capture is where the beam and target nuclei fuse and cool solely by γ-ray emission. Such a process is both common and well understood for light ions. Indeed, (p,γ) reactions have an important role in determining elemental abundances in the astrophysical rp process. Comparatively few studies have been made of Heavy Ion Radiative Capture (HIRC) as the cross-section is very low ($< 10\mu$b). This is unfortunate as HIRC can tell us a great deal about the dynamics and timescale of the fusion process.

The principal information on the HIRC process derives from the seminal work on the ^{12}C(^{12}C,γ) reaction by Sandorfi and Nathan at Brookhaven National Laboratory twenty years ago [1,2]. They observed decay from the compound nucleus ^{24}Mg by large energy ($\sim$ 20 MeV) gamma rays to the ground and first excited states. This was interpreted as a coupling to the nuclear giant quadrupole resonance strength. However, the experimental set-up employed at the time did not allow of the possibility of searching for multi-step decays. Such species of decay are of particular interest since they may proceed through intermediate states with exotic structure and/or a strong overlap with the entry resonance – so-called 'doorway' states.

With the advent of large arrays of high-purity germanium detector arrays, it has become practical to reopen study of the HIRC process and examine the decay pathways in far greater detail. We have developed a sensitive technique of selecting radiative capture events from the very high background from particle emission channels by using the Gammasphere array as a calorimeter. This technique relies upon the large difference in sum energy of emitted γ-rays between radiative capture and particle emission events, a consequence of the markedly different reaction Q-values, ensuring very clean separation of radiative capture events. Having selected those events with the highest sum energies we deconvolute them into their constituent gamma rays in order to examine the radiative capture cascade in detail on an event-by-event basis.

This technique has recently been applied to the study of the ^{12}C(^{12}C,γ), ^{12}C(^{16}O,γ) and ^{16}O(^{16}O,γ) reactions at Gammasphere. The decay following the ^{12}C(^{12}C,γ) reaction proceeds mainly in a non-statistical fashion via particular high-lying states and states in a K=2 rotational band. Such multi-step decay processes appear to be an order of magnitude more prevalent than the GQR decays reported in ref [1,2]. This work was supported by the U.S. Department of Energy grant W-31-109-ENG38 and DE-FG02-95ER40934.

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THE HALO NUCLEUS ^{14}Be AND THE UNBOUND NUCLEUS ^{13}Be*

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'Borromean' nuclei are three-body systems where the constituent two-body subsystems are unbound. Structural information on the unbound intermediate subsystems is essential to the understanding of these unusual nuclear few-body systems. Two Borromean halo nuclei, ^{6}He and ^{11}Li have been studied extensively, but there is much less information on ^{14}Be, the next heaviest system of this type. By measuring coincidences between the ^{12}Be core and the associated neutron following the breakup of a ^{14}Be beam, it is possible to reconstruct the unbound states in ^{13}Be.

An experiment has been performed using the LISE spectrometer at GANIL to produce a beam of ^{14}Be by the fragmentation of a primary 63 MeV/A ^{18}O beam on a natural beryllium production target. Breakup of ^{14}Be induced by secondary carbon and lead targets has been analyzed. The ^{14}Be ions were identified from the other constituents of the secondary beam on an event-by-event basis using the time of flight through LISE3 and the energy loss in a silicon detector placed before the target. The charged fragments were measured in a 0° telescope and the neutrons in the DeMoN array of 99 liquid scintillators.

The kinematical reconstruction of the ^{12}Be + n system[1] reveals significant s-wave strength, in addition to the previously measured d-wave resonance[2]. The angular distribution of neutrons in the decaying ^{13}Be system suggests the inclusion of p-wave neutron decay. Additionally, the parallel momentum distribution of the reconstructed ^{13}Be provides information about the single particle ground state structure of ^{14}Be.

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NARROW SPREADING WIDTHS OF EXCITED BANDS IN A SUPERDEFORMED WELL*

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Excited states within a superdeformed (SD) well provide opportunities to investigate: (i) the excited states of a false vacuum; (ii) a transition from ordered motion along the yrast line to chaotic motion above, where quantum numbers and symmetries break down, perhaps through an ergodic regime; (iii) the robustness of collectivity with increasing excitation energy; (iv) the evolution with energy and spin of moments of inertia, collective spreading widths, in-band probabilities, quadrupole moments; and (v) the largely-unexplored feeding mechanism of SD bands.

Data for the present work came from a Gammasphere experiment [1] conducted at LBNL with the ^{150}Nd(^{48}Ca,4n)^{194}Hg reaction. E_γ-E_γ matrices were constructed from pair wise gates on (a) SD and (b) normal-deformed (ND) transitions in ^{194}Hg; (a) selects only transitions feeding SD band 1, while (b) includes other SD transitions, which do not necessarily feed into the SD yrast line, but continue to lower spin. In the SD-gated matrix, 3 ridges (parallel to the diagonal) with $E_\gamma > 450$ keV could be seen and, in the other matrix, 5-6 ridges, which persist down to ~340 keV. The former matrix represents the first instance where ridges are detected with gates on SD transitions. The persistence of ridges to lower energy in the ND-gated matrix occurs because the γ cascades are not forced into the SD yrast line and implies small tunneling to ND states - even ~2 MeV above the SD minimum. The ridges reveal the following properties: (1) narrow spreading widths (~5-10 keV), which increase with spin; (2) ridge spacings and, hence, $\mathcal{J}^{(2)}$ identical to that of SD band 1; (3) $N_{path} \sim 100$, from fluctuation properties; (4) in-band probability ~1, for $E_\gamma > 790$ keV; and (5) ratio of ridge intensity/total E2 strength ~1 for $E_\gamma < 770$ keV. The large number of unresolved bands suggests that they are excited, probably from an interval 1.5-2 MeV above the SD yrast line. Yet, unexpectedly, the moments of inertia are nearly identical to that of the yrast SD band.

Features (1-3) have been anticipated by theory [2]; further analyses indicate that there are 2-8 components in the wave functions, which are, hence, quite complex. Despite this large mixing among many bands, which should broaden the rotational strength, the ridge spreading widths are narrow. This implies surprisingly small changes in the amplitudes and phases of the wave function with repeated spin increments of $2\hbar$, suggesting rotational coherence. Is there a deep reason? Perhaps the excited unresolved SD bands in ^{194}Hg are candidates for ergodic bands [3].

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SENSITIVE CRITERION FOR CHIRALITY; CHIRAL DOUBLET BANDS IN $^{104}_{45}Rh_{59}$*

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An island of nuclear chirality has been observed in odd-odd N=73 and 75 isotones in the A∼130 region[1-4]. Triaxial cores along with the valence unique-parity $h_{11/2}$ proton particle and neutron hole result in an approximate mutually perpendicular coupling of the core rotation and the valence nucleon angular momenta. Because of chiral symmetry breaking†, this geometry manifests as nearly degenerate doublet ΔI=1 $\pi h_{11/2}\otimes\nu h_{11/2}$ rotational bands.

A new criterion for chirality, in addition to the doublet-band energy degeneracy, for the purity of the chiral geometry has been discovered. It can be shown that the quantity $S(I)=\frac{[E(I)-E(I-1)]}{2I}$ is nearly constant as a function of spin I, if the pure chiral geometry is realized. With the perpendicular coupling of the three angular momenta from the core rotation and the valence proton and neutron, the Coriolis and $\vec{j}_\pi\cdot\vec{j}_\nu$ contributions to the particle-rotor Hamiltonian are negligible. For a triaxial γ=30° core with a constant hydrodynamic moment of inertia, the S(I) is then effectively independent of spin I. This criterion is used to show that the nearly degenerate chiral doublet bands observed in the current study of ^{104}Rh are comparable to those in the best chiral nucleus known so far, namely ^{134}Pr, indicating the existence of a new chiral island and extending the general phenomenon of chirality in nuclei.

The new chiral doublet bands were found in ^{104}Rh, the heaviest Rh isotope that could be produced via fusion evaporation reactions. The excited states of ^{104}Rh were populated using the ^{96}Zr(^{11}B,3n) reaction. Two experiments were performed, the first with a backed target at SUNY at Stony Brook and the second with a backed and thin target at LBNL using GAMMASPHERE, which extended the doublet bands to higher spin. DCO analysis showed that the side band has the same parity as that of the negative parity $\pi g^{-1}_{9/2}\otimes\nu h_{11/2}$ yrast band. This assumed doublet-band configuration involves two unique-parity orbitals, and thus it is expected to be free of admixtures. The resulting data revealed that the doublet bands achieved a remarkable degeneracy, to less than 2 keV, at the (17$^-$) band members. With the expected stability of the triaxial deformation in this region, the chiral conditions are similar to those of the A∼130 region; in ^{104}Rh, the valence $\pi g^{-1}_{9/2}$ proton has the hole character and the $\nu h_{11/2}$ neutron the particle character, reversing the roles played in the A∼130 region. Furthermore, the extracted S(I) values for both bands exhibit flatness over several spins consistent with the new criterion.

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† Since the word *chiral* implies a state with handedness, by *chiral symmetry* we refer to a symmetry which will be broken by the onset of handedness.

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GAMMA-RAY TRACKING WITH THE MARS DETECTOR*

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The concept of γ-ray tracking is to identify the individual γ-rays by reconstructing their scattering paths through the array. Therefore, the determination of the three-dimensional position and the energy deposit for every interaction point is a crucial step. This aim will be achieved by analysis of the shapes of the signals from the highly segmented detectors.

The MARS prototype detector is a cylindrical closed-end crystal of n-type HPGe and has a 25-fold segmentation of the outer contact: 6 angular "sectors", 4 "slices" in depth, and an additional segment on the front face [1].

Usually, there is more than one interaction in the detector or even in one segment and the measurable signals are the sum of the signals originating from the individual points. Task of the pulse shape analysis is the decomposition of multiple interactions and the characterisation of each of them. Our approach applies a genetic algorithm (GA) which uses a base of signals calculated by our computer program [2].

Goal of the in-beam experiment we performed is to evidence the properness of the results of our algorithm by the capability for Doppler correction of γ-rays emitted in flight. The knowledge of the emission angle of a γ-ray, in fact, is identical with the determination of its first point of interaction in the detector. In order to generate γ-rays emitted at high velocities, we employed Coulomb excitation of a ^{56}Fe beam at 240 MeV impinging on a lead target. Since the γ-rays (E_γ = 846.8 keV) were detected in coincidence with the scattered projectiles, the complete kinematics of the process was defined experimentally.

The set-up of our experiment was chosen carefully in a way that the contribution to the broadening of the line caused by the finite opening angle of the γ-detector, thus the variable we can reduce by determination of the first point of interaction, outranges the other contributions, i.e. the finite opening angle of the particle detector, the size of the beam spot, and the blur of the velocity due to the energy loss of the projectiles in the target before and after the scattering.

In a preliminary analysis, a resolution of about 6.5 keV has been obtained applying a Doppler correction with respect to the centre of the hit segment. Performing the correction with respect to the first point of interaction localised by our algorithm, this value improves to approximately 4.2 keV which agrees with the 4.1 keV expected from simulations.

* This work is supported by the EC under contract ERBFMRX-CT97-0123.

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HIGH-SPIN ISOMERS, RESIDUAL INTERACTIONS AND OCTUPOLE CORRELATIONS IN NEUTRON-RICH NUCLEI NEAR ^{208}PB

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Investigations of excited states in nuclei near doubly closed-shells are of special importance because the single-particle excitation energies and the residual interactions deduced from multi-particle states provide the building blocks for calculating more complex configurations. Therefore, it is unfortunate that the paucity of conventional heavy-ion fusion reactions which are available using stable beams and targets has prevented the study of the structure of many of the neutron-rich nuclei near ^{208}Pb. Thus, many of the important residual interactions for couplings of high-spin orbitals are currently unknown.

Collective excitations are also important in the spectrum of excited states in nuclei near ^{208}Pb. Electric octupole transitions are a fingerprint of octupole collectivity and many examples are found where collective octupole-vibrational states compete with single-particle excitations. Furthermore, in the light-actinide region, the nuclear ground states exhibit a static-octupole deformation. The study of the evolution from collective octupole vibrations near ^{208}Pb to static octupole deformation in the actinide region suffers from a lack of experimental information on the neutron-rich nuclei lying in between.

We have recently performed a series of experiments using a variety of reaction techniques to populate high-spin states in these important neutron-rich nuclei. Deep-inelastic collisions between a beam of ^{238}U ions from the ATLAS accelerator at Argonne National Laboratory and a ^{208}Pb target were studied using Gammasphere to identify the emitted gamma-rays. New high-spin states were observed in neutron-rich nuclei, including ^{206}Hg [1], ^{210,211}Pb [2], ^{211}Bi [2] and ^{237,239,240}U [2]. In addition, experiments using incomplete-fusion reactions have been performed at the Australian National University using light ion beams from the 14UD tandem accelerator. In particular, high-spin states in ^{213}At have been studied via the ^{209}Bi(^{7}Li,p2n) reaction.

These new results will be summarised with a view towards indentifying some of the unknown residual interactions in the ^{208}Pb region as well as understanding the microscopic structure of the octupole vibration. For example, the level scheme deduced for ^{213}At will be presented, including a new high-spin isomeric state with a very long lifetime. This state decays via an E3 transition and the measured transition strength provides new insight into the nature of the collective octupole vibration in the vicinity of ^{208}Pb.

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LINKING OF YRAST AND EXCITE SUPERDEFORMED BANDS IN $^{152}_{66}Dy_{86}$*

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The excitation energy, spin and parity of the yrast superdeformed band (band-1) in ^{152}Dy have been firmly established[1]. The evidence comes mainly from the measured properties of a 4011 keV single–step transition connecting the yrast superdeformed level fed by the 693 keV transition to the 27^- yrast state. Four additional, weaker, linking γ rays have been placed as well. The excitation energy of the lowest superdeformed band member is 10,644 keV and its spin and parity are determined to be 24^+. Thus, fifteen years after its discovery[2], the first superdeformed band is finally linked to the normal yrast states and its spin, parity and excitation energy have been established.

Furthermore, three transitions of dipole character have been identified, which connects the excited superdeformed band-6 in ^{152}Dy to the yrast SD band-1. As a result, the excitation energy of the lowest level in the excited SD band has been measured to be 14,239 keV. The states in this band have been determined to be of negative parity and odd spin (29^- or 31^-). The measured properties are consistent with an interpretation in terms of an octupole vibrational band. A comparison with an RPA calculation by Nakatsukasa *et al.*[3] suggests that the spin of the lowest SD band-6 level is 31^-. This is the first time an excited SD band in the mass 150 region has been linked to an yrast SD band, which in turn is linked to the normal states it decays into[1].

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GRETA – GAMMA RAY ENERGY TRACKING ARRAY

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A gamma-ray tracking array consisting of a shell of highly segmented Ge detectors is a new concept for the detection of gamma radiation. In such an array the individual interactions of all the gamma rays are identified by their energies and positions. This is achieved by pulse-shape analysis of the signals from the two-dimensionally segmented detector. Then, using tracking algorithms based on the properties of gamma ray interactions (photo absorption, Compton scattering and pair production), the scattering sequences are reconstructed. This array will give high peak efficiency, high peak-to-background ratio, and be able to handle high multiplicity events. In addition, the good position resolution will provide more accurate Doppler correction capability. It will have a factor of 100 – 1000 gain in resolving power over the current generation of gamma-ray detector arrays, such as Gammasphere, for a wide variety of experiments. This array is vital to fully exploit the physics opportunities provided by the existing stable beam and radioactive beam facilities as well as from future facilities.

One implementation of this concept, called GRETA (Gamma Ray Energy Tracking Array), is currently being development by the US nuclear physics community. In this presentation I will introduce this new concept of gamma-ray tracking and will show the progress which has been made in four key areas: the manufacture of segmented detectors and pre-amplifiers that can provide high quality signals needed to resolve and locate individual interaction points; a data processing system including fast ADCs and processing units to digitize and process the segment signals; signal processing methods for determining energy, time, and position based on pulse shape digitization and digital signal processing; the development of a tracking algorithm that uses the energy and position information to identify interaction points belonging to a particular gamma ray. Future plans and prospects of the GRETA project will also be discussed.

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LOW LEVEL DENSITY IN ODD-ODD N = Z NUCLEI IN THE A ~ 70 REGION

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Studying odd-odd N = Z nuclei above nickel is topical for several reasons. The nuclei lie along the explosive rp-nucleosynthesis path, so their masses, shapes, decays and isomers need to be known for modeling x-ray bursts. The nuclei decay by "super allowed" Fermi β-decays, which, if precisely measured, can allow searches for physics beyond the standard model as long as small structure-dependent corrections can be made. Finally, the nuclei have near-degenerate low-lying configurations with T = 0 and T = 1 symmetries, so information on both long- and short-range np correlations may be sought. The experiments are technically challenging, as the production cross-sections are always low, and the decay patterns complicated. The key information lies in the low spin states, but only heavy-ion reactions, either through fragmentation or fusion, can allow us access to these nuclei for spectroscopy. However, in the last few years heroic progress has been made in experiments on copper, gallium, arsenic, bromine, rubidium and yttrium nuclei which span this region. There have also been dozens of theoretical investigations into these matters. We will focus on a recent study of ^{70}Br [1] to illustrate the challenges of this kind of experiment, the progress that has been made, and the prospects for the future.

A compilation of information from all the odd-odd nuclei in the region reveals a striking difference between the N = Z nuclei and their neighbors. Several conclusions can be drawn from the data collected to date:

(1) The number of states in the first MeV of excitation in the N = Z nuclei is very low. This does not seem to be an experimental artifact.
(2) There is little evidence for low-lying $J^\pi = 1^+$ states, which would be a fingerprint of very strong T = 0 np-pairing correlations.
(3) The low-lying shapes of the odd-odd nuclei seem to closely follow their neighboring even-even cores.
(4) The location of analogs to the ground state bands in (Z - 1,N + 1) isobars is difficult, as these states are quite non-yrast, so "mirror symmetry" tests are extremely challenging.
(5) The known isomers arise from a wide variety of shapes and structure and do not have a single, common cause.

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ODD-ODD N=Z NUCLEI AND NP PAIRING*

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The roles of isoscalar (T=0) and isovector (T=1) pairing correlations at the N=Z line have recently received renewed attention both theoretically and experimentally. The existence of a *deuteron-like* (*np*, T=0) pair condensate is a subject of debate, in particular as to what constitutes a clear signature of the formation of correlated isoscalar *np* pairs. One thing that is clear, is the fact that nuclei along the N=Z line provide the best ground for *np* correlations to develop.

We will review the analysis of experimental data on binding energy differences between odd-odd and even-even nuclei along the N=Z line [1,2], and interpret the results with calculations based on single l and single j shell models. In spite of their simplicity, these models incorporate the main ingredients of *np* pairing correlations and provide a firm basis to support some general arguments that can be used to probe the formation of a condensate of isoscalar *np* pairs

Near closed shells, the strength of the pairing interaction relative to the single-particle level-spacing is expected to be smaller than the critical value needed to develop a "superconducting state" and therefore the pairing field can only generate a collective phonon. In this presentation we will also summarize a new analysis of the pairing vibration degree of freedom near ^{40}Ca and ^{56}Ni [3], and show that a consistent picture emerges indicating a clear collectivity for the isovector pairing but a single-particle character for the isoscalar channel.

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BETA DECAY STUDIES OF NEUTRON-RICH NUCLIDES NEAR $N = 32$*

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The first excited 2^+ state in ${}^{52}_{20}Ca_{32}$ has energy 2.56 MeV [1], well above that observed in its even-even neighbor, ${}^{50}Ca_{30}$. This increase in $E(2^+_1)$ was attributed to a filled neutron $2p_{3/2}$ single-particle orbital, suggesting a significant subshell closure at $N = 32$. An increase in binding for ${}^{52}Ca$ was also inferred from the mass of ${}^{52}Ca$ [2]. It has been suggested that a neutron subshell closure at $N = 32$ could occur when reinforced by the $Z = 20$ proton shell closure [3]; however, a peak in $E(2^+_1)$ at ${}^{56}_{24}Cr_{32}$, which has four protons in the $1f_{7/2}$ orbital, has been confirmed by our group [4]. We have attributed the appearance of the $N = 32$ neutron subshell closure for neutron-rich nuclides to a diminished proton $f_{7/2}$ – neutron $f_{5/2}$ monopole interaction as protons are removed from the $1f_{7/2}$ single-particle orbital.

We have continued our investigations of neutron-rich nuclides near $N = 32$ with a study of the low-energy levels of ${}^{56}Cr_{32}$ and ${}^{54}Ti_{32}$ populated following the beta decay of ${}^{56}V$ and ${}^{54}Sc$, respectively. The parent nuclei were produced following projectile fragmentation of a 140 MeV/nucleon ${}^{86}Kr$ beam, provided by the Coupled Cyclotron Facility at the National Superconducting Cyclotron Laboratory at Michigan State University, in a Be target. The isotopes of interest were separated using the A1900 fragment separator and implanted into a silicon microstrip detector. Six detectors from the MSU Segmented Germanium Array [5] were placed around the silicon implantation detector to measure beta-delayed gamma rays.

We will report our results on the beta decay half-lives of ${}^{56}V$ and ${}^{54}Sc$ and the low-energy structures of ${}^{56}Cr$ and ${}^{54}Ti$. These new results lend additional support to the presence of a subshell closure at $N = 32$ for neutron-rich nuclides having $Z \leq 24$.

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ROTATIONAL DAMPING AND COMPOUND FORMATION IN WARM ROTATING NUCLEI.

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The formation of compound states with increasing thermal excitation energy is considered an order-to-chaos transition in nuclear systems. The rotational damping, i.e. the spread of rotational E2 transition into many decay branches, is a direct consequence of this. The cranked shell model consisting of the rotating mean-field and the residual two-body effective interaction[1] has been successful in explaining key observed features concerning the onset of rotational damping. By using this model, we present in this talk a theoretical overview of the properties of two fundamental quantities; the width of the rotational damping Γ_{rot} and the compound damping width Γ_{comp}, that characterizes energy- or time scales of compound state formation.

Experimentally, the compound width and the rotational damping width are difficult to separate and measure directly. However, in principle the sensitivity to the two quantities is different in 2- and 3-fold correlations. In these γ-correlation spectra characteristic profiles of the narrow and wide distributions around the ridge position may be found and related to Γ_{rot} and Γ_{comp}[2]. Most significant is the three-γ correlation spectra which exhibit, when plotted in a perpendicular cut (the transverse plane), a prominent structure resembling "rim and ridges of a volcano" that originates from the narrow component.

We also discuss our recent efforts[3] to search for the narrow component directly in the experimental spectra. To help the search, we have further developed a new method that utilizes a simple functional parameterization of the two- and three-γ correlations, which contains Γ_{rot}, Γ_{comp}, and the intensity of the narrow component as fitting parameters. An analysis of this type is in progress for nuclei in the rare earth region.

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PERIODIC ORBITS AND DEFORMED SHELL STRUCTURE

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Existence of superdeformed nuclei is often explained in terms of the superdeformed magic numbers of the harmonic-oscillator potential with axis ratio 2:1. It appears, however, that we need a more general explanation not restricted to the harmonic-oscillator potential, since, up to now, more than 200 superdeformed bands have been found in various regions of nuclear chart and their shapes in general somewhat deviates from the 2:1 shape. In this talk, I shall discuss the mechanism how and the reason why the superdeformed shell structure emerges. The major tool for this purpose is the trace formula which links the quantum shell structure to classical periodic orbits for single-particle motions in a given mean field. Here, shell structure is defined as regular oscillation in the single-particle level density coarse-grained to a certain energy resolution. Utilizing the spheroidal cavity model, we identify classical periodic orbits responsible for emergence of the superdeformed shell structure and their relative contributions to the shell structure energies are evaluated. We present both the Fourier transforms of quantum spectra and the semiclassical calculations based on the periodic-orbit theory. The results clearly show that three-dimensional periodic orbits (that are absent in spherical and normal deformed systems and are born out of bifurcation of planar orbits) generate a new shell structure at large prolate deformations (not restricted to the geometrical shapes with the axis ratio 2:1), which may be called the superdeformed shell structure.

The periodic-orbit theory reveals intimate relationships between regular oscillating patterns in the coarse-grained energy spectrum (shell structure) and classical periodic orbits in the mean fields. Thus, it provides a basic tool to get a deeper understanding of microscopic origin of symmetry breaking in the selfconsistent mean field; it sheds light, in addition to the stability of superdeformed states mentined above, on the reason of prolate dominance in normal deformed nuclei, on the origin of left-right asymmetric shapes, etc. It is useful for finite Fermi systems in general, including nuclei, metallic clusters and quantum dots. In this talk, I shall try to give a brief overview of such applications of the periodic-orbit theory (without going into its mathematical details) and summarize open problems to be solved for a better understanding of nuclear shell structure.

GAMMA-RAY SPECTROSCOPY OF VERY NEUTRON-DEFICIENT BI ISOTOPES

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There exists a rich variety of nuclear shapes in the lead region. For example, in the neutron-deficient even-even Hg and Pb isotopes, low-lying oblate and prolate states are associated with excitations of two (oblate) or more (prolate) protons across the $Z = 82$ shell gap [1]. In odd-A Bi isotopes, the observed intruder states are of configuration $2p - 1h$, from which the $1/2^+$ states are observed down to the lightest known Bi isotope ^{185}Bi [2-4]. The behaviour of these $1/2^+$ states in light Bi isotopes resembles that of the 0^+ intruder states in Pb isotopes in contrast to that of the $9/2^-$ intruder states in Tl isotopes. This may be due to the observation of a prolate $1/2^+$ state instead of the presumably oblate-deformed state [5]. An isomeric $13/2^+$ state has been observed in odd-A Bi isotopes down to ^{195}Bi [6]. This state has been interpreted to originate from the coupling of a proton in the $i_{13/2}$ orbital to the Pb core and its excitation energy decreases rapidly below $A = 199$.

In order to examine the character of the $1/2^+$ and $13/2^+$ states, properties of the associated bands based on these states need to be studied. Experiments for ^{191,193}Bi were performed at the Accelerator Laboratory of University of Jyväskylä, Finland. The fusion-evaporation residues were separated from the background using the gas-filled recoil-separator RITU. The γ-rays emitted by the Bi isotopes were detected by Ge-detector arrays and resolved by using various tagging techniques. In both ^{191}Bi and ^{193}Bi, the excitation energy of the $13/2^+$ isomeric state was established and bands based on the $1/2^+$ intruder state and the $13/2^+$ isomeric state were observed. In addition, a cascade of γ rays following the de-excitation of a microsecond isomer and feeding the ground state was observed in ^{193}Bi. In this contribution, the results obtained will be presented and the level systematics of Bi isotopes will be discussed.

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FRONTIERS OF NUCLEAR SHELL MODEL

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Recent developments of the shell mocel calculations, mainly by our Monte Carlo Shell Model [1], will be overviewed. The predictions will be contrasted with experimental data. Nuclei in different regions in the nuclear chart will be included, covering from p-shell to heavy nuclei (A=150). The spin/isospin effects on shell gaps and magic numbers have been pointed out with a new magic number [2]. In this talk, their effects, for instance, magnetic moments and GT properties will be discussed. The disappearance of magic numbers and the variation of shell gaps will analyzed with their consequences in deformation and level schemes including high spins. The triaxial deformation will be analyzed in various regions of nuclei including ^{32}Mg, Zn isotopes, and Xe-Ba nuclei. The last ones are discussed in connection to O(6) and E(5) symmetries. Overall variation of the 2^+ energy level and separation energy will be presented, with attention to the possible breakdown and/or emerging of some magic numbers in certain regions, which may change neutron capture, electron/muon capture, etc.

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CONSTRUCTING THE PHASE DIAGRAM OF FINITE NUCLEAR MATTER

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The low-energy portion of the phase diagram of finite nuclear matter has been obtained. This was achieved by analyzing the fragmentation yields of the EOS [1] and ISiS [2] collaborations using Fisher's droplet formalism. The critical exponents tau and sigma, the surface energy coefficient, and the critical temperature associated with the liquid-vapor phase transition have all been extracted from the data. Using the ideal gas law, one can construct pressure-temperature and temperature-density coexistence curves for finite nuclear matter. At much lower energies, compound nucleus reactions are also described by the Fisher formalism when one considers the ensemble average of first-chance emission of rare particles. A pressure-temperature correlation inferred from the mean emission times (measured by the ISiS collaboration) agrees very well with the pressure-temperature correlation inferred from the fragment yields.

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NUCLEAR PHYSICS WITH A FREE ELECTRON LASER*

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The electron storage ring at the Duke Free Electron LASER Laboratory operates at electron energies between 0.2 and 1.1 GeV. Its beam drives the OK-4 Free Electron LASER with tunable wavelengths in the optical range. The high photon density inside of the optical cavity enables one to obtain a large luminosity for Compton scattering processes between the polarized optical laser photons and the relativistic electrons in the ring. Compton scattered photons experience a forward-peaked Lorentz-boost by a factor of 10^6–10^8 by transformation to the lab system and they form after collimation a nearly monochromatic, tunable, completely polarized γ-ray beam with an intensity of up to 10^9 γ's/sec. This "High Intensity γ-ray Source" (HIγS) [1], with a degree of linear polarization of $P_\gamma > 99\%$ [2] and a narrow band width of $\Delta E_\gamma / E_\gamma < 4\%$, offers new conditions for experiments with photo-nuclear reactions, *e.g.*, for the photo-disintegration of the deuteron or for Nuclear Resonance Fluorescence (NRF) close to the particle emission threshold. First NRF experiments have recently been performed [3] at HIγS. Parity quantum numbers of $J = 1$ states of ^{138}Ba [3] and ^{88}Sr [4] have been measured. The results demonstrate the experimental progress made by the new technique [5] which has initiated a new experimental program of Nuclear Resonance Fluorescence in the U.S.
Recent experimental results on N=50 and 82 neutron closed-shell nuclei are presented and their impact on our understanding of nuclear low-spin structure at energies close to the binding energy is discussed. We, further, report on the future direction of NRF studies at HIγS.

* This work supported by the AFOSR, by the U.S.-DOE, by the Emmy Noether-Program of the DFG, and by the Dean of Natural Sciences, Duke University.

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PHYSICS WITH HEAVY NEUTRON RICH RIBS AT THE HRIBF*

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The Holifield Radioactive Ion Beam Facility (HRIBF) at the Oak Ridge National Laboratory (ORNL) has recently produced the world's first post-accelerated beams of heavy neutron-rich nuclei. These neutron-rich Radioactive Ion Beams (RIBs) open the possibility of a wide range of new spectroscopic studies around ^{132}Sn, such as Coulomb excitation and nucleon transfer reactions in inverse kinematics.

$B(E2; 0^+ \rightarrow 2^+)$ values for neutron-rich ^{126,128}Sn and ^{132,134,136}Te isotopes have been measured by Coulomb excitation of radioactive ion beams in inverse kinematics. Scattered target ions were detected in the ORNL HyBall particle detector array, and coincident γ rays in the CLARION Ge clover detector array. The ratio of γ-carbon coincidence yield to carbon singles yield gives the excitation probability, and thus the $B(E2; 0^+ \rightarrow 2^+)$ value. The results for ^{132}Te and ^{134}Te (N=80,82) show excellent agreement with systematics of lighter Te isotopes, but the $B(E2)$ value for ^{136}Te (N=84) is unexpectedly small. While shell-model calculations using realistic effective interactions are in good agreement with other experimental data near ^{132}Sn, they fail to reproduce the small $B(E2)$ value in ^{136}Te.

The single-neutron transfer reactions ^{9}Be(^{134}Te,^{8}Be)^{135}Te and ^{13}C(^{134}Te,^{12}C)^{135}Te were identified using a ^{134}Te beam on ^{nat}Be and ^{13}C targets at energies just above the Coulomb barrier. Again, recoiling light ions were detected in HyBall, and coincident γ rays in CLARION. The use of the Be target provided an unambiguous signature for neutron transfer through the detection of two correlated α particles in the HyBall detectors, arising from the breakup of unstable ^{8}Be. Transitions previously identified in the decay of ^{135}Sb to ^{135}Te, in addition to several new, previously unidentified transitions, were clearly seen.

The results of these experiments will be discussed, togther with plans for future experiments with these heavy n-rich RIBs.

* Oak Ridge National Laboratory is managed by UT-Battelle, LLC, for the U.S. D.O.E under contract DE-AC05-00OR22725. This work is also supported by the U.S. D.O.E under contracts DE-AC05-76OR00033, DE-FG02-91ER-40609 and DE-FG02-88ER-40417.

RECENT DEVELOPMENTS IN HIGH-SPIN CRANKING CALCULATIONS

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In theoretical descriptions of high-spin rotational bands, it is important to be able to fix the corresponding configurations as accurate as possible. In the principal axis cranking model, parity $\pi = +, -$, and signature, $\alpha = +1/2, -1/2$, are preserved quantum numbers for the single-particle states. Therefore, it is straightforward to keep track of the number of particles in 4 (π, α) groups. However, if one wants to trace the rotational bands over large regions of spin and deformation it is a big advantage if the configurations can be specified in more detail.

For this purpose, a formalism was developed in Ref. [1] where, using the eigenfunctions of the rotating oscillator as basis states, the number of quanta $\mathcal{N}$, which is an approximate quantum number in the modified oscillator potential, was treated as pure. Using this formalism, it became straightforward to follow many bands to their maximal spin values. For example, rotational bands terminating at spin values $I = 40 - 50$ were predicted in the Er/Dy nuclei with $N \approx 90$ and soon afterwards, terminating bands of this kind were seen experimentally.

Further studies indicated the need to be able to distinguish between the high-j intruder orbitals and the other 'low-j' orbitals within an $\mathcal{N}$-shell. When such a formalism was introduced, it turned out to be especially important for nuclei in the vicinity of shell closures. Within this formalism, a large number of high-spin bands in nuclei with a few particles outside the $Z = N = 50$ and $Z = N = 28$ closed shells were identified as smooth terminating bands, thus giving an illustrative understanding and a reliable assignment of these bands [2].

Recently, some further developments along similar lines have been introduced:

- It is sometimes possible to make a more detailed classification of the orbitals within an $\mathcal{N}$ shell, e.g. to distinguish between orbitals of $(g_{7/2}d_{5/2})$ and $(d_{3/2}s_{1/2})$ character, respectively, in the $\mathcal{N} = 4$ shell. With this distinction, it has been possible to describe two bands tentatively observed to termination at $I = 58^+$ and $I = 62^+$ in ^{156}Dy.
- It is straightforward to describe excited bands within the different configurations but it is often difficult to interpret the results because different excitations might be lowest in energy at different deformations. In order to get smoother excited bands, a formalism has recently been developed, where it is possible to define exactly within which group of orbitals the excitation takes place. This has been applied to the observed spectrum of ^{64}Zn [3] where it appears that two bands having identical configurations in our scheme, $\pi(f_{7/2})^{-1}(p_{3/2}f_{5/2})^2\,(g_{9/2})^1\;\nu(p_{3/2}f_{5/2})^4\,(g_{9/2})^2$, have been observed to termination.
- The formalism above can also be used to follow the 'collective branch' of terminating bands to lower spin values even in cases when other non-collective states in 'the same' configuration are lower in energy. This can be applied e.g. to the magnetic band terminating at $I = 42^-$ in ^{154}Dy or to the band terminating at $I = 46^+$ in ^{158}Er.

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THE HIGHS AND LOWS OF THE MASS 100 REGION

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Nuclei with Z=42-46 and A~100 are often described in general terms as being 'transitional'. This broad definition belies a richness in structure which includes examples of vibrational, triaxial and quadrupole deformed excitations. In the low-spin regime, the β-stable Mo (Z=42) and Ru (Z=44) nuclei around A=100 are home to anharmonic multi-phonon structures [1] and are candidates for the E(5) critical point symmetry [2]. At spins of $10\hbar$ and above, their near yrast states can be interpreted in terms of a rotational picture [3], where the alignment properties of the $h_{\frac{11}{2}}$ intruder neutrons play a significant shape driving role. For higher spins, deep superdeformed minima are predicted [4]. Here, we report on two recent works which probe the near-yrast structure of these nuclei. The first experiment, carried out using the YRASTBALL array at the WNSL, Yale, investigated the alignment properties in ^{101}Ru following the fusion-evaporation reaction ^{96}Zr(^{9}Be,4n)^{101}Ru. The results show a significant difference in the properties of the 'intruder' $h_{\frac{11}{2}}$ band (see fig. 1) compared to the heavier N=57 isotones [5], which can be explained by the differing core deformations along the isotonic chain. The second experiment focusses on high-spin states in the potentially 'doubly-magic' superdeformed nucleus [3] ^{100}Mo, populated via binary collisions between a ^{136}Xe beam and a ^{100}Mo target. This was carried out at the Lawrence Berkeley National Laboratory, using GAMMASPHERE with CHICO to select the reaction fragments. The preliminary results of both experiments will be presented, together plans for low-spin investigations and future directions for this work.

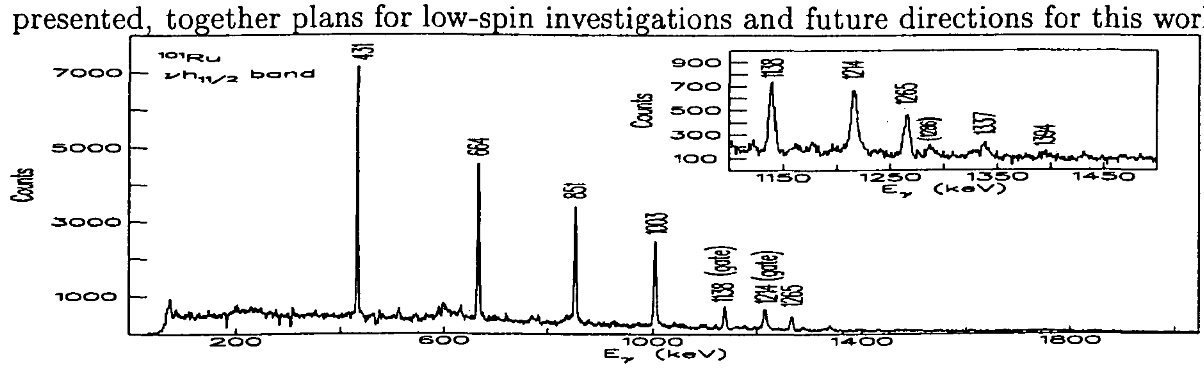

Figure 1: Sum $\gamma-\gamma$ gates highlighting the $[550]\frac{1}{2}^{-}$ intruder band in ^{101}Ru.

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SUPERDEFORMED BANDS IN $^{80-83}$SR, $^{82-84}$Y, AND ^{83,84}ZR: TRANSITION QUADRUPOLE MOMENTS, MOMENTS OF INERTIA, AND CONFIGURATION ASSIGNMENTS*

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In the mass 80 region, 40 superdeformed (SD) bands in 15 different nuclei have been identified. These bands are observed up to a rotational frequency of about 1.3 MeV, a value twice as high as the maximum frequencies encountered for the SD bands in next heavier region of SD shapes around mass 150. Therefore, the study of the properties of these SD bands remains a challenging task.

The data under discussion are from a "backed-target" experiment using the 130 MeV ^{28}Si + ^{58}Ni and ^{29}Si + ^{58}Ni reactions and the Gammasphere and Microball 4π detector arrays. Some but not all results obtained in this experiment have been reported in Ref. [1]. Here we present the complete information obtained: the properties of 20 SD bands in the nuclei $^{80-83}$Sr, $^{82-84}$Y, and ^{83,84}Zr. Among these SD bands are 7 bands newly observed or reported in detail for the first time. Most importantly, for 15 of these SD bands an average transition quadrupole moments (Q_t) could be accurately measured.

The significance of these data is the coverage of a large fraction of the mass 80 island of superdeformation including its doubly magic nucleus ^{84}Zr. This allows for a systematic study of the island. Combining the experimental findings with theoretical calculations of the Woods-Saxon Strutinsky type, the following issues will be discussed:

- Trends of the Q_t moments: changes of the Q_t's of the yrast SD bands as a function of proton and neutron number and comparisons between the Q_t's of some excited and the corresponding yrast SD bands.
- $J^{(2)}$ moments of inertia: low-frequency band interactions at high-frequency rotational alignments.
- Isospectral SD bands in ^{82,83}Sr and ^{83,84}Y: near identicality of the Q_t moments.
- "Singularities": band interaction between SD bands in ^{81}Sr.

From this discussion, configuration assignments for all SD bands in $^{80-83}$Sr, $^{82-84}$Y, and ^{83,84}Zr are proposed and some of the previously made assignments (except those in Ref. [1]) are revised. The assignments for different SD bands have in common that one or more nucleons occupy the N=5 $h_{11/2}$ intruder orbital and substantiate the picture that ^{84}Zr is the "central" SD nucleus in the region.

*Work supported by US DOE.

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POSSIBLE TRIAXIAL SUPERDEFORMED BANDS IN ^{174}Hf*

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Possible triaxial superdeformed (TSD) bands have been observed in several odd-Z Lu nuclei (see Ref. [1], and references therein) near $N = 94$. The occupation of the $i_{13/2}$ proton orbital plays a significant role for the large deformation, while the triaxiality likely results from a shell gap at $N = 94$ with $\gamma \approx 20°$ [2]. For this reason, it was expected that TSD bands would be a general phenomenon in this mass region. Despite many searches for similar sequences in light Hf nuclei (with $N \approx 94$), TSD structures have only been reported in ^{168}Hf [3] for these $Z = 72$ isotopes.

A recent experiment on the even-even nucleus ^{174}Hf revealed a surprising result. The intent of the experiment was to identify new high-K isomers and the bands based upon these states. Gammasphere was used to detect the emitted γ rays from the ^{130}Te(^{48}Ca,4n) reaction; however, only one day of the experiment was utilized for strictly detecting prompt transitions with a thin self-supporting target. Within this one day of data, though, four possible TSD bands were observed and associated with ^{174}Hf, which is *six nucleons* away from the nearest reported superdeformed nucleus. The dynamical moments of inertia for all four bands are similar to the yrast TSD band in ^{168}Hf, whose transitional quadrupole moment has been measured to be $Q_t =$ 11.4(11) eb [3]. Ultimate cranker calculations do predict superdeformed wells with substantial triaxial deformation of $\gamma \approx \pm 18°$ for ^{174}Hf. No linking transitions to normal deformed states or between the superdeformed bands have been presently observed. Therefore, it is not clear whether a wobbling excitation has been observed at this time. An experiment has very recently been performed in order to determine the quadrupole moment of these structures.

* This work is supported by the U.S. DOE under contracts No. DE-FG02-96R40983 and W-31-109-ENG-38.

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QUADRUPOLE COLLECTIVITY IN NEUTRON-RICH LIGHT NUCLEI.

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Nowadays, quadrupole collectivity properties of neutron-rich light nuclei is the focus of many experimental and theoretical studies. The reason is that, for those nuclei the N=20 and N=28 shell closures seem to be weakened opening up the possibility of quadrupole deformed ground states. The theoretical study of such phenomena allows to check the suitability of the effective nuclear interactions used nowadays as well as the many body techniques used in the description of the nuclear structure at low energy.

The best example, up to know, of the erosion of the N=20 shell closure corresponds to the first excited 2^+ state in ^{32}Mg [1]. Both its excitation energy and its $B(E2)$ transition probability indicate [2] that this state is the member of a strongly deformed rotational band. From a theoretical point of view, this nucleus has been studied with the shell model (SM) and with the mean field method. In the later method the key ingredient to obtain a deformed ground state in ^{32}Mg is the rotational energy correction [3] which is usually disregarded in mean field calculations for heavier nuclei. In order to study the properties of the neutron rich nuclei around N=20 and N=28 we have used the Gogny interaction (D1S parameterization) to perform, as an initial step, HFB calculations constrained in their quadrupole moment for several nuclei of the mentioned regions. To evaluate the effect of the restoration of the rotational symmetry we have computed [4] the angular momentum projected (AMP) energy curves for the quadrupole constrained HFB intrinsic states. The main conclusion of those calculations is that the AMP dramatically changes the HFB energy landscape modifying in a substantial way the properties of the ground state. We have also found that in many cases two coexisting minima appear after the AMP has been carried out. Therefore, for a proper description of the ground and excited states of the nuclei considered a configuration mixing calculation in the spirit of the GCM is called for.

In my talk I will present the results of such AMP-GCM calculations for several neutron rich and light nuclei. To be more precise, I will discuss the isotopic chain $^{20-40}$Mg to illustrate the erosion of the N=8, 20 and 28 core, the isotopic chain $^{38-44}$S and the isotonic chain ^{40}Mg-^{48}Ca to illustrate the erosion of the N=28 core, and the isotopic chain of the Ne nucleus to illustrate the effect of deformation in the neutron drip lines. The theoretical results for two neutron and two proton separation energies, excitation energies and $B(E2)$ transition probabilities agree well with both experimental results and the calculations carried out with other interactions and/or methods.

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THE RARE ISOTOPE ACCELERATOR PROJECT*

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A major new frontier for low-energy nuclear science involves studies with beams of radioactive ions. The broad physics issues that can be addressed with radioactive beams require a new generation radioactive beam facility with capabilities far beyond those presently available, in both absolute intensity and reach of radioactive beams available. The Rare Isotope Accelerator, RIA, is the facility planned and recommended by the nuclear physics community to fulfill these needs in the US.

RIA aims at producing intense beams of radioactive isotopes and providing them to experimental stations with energy variable from ion source energy to a few hundred MeV/u. To perform this task, RIA will combine standard ISOL and fragmentation techniques together with novel approaches combining advantages of both techniques to obtain high quality beams of the produced isotopes at all energy regimes. RIA is based on a 400 kW superconducting heavy-ion driver linac to produce the activity, on various target/ion source approaches to extract the activity quickly and with high efficiency while withstanding the primary beam power, and finally on a very efficient post-acceleration scheme based on low-frequency RFQs injecting a superconducting linac to obtain maximum intensity and excellent beam quality at the experimental stations.

The development of the RIA concept required new ideas and significant technical advances. These advances touch all aspects of the facility, varying in scope from the primary accelerator which will provide beams of all elements from protons at 900 MeV/u to Uranium at 400 MeV/u and that will use multiple charge state acceleration for the heaviest elements to obtain the required intensity, to flowing liquid lithium fragmentation targets to sustain the high primary beam power, to production targets using secondary neutrons to induce fission and minimize the power deposited in the targets, to large high-purity gas cell to thermalize fragmentation products and feed them to the post-accelerator, to a post-accelerator design capable of accelerating singly-charged radioactive ion from ion source energy. An overview of the proposed facility and of the key new technologies that enable it will be given and the expected impact of these new capabilities on nuclear structure studies will be highlighted.

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PROTON DECAY STUDIES AT ATLAS*

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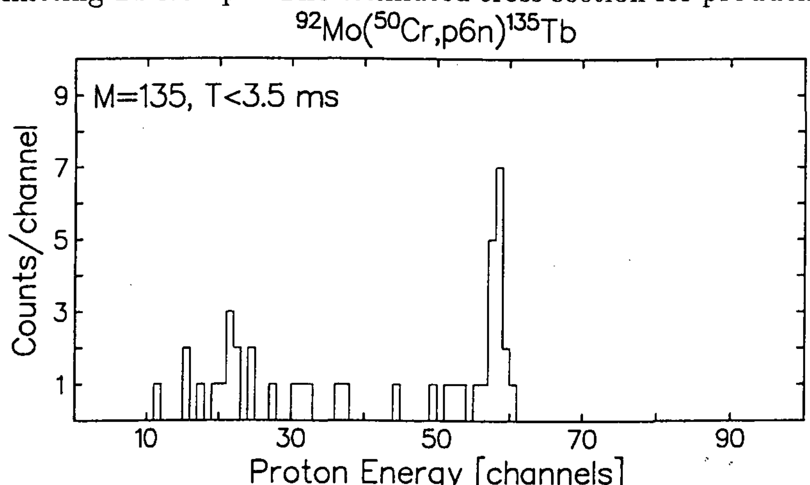
The phenomenon of proton decay has been transformed in recent years from a curiosity into a powerful nuclear structure tool far from the line of β stability. Improved detection methods and systems have resulted in the discovery of new proton emitting nuclei and provided more data on the known proton emitters. Several searches for new proton emitters were performed recently at ATLAS using the Fragment Mass Analyzer equipped with a Double-Sided Si Strip Detector. Proton emitting states were observed in odd-odd spherical nuclei ^{164}Ir and ^{170}Au. ^{164}Ir is the fourth isotope of Ir emitting protons. A proton line was also associated with the highly deformed odd-odd nucleus ^{130}Eu. The proton emitter ^{135}Tb was also observed (see figure). It is the first proton emitting Tb isotope. The estimated cross section for producing ^{135}Tb is about 2 nb.



To describe the increasing body of experimental data several models were developed for calculating observed proton-decay rates in both spherical and deformed nuclei, including decay branches to excited states in daughter nuclei. In order to improve the accuracy of the models proton-neutron coupling, pairing interaction, Coriolis interaction, vibrational degrees of freedom, among other effects, have to be taken into account.

The present data helped to understand the role of proton-neutron residual interaction both in spherical and deformed nuclei. In fact, it illustrates that proton decay rates can be used to learn about neutron states. The decay rate measured for ^{135}Tb, together with data on the decay and excited states of the proton emitter ^{131}Eu, shed light on the contributions of the $3/2^+[411]\ d_{5/2}$ and $5/2^+[413]\ g_{7/2}$ orbitals to the ground states in these nuclei.

The present results show that the full delineation of the proton drip-line between Z=50 and Z=83 is feasible. To extend proton-decay studies below Z=50 and above Z=83, and to advance further beyond the proton dripline, several improvements of the FMA implantation station are being implemented. Tests were also performed at the target position to observe proton emitters with half lives down to 10 ns. These initiatives and first results will also be discussed.

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THE SCIENCE OF THE RARE ISOTOPE ACCELERATOR, RIA

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The 2002 Nuclear Science Advisor Committee Report has recommended the construction of the Rare Isotope Accelerator RIA [1]. RIA was given the highest priority for major new construction; a priority that signals a significant interest in the overall nuclear physics community in nuclear structure studies. A schematic representation of the RIA concept is shown in figure 1. RIA is intended to provide a wide range of rare isotopes at a variety of secondary beam energies. These capabilities will maximize the scientific output of RIA and allow for a diverse experimental program. Planed in the facility are the capabilities to allow independent, simultaneous experiments in at least two, but hopefully all four of the experimental areas. This talk will present a general overview of the RIA concept, a bit of the history of RIA, and outline the scientific justification. An emphasis will be placed on the new capabilities that RIA will provide and hopefully help to simulate further thinking on the possibilities and required experimental equipment.

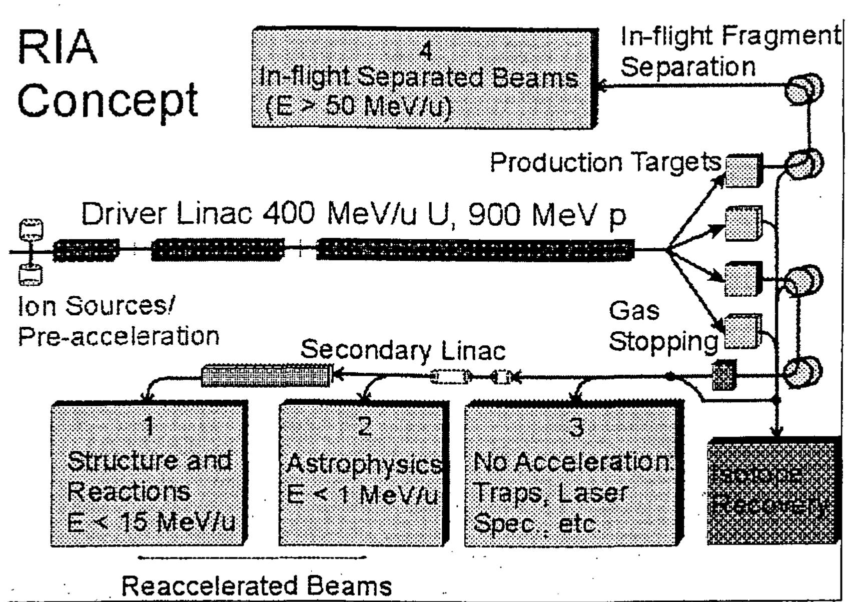

Figure 1. A conceptual layout for the RIA facility. Experiments will be possible with a wide range of rare isotopes and over a large range of energies.

1. 2002 NSAC Long Range Plan for Nuclear Science:
http://www.er.doe.gov/henp/np/nsac/LRP_5547_FINAL.pdf

EVOLUTION OF OCTUPOLE DEFORMATION IN ^{222}Th

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The largest octupole deformations are observed in the light-actinide nuclei, near $^{224}_{90}$Th$_{134}$, where the octupole-driving $\Delta\ell = \Delta j = 3$ orbitals are ($f_{7/2}$ and $i_{13/2}$) for protons and ($g_{9/2}$ and $j_{15/2}$) for neutrons. The experimental evidence for octupole deformation in this region is well documented, and has recently been reviewed comprehensively in Ref. [1] Experimentally, the signature of octupole deformation is a band of states of alternating parity, connected by enhanced electric-dipole transitions (10^{-4} to 10^{-2} W.u. compared to 10^{-5} W.u. in reflection-symmetric nuclei). In the light-actinide region, octupole bands have now been observed in over 20 nuclei, with the best examples being in the $_{88}$Ra and $_{90}$Th nuclei. Also, in many of these isotopes, super- and hyper-deformed minima are predicted at relatively low excitation energies of about 5 MeV, and are expected to become yrast at spins of about $30\hbar$. Despite the motivation to study these nuclei, the lack of neutron-rich beams, and of stable targets above ^{209}Bi, means that nuclei in this region are not easy to populate, especially at high-spins. However, one nucleus which can be populated at high spin is ^{222}Th, by use of the ^{208}Pb(^{18}O,4n) reaction. For this reason, the yrast band in ^{222}Th now represents one of the best known examples of a high-spin octupole band [2], and is perhaps the best nucleus in which to study the behavior of an octupole band at the highest spins.

An experiment was performed in September 2001, in order to study the behavior of the octupole band of ^{222}Th at the highest accessible spins, and to search for the predicted highly-deformed bands. The ^{208}Pb(^{18}O,4n) reaction was used and de-excitation gamma rays were detected using the Euroball-IV gamma-ray detector array. The ^{18}O beam, at 95 MeV, was provided by the Vivitron accelerator at the IRES laboratory in Strasbourg, France. The BGO inner ball of Euroball-IV was used as a sum-energy filter in order to suppress the large background of gamma rays from prompt fission fragments; this was a method which has proven to be highly effective. This work represents first use of the Euroball BGO inner ball as a fission suppressor. Analysis of the high-spin data is presently underway at the University of Manchester. Results concerning the high-spin behavior of ^{222}Th will be presented and discussed.

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LIMITS OF THE ENERGY-SPIN PHASE SPACE BEYOND THE PROTON DRIP LINE: ENTRY DISTRIBUTIONS OF Pt AND Au ISOBARS*

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Nuclei lying beyond the proton drip line provide an ideal laboratory for the study of the amount of energy and angular momentum which a weakly-bound system can sustain. These limits of existence can be determined by measuring the entry distribution [1] populated in a fusion-evaporation reaction. The entry distribution is the initial population as a function of excitation energy E and spin I, after particle evaporation from the compound system, from which γ emission to the ground state originates. It has been suggested [2] that the entry distribution should be limited beyond the drip line, since only a small region of the energy-spin phase space, just above the yrast line, does not decay by proton emission.

Entry distributions have been measured for $^{173-177}$Au nuclei, all of which lie beyond the drip line, and compared with those of the more stable Pt isobars. These systems were populated following the bombardment of ^{92,94,96}Mo targets by beams of ^{84}Sr, provided by the ATLAS accelerator. Fusion-evaporation products were selected using the Argonne fragment mass analyzer, and the recoil-decay tagging method was used to select the α-decaying states of interest. Prompt γ rays were detected using the 106-module GAMMASPHERE array as a calorimeter. Total modular energy H and multiplicity K were measured. The response functions of the array enable the conversion of modular (H, K) to energy and multiplicity, which can be related to spin by realistic assumptions [1] of the angular momenta carried by the components of the γ-ray cascade. Comparisons have been made between the entry distributions associated with odd-A Au and Pt isobars. In ^{173}Au the first evidence is seen for the limits of excitation energy and angular momentum which a nucleus beyond the proton drip line can sustain. The observed results cannot be explained by simple calculations based on Q-values or by statistical model calculations, both of which predict similar distributions for isobars.

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ROTATIONAL DAMPING IN YTTERBIUM (YB) NUCLEI

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When as little as one MeV of thermal energy is added to rotational nuclei, the level density becomes high and the levels mix. This process is the damping of the nucleonic motion from ordered to chaotic. However, this same high level density causes the emitted γ-ray spectra to consist of very many lines, currently unresolvable, making studies difficult. The unmixed bands generally have different rotational properties so that levels of the same spin emit rotational γ rays of different energies. The mixed levels can then emit γ rays having any of these energies. This "rotational damping" is an important change because a level of spin I no longer decays to a single level of spin $I-2$ but to any of a number of levels. The resulting distribution of γ-ray energies emitted by a single level has a FWHM that is called the "rotational damping width" (Γ_{rot}).

To study rotational damping we can look at correlations in the spectrum in coincidence with a given γ-ray energy (the gate). In a rotational nucleus a γ ray in the gate will be in coincidence with all the others in the rotational cascade, but not with itself. This generates a strong negative correlation at the gate energy, called the "rotational" correlation. We have found that this rotational correlation from damped bands is generally masked by a positive "feeding" correlation, which must be removed. We first fit the data with a simulated spectrum (containing both the rotational and the feeding correlations). The gate in the simulated spectr um is then allowed to be in coincidence with itself, thereby removing the rotational correlation. This "feeding simulation", which contains only the feeding correlation, is then subtracted from the data correlation spectrum to isolate the rotational correlations. The best values for Γ_{rot} in some Yb nuclei studied in this way were found [1] to be 300 keV for gates in the range, 1.2 to 1.5 MeV. Simulations with varying inputs and Γ_{rot} values show that the uncertainty limits on Γ_{rot} are about $\pm 20\%$.

These data may contain information about two additional interesting phemomena: compound damping and motional narrowing. Compound damping reflects the spreading width (Γ_{μ}) of the basis states. Motional narrowing occurs at high thermal excitat ion energies, E*, where Γ_{μ} is larger than Γ_{rot} and a given state tends to emit the average γ-ray energy of the admixed basis states rather than the full range.

To study these phenomena we have developed a more sophisticated simulation code which has a competitive cascade of rotational and statistical γ-ray transitions together with inputs for Γ_{μ} and Γ_{rot} as a function of both spin an d E*. We can get information on Γ_{μ} from the behavior of the ridges and on E* from the statistical γ rays. Very preliminary results suggest: 1) the values for Γ_{μ} [2] and Γ_{rot} [3] from theory are reasonable (as fou nd also in [1]); 2) the E* values are higher than initially thought; and 3) the combination of 1) and 2) imply motional narrowing at high spins in the Yb nuclei studied.

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HIGHLY-DEFORMED ROTATIONAL STRUCTURES IN THE $A \sim 40$ MASS REGION

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Recent experiments with GAMMASPHERE and the MICROBALL charged-particle detector array have led to the identification, and have enabled the detailed spectroscopic study, of highly-deformed and superdeformed rotational bands in a number of $A \sim 40$, $N \approx Z$ nuclei. These rotational bands are built on multi-particle multi-hole excitations across the $N, Z = 20$ shell gap from the *sd* to the *pf* shell and, in the context of the Nilsson scheme, are associated with the shell gaps formed at large prolate deformation for particle numbers $N, Z = 16, 18, 20$ as *pf*-shell intruder orbitals are occupied. In analogy with well-developed rotational motion in heavy nuclei, these highly collective rotational structures involve active valence particles in two major shells for both protons and neutrons, yet the $A \sim 40$ bands possess the unique advantage that the valence space dimension remains small enough to be approached from a shell-model perspective. These rotational bands thus provide an ideal opportunity for detailed comparisons between experimental data and both microscopic and macroscopic models of collective motion in nuclei. This presentation will provide an overview or recent experimental results in this mass region, progress in understanding these data in terms of both mean-field and large-scale shell model calculations, and prospects for achieving a more complete microscopic understanding of collective rotational motion in these light nuclei.

THERMODYNAMICAL PROPERTIES OF ^{56}Fe*

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The Oslo Cyclotron Group has developed a method to extract average level densities and radiative strengths simultaneously [1]. This method relies on primary γ rays from excited levels populated during the reaction processes. A primary γ spectrum represents γ-decay probability distribution, and is proportional to the product of the level density at the decaying level and the radiative strength, according to Brink-Axel hypothesis [2,3]. The method has been applied to study many mid-shell rare-earth nuclei where the level density is high, and thermodynamical properties of these nuclei have been extracted [4-6]. However, the light-mass region is yet to be investigated. Recently the method has been extended to study the ^{56}Fe nucleus, which is close to a doubly magic core, in the light mass region. The experiment was carried out with a 45-MeV ^{3}He beam using the (^{3}He,α) reaction on a ^{57}Fe target at the Oslo Cyclotron Laboratory.

Thermodynamical quantities for ^{56}Fe have been investigated theoretically by Rombouts et al. using a finite-temperature quantum Monte Carlo method [7]. In addition, the heat capacity of several iron isotopes has recently been calculated by Liu and Alhassid within the interacting shell model using the complete $(pf + 0g_{9/2})$-shell [8]. A signature of a pairing phase transition in the heat capacity is identified in the ^{56}Fe isotope in both calculations.

The experimental method and results for the level density, radiative strength, and thermodynamical properties of ^{56}Fe will be presented.

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Low-Lying Dipole Strength in ^{20}O*

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The availability of fast radioactive beams offers the possibility for studies of $E1$-strength in projectiles via Coulomb excitation. Theoretical calculations predict that a significant fraction of this strength is shifted towards lower excitation energies in neutron-rich systems (e.g., Refs. [1-4]). At the NSCL, virtual photon scattering was used to probe the discrete structure of both ^{18}O and ^{20}O for levels in the region between 1 and 8 MeV. Two 1^- levels at 5.35 and 6.85 MeV were observed for the first time in ^{20}O. The observed γ-ray spectrum for ^{20}O is, in fact, dominated by transitions resulting from $E1$ excitations to these states. The extracted $B(E1)\uparrow$ values of ~0.062 e^2fm^2 and ~0.035 e^2fm^2 for the 5.35 and 6.85 MeV levels, respectively, are larger than shell model calculations predict [5]. Such large dipole strengths are not observed for low-lying 1^- states in ^{18}O, indicating a shift of dipole strength towards lower energies as one approaches the neutron drip-line.

100 MeV/nucleon beams of $^{18,20}O$ impinged on a 30 mg/cm^2 enriched ^{208}Pb target. De-excitation γ rays were detected with the ORNL-TAMU-MSU BaF_2 array placed at forward angles surrounding the beam pipe. The γ-ray energies were Doppler-corrected and the nearest neighbor add-back was performed, improving the response of the array. The γ-ray energy was correlated with projectile energy-loss measured with the S800 spectrograph. Monte Carlo simulations which have incorporated theoretical predictions for ^{20}O and made use of the detector simulation code GEANT were used to make direct comparisons with the experimental results and extract quantitative information.

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SHAPE COEXISTENCE IN LIGHT POLONIUM ISOTOPES

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Different shapes, coexisting at low excitation energies and interacting at low spin, form a well-established phenomenon in nuclei near the Z=82 proton-shell closure [1]. In neutron-deficient polonium nuclei, proton pair excitations across the Z=82 gap, lead to oblate (4 particle-2 hole) and prolate (6p-4h or 8p-6h) configurations that coexist with the nearly-spherical (2p-0h) states. Potential energy surface calculations predict that the deformed structures come down in energy when moving towards the neutron mid-shell at N=104, the oblate 0^+ state is the lowest in energy in ^{192}Po and ^{190}Po, in ^{188}Po the prolate configuration becomes lowest in energy.

In this contribution a review of the latest experimental results from complementary in-beam γ-ray spectroscopy and α decay measurements of the lightest $^{188-192}$Po isotopes will be presented and compared with recent theoretical calculations.

In-beam studies, carried out with the Jurosphere array in conjunction with the RITU separator (JYFL, Finland), identified mainly yrast states in the light Po isotopes, the low-spin part of the yrast structure being determined by the mixing between the low-lying coexisting states. In ^{190}Po the yrast structure above spin 2^+ has been associated to the prolate configuration.

α-decay fine structure measurements down to ^{188}Po have been carried out at the SHIP separator (GSI, Germany). Low-spin excited states in the daughter lead nuclei have been identified and information on their structure and on the structure of the ground state of the α-particle decaying nucleus has been obtained. In ^{192,190}Po the oblate structure is the dominant component in the ground state wave function, in ^{190,189,188}Po an increased contribution from the prolate configuration has been observed.

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ISOSPIN-MIXING IN THE N=Z NUCLEUS ^{54}Co *

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There is currently great interest in the measurement of the size of isospin-mixing in N=Z nuclei, because of the impact of these data on the nuclear physics part of the unitarity test for the Cabibbo-Kobayashi-Maskawa (CKM) matrix [1]. Although the common road to the measurement of isospin-mixing is the study of super-allowed Fermi β-decay, we will show that the study of electromagnetic, 'super-allowed' magnetic dipole transitions can also give this information. The reason is that although the isoscalar magnetic dipole transitions are not strictly forbidden they are very much hindered in comparison to the magnetic isovector transitions, which are often very large.

The T=1 admixture into the T=0 member of a recently discovered $J^{\pi} = 4^{+}$ isospin-doublet in ^{54}Co [2] is obtained from the measured electromagnetic E2/M1 multipole mixing ratio, $\delta = 0.12(4)$, of the T = 0, $4^{+} \rightarrow 3^{+}$ transitions. Furthermore, the isospin-mixing can be also obtained from the intensity branching ratio R = 0.51(3) of the electromagnetic decays: $4^{+} \rightarrow 5^{+}$ and $4^{+} \rightarrow 3^{+}$. This branching ratio, R, is changed by about a factor of 50 due to isospin mixing.

The reason for the enhanced sensitivity of these transitions to isospin-mixing is that the $T = 1, 4^{+} \rightarrow T = 0, 3^{+}$ transition is an isovector magnetic dipole transition with a B(M1) value of a few μ_N^2. On the other hand, the $T = 0, 4^{+} \rightarrow T = 0, 3^{+}$ transition is an isoscalar magnetic dipole transition and, therefore, very weak. Thus, even a small mixing of the T=1, 4^{+} state into the T=0 , 4^{+} wave function will lead to a strong $T = 0, 4^{+} \rightarrow T = 0, 3^{+}$ transition. Combining these data with shell model calculations for strong isovector M1 and isoscalar E2 electromagnetic matrix elements one obtains a value of the T=1 admixture into the T=0, 4^{+} state of $0.23^{+0.29}_{-0.10}$%. This value agrees with the value (0.35(10)%) by Brown et al. [3] for the 0^{+} T=1 ground state of ^{54}Co. It is a little bit smaller than the value (0.7%) given by Colo et al. [4]. It is of course to be expected that the isospin admixtures to different states with different spins are different. The corresponding mixing matrix element in the 4^{+} doublet is $V_{mix} = 10$ keV.

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RELATIVISTIC MEAN-FIELD AND RPA DESCRIPTION OF EXOTIC NUCLEAR STRUCTURE

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The relativistic random phase approximation, based on effective mean-field Lagrangians with nonlinear meson self-interaction terms, has been applied in the analysis of the evolution of the isovector dipole response in nuclei with large neutron excess [1,2]. The dipole response is characterized by the fragmentation of the strength distribution and its spreading into the low-energy region, and by the mixing of isoscalar and isovector modes. In light nuclei the low-lying dipole strength is due to single particle excitations of the loosely bound neutrons. In heavier nuclei, among several peaks characterized by single particle transitions, a single collective isovector dipole state is identified below 10 MeV. A coherent superposition of many neutron particle-hole configurations characterizes its RRPA amplitude. An analysis of the corresponding transition densities and velocity distributions reveals the dynamics of the dipole pygmy resonance: the vibration of the excess neutrons against the inert core composed of equal numbers of protons and neutrons. The relativistic random phase approximation has also been employed in the analysis of the dynamics of isoscalar dipole and compression modes [3,4]. Two basic isoscalar dipole modes have been identified from the analysis of the velocity distributions. It has been suggested that the recently observed low-lying component of the isoscalar dipole mode might correspond to the toroidal giant dipole resonance [5].

The Relativistic Hartree Bogoliubov (RHB) model has been applied in the description of exotic nuclear structure phenomena in nuclei far from stability. In particular for nuclei close to the drip-lines the RHB framework provides a unified and self-consistent description of mean-field and pairing correlations. On the proton-rich side, ground-state properties of drip-line odd-Z nuclei in the regions $31 \leq Z \leq 49$ and $53 \leq Z \leq 73$ have been studied [6,7]. For the elements which determine the astrophysical rapid proton capture process path, as well as for odd-Z ground state proton emitters, the location of the proton drip-line, the ground-state quadrupole deformations and one-proton separation energies at and beyond the drip-line, the deformed single-particle orbitals occupied by the odd valence proton, and the corresponding spectroscopic factors have been compared with available experimental data.

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HIGH SPIN STUDIES OF N~Z NUCLEI IN THE MASS 70 REGION*

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In recent years there has been great interest in the structure of nuclei with equal or approximately equal numbers of protons and neutrons. This is primarily because studies of the heaviest N=Z nuclei are expected to provide important information on the *np* pairing interaction. N~Z nuclei in the A~70 region are also interesting since they have been found to exhibit shape co-existence between near-degenerate well deformed oblate and prolate shapes. Studies of odd mass nuclei in this mass region allow detailed investigations to be made of the nuclear shapes and of alignment blocking effects and the subsequent destruction of pairing correlations at high spins.

In the present work we have investigated the high spin structure of ^{72}Kr using the ^{40}Ca + ^{40}Ca reaction at 164 MeV and ^{73}Kr using the ^{36}Ar + ^{40}Ca reaction at 145 MeV and the former reaction at 160 MeV. The experiments were carried out using various combinations of GAMMASPHERE, MICROBALL and the neutron shell. In ^{72}Kr we have evidence for a second high spin structure in addition to the original structure reported by Fischer et al [1]. This will be discussed and compared to the results of various model calculations. In ^{73}Kr the three previously known bands [2] have been extended up to high spin. The interesting features here are that in the negative parity bands the anticipated double $g_{9/2}$ proton and neutron alignment does not account for the observed data. Furthermore, the observation of crossover transitions at low spin in both the negative parity bands and between the known positive parity band and a potential new signature partner, indicate that all the structures are prolate. The results will be discussed in terms of various mean-field calculations.

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STRUCTURE OF NEUTRON-RICH NUCLEI IN A~100 REGION OBSERVED IN FUSION-FISSION REACTION *

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Neutron-rich nuclei around A=100 were populated as fission fragments produced by the $^{238}U(\alpha, f)$ fusion-fission reaction. The experiment was performed at the 88-inch cyclotron facility of the Lawrence Berkeley National Laboratory by bombarding a ^{238}U target with an α beam at E_{lab}=30MeV. By using a thin-target, the deexcitation γ rays were detected by Gammasphere in coincidence with the detection of both fission fragments by the Rochester 4π heavy-ion detector array, CHICO. Compared to the previous spontaneous fission experiments [1,2], which used targets thick enough to stop fission fragments in order to avoid Doppler effect broadening, this technique allowed Doppler-shift corrections to be applied for the observed γ rays on an event-by-event basis and the origin of γ rays from either fission fragment to be established. Consequently the resultant spectra were cleaner and more straightforward to interpret, without relying on the systematics of the γ ray coincidence relationships. More important was that it removed the difficulty of studying γ-ray transitions from states with short lifetimes. In addition, this technique provided refined mass distributions with unit Z and A resolution by using the characteristic γ rays, and thus added a new dimension to the study of fission dynamics providing an exquisite detail not available previously.

The neutron-rich nuclei in A~100 region exhibit a wide variety of structural phenomena, such as an abrupt transition from spherical to highly deformed ground states at N~60 for Sr and Zr isotopes [1], spherical and deformed shape coexistence in ^{100}Zr. The ^{106}Mo nucleus was found to have a two-phonon vibrational state [3]. For increasing the proton number above Z=40, the nuclear shape evolves from axial symmetric nuclei to soft triaxial rotors, and there is a predicted prolate to oblate shape transition in the Pd nuclei, etc. Exploiting the experimental advantages mentioned above has allowed study of interesting new phenomena. For example, the yrast sequences for the deformed nuclei $^{103,105}Mo$ have been extended to much higher spin states and the ground band of ^{104}Mo followed throughout the band crossing region. The newly acquired knowledge for the high-spin states of these neutron-rich nuclei makes it possible to identify the quasiparticle configuration responsible for the observed band crossing in ^{104}Mo [4]. In the Pd region, the level scheme of ^{118}Pd was found to be different from the early claims of both induced fission and spontaneous fission studies. The two previous results are inconsistent with each other and both differ from our results derived from much cleaner spectra. The establishment of systematics for the yrast sequence for very neutron-rich Pd isotopes is important for locating the prolate to oblate shape transition, etc. The present analysis shows that interesting phenomena can be addressed, such as collectivity, shape coexitence, and shape transitions, in the Sr, Zr, Mo, Ru, Pd region, and that the fission-fragment γ-ray coincident technique is a powerful probe of neutron-rich nuclei.

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PAIRING CORRELATIONS AND FUNDAMENTAL EXCITATIONS IN N=Z NUCLEI

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N=Z nuclei form an exciting laboratory for nuclear structure studies. The double degeneracy of proton and neutron wave function allows for the simultanous presence of T=0 and T=1 Cooper pairs in the nuclear ground state. A longstanding problem relates to the collectivity of the T=0 pair field. The standard T=1 seniority pairing force accounts for a variety of nuclear structure effects. However, mean field calculations restricted to T=1 pairing face severe problems in N=Z nuclei. On the other hand, the presence of a static T=0 pair field can in a simple fashion account for several nuclear structure effects of nuclei close to the N=Z line, like the Wigner energy[1], the excitation energy of the isobaric analogue states as well as the near degeneracy of T=1 and T=0 states in odd-odd nuclei[2,3]. In addition, there is an appealing analogy of the response of the T=0 and T=1 pair field to rotations in real and iso-space, respectively[2,4]. The presence of T=0 pairing can also affect the bandcrossing frequency as well as induce novel kind of band crossings[5,6,7]. In this talk, we will review some of the properties of the T=0 and T=1 pair condensate and discuss the fundamental excitations in N=Z nuclei. The mass differences of the isobaric multiplets will be given special attention. The effect of T=0 pairing on the rotational motion as well as band crossing frequencies will be discussed for representative cases. The consequence of T=0 pairing for the rotational spectrum of ^{73}Kr is reviewed.

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Poster Presentations

COULOMB EXCITATION AND FEW NUCLEON TRANSFER REACTIONS WITH ^{209}Bi BEAMS ON ^{237}Np AND ^{241}Am TARGETS*

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The actinide nuclei have long been known to be an excellent laboratory for the study of collective motion. Most of the available data on high-spin states in these nuclei have been obtained using Coulomb excitation and deep-inelastic reactions. Several measurements have been performed at ATLAS using ^{207,208}Pb and ^{209}Bi beams, at bombarding energies $\sim$ 15% above the Coulomb barrier, incident upon a number of actinide targets. Large sets of γ-ray coincidence data were collected using the Gammasphere array. Initially, our studies concentrated on a series of Pu isotopes ranging from A=238 to 244 [1]. Based on comparisons between the yrast band and the lowest lying excited band built on an octupole vibration, it was suggested that octupole deformation stabilizes at high-spin for A$\sim$240. Part of the evidence which led to this conclusion came from the fact that a sharp upbend at $\hbar\omega \sim 0.25$ MeV seen in the heavier Pu isotopes was not observed in either ^{239}Pu or ^{240}Pu.

In order to better understand this anomaly in the alignment patterns, we examined the available data on odd-A nuclei in this mass region. While some information was available on a number of odd neutron nuclei, the odd proton systems were poorly known. As a result, two experiments were performed using ^{237}Np and ^{241}Am targets. In both cases, rotational bands built on a $\pi i_{13/2}$ configuration were observed to high-spin in the target nuclei. From these new data and those available for even- and odd-A U and Pu isotopes, we have concluded that the $i_{13/2}$ quasiprotons dominate the observed alignments in this mass region and that there is little contribution from aligning $j_{15/2}$ neutron pairs. This is unexpected based on Cranked Shell Model predictions which indicate that both quasiparticle pairs should be involved in the observed alignment processes. Furthermore, the new data give a strong indication that both the neutron and proton pairing are reduced significantly relative to what current models predict.

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TRIAXIALITY AND THE WOBBLING MODE IN ^{167}Lu*

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The wobbling mode is a direct consequence of rotational motion of a triaxial body. The wobbling degree of freedom introduces sequenses of bands with increasing number of wobbling quanta [1], and a characteristic Δ I=1 decay pattern between the bands in competition with the in-band decay. Several, presumably triaxial, superdeformed bands (TSD's) involving an aligned $i_{13/2}$ proton, have been reported in recent years, and for the first time, the wobbling excitation was established experimentally in ^{163}Lu, lately [2]. The presence of an aligned $i_{13/2}$ proton strongly influences the decay from a wobbling excitation [2].

High spin states in ^{167}Lu were populated through the ^{123}Sb(^{48}Ca,4n) reaction at 203 MeV from the 88 inch Cyclotron at LBNL. Five TSD bands were found in ^{167}Lu. The two strongest populated, TSD1 and TSD3, have been firmly linked to normal deformed (ND) structures. Most importantly, several transitions connecting TSD2 to TSD1 were also identified. From experimental mixing and branching ratios large values of $B(E2)_{out}/B(E2)_{in} \sim 0.22$ could be determined, comparable to the values found in ^{163}Lu [2]. The present evidence for the wobbling mode in ^{167}Lu, four neutrons away from ^{163}Lu, is an important step to support the wobbling mode as a general phenomenon, and it establishes stable triaxiality in a broader region.

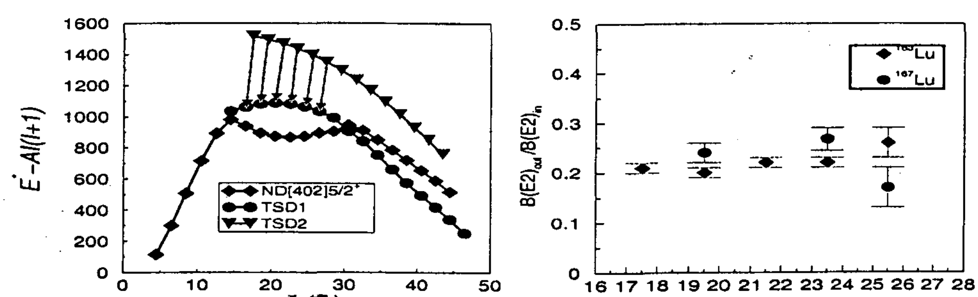

Figure 1: Left: *Excitation energies for selected TSD and ND bands ^{167}Lu. Transitions linking the wobbler candidate in ^{167}Lu and the yrast TSD band are indicated with arrows.*
Right: *Properties of the TSD2→TSD1 $\Delta I = 1$ transitions in ^{167}Lu compared to corresponding experimental values [2] for ^{163}Lu.*

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α-DECAY SPECTROSCOPY, NUCLEAR SPIN AND MAGNETIC MOMENT MEASUREMENTS OF THE LONG-LIVED ISOMERIC STATES IN ^{185}Pb

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IS387 Collaboration and ISOLDE Collaboration

By using the Resonance Ionization Laser Ion Source (RILIS) the decay properties of the neutron-deficient isotope ^{185}Pb were studied at the PSB-ISOLDE (CERN) on-line mass separator. The nuclei of interest were produced in a 1.4 GeV proton-induced spallation reaction of a uranium graphite target. After resonance ionization in the hot cavity of RILIS, extraction and A=185 mass-separation in the General Purpose Separator of ISOLDE, the ions were implanted in a thin movable tape, surrounded by the Si- and Ge- detectors for the spectroscopic measurements.

In contrast to previous studies two α-decaying isomeric states were found in ^{185}Pb. The relative production of the isomers, monitored by their α-counting rates, could be significantly changed when a narrow-bandwidth laser at the RILIS setup was used to scan through the atomic hyperfine structure. Based on the atomic hyperfine structure measurements, along with the complementary data on the α decay, the spin and the parity of these states were interpreted as $3/2^-$ and $13/2^+$ and their nuclear magnetic moments were deduced. The change in charge radius and deformation between two isomeric states in ^{185}Pb was deduced and compared with the known data in the heavier odd-mass Pb nuclei. The comparison shows that the value $\delta < \beta^2 >^{m1,m2}$ is practically the same for ^{185}Pb and ^{197}Pb, despite the fact that the former nucleus has 12 neutrons less than the latter and lies beyond the mid-shell at N=104.

By using the α-γ coincidence technique, information on new excited states in the daughter ^{181}Hg was obtained. A striking similarity of the decay patterns (e.g. hindrance factor values, excitation energies) in the ^{187}Pb$\rightarrow$^{183}Hg and ^{185}Pb$\rightarrow$^{181}Hg decay chains was found and will be discussed in the contribution.

HIGH SPIN STATES IN ^{38}Ar

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Recently superdeformed rotational bands have been discovered in ^{36}Ar[1], and ^{40}Ca[2]. The emergence of superdeformation in this mass region provides us with an opportunity to study the interplay between macroscopic and microscopic effects in light nuclear matter. The N$\neq$Z nucleus ^{38}Ar lies 2 neutrons more than ^{36}Ar and 2 protons less than ^{40}Ca. Highly deformed bands, firmly linked to states in ^{38}Ar, have been observed[3]. A level scheme and B(E2)'s for the bands of interest in ^{38}Ar will be presented. The ^{24}Mg(^{20}Ne,α2p)^{38}Ar reaction was used to populate the nuclide in an experiment conducted with the GAMMASPHERE array in concert with the MICROBALL charged particle array.

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A New Precision Measurement of the $^{7}Be(p,\gamma)^{8}B$ Cross Section with an Implanted ^{7}Be Target

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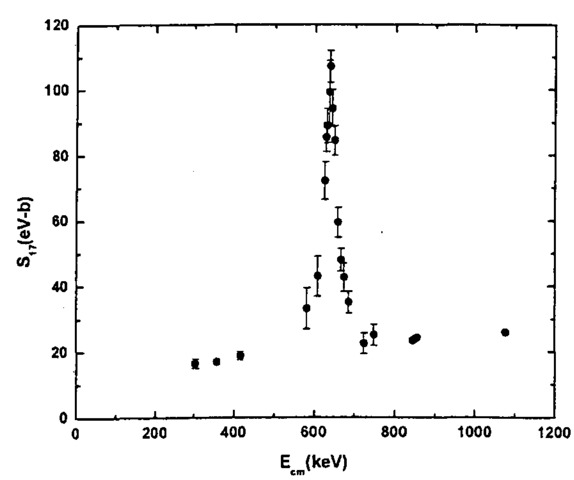
ABSTRACT

The $^{7}Be(p,\gamma)^{8}B$ reaction plays a central role in the estimates of solar neutrinos fluxes and in understanding the issue of possible neutrino mass oscillation.

We report on a new precision measurement of the cross section of this reaction following our previous experiment with an implanted ^{7}Be target, a raster-scanned beam and the elimination of the backscattering loss. The present measurement incorporates several experimental improvements: an order-of-magnitude more ^{7}Be atoms in the implanted target, a thinner α detector reducing the pile-up noise, higher precision in the target activity calibration and a careful monitoring of the background. Several recent experiments have used similar methods and reported precision results. Nevertheless, there still exist discrepancies, much larger than the quoted errors, between the published *experimental* cross sections and the resulting $S_{17}(0)$ values. We address these discrepancies and aim to provide a new, firm input for the determination of this cross section. Fig. 1 presents the preliminary summary of the present data. We note the point at E_{CM}=845 keV, corresponding to the E_p(lab) = 992 keV resonance of the $^{27}Al(p,\gamma)^{28}Si$ reaction which was measured at very high precision.

Final analysis of the data is now in progress. The results will be presented and discussed

Fig. 1: Preliminary results of the extracted astrophysical S_{17} factor.



SEARCH FOR ^{16}Be*

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The recently reported emergence of new shell structures in very neutron-rich nuclei initiated a re-evaluation of binding energies along the neutron dripline. New shells might be responsible for the fact that ^{26}O is unbound while ^{31}F is still bound [1]. Revisiting even lighter nuclei, shell-model configuration-mixing calculations [2] predict the nuclei ^{22}C, ^{19}B, and ^{16}Be to be unbound. However, since the nuclei ^{22}C and ^{19}B are bound [3], it could be possible that ^{16}Be is bound as well.

The search for ^{16}Be has been undertaken at the newly completed Coupled Cyclotron Facility at the National Superconducting Cyclotron Laboratory at Michigan State University, which produced a primary beam of ^{40}Ar at 140 MeV/nucleon. Neutron-rich fragmentation products emerging from a beryllium production target were separated using the A1900 fragment separator. The isotopes ^{6,8}He, ^{9,11}Li, ^{12,14}Be, ^{17,19}B, and ^{20}C were identified using time-of-flight and energy-loss information, but no events of ^{16}Be were recorded.

We used the simulation code LISE [4,5] to calculate event rates taking into account extrapolated production cross sections and ion optical transmission. From this simulation one would expect to detect ^{16}Be at a higher rate than ^{19}B if the beryllium isotope was bound. The fact that ^{16}Be was not detected leads to the conclusion that it is unbound.

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EARLY RESULTS FROM THE SASSYER GAS FILLED RECOIL SEPARATOR

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The Small Angle Separator System at Yale for Evaporation Residues (SASSYER) is now commissioned at Yale University where it is coupled to the YRAST Ball gamma-ray spectrometer. SASSYER, formally the SASSY II separator at LBNL, consists of 3 magnets, a gradient field vertically focusing dipole, followed by a horizontally focusing quadrupole and a second vertically focusing dipole. The flight path from target to focal plane is on the order of 2 m or, typically, $\leq 1\mu s$ flight time, making SASSYER a very compact device. The target chamber and magnets are operated at 1 Torr He gas which, via charge exchange reactions brings the recoiling fusion evaporation products to an average charge state greatly increasing the transmission efficiency of recoils from the target to the focal plane. Such gas filled separators, for example, the RITU separator in Jyvaskyla, have proven to be extremely powerful channel selection devices and spectroscopic tools when coupled to a high efficiency gamma-ray spectrometer. YRAST Ball, consisting of up to 9 segmented clover detectors and 11 smaller coaxial detectors has a photopeak efficiency of $\sim 3\%$ when coupled to SASSYER. A variety of focal plane detectors have been developed for use with SASSYER. These include a PPAC, and a 30 element solar cell array for recoil detection. A DSSD is also available. Several early commissioning experiments, utilizing S and Ti induced reactions on a Sn target have been carried out and results of these, including transmission efficiencies will be presented. The first physics production runs are currently underway and these and possible future research directions will be discussed.

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COLLECTIVITY AND SINGLE PARTICLE DEGREES OF FREEDOM; STUDIES OF LIGHT $f_{7/2}$ NUCLEI AT EUROBALL IV AND RECOIL FILTER DETECTOR

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Superdeformation discovered in ^{36}Ar and ^{40}Ca [1,2] is a feature rather unexpected for such light nuclei. However, recent shell model calculations have predicted the existence of very deformed states, i.e. having a very large quadrupole momentum and connected by fast E2 transitions, which could be associated with the observed SD bands. In the shell model approach for light nuclei at relatively high spin, very large deformation can be generated using complex calculations within large and properly selected configuration space.
In this description, the superdeformation in ^{36}Ar and ^{40}Ca results from rather complicated multi-particle multi-hole core excitations. Unlikely, in the vicinity of ^{48}Cr, in the middle of the $f_{7/2}$ shell, the observed rotational behavior is well accounted for by calculations restricted to the valence nucleons in the extended fp shell [3].
In the light odd $f_{7/2}$ shell nuclei ^{45}Sc and ^{45}Ti which are the object of our investigations, various aspects of collectivity resulting from a coupling of valence fp nucleons and particle-hole excitations of the ^{40}Ca core can be studied and compared with the shell model predictions.

The high spin states in ^{45}Sc, ^{45}Ti and several neighboring nuclei were populated in a fusion–evaporation reaction at VIVITRON tandem accelerator of IReS in Strasbourg. A thin ^{30}Si target was bombarded by a 70MeV ^{18}O beam. Gamma rays were measured in the EUROBALL IV array. In addition, the velocity vector of every recoiling nucleus was determined by the Recoil Filter Detector. This provided a very efficient way to reduce γ-line Doppler broadening and allowed the observation of high energy γ-rays with good resolution [4].

The results of the experiment show that in the ^{45}Sc nucleus, the $K^{\pi}=3/2^{+}$ intruder deformed band terminates at the maximum aligned spin of 31/2. This effect is very well described by the shell model calculations. On the other hand, a rotational band based on the 2-particle 2-hole excitation in ^{45}Sc, observed up to the spin of 35/2, resembles the SD bands reported both in ^{36}Ar and ^{40}Ca. Very short lifetimes estimated from γ-line shapes for those states point out to a large deformation associated with this excitation.
On the contrary, the level structure of ^{45}Ti can be interpreted as a signature of competition between a collective excitation and a T=1 proton-neutron coupling. In this nucleus, a deformed $K^{\pi}=3/2^{+}$ intruder band, well developed at low spin, terminates much below the maximum alignment. Whereas at high spin, a band analog to the T=1 ground state band in ^{46}V dominates.The shell model calculations performed for ^{45}Ti point out that the two structures should simultaneously appear in the whole range of available angular momentum.

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PROBING THE ^{11}Li HALO STRUCTURE THROUGH THE STUDY OF EXCITED STATES AND β-DECAY IN A THREE BODY MODEL

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A Three Body Model for ^{11}Li proposed earlier (S.Dasgupta, I.Mazumdar and V.S.Bhasin, Phys.Rev.C 50,R510 (1994)) employing separable potentials for n-n ans n-^{9}Li interactions has been extended to study the recently observed excited states in ^{11}Li above the three-body break-up threshold. The n-^{9}Li potential used here includes both s- and p- state interactions so as to incorporate the virtual s-state and p-wave($J^{\pi} = 1/2^{-}$) resonance observed experimentally. The resulting coupled integral equations for the spectator functions have been computed using the method of rotating the integral contour of the kernals in the complex plane. The model predicts the ground state energy as well as the energies of the three excited states, viz; $E_0 = -0.286\,\text{MeV}, E_1 = 0.047\,\text{MeV}, E_2 = 1.087\,\text{MeV}$ and $E_3 = 2.080\,\text{MeV}$ in reasonable agreement with the experimental data. The analysis also shows that in the three-body wavefunction, while the component representing the n-n correlation and the spectator function of the ^{9}Li core contributes more than 57%, the other components constituting s- and p-wave n-^{9}Li correlation and the corresponding spectator functions of the halo neutron contribute about 42.5% and 0.5% respectively. It turns out that the contribution of p-wave resonance in n-^{9}Li interaction has only a marginal role to play as compared to that of the virtual s-state interaction in determining the ground and excited state energies of ^{11}Li.

To probe further the sensitivity of the ^{11}Li wavefunction computed above, we extend our investigation to study β-transition of ^{11}Li into a high lying state at about 18.5 MeV of daughter nucleus ^{11}Be. This investigation aims at not only determining the value of the large Gamow-Teller strength, B_{GT}, but is also expected to shed light on the contribution of $(p_{1/2})^2$-configuration in the ^{11}Li wavefunction. The results on these calculations will be reported in the Conference.

TRIAXIAL SUPERDEFORMATION IN ^{161,162}Lu*

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The nuclei around N=92 and Z=72 provide an opportunity to study superdeformed shapes for which a pronounced triaxiality ($\gamma=\pm20°$) is predicted theoretically. In recent years about twenty rotational bands which may be associated with these shapes have been discovered in Lu and Hf isotopes. In several cases the large deformation has been verified by lifetime measurements [1,2,3] and in one case, ^{163}Lu, the triaxiality has been proven by the discovery of the wobbling mode [4]. However, the theory has difficulties to predict the exact location of the shell gaps that are responsible for the triaxial superdeformed (TSD) minima in the total energy surfaces of the nuclei in this mass region. It is therefore important to localize these shell gaps experimentally and to provide information on the position of the deformation-driving intruder orbitals. Therefore, we have performed an experiment to search for TSD bands in ^{161}Lu and ^{162}Lu. High-spin states in these isotopes were populated in the ^{100}Mo(^{65}Cu,xn) reaction. The 260 MeV ^{65}Cu beam was provided by the Tandem accelerator at LNL. Gamma-ray coincidences were measured with the GASP spectrometer array. Two- and three- dimensional matrices were created with different requirements on the multiplicity measured with the inner-ball of BGO detectors. A preliminary analysis of these data allows to extend the previously known normal-deformed level schemes of ^{161}Lu [5] and ^{162}Lu [6]. In addition, a search for TSD bands revealed two candidates for TSD bands, one in ^{161}Lu and one in ^{162}Lu. These bands are very similar to known TSD bands in ^{163}Lu [7] and ^{164}Lu [8], respectively.

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DRAMATIC STRUCTURE CHANGES ALONG THE YRAST LINE IN ^{160}Yb

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The rare-earth transitional nuclei offer perhaps our best hope of pushing discrete line normal deformed spectroscopy into the ultra-high I~60 regime where new phenomenon and structural changes are expected. Dramatic shape changes are predicted to occur in ^{160}Yb at high spin, near 40 and 60, from prolate collective, to oblate non-collective, rotation and then to superdeformed triaxial shapes respectively [1]. Such an evolution of spectacular shape effects, brought about by the underlying effects and variations in shell structure as a function of spin have not been observed in a single rare-earth nucleus before. In addition certain peculiarities occur in ^{160}Yb near I=40 [2,3]. It has been suggested [2] that the anomaly in the prolate collective yrast band at I=36^+ is due to the presence of a close lying non-collective oblate state. Gammasphere, with Lawrence Berkeley National Laboratory's 88" Cyclotron and the reaction ^{120}Sn (^{44}Ca,4n), at 210 MeV, was employed to investigate the rich evolution of shapes predicted for ^{160}Yb at high spin and verify to speculation regarding the anomalous occurrences near spin I=40.

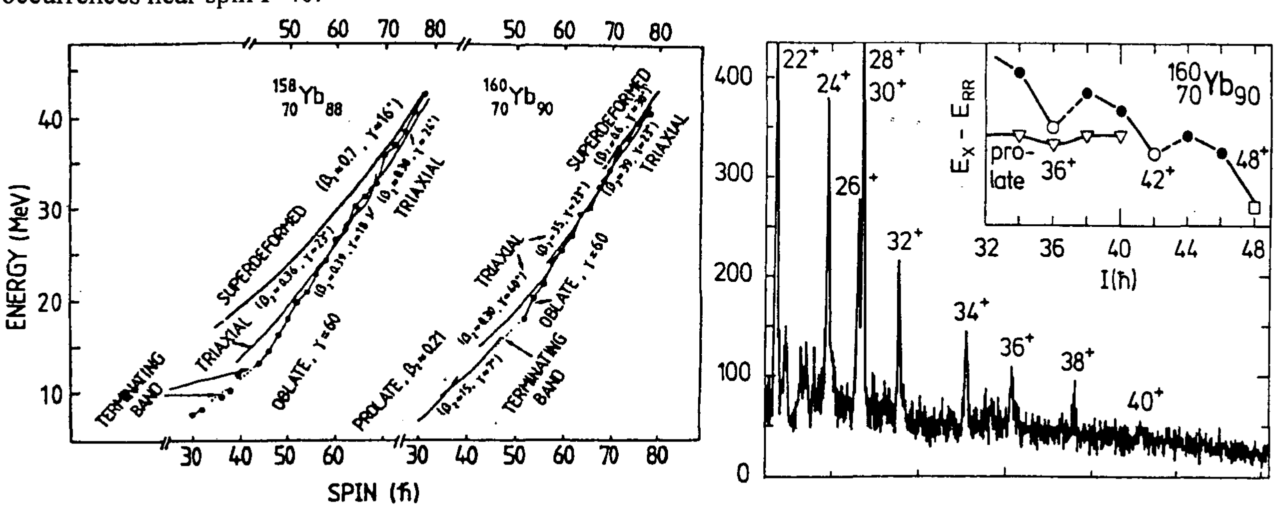

Figure 1: (left)Plot showing the calculated near yrast spectroscopy of 158,160Yb [1]. (right) Previous best spectrum for the yrast band of 160Yb, note the slight perturbation of the 36+ transition. The inset shows the band proposed in the current explanation [2].

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COMPLETE DECAY OUT AND SPIN-PARITY ASSIGNMENT FOR A MAGNETIC-ROTATIONAL BAND IN ^{124}Xe*

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The magnetic dipole bands in the A$\sim$130 Xe-Ba region have been recently suggested to exhibit a novel feature intermediate between a high-K band and a shears band [1]. It is energetically favourable to generate angular momentum from both collective rotation as well as the shearing of the constituent high-j proton-neutron angular momentum vectors. The proton and neutron angular momenta are almost perpendicular at the band-head, as in a shears geometry. Such bands are not well characterised in this region. For example, many of these bands are not firmly linked to the rest of the level scheme. Hence the spin-parity is not known experimentally [2].

States in ^{124}Xe were populated using the 88" Lawrence Berkeley Cyclotron with the reaction ^{110}Pd(^{18}O, 4n)^{124}Xe. The Gammasphere array, consisting of 100 Compton-suppressed high purity Germanium detectors, was utilised to detect the gamma-rays in this reaction. Thin self-supporting and a gold backed ^{110}Pd targets were used in the experiment. A total of 2 x 10^9 four and higher fold events were accumulated in eleven shifts. The data were subsequently sorted into gated matrices, symmetric/asymmetric cubes and a hypercube. The data were analysed using the Damm, Radware, Gavsort and Ana analysis packages. From this data set, the decay out of the magnetic dipole band in ^{124}Xe has been fully mapped out. We have placed more thann ten gamma-transitions connecting this band to rest of the level scheme. These transitions drain the full band intensity into the different band structures, new and old, established at lower and higher spins. A positive parity has been assigned to this band through the observation of a 961 keV E2 γ-transition to the γ-band. The crucial E2 assignment was made using the ratio of directional correlation of oriented states method from the data sorted into an asymmetric cube. The E2 decay out occurs as a consequence of an accidental degeneracy between the 17^+ levels of the dipole band and the γ- band (separated by 10 keV). This results in a weak mixing, probably mediated via the overlap of the tails of the wave-functions of the two states, resulting in the observation of the inter-band decay. A positive parity assignment is now consistent with the previously suggested, $\pi(h_{11/2} \otimes g_{7/2}) \otimes \nu(h_{11/2} \otimes g_{7/2})$ configuration of the band.

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A SEARCH FOR THE WOBBLING MODE IN ^{123}Xe AND ^{124}Xe NUCLEI*

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The proton Nilsson single particle structure at Z=54 shows a large shell gap for a γ value close to 23°. Thus, a strong motivation to study the axially asymmetric nuclei, ^{123,124}Xe, was to search for a predicted wobbling mode. In ref [1] it has been suggested that for a specific Fermi level the collective angular momentum is tilted in the unfavoured-signature states in odd-A triaxial nuclei. Such a coupling scheme gives rise to a wobbling-like motion. Numerical calculations within the framework of a Cranked random phase approximation model predict a wobbling mode in the unfavoured signature states of the γ-S band in ^{124}Xe [2]. This is manifested in a staggering of the collective ΔI=1 $E2$ decays between the γ-S band and the vacuum 'S'-band . ^{124}Xe is the only nucleus in this region where a odd-spin extension of the γ-band has been identified to exist beyond quasi-particle alignment. Gammasphere, sited at the LBNL 88" Cyclotron, was used to detect states in these two nuclei, which were populated with the reaction ^{110}Pd(^{18}O, 3n,4n)^{123,124}Xe at a beam energy of 86 MeV.

We have observed an unusual energetic ordering of the favoured(f1)-unfavoured(u1)-unfavoured(u2)-favoured(f2) sequence of 1-quasiparticle $\nu h_{11/2}$ bands in ^{123}Xe. The observation of such structures was suggested to be an indication of substantial deviation from axial symmetry [1]. It is to be noted that in axially symmetric odd-nuclei the normal energetic ordering would consist of the favoured(f1)-unfavoured(u1)-favoured(f2)-unfavoured(u2) sequences. One q.p bands labelled (2) are non-yrast and therefore difficult to observe in a heavy-ion fusion reaction. However, a specific triaxial shell-structure supported by the aligned-particle can cause these non-yrast sequences to be near-yrast, as suggested in a wobbling scenario. Interestingly, strong ΔI=1 gamma-decays between bands u1→f1 and u2→f1 have been observed. The E2/M1 mixing ratio of the inter-band transitions constitutes the most important element in the evaluation of candidate Wobbler's. Below back-bends no gamma-decays between the bands u1 and u2, which are of same spin-parity, could be seen. In ^{124}Xe the odd-spin extension of the γ-S band has been extended to high spins and is crossed by a four-quasiparticle structure. In addition, a forking at spin 17^+ has been observed. No gamma-decays could be observed between the γ-S and S-band. These observations will be compared with the expected selection rules discussed in ref. 1 (b).

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UNUSUAL DECAY PATTERN OF A TERMINATING NON-COLLECTIVE OBLATE STRUCTURE IN ^{124}Xe*

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Non-collective oblate states are predicted to be yrast at spins 22-24 in several Xe nuclei [1,2]. In this study we have identified such structures in ^{120}Te, ^{123,124}I, ^{123,124}Xe. In this contribution we report on a rather unusual decay pattern of a newly identified non-collective oblate terminating structure in ^{124}Xe. This structure is yrast at spin 24^+, and has an novel decay pattern mainly to mixed spherical-deformed non-yrast states. The decay of such a structure has given access to several highly non-yrast states embedded in this nucleus. The Gammasphere array sited at the 88" Lawrence Berkeley Cyclotron was utilised to detect states in ^{124}Xe, populated with the reaction ^{110}Pd(^{18}O, 4n)^{124}Xe at a beam energy of 86 MeV.

Apart from several new band-structures a irregular structure comprising of the coincident sequence of γ-transitions, i.e 797, 1152, 1365, 1018, 663, 193 and 1129 keV extending to spin 34^+, crosses the yrast S-band at spin 24^+. This structure drains into several states in ^{124}Xe at 9 MeV in excitation energy. The high sensitivity afforded by the hyper-cube has enabled us to track down the fragmented decay pattern to a new near degenerate triplet of non-yrast 20^+ states. The decay of one the new 20^+ states has enabled us to uncover the existence of a new, possibly 4-qp, yrare-band structure. The decay of these yrare-states has many features. There is a near degeneracy of the triplet and quartet of 20^+ and 18^+ states, respectively. Several yrare inter-band $E2$-decays, typical of interacting bands, have been observed. Coupled with the direction-correlation analysis they add to the confidence in spin-parity assignments. The high efficiency of Gammasphere has helped to discover several high-energy (1400-1800 keV) ΔI=2 E2 interband decays from these highly-excited and non-yrast states, to the yrast S-band. In addition, several ΔI=0 gamma transitions between the yrare states and the yrast S-band were observed. The observation of these ΔI=0 gamma transitions is indicative of mixing as well as a difference in the quadrupole moment of the respective states. We identify several of the non-yrast states as being the lower spin components of the irregular structure obtained by recoupling the angular momentum vectors of the constituent protons and neutrons. As they have a different structure from the deformed bands there is very little overlap between the two. Small mixing matrix elements have been estimated based on an approximation of a two-band mixing analysis. Due to near degeneracy of states the spherical-deformed interference is probably mediated via the overlap of the tails of the wave-functions of the two states.

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HIGH SPIN STATES IN THE STABLE NUCLEUS ^{96}Mo*

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Nuclei near the N=50 closed shells have a rich structural content related to the quadrupole, octupole vibrations and the very recently identified mixed symmetry states [1]. These nuclei are accessible to spherical shell-model calculations and the predictive power of the shell model can be tested through experiments. In an effort to gain new information on the high spin states in the stable and relatively neutron rich nucleus ^{96}Mo, an experiment was performed at the FN-Tandem accelerator at the Institut für Kernphysik. An array of six CS-HPGe detectors was used to detect the states populated in the reaction, ^{82}Se(^{18}O, 4n)^{96}Mo, at a beam energy of 55 MeV. The target consisted of a 4 mg/cm^2 ^{82}Se foil rolled onto a gold backing of 4mg/cm^2. In addition, a thin front layer of 1 mg/cm^2 Au foil was deposited to avoid beam induced evaporation of the very sublime Se. The experiments consisted of excitation function, two fold gamma-gamma coincidences and angular correlation of oriented states. About 400 million two fold events were accumulated in a ten day run. About 30 new gamma-transitions and 20 new energy levels were deduced from the analysis of this data. It considerably extends the hitherto known [2] high spin level scheme of ^{96}Mo to a excitation energy of 11 MeV and to a tentative spin of 23$\hbar$.

Spherical shell model calculations were performed using surface-delta residual interaction assuming ^{88}Sr as a core. The configuration space for the four valence protons was restricted to $p_{1/2}$ and $g_{9/2}$ valence orbitals and the four neutrons were allowed to occupy the $d_{5/2}, g_{7/2}, d_{3/2}, s_{1/2}$, and $h_{11/2}$ orbitals. It was shown that the structure of newly found positive and negative parity states is reasonably well understood without breaking the N=50,Z=38 core using simple schematic interaction. Interestingly the shell model calculations suggest that the two 10^+ are symmetric and antisymmetric with respect to the proton-neutron degree of freedom.

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SPECTROSCOPY OF THE A=43 AND A=45 MIRROR PAIRS

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In recent years the study of mirror nuclei in the $f_{\frac{7}{2}}$ shell has yielded some remarkable results. It has been shown that the Coulomb Energy Differences (CED) between the states in mirror pairs are an extremely sensitive probe of both microscopic and macroscopic changes in the nuclear structure, such as rotational alignments, band termination and shape changes. The unique isolation of the $f_{\frac{7}{2}}$ shell also provides an excellent ground for examining cross-conjugate symmetry, a recent example being the A=47 and A=49 mirror pairs. Although the energy levels in the cross-conjugate pairs (^{49}Cr/^{47}V and ^{49}Mn/^{47}Cr) were not identical, the CED data followed the trend predicted bby cross-conjugate symmetry arguments.

In order to study these effects away from mid-shell, an experiment was performed to populate states in the A=43 and A=45 mirror pairs in the symmetric reaction ^{28}Mg + ^{28}Mg at a beam energy of 90 MeV. Gamma rays were detected in the EUROBALL array and channel selection was afforded by the Euclides charged particle array and the Neutron Wall.

Preliminary results will be presented and interpreted in terms of Coulomb effects. Results will not only be compared across the N=Z line (i.e. mirror symmetry) but also across the $f_{\frac{7}{2}}$ shell (i.e. cross-conjugate symmetry) with the A=51 and A=53 mirror pairs.

SIGNATURE INVERSION IN DOUBLY ODD ^{124}La*

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The doubly odd nucleus ^{124}La has been populated using the ^{64}Zn(^{64}Zn,3p1n) reaction in order to analyse the characteristic signature inversion [1] that is known to be present in this region. The experiment was performed at the Argonne National Laboratory using a 260-MeV ^{64}Zn beam supplied by the ATLAS superconducting linear accelerator. Gammasphere was used in conjunction with the Microball charged-particle detector, the Neutron Shell and the Fragment Mass Analyser (FMA) to cleanly select the desired evaporation residues. High-spin states of ^{124}La have been observed and the level scheme extended with the addition of two new bands. The spin and parity of many states have been inferred for the first time due to the observation of linking transitions between four of the five observed bands. Two of these bands have been assigned the $\pi h_{11/2}\otimes\nu h_{11/2}$ configuration with the yrast sequence exhibiting signature inversion in its level energies *below* I=18.5$\hbar$ while the excited band exhibits this phenomenon *above* I=18.5$\hbar$. The observation of these $\pi h_{11/2}\otimes\nu h_{11/2}$ near-degenerate twin bands has also been linked to evidence for chirality [2] which is attributed to triaxial deformation of this nucleus. B(M1)/B(E2) ratios of reduced transition probabilities have been measured and display a signature dependence (staggering) in the two $\pi h_{11/2}\otimes\nu h_{11/2}$ bands.

Another band that is not in prompt coincidence with the main structures has been identified in ^{124}La and is believed to be built upon the high-spin isomer observed in previous β-decay studies [3]. The ΔI=1 transitions of this band have angular distributions with positive A_2 coefficients implying positive E2/M1 multipole mixing ratios. Positive mixing ratios are evident in the $\pi g_{9/2}\otimes\nu h_{11/2}$ bands of neighbouring doubly odd antimony and iodine isotopes; this configuration, with $K^\pi = 8^-$, is therefore attributed to the band and it represents the first evidence of the $\pi g_{9/2}$ proton orbital in a doubly odd lanthanum isotope. A rotational alignment of $h_{11/2}$ protons occurs in the band at a similar rotational frequency to those seen in the $\pi g_{9/2}$ bands of neighbouring odd-A lanthanum isotopes; this alignment is blocked in all the other bands of ^{124}La.

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MEASUREMENT OF B(M1)-VALUES IN THE BAND CROSSING REGION OF SHEARS BAND 1 IN ^{197}PB AND THEIR INTERPRETATION IN THE SEMI-CLASSICAL MODEL*

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Subpicosecond lifetimes of states in shears band 1 in ^{197}Pb were measured by means of the recoil distance method employing Gammasphere and the New Yale Plunger Device. The extracted reduced matrix elements, B(M1), show a clear sensitivity to the crossing of different shears configurations reflecting the closing and reopening of the shears blades. The energies and B(M1) values in the band crossing region are successfully described in the framework of the semi-classical model of the shears bands. The relevance of the core rotation contribution is shown. The results point to the existence of shears states with an angular momentum coupling angle larger than 90°.

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LOW-MOMENTUM NUCLEON-NUCLEON POTENTIAL FOR REALISTIC SHELL-MODEL CALCULATIONS*

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A fundamental problem in nuclear structure theory is the determination of the effective nucleon-nucleon (NN) interaction to be used in shell-model calculations. There have been a number of successful approaches for this determination, ranging from empirical fits of experimental data, to deriving it microscopically from the free NN potential (V_{NN}). In this latter approach, however, V_{NN} cannot be used directly owing to the strong repulsive core contained in all modern NN potentials. To overcome this difficulty, the Brueckner G matrix has traditionally been the starting point.

Here, we present a new approach that is motivated by the recent application of effective field theory (EFT) and renormalization group (RG) to low-energy nuclear systems [1].

A central theme of the RG-EFT approach is that physics in the infrared region is insensitive to the details of the short-distance dynamics [2]. In RG language, the short-distance pieces of V_{NN} are like irrelevant operators since their detailed form cannot be resolved from low-energy data. Motivated by these considerations, we derive a low-momentum NN potential V_{low-k} by integrating out the high-momentum components of V_{NN} in the sense of the RG [3]. This potential is therefore defined within a certain cut-off momentum Λ, and may be used directly in nuclear structure calculations.

Shell-model calculations for different mass regions using V_{low-k} will be presented. For cut-off momentum Λ in the vicinity of 2 fm^{-1}, our calculated low-lying spectra are in good agreement with experiment.

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BLUE: A STRUCTURED DATABASE FOR THE ANALYSIS OF DATA FROM HIGH-FOLD GAMMA-RAY SPECTROMETERS*

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The high sensitivity of modern gamma-ray spectrometers such as GAMMASPHERE, EUROBALL and future instruments such as GRETA is realized by dispersing less correlated background events over a space of high dimensionality. The optimal fold for the analysis of high-spin nuclear-structure experiments, given by the number of gates which are sufficient to dilute the background correlations yet maintain adequete statistics in the correlations of interest, is 4 for Gammasphere and probably 6 to 7 for GRETA. As spectrocopic analysis requires a dispersion of more than 10^3 channels and the number of histogram cells required grows geometrically with fold, histogram-based storage of these correlations is problematic at fold 4 and impractical for folds above 4.

To address the problem of efficient storage of and fast access to high-fold coincidences we have developed *Blue* [1], a specialized list-mode database. Each coincidence event in the database is stored in its native fold eliminating statistical artifacts which can be introduced by unfolding a single high-fold event to several lower-fold events. The database employs a tree-like index, similar to a *kd*-tree [2,3], which adapts to the density distribution of coincidences in the hypercube. A simple yet flexible query system is implemented using this index enabling standard rectangular gating as well as arbitrary range queries. This indexing mechanism also facilitates the implementation of a simple compression scheme. The time required to query the database is largely independant of the fold of the database and decreases with the number of gates taken. Queries such as taking an $(f-1)$-fold gate on f-fold database can be completed interactively (seconds) while taking an $(f-n)$-fold gate on an f fold database can be completed near interactively (minutes). A set of databases corresponding to all folds collected in the experiment can be queried to provide true "fold-independant" gating.

In addition to storing gamma-ray energies, *Blue* databases can also be used to store auxiliary parameters such as energies, times and detector angles. This allows for complex angular correlation and isomer analysis which were previously impractical due to the time required for sorts from data tapes. The database system is implemented as a library to allow it to be linked to existing analysis and histogram display programs. *Blue* databases have been successfully used by several groups in the analysis of a variety of Gammasphere datasets.

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IDENTIFICATION OF EXCITED STATES IN ^{140}Dy*

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Excited structures in the proton-rich nucleus ^{140}Dy have been established [1] using recoil-isomer tagging [2] on the decay of a $K^\pi = 8^-$ isomer. The experiment was performed using the Argonne Fragment Mass Analyser and a close-packed array of seven hyper-pure germanuim detectors at its focal plane. The excitation energy of the isomer is established to be 2.16 MeV with a half-life of 7.3±1.5 μs. The isomer decays into the yrast line at the 8^+ state, revealing a rotational band with a deduced deformation of $\beta_2 = 0.24(3)$. The isotope ^{140}Dy is the daughter of the deformed proton emitter ^{141}Ho. The new information obtained from this work supports the role of deformation in proton emission and the previous assignments of single-particle configurations to the two proton emitting states in ^{141}Ho [3]. In addition, the reduced hindrance factor measured for the $K^\pi = 8^-$ isomeric-state decay is consistent with the trend observed in the $N = 74$ isotones.

* This work supported by the EPSRC.

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PULSE SHAPE ANALYSIS ON A 6 × 4-FOLD SEGMENTED HPGE DETECTOR

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Pulse Shape Analysis methods on highly segmented HpGe detectors are currently being developed in order to improve the position resolution and to enable γ-ray tracking to be performed [1-2].

TIGRE is a 6 × 4-fold HpGe prototype detector manufactured by Ortec. It consists of a coaxial high-purity n-type germanium crystal, 65 mm diameter by 80 mm length, with a n^+ lithium drifted inner contact and a p boron implanted outer contact presenting a 2D segmentation. Each contact is provided with fast charge sensitive preamplifiers based on the University of Cologne design and fitted with warm FETs [3]. Due to its high granularity and its fast electronics, TIGRE represents a unique example of a tracking detector. The performance of the detector is excellent: low noise output signals (about 2.5 mV peak-to-peak, i.e. ~10 keV), fast rise time and good energy resolution (from ~2.1 to ~2.5 keV measured at 1332 keV on the outer contacts) combined with high quality pulse shapes (mirror charge amplitudes range up to 40% of the corresponding real charge). No significant cross-talk problems have been observed so far.

In order to improve the effective granularity of the detector and to allow the development of algorithms which relate the pulse shape features with the interaction position, a calibration of pulse shape with respect to the entry point of the γ-ray in the detector volume has to be made. The only way to gain this knowledge is to perform a scan of the detector. A scanning apparatus has been built at the University of Liverpool. A scanning table driven by an automated stepper motor enables the movement of a well collimated source across the whole front face of the germanium crystal. The pulse processing occurs via a compact PCI (Peripheral Component Interconnect) crate compatible system, consisting of three cM6 cards manufactured by Entegra (40 MHz sampling rate and 12 bit dynamic range) and a VMEbus hosting a Joerger card (100 MHz sampling rate and 12 bit dynamic range), for a total of 25 electronic channels. The system runs with an external trigger provided by the centre contact signal. The front face of the detector was scanned in 2 mm steps with a ^{137}Cs source and a ^{152}Eu source. Quantitative results from the two scans will be presented.

* This work supported by the TMR project (EU) and by a Novel Instrumentation grant from EPSRC (UK).

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DENSITY-DEPENDENCE OF PHENOMENOLOGICAL TWO-BODY INTERACTIONS BEYOND THE MEAN-FIELD APPROXIMATION.

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The use of phenomenological density-dependent two-body interactions in self-consistent mean-field calculations is a commonly accepted fact. In these calculations, the density dependence is naturally expressed in terms of the local *mean-field* density $\rho(\vec{r})$ through some functional $q[\rho(\vec{r})]$. When going beyond the mean-field approximation through configuration mixing as in the Generator Coordinate Method (GCM) or the Projected Mean-Field Method (PMFM), there is no longer a natural choice for the local density to be used in matrix elements of the effective Hamiltonian between two different vacua appearing when calculating the energy in the trial state.

In order to find arguments in favor of a local density to be used in such calculations, we have first derived an extended Goldstone-Brueckner perturbation theory written in terms of mixed non orthogonal Slater determinants [1]. This perturbative scheme has allowed to define a new Brueckner G matrix summing *generalized* particle-particle ladder diagrams and solving, in this extended context, the problem appearing in any perturbative expansion written in terms of a strongly repulsive interaction at short distance. Moreover, the energy one would obtain using a configuration mixing state is recovered as the lowest-order of this expansion and show that this new G matrix on the energy shell is to be seen as the in-medium effective interaction to be used in this context. Performing a local-density approximation of this G Matrix, a theoretically grounded prescription for the local density of a Skyrme or a Gogny force used in GCM or PMFM calculations has been obtained [1]! .!

The same question has been treated when considering the density-dependence of phenomenological two-body interactions as originating from *multi-body forces* effects renormalization [1], in addition to the resummation of two-body correlations. We have shown how a density-dependent two-body interaction is formally able to renormalize three-body as well as higher order multi-body forces effects within the framework of a configuration mixing calculation. However, the local density to be used in this case in each matrix element of the Hamiltonian is different from the one deduced in the first case, even if these two quantities reduce to the mean-field density when coming back to the mean-field approximation.

The two different prescriptions found for the density-dependence to be used beyond the mean-field open a new degree of freedom in the effective force. Their respective importance is discussed through GCM calculations in ^{186}Pb using a basis of HF+BCS wave-functions, constrained on the axial quadrupole moment and projected on particle numbers. This neutron deficient lead is a very challenging testing case since the three low-lying 0^+ states experimentally seen [2], and interpreted as shape coexistence, have been unsatisfactorily reproduced up to now by microscopic calculations [3].

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BEHAVIOR OF SHELL EFFECTS WITH THE EXCITATION ENERGY IN ATOMIC NUCLEI

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We study the behavior of shell effects, like pairing correlations and shape deformations, with the excitation energy in atomic nuclei. The analysis is carried out with the finite temperature formalism and a finite range density dependent force (the Gogny force). First the finite temperature Hartree-Fock-Bogoliubov (FTHFB) method has been applied. For the first time, properties associated with the octupole and hexadecupole deformation and with the superdeformation as a function of the excitation energy are studied [1]. Numerical results are obtained for the well quadrupole deformed ^{164}Er and ^{162}Dy, superdeformed ^{152}Dy, octupole deformed ^{224}Ra and spherical ^{118}Sn nuclei. We find, in particular, the level density of superdeformed states to be 4 orders of magnitude smaller than for normal deformed ones.

The nucleus is a finite system and fluctuations around the most probable values calculated in the FTHFB are very important. Toward this end we have included shape fluctuations in the calculation of the above mentioned quantities [2]. As a main output we find that the melting of shell effects appear at lower temperatures as predicted by the FTHFB and in better agreement with the experimental results.

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ISOSPIN MIXING PHENOMENA IN THE ^{64}Ge NUCLEUS

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The high-spin structure of the $N = Z = 32$ nucleus ^{64}Ge has been investigated in two experiments at the Laboratori Nazionali di Legnaro using the GASP spectrometer coupled to the ISIS Si-ball [1] and the EUROBALL γ-ray spectrometer coupled to ISIS and to a highly-efficient n-Wall [2], allowing to solve some uncertainties in the known level scheme previously studied by Ennis et al. [3]. Extensive angular distribution and polarization analysis were performed, which suggest an $E1/M2$ character with large multipole mixing ratio for the intense 1665 keV transition reported in the work of Ennis. The observation of an $E1$ transition in somehow surprising, since $E1$ transitions between pure $T = 0$ states are strictly forbidden by isospin conservation [4], and points to Coulomb-induced mixing between $T = 0$ and $T = 1$ states with the same spin and parity. The degree of mixing can be estimated from the experimental electric dipole strength, which has been determined through an experiment performed at Strasbourg with EUROBALL coupled to the Köln plunger device [5]. Our estimate is consistent with the theoretical expectations of Dobaczewski and Hamamoto [6].

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ELECTRON-CAPTURE-DELAYED FISSION IN ^{232}AM AND ROTATIONAL STRUCTURE IN ^{232}PU

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The electron-capture-delayed fission (ECDF) process allows us to study structure in very neutron-deficient nuclei that could not be directly produced in a fusion reaction. This decay mode may be important in the production of heavy elements in the r-process. The ECDF nuclide ^{232}Am was produced at the Lawrence Berkeley National Laboratory 88-Inch Cyclotron in the ^{237}Np(^{3}He, 8n) reaction using a stack of 10 thin (124-197 $\mu g/cm^2$ each) targets at a beam energy of 75 MeV incident on the first target. Recoiling activities were collected and transported to a specially designed "Sample Changer" that moved samples into Gammasphere for analysis. The latest results on ECDF in this nuclide and rotational structure in the electron capture daughter ^{232}Pu will be discussed. These experiments show the promise of using Gammasphere to study nuclei that would otherwise be inaccessible due to the need for radioactive targets or pre-separation in the Berkeley Gas-Filled Separator.

Are np-pairs playing a role in the $A = 46$, $T = 1$ triplet?

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Nuclei along the $N = Z$ line have become a laboratory for the study of np-pairing correlations. Critical to this study is detailed spectroscopy, which is often difficult. As a result of an experiment using GAMMASPHERE and the FMA to search for excited states in ^{46}Cr, the experimental knowledge for ^{46}Cr, ^{46}V, and ^{46}Ti has increased to such a degree that it is now one of the best known $T = 1$ triplets. The isovector and isotensor Coulomb energy differences have been extracted and compared to full fp-shell model calculations [1]. Independently, lifetime information has also recently become available for ^{46}V [2]. Combining all available information, together with the shell model calculations, we examine this $T = 1$ triplet to search for indications that np pairs are playing a role and their evolution as a function fo spin.

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SPECTROSCOPY OF PROTON-RICH N=82 ISOTONES*

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Proton-rich N=82 isotones have been populated in the reaction ^{96}Ru(^{58}Ni,xp) with a beam energy of 250 MeV. Gamma rays were detected with the Gammasphere array at Lawrence Berkeley National Laboratory and charged particles were identified by the Microball detector for channel selection. The strongest reaction channels are the $3p$ channel leading to ^{151}Tm and the $2p$ channel leading to ^{152}Yb.

The main focus of the experiment was to search for shears bands around ^{152}Yb. Analogous to the shears bands in neutron-deficient Pb isotopes, which are built on proton excitations across the Z=82 shell gap coupled to neutron-hole excitations in the $\nu i_{13/2}$ shell, similar excitations can be expected in the very neutron-deficient N=82 isotones around ^{152}Yb. In this case the role of protons and neutrons is exchanged and particle-like excitations across the N=82 shell gap may couple to hole excitations in the $\pi h_{11/2}$ shell.

High-spin states in ^{152}Yb above the $(\pi h^2_{11/2})10^+$ isomeric state and in other extremely neutron-deficient neighboring nuclides have been observed for the first time in this experiment.

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TRANSITION FROM $T = 1$ PAIRS TO $T = 0$ PAIRS IN ROTATIONAL STATES OF THE $N = Z$ NUCLEUS ^{80}Zr

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HFB calculations for the $N = Z$ nucleus ^{80}Zr give a ground state band with $T = 1$ Cooper pairs and an excited band with $T = 0$ Cooper pairs. The bands cross at spin $I \approx 5\hbar$, providing a "phase transition" from $T = 1$ pairs for $I < 5\hbar$ to $T = 0$ pairs for $I > 5\hbar$. There is also a $T = 0 + T = 1$ pair band, which forms an envelope to the $T = 1$ pair band and the $T = 0$ pair band. In this band there is a more gradual transition from $T = 1$ pairs at $I = 0$ to $T = 0$ pairs at high spins, with $T = 0$ pairs and $T = 1$ pairs co-existing at intermediate spins. The Coriolis anti-pairing effect breaks the $T = 1$ pairs, but there is no CAP effect for $T = 0$ pairs in which the n and p occupy identical space-spin orbitals. The $T = 1$ pair band has a moment of inertia $\mathcal{I}(\omega)$ which backbends at spins between $8\hbar$ and $14\hbar$, but the $T = 0$ pair band does not backbend. Both bands have $g_{9/2}$ spin alignments. For the $T = 0$ pair band, the dominant angular momentum of a pair is $J = 5$, not $J = 1$ or $J = J_{max} = 9$ as was anticipated. For a rotating $N = Z =$ even nucleus, $T = 0$ pairing produces a two-fold degeneracy in the canonical orbital occupation probability v^2, although $T = 1$ pairing produces a four-fold degeneracy in v^2.

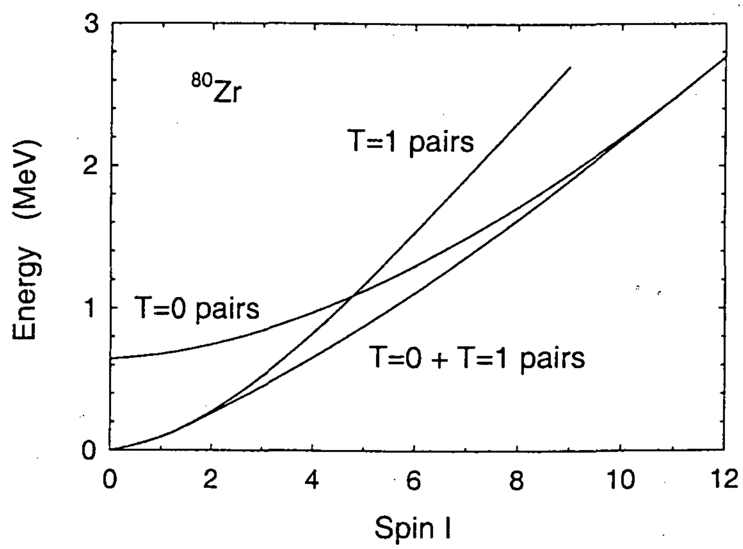

Figure 1: Energies of the rotational bands with $T = 1$ pairs and $T = 0$ pairs.

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COULOMB EXCITATION PATHS OF HIGH-K ISOMERS IN ^{178}HF*

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Three distinctly different mechanisms are shown to populate the $K^{\pi} = 6^{+}$, 16^{+} and 8^{-} isomer bands of ^{178}Hf by Coulomb excitation. In this experiment a 650 MeV ^{136}Xe beam provided by ATLAS was used to Coulomb excite a thin target of ^{178}Hf. Gammasphere was used to detect the deexcitation gamma rays, and CHICO provided event-by-event Doppler correction by recording the kinematics of scattered ions. Isomer bands in ^{178}Hf were populated up to spin 13^{+} in the $K=6^{+}$ band, spin 20^{+} in the $K=16^{+}$ band and spin 14^{-} in the $K=8^{-}$ band. Even though direct population of these high-K isomer bands is highly K-forbidden, in-band γ-ray yields were seen at 10^{-4} of the $8^{+} \rightarrow 6^{+}$ yield in the ground-state band (GSB).

The $K=6^{+}$ (77ns) isomer decays were observed between beam pulses, allowing for the *measurement* of $B(E2)$ values of isomer transitions to levels in the GSB and γ-band and, for the first time, to the $K=4^{+}$ band head. These $B(E2)$ values yielded intrinsic matrix elements using the Alaga rule for K-allowed transitions, and a K-mixing model[1] for K-forbidden transitions where the mixing strength increases strongly with spin. Coulomb excitation calculations with the *measured* intrinsic matrix elements simultaneously reproduce the observed $K=6^{+}$ in-band yields and the decay branches of the isomer. This reveals that the $K = 6^{+}$ isomer band is populated about equally by two-step and three-step excitation along the path GSB $\rightarrow K=2^{+} \rightarrow K=4^{+} \rightarrow K=6^{+}$ and $\sim 10\%$ by direct population, GSB$\rightarrow K=6^{+}$. The K-allowed matrix element, $\langle K = 6^{+} | E2 | K = 4^{+} \rangle$, is found to be 0.0943(33) eb. K-forbidden transitions are most important at $I \sim 14\hbar$, where E2 transition strengths are ~ 1 W.u. for $K=2^{+} \rightarrow K=6^{+}$ excitation and range from 0.01 to 0.1 W.u. for GSB$\rightarrow K=6^{+}$ excitation.

In contrast, the 8^{-} (4s) isomer band is populated by one-step E3 excitation from the GSB, with feeding by γ-decay being responsible for less than 10^{-4} of the population. A single parameter, $\langle K = 8^{-} | E3 | GSB \rangle$, was *fit* to the in-band γ-yields using spin-dependent mixing, showing that excitation occurs mainly to the intermediate spin levels ($\sim 12\hbar$) with $B(E3; K=0^{+} \rightarrow K=8^{-})$ ranging from 0.24 to 96 W.u., in contrast with the upper limits of $B(E3; 8^{-}_{K=8} \rightarrow 6^{+}_{GSB}) = 2.7 \times 10^{-9}$ W.u. and $B(E3; 8^{-}_{K=8} \rightarrow 8^{+}_{GSB}) = 1.2 \times 10^{-4}$ W.u. on the transition strengths depopulating the isomer; this indicates that strongly spin-dependent mixing is required to sufficiently populate the band.

The unexpected population of the yrast 16^{+} (31y) isomer band occurs via feeding through K-forbidden γ-decay branches from the upper GSB, whereas direct excitation is negligible. The $B(E2; GSB \rightarrow K=16^{+})$ values range from 10^{-4} to 3.5 W.u. for a one-parameter fit using spin-dependent mixing. Non-observation of the γ-decay feeding from the GSB implies that there must be a rapid increase in K-mixing with increasing spin.

* This work is supported by the NSF.

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A TRACE OF HYPERDEFORMATION OR JACOBI TRANSITION IN ^{126}Ba.

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In recent attempts to search for exotic shapes, hyperdeformation, and Jacobi transitions in Hf and Ba-Xe nuclei, using *Gammasphere* (GS) we have now for the first time, observed a ridge structure of rotational bands from very elongated nuclei in ^{126}Ba. The cold fusion reactions, ^{64}Ni + ^{64}Ni were used. The structures are only observed in the 2n evaporation channel, ^{126}Ba, which was populated very weakly (< 2%), at the very highest spins the nucleus can accomodate. By a newly developed selective filtering technique [1] it was possible on a background of 98 % to enhance the 2n product by a factor of 10. Furthermore, pure rotational correlations selected by applying the equation: $(E_x + E_y - 2E_z) = \delta = 8$ keV) were sorted into a rotational plane, (E_x, E_y) [2]. This selection of event containing 3 sequential transitions, deviating less than ± 4 keV from a pure rotational sequence with constant moment of inertia, enhanced the rotational structures by an additional factor of 5 - 10. The result of this Double-Selection Filter-Technique (DSFT) can be seen in fig. 1., where ridges from "warm" rotational bands in strongly deformed nuclei are observed with a moment of inertia of $\Im^{(2)} \approx 75\ \hbar^2 MeV^{-1}$. This selective method was also applied to the neighboring xn channels, 3n and 4n, but no ridge structures with large moment of inertia were observed in those nuclei. Extensive searches for individual discrete HD-bands in the present data set have not given any positive results, so far.

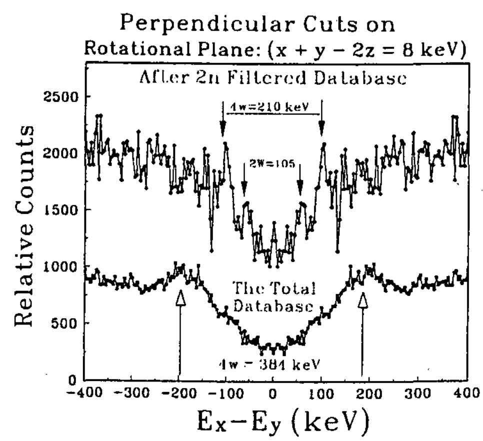

Figure 1. Perpendicular cut on the selected 2D spectrum, ^{126}Ba, at $(E_x + E_y)/2 = 1440 \pm 142$ keV accross the diagonal $E_x = E_y$ of the rotational plane for the 2n filtered database (upper), compared to a similar cut on the full Database (lower). The 2n filtered spectrum shows a ridge structure corresponding to a moment of inertia almost twice that of the full dataset.

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STRUCTURE OF $T = 2$ ^{24}NE FROM ^{14}C ON ^{14}C†

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The neutron-rich Ne isotopes provide a test of a proposed new magic number at $N = 16$ [1]. The effects of such a shell gap should be visible nearby, and, indeed, there are indications of spherical shape in $N = 14$ ^{24}Ne from what was previously known about the level scheme [2]. The excitation energy of the lowest 4^+ state is exactly twice that of the 2^+ one and the second 2^+ state lies close to the 4^+ state. Only the second 0^+ state, which lies 800 keV away, breaks the picture of a nearly perfect two-phonon multiplet of a spherical vibrator. However, very little was known about ^{24}Ne above this, and the current work was undertaken to further explore its structure. Also, the shell model using the "universal s-d interaction" has been very sucessful in describing the structure of *s-d* shell nuclei near stability with low isospin T, but has not been fitted or tested much for nuclei with a greater imbalance in neutron and proton numbers. Very few $T = 2$ and no $T = \frac{5}{2}$ excited states were included in the fit.

In the present work, the ^{14}C(^{14}C,α) reaction at 22 MeV was used to study ^{24}Ne. Charged particles were detected using a Si detector telescope in coincidence with γ-ray detection by an array of three Compton-suppressed "clover" detectors with seven Compton-suppressed single Ge detectors. The α-γ and α-γ-γ coincidences from the reaction were analyzed to study the structure of ^{24}Ne. Eighteen new γ rays and eleven new energy levels were observed, including the lowest 5^+ and 6^+ states. These are shown in the figure below. Comparisons with the shell model and implications for the $N = 16$ shell gap will be discussed.

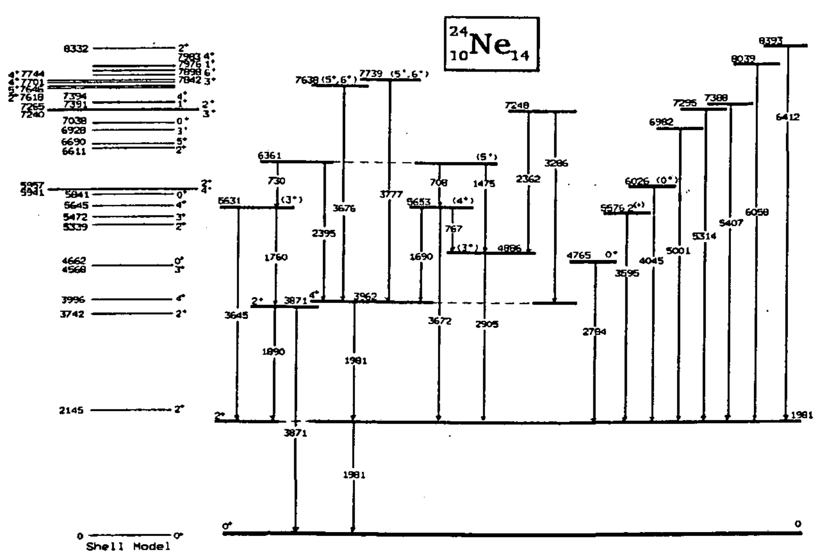

Figure 1: The level scheme of ^{24}Ne along with shell model predictions.

† This work was supported in part by the U.S. National Science Foundation.

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WOBBLING PHONON EXCITATIONS IN ^{163}Lu*

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In a search for the two-phonon wobbling excitation in the nucleus ^{163}Lu high spin states have been populated through the fusion-evaporation reaction ^{139}Lu(^{29}Si,5n)^{163}Lu, with a beam energy of 157 MeV provided by the Vivitron at IReS in Strasbourg. Approximately $6 \cdot 10^9$ events were collected with the Euroball IV detector array. The yrast TSD band (TSD1) is interpreted as a $\pi i_{13/2}$ excitation. The lowest excited band (TSD2) was in a previous Euroball experiment connected to the yrast band (TSD1) by 9 $\Delta I = 1$ transitions. Firm spin and parity of TSD2 have been determined based on DCO, angular distribution and polarization measurements of the 5 strongest connecting transitions. $B(E2)_{out}/B(E2)_{in}$ values ~ 0.2 for these transitions are in good agreement with calculations for a wobbling excitation, and TSD2 has therefore been assigned as a one-phonon wobbling excitation built on TSD1 [1]. Other configurations for TSD2 could be excluded. Another band (TSD3) was observed to decay into TSD1 via $\Delta I = 2$ transitions. TSD3, having moments of inertia and alignment very similar to TSD1 and TSD2, is a candidate for a two-phonon wobbling excitation [2].

In the present experiment a search for connecting transitions between TSD3 and TSD2 has so far resulted in one firmly established $\Delta I = 1$ transition of 476 keV ($I = 45/2^+$,TSD3$\rightarrow$ $I = 43/2^+$,TSD2), which is important for the assignment of TSD3 as a two-phonon wobbling excitation. From calculations $B(E2)_{out}/B(E2)_{in}$ values ~ 0.42 [3] are expected, which is within errors in agreement with the preliminary experimental value of ~ 0.49 for the 476 keV γ-ray. The analysis of a fourth TSD band (TSD4), also decaying into TSD1, is in progress.

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FEEDING AND DECAY OF SUPERDEFORMED BANDS IN ^{198}Po AND ^{195}Pb*

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The population and decay of superdeformed (SD) nuclei remains an area of high current interest in nuclear structure studies. In particular, relatively little is known about the entry distribution associated with the population of SD excitations, especially in more fissile systems where fission dominates at high angular momentum. The study of the quasicontinuous spectrum associated with SD excitations provides a more detailed probe of the feeding of the SD band, while the study of the quasicontinuous decay spectrum can provide information on the excitation energy and spin of these elgonated structures.

To study the population and decay of an SD excitation when there is significant competition with fission, the ^{174}Yb(^{29}Si,5n) reaction was used to populate excitations in ^{198}Po, the most fissile nucleus for which an SD band has been identified at high spin [1]. The measurements were performed at the 88-Inch Cyclotron facility at LBNL using the Gammasphere array without heavimet shields and with 101 Compton-suppressed Ge detectors and gold-backed targets. The response functions of the array enable the conversion of modular (H, K) to energy and multiplicity, which can be related to spin by realistic assumptions [2] of the angular momenta carried by the components of the gamma-ray cascade. These data also allow a measurement of the fission barrier.

To study the decay of the four known SD bands in ^{195}Pb [3], the ^{174}Yb(^{26}Mg,5n) reaction was used with gold-backed targets. The measurements were performed at the same facility with 95 Compton-suppressed Ge detectors with heavimet shields. Four SD bands and associated quasicontinuous spectra have been extracted and analyzed.

The present results for the entry distribution and quasicontinuous spectrum for the SD band in ^{198}Po will be constrasted to the spectra associated with the ND excitations in ^{198}Po, as well as the results for ^{195}Pb, ^{192,194}Pb [4] and ^{192,194}Hg [5] for which similar analyses have been reported.

* This work supported by the National Science Foundation and the Department of Energy.

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HIGH-SPIN STUDY OF THE VIBRATIONAL NUCLEI ^{112,114}Cd

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The even-mass Cd isotopes near the middle of the N = 50 - 82 neutron shell are among the textbook examples of quadrupole vibrational nuclei. In addition to collective vibrational excitations, rotational bands built on two-particle two-hole proton excitations across the Z = 50 shell closure have been observed in ^{112,114}Cd. Many theoretical studies, e.g. using algebraic models, dealt with the simultaneous description of these two rather distinct families of excitations, namely anharmonic quadrupole vibrations and more deformed intruder particle-hole excitations. Whereas both isotopes have extensively been studied at low spin using a variety of different techniques such as inelastic scattering, transfer reactions, neutron capture and α-induced reactions, the available information on high-spin states in these nuclei is scarce. This is mainly because they cannot be produced in heavy-ion induced fusion-evaporation reactions. Whereas in ^{112}Cd states with spins as high as 14^+ are known from (α, xn) reactions [1], ^{114}Cd can not even be reached using this reaction and the only information about its high-spin structure comes from recent studies using fusion-fission reactions and heavy-ion collisions [2,3].

It would be very interesting to gain more information about ^{112,114}Cd at high spin because in the lighter even isotopes $^{104-110}$Cd, a number of rotational bands involving the deformation-driving low-K $h_{11/2}$ neutron orbital have been observed. The study of the interplay between these neutron intruder and vibrational excitations in the mid-shell isotope ^{114}Cd will be particularly interesting because it is expected that the $h_{11/2}$ orbit plays a much more dominant role, even at low spin, in ^{114}Cd than in the lighter isotopes. Since the $h_{11/2}$ intruder orbit is close to the Fermi surface already at the spherical shape, the intruder bands might be less deformed leading possibly to a stronger mixing with the vibrational excitations in ^{114}Cd.

In this contribution we will report on our recent study of the high-spin structure of $^{112-114}$Cd using the incomplete fusion reaction ^{110}Pd + ^{7}Li and the GASP γ-spectrometer in conjunction with the ISIS Si ball for the detection of fast protons and deuterons at the Laboratori Nazionali di Legnaro. In all three isotopes, a large number of new states were identified and we will discuss this new information in comparison to the lighter Cd isotopes and within different nuclear models.

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A SEARCH FOR MULTI-QUASIPARTICLE ISOMERS IN ODD-MASS NUCLEI NEAR A~130*

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A characteristic feature of many deformed nuclei near A~180 is the presence of multi-quasiparticle K-isomers with half-lives ranging from a few nanoseconds to hundreds of years [1]. Many of the associated configurations involve the $9/2^-[514]$ and $7/2^+[404]$ *proton* orbitals. For instance, $\pi^2(7/2^+[404], 9/2^-[514])[8^-]$ isomers have been observed in the chain of even-even Hf and W isotopes. Importantly, long-lived states formed by the coupling of the $\pi^2[8^-]$ configuration to an unpaired proton (neutron) have been discovered in neighboring odd mass nuclei. In the Nilsson spectrum for neutrons, the equivalent $9/2^-[514]$ and $7/2^+[404]$ orbitals lie near the Fermi surface at about N=74 leading to a chain of 8^- isomers in the A~130 region [1,2]. Only limited information, however, is available about related isomers in the neighboring odd mass nuclei.

New measurements aimed at searching for isomers in odd-mass nuclei in the A~130 region were performed at the heavy-ion facility of the Australian National University. The experiments combined the efficiency and resolving power of the CAESAR γ-ray array with the enhanced selectivity offered by the flexible pulsing system of the 14UD Pelletron accelerator. A number of beam (^{35,37}Cl, ^{32}S and ^{30}Si) and target (^{98,100}Mo and ^{106}Cd) combinations were utilized with pulsing conditions ranging from a few ns up to several milliseconds.

Results from these measurements will be presented. While there are similarities in the 8^- isomers, the A~130 nuclei are less deformed and more susceptible to shape changes, shape co-existence and triaxiality than the well-deformed A~180 nuclei. These differences will affect both the decay transition strengths (and therefore lifetimes) and also the likelihood of isomers occurring in the odd-A nuclei since their properties may change significantly due to effects from the odd particle.

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NUCLEAR STRUCTURE AND DECAY DATA EVALUATION: CHALLENGES AND PERSPECTIVES*

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The expression ``Nuclear Structure Data" refers to complex nuclear level schemes and tables of numerical values, which quantify fundamental nuclear structure information, such as level energies, quantum numbers and state lifetimes, as well as various decay modes and associated properties. These data are not only at the core of basic nuclear structure and nuclear astrophysics research, but they are also relevant for many applied technologies, including nuclear energy production, reactor design and safety, medical diagnostic and radiotherapy, health physics, environmental research and monitoring, safeguards, material analysis, etc.

The mission of the Nuclear Structure and Decay Data Working Group of the US DOE funded Nuclear Data Program is to evaluate, compile, maintain, and disseminate nuclear structure and decay data for all known nuclei (more than 2900!). The research centers participating in the network also are involved in developing nuclear data measurement, analysis, modeling, and evaluation methodologies for implementation in basic science research and technology. In recent years, special attention has been given to specialized (horizontal) evaluations that are urgently needed by the nuclear structure community, such as log *ft* values, α- and proton decay properties, super-deformed and magnetic dipole collective structures, nuclear moments, and nuclear isomers (under development).

This presentation will briefly review recent achievements of the network, present on-going activities, and reflect on ideas for future projects and challenges in the field of evaluated nuclear structure and decay data.

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FIRST OBSERVATION OF EXCITED STATES IN DRIP LINE NUCLEUS ^{140}DY

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In an experiment performed at Oak Ridge we identified a new 7 μs K-isomer in the drip line nucleus ^{140}Dy [1]. ^{140}Dy ions were selected from the products of the ^{54}Fe (315 MeV) + ^{92}Mo reaction by the Recoil Mass Spectrometer and implanted in a passive catcher placed in the center of the Clover Array for Recoil Decay Spectroscopy. An MCP detector provided a recoil implantation reference time and enabled a recoil – delayed γ-γ coincidence study. We have identified a new cascade of γ-rays at 202, 364, 476, 550 and 574 keV with a half-life of 7.0(5) μs correlated with the implantation of the $A = 140$ recoils. Based on the intensities and energies of the transitions, a level scheme resembling a rotational band in a deformed nucleus fed by the isomeric level, see Fig. 1, was constructed. A comparison to the decay patterns of $I^\pi = 8^-$ K-isomers in the less exotic $N = 74$ even isotones displayed in Fig. 1 shows striking similarity. This leads us to the interpretation of the isomeric level at 2166 keV as an $I^\pi = (8^-)$ $\{\nu 9/2^-[514] \otimes \nu 7/2^+[404]\}$ K-isomer decaying via the ground-state band in ^{140}Dy. A hindrance per degree of K-forbidness f_ν was determined to be 24.5(3), a value very close to the ones found for less exotic $N = 74$ isotones displayed in Fig. 1. Our findings were recently confirmed in an independent experiment [2].

The experimental level scheme of ^{140}Dy provides reliable input for the predictions of proton emission rates from ^{141gs,m}Ho. Moreover, the precisely known energy of the 2^+ state in ^{140}Dy was an essential aid in the search for fine structure in ^{141}Ho proton decay [3].

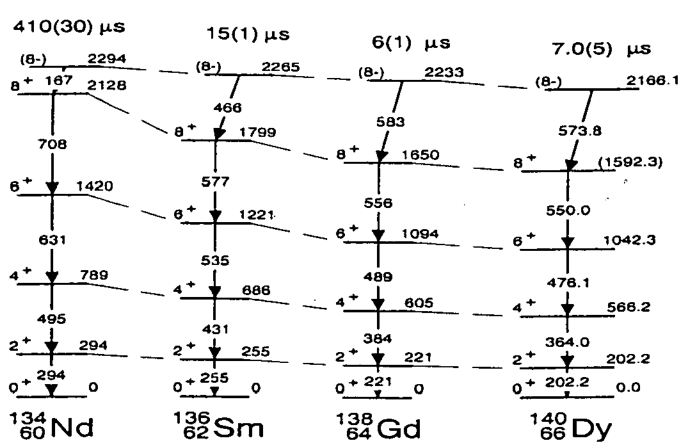

Figure 1: The level scheme of ^{140}Dy and the decay of 8^- isomers in $Z \geq 60$, $N = 74$ isotones.

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Transition Matrix Elements in Neutron-rich Fission Fragments

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In view of the prospects of studying neutron-rich nuclei far from stability using beams of radioactive ions, it is important to get structural information on those nuclei already accessible today by means of prompt and delayed spectroscopy following spontaneous and induced fission. The systematic knowledge of transition matrix elements in these nuclei is key to observe modifications of the shell structure and evolution of collectivity of nuclei far from stability. Recently, new lifetime results using a differential recoil distance method were reported in Refs. [?, ?].

In this contribution we report on a new recoil distance Doppler-shift experiment using Gammasphere and the New Yale Plunger Device to measure lifetimes of excited states in neutron rich nuclei produced in the spontaneous fission of ^{252}Cf. Fission fragments emitted in a cone of $\pm$ 20° from a thin 50 μCi ^{252}Cf source were detected by a set of photo cells. Complementary fragments were stopped in a gold stopper after traveling a variable distance. Gamma rays in coincidence with fission fragments were detected by the Gammasphere array. γ-γ-γ coincidences were collected at 22 distances ranging from 9 μm to 7000 μm, corresponding to flight times of about 1 ps to 1 ns.

We will present lifetimes and transition matrix elements for yrast and off-yrast transitions in A$\approx$100 and 140 nuclei and use these results to discuss their structure. For example, we will present the first measurement of the E1 strength in the octupole deformed nucleus ^{144}Ba. We also will present results for nuclei, such as ^{100}Zr, ^{104}Mo and ^{108}Ru. Our results will give us a more detailed understanding of the structural evolution in neutron-rich nuclei.

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SIGNAL DECOMPOSITION AND TRACKING WITH THE GRETA PROTOTYPE DETECTOR

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The ability to determine the positions and energies of individual γ-ray interactions within a highly-segmented Ge crystal is key in the concept of GRETA. Previous work in this area has shown that the position sensitivity of the GRETA Prototype detector is sufficient to resolve interactions down to the desired position resolution of 2 mm [1]. For the first time, using both simulated and measured detector signals, we have examined the decomposition and tracking process for a single GRETA detector.

The simulation process was performed by modeling interactions from a 662 keV and 1332 keV source 12 cm from the detector. Signals were calculated for each of the modeled events and then put through the decomposition process. The decomposition code developed utilizes a sequential quadratic programming (SQP) method to minimize the difference between the input simulated signal and a set of basis signals representing single interactions on a grid throughout the crystal. The code was constructed to allow for up to two interactions per detector segment and returned the position and energy of each interaction determined. The position and energies of the interactions were then put through a tracking algorithm which calculated a figure of merit for each of the events. The figure of merit represents the fit of the tracked interactions to that of the Compton-scattering formula. By placing constraints on the figure of merit values the relative peak-to-total and efficiency values have been examined.

This process was also performed using measured signals from the GRETA prototype detector. Detector signals, from both a 662 keV and 1332 keV source 12 cm from the detector, were digitized. These signals were then put through the same decomposition and tracking process as the simulated signals. Similar results were obtained for both the simulated and measured signals showing that a substantial improvement in peak-to-total ratio can be made with the implementation of tracking. We believe that, with further improvement in the decomposition process, additional gains will be possible in the trade-off between peak-to-total and efficiency. These results were obtained using the full implementation of all data analysis algorithms and thus represent a major step in GRETA development.

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THIN TARGET FRAGMENTATION FOR IN-BEAM GAMMA-RAY SPECTROSCOPY

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In general, gamma-ray spectroscopy following projectile fragmentation reactions has been limited to the study of decays from micro-second isomeric states (eg. [1]), with tagged, 'in-beam' spectroscopy being limited to systems with A<50 (eg. [2]). This paper reports on the preliminary analysis of a 'thin-target fragmentation' experiment aimed at investigating the feasibility of performing in-beam fragmentation studies, *without* the use of a fragment separator. The ultimate aim is to allow detailed spectroscopy of heavy, neutron-rich nuclei using decays from isomeric states and/or characteristic X rays as experimental tags. A test experiment was performed using a 30 MeV per nucleon ^{12}C beam incident on a self-supporting 30 mg/cm^2 ^{197}Au target at the iThemba Laboratory, South Africa. Gamma and X rays were detected using the AFRODITE spectrometer, which comprised 8 clover germanium detectors and 7 LEPS detectors. Both in-beam and decay data (see figure 1) were taken and compared with yield predictions from the relativistic fragmentation parameterisation, EPAX [3]. The first results will be presented, along with comments on future possibilities using this technique.

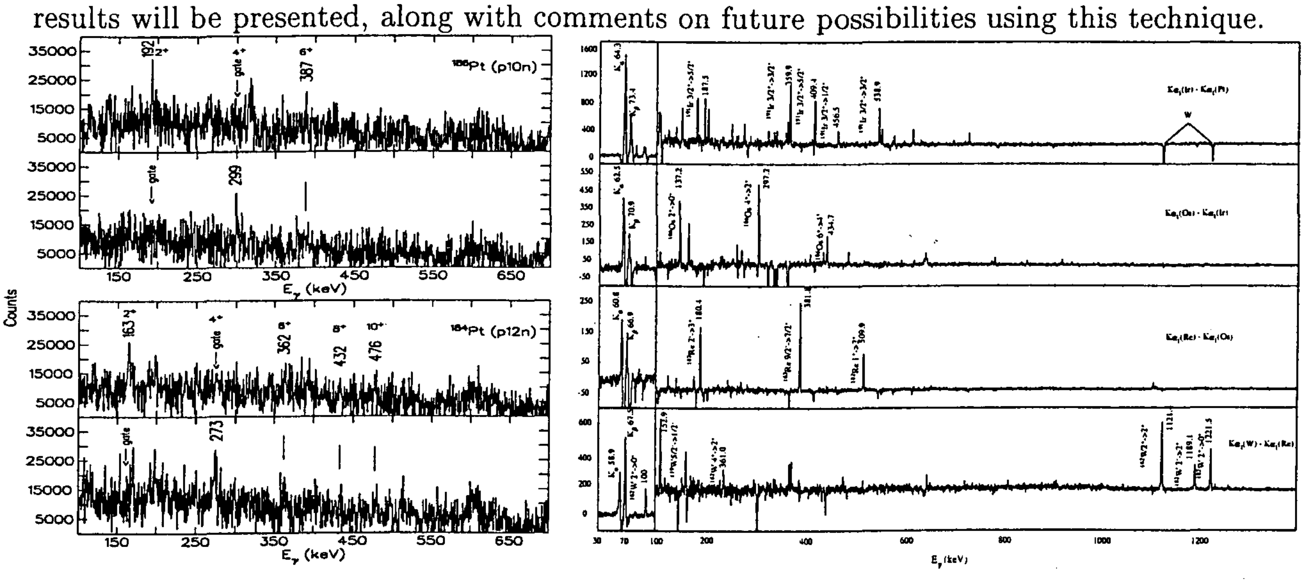

Figure 1: (Left) In-beam and (Right) X-ray gated decay spectra from the current work.

*This work supported by the EPSRC(UK), and the Marie Curie (EU) scheme.

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TRANSITION PROBABILITIES IN STRETCHED E2 BANDS OF ^{144}GD*

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The level scheme of ^{144}Gd has been studied to high spin states using the ^{100}Mo(^{48}Ti,4n) reaction at 215 MeV with EUROBALL at LNL, Italy and as a result a number of irregular dipole as well as stretched E2 bands have been extended. In Fig.1, left part, a partial level scheme showing the 20^+ to 28^+ levels of the quadrupole bands 4 and 5 of ^{144}Gd is presented.

For the lifetime extraction γ-γ coincidence data resulting from a GASP experiment [1] have been sorted for small fold values of $F = 8 \div 19$. Special investigations have been carried out to reproduce the side-feeding time pattern using parameters obtained from the fold spectra study and the lineshape of the 837 keV $26^+ \rightarrow 24^+$ transition in ^{144}Gd [2]. Some special methods of lineshape treatment have been developed and used. In particular in case of the 24^+, 22^+ and 20^+ levels the "narrow gate on transitions below" procedure [3] has been used in a generalized variant, allowing to use gates of any widths.

B(E2) values, obtained from the measured lifetimes are presented in Fig.1, middle part. The irregular spin dependence of B(E2) probably result from band crossings as shown in the right part of Fig.1. The E2 cascades in ^{144}Gd can be considered to have configurations involving rotation aligned $h_{11/2}$ protons as well as neutron holes followed by the alignment of $h_{9/2}$ neutrons resulting in a well deformed triaxial nuclear shape and our results may support this interpretation.

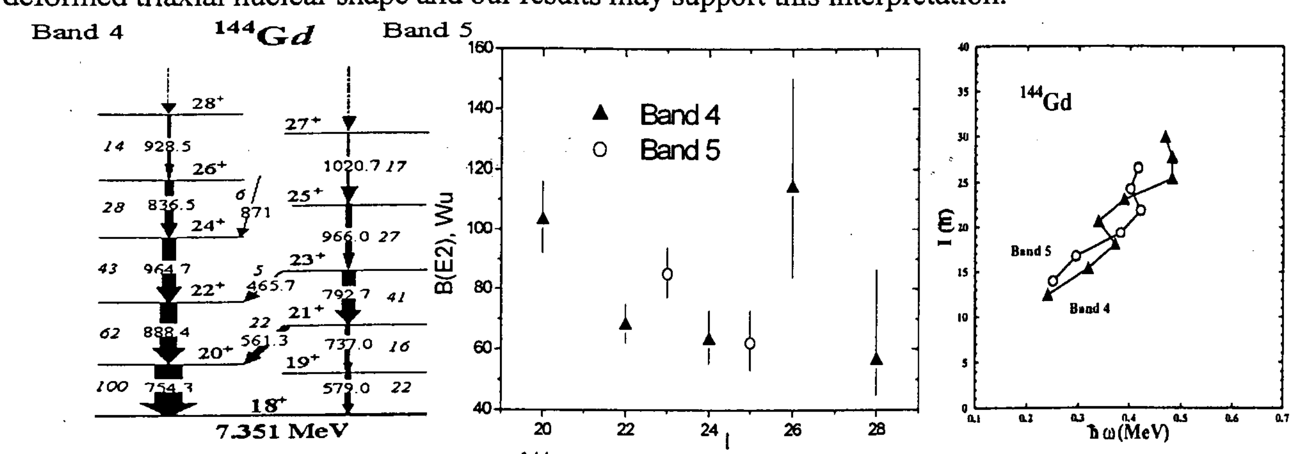

Figure 1 **Left:** Partial level scheme of ^{144}Gd. The intensities of the transitions (in italics) were taken from the ^{114}Cd(^{36}S, 6n) reaction at E = 182 MeV. **Middle:** B(E2) values of stretched quadrupole bands in ^{144}Gd. **Right**: Backbending plot for bands 4 and 5.

*Partly supported by IB of BMBF at DLR under the WTZ contract RUS 99/191

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NE, NA AND AL BURNING IN ASTROPHYSICALLY IMPORTANT (p,γ) REACTIONS

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The breakout from the CNO burning cycle that is needed to produce heavier elements is through thermonuclear processes involving (p,γ) and (α,γ) capture reactions. The synthesis sites need to be hydrogen and helium rich, and are thought to occur in massive stars ($T \sim 10^8$ K) or in nova explosions ($T > 10^9$ K). The reactions rates are sufficiently high that many of the target nuclei are unstable, as they undergo new reactions faster than they can decay back to stability. The reaction rates are dominated by the properties of a few levels near the reaction threshold. Locating these key states and their quantum numbers is crucial in establishing the reaction rates, which, after suitable modeling, can tell us a great deal about both the synthesis sites and the final isotopic abundances. For stable nuclei, the (p,γ) and (α,γ) capture rates can be studied directly in the laboratory. The particle unbound states of interest are those with relatively large gamma branching ratios ($\Gamma_\gamma/\Gamma_{tot}$). For unstable nuclei, which are very important in this problem, the issue is more challenging and a variety of ingenious experimental approaches have been used to infer reaction rates. These include fabrication of radioactive targets, using direct reactions like (^{3}He,d), producing radioactive beams then studying kinematically inverse reactions, and invoking isospin symmetry to infer the positions and properties of the key states.

Big arrays, like Gammasphere, can shed new light on this interesting problem. Using near-barrier heavy-ion reactions, a broad range of states in the excitation region of interest can be populated. As only γ-rays are measured, the experiments are most sensitive to the key states of interest, those with relatively large γ-branches. The excitation energy of the states can be determined to a few keV, angular distributions can constrain spins, lifetimes can determine total widths, and γ–γ coincidences can resolve close-lying doublets. These data, when taken in conjunction with information from reaction studies, can strongly constrain the problem. We have used the ^{12}C(^{12}C,n)^{23}Mg, ^{12}C(^{12}C,p)^{23}Na and ^{12}C(^{16}O,n)^{27}Si reactions to investigate the ^{22}Na(p,γ)^{23}Mg, ^{22}Ne(p,γ)^{23}Na and ^{26}Al(p,γ)^{27}Si sodium, neon, and aluminum burning processes. The experiments used intense (up to 150 pna) beams of low energy (20-30 MeV) carbon and oxygen from the ATLAS accelerator at ANL and the 88" cyclotron at LBNL, impinging on thin, (50-100 μg/cm^2) isotopically enriched carbon targets. Many results were obtained for the astrophysically critical states, and some new states found. The impact of these new measurements has been evaluated by recalculating the reaction rates as a function of temperature. The predicted reaction rates have been redetermined. In some places they have changed by orders of magnitude and the uncertainties are greatly reduced. It appears that this technique is quite general and many similar problems might be addressed this way. This research was supported by the U.S. Department of Energy under contracts W-31-109-ENG-38 and DE-FG02-95ER40934 and by grants from the U.K. EPSERC.

LEVELS OF NEUTRON-RICH ^{111}Rh AND NEARBY ODD-A ISOTOPES*

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The neutron-rich nucleus ^{111}Rh (Z=45) from spontaneous fission of ^{252}Cf was studied by our collaboration in Gammasphere. The assignment of transitions to ^{111}Rh comes from coincidence with complementary heavy fragments ^{137}I and ^{136}I (Z=53). We see only four of the known transitions from beta-decay work, namely, the 211.7 keV M1 transition from the $9/2^+$ first excited state to the $7/2^+$ ground state, the 303.8 keV transition from a $3/2^+$ state to ground, the 189.3 keV transition from a $1/2^-$ state to the $3/2^+$ state and the 189.0 keV transition from a $3/2^-$ state to the $1/2^-$ state. Spin assignments are in parentheses as tentative in the Table of Isotopes [1]. We have proposed 32 new levels in several bands, making use of analogies with the fusion-fission-gamma work of Venkova et al. [2] on ^{107,109}Rh. Our proposed level scheme is shown in Fig. 1.

Of the seven bands proposed in ref. [2] for ^{107,109}Rh, we can assign our transitions in ^{111}Rh to five analogous bands, their bands 1, 3, 5, 6, and 7. In part this may be because spontaneous fission of Cf imparts a higher average angular momentum that more strongly favors yrast levels. We also observed band 8 at $1/2^+$, and trace the other bands to higher spin than they do in the bands in common. We concur with their assignments of band 1 as $7/2^+$ [413] proton state, band 3 as $1/2^-$[301], band 5 as $1/2^+$[431] intruder from the shell above, and band 6 as the coupling of the ground-band configuration to the 2^+ γ-phonon of the core. Band 7, which appeared to be a cascade of stretched M1 transitions without cross-overs was not given a configuration assignment in ^{109}Rh in ref. [2]. We observed the weak cross-overs in band 7 of ^{111}Rh and suggest that it is a tilted-rotor band [3]. Band 8 is interpreted as K=1/2 intruder band.

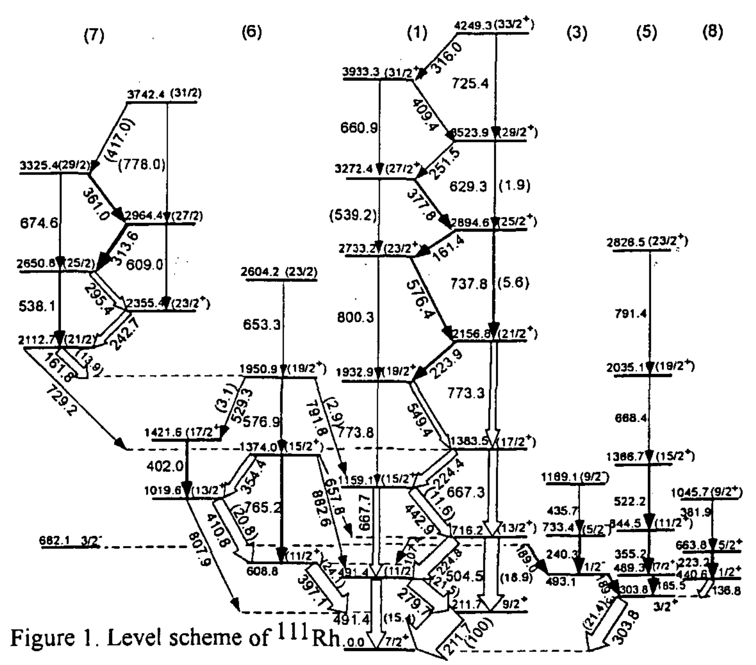

Figure 1. Level scheme of ^{111}Rh

*This work mainly supported by U.S. Department of Energy under Grants and Contracts with Vanderbilt University, Lawrence Berkeley National Laboratory, and Lawrence Livermore National Laboratory.

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MONA: THE MODULAR NEUTRON DETECTOR

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The Modular Neutron Array (MoNA), a highly efficient time-of-flight neutron detector, is being built by a collaboration of ten institutions to measure 50 - 250 MeV neutrons from radioactive ion beam reactions at the National Superconducting Cyclotron Lab (NSCL).

The design of this detector is based on plastic scintillator blocks of $200 \times 10 \times 10$ cm^3. Each of these scintillator blocks is connected via a light guide to a two-inch diameter photomultiplier tube on each end. The position along the scintillator block where the light is emitted can be reconstructed by measuring the time difference between the signals from the two photomultipliers. The average of the two times can be used to determine the neutron's time of flight. The vertical position information is given by the block that detected the neutron.

Sixteen of the scintillator blocks stacked on top of each other form one layer of 2.0×1.6 m^2. The complete detector consists of nine vertical layers of plastic scintillator and additional iron sheets between the layers that function as passive converters. By careful distribution of iron converters between the scintillator layers the overall thickness of the detector can be reduced while maintaining a high detection efficiency. The basic configuration yields calculated detection efficiencies of 70% for 100 MeV neutrons [1]. The modular design of the detector allows it to be configured to maximize efficiency for a variety of neutron energy ranges and accommodate differing experimental requirements.

The bulk of the construction and testing will be done by undergraduate students at the ten institutions in the MoNA Collaboration. These undergraduate students gain will significant educational and training benefits from the work and the labor is spread among many institutions.

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SEARCH FOR THE JACOBI TRANSITION AND FISSION LIMITS IN LIGHT NUCLEI*

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It is well known that a nucleus changes its equilibrium shape from spherical (or prolate) to oblate under the stress of the centrifugal force. The size of the oblate deformation increases with the angular momentum and at a certain value of angular momentum another abrupt change of equilibrium shape from an oblate non-collectively rotating ellipsoid to a triaxial or prolate rotating body, is expected. This phenomenon, called *Jacobi transition* [1], was formulated in semi-classical models by Myers and Świątecki (e.g. Ref.[2] and references therein). The experimental signatures of such abrupt change of nuclear shape are expected to be found in those observables which are influenced by the moment of inertia. Especially useful for the search of Jacobi nuclear shape transitions are: 1) the *γ-decay of GDR* built on such states; 2) the *giant backbend of the E2 γ-transition energies*; 3) the *angular distribution of* the emitted *charged particles*.

So far the problem of Jacobi transition in light nuclei has been addressed in two experiments only by studying the high-energy γ-decay of the GDR from compound nuclei: in one inclusive measurement of the GDR in $^{45}Sc^*$ performed by the Seattle group [3], and in the other, discussed here by us using the HECTOR array and HELENA multiplicity filter, to detect the GDR in $^{46}Ti^*$ [4]. The experimental results compared to the recent theoretical predictions [5] will be presented.

In order to obtain a more complete and consistent picture of the Jacobi shape transition in the hot ^{46}Ti nucleus, we most recently (February this year) made an experiment, using the EUROBALL IV Ge-array equipped by both the HECTOR array and the charged particle array EUCLIDES. The aim of this experiment was to measure simultaneously, for the first time, as a function of γ-fold from the Innerball and all other detectors, the *Splitting of the Giant Dipole Resonance,* the *E2-Giant-backbend*, and the *Enhanced Angular Distribution Function* of charged particles, generated by the *Jacobi Transition*. In addition, the GDR measurements and the E2 bump could be related to specific transitions in different residual nuclei selected by gating on discrete transitions. In addition we also studied the fission limits imposed by angular momentum in this experiment.. The data are being analyzed at present and the preliminary results will be presented.

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T=0 VERSUS T=1 STRUCTURES IN THE N=Z ^{66}As AND ^{70}Br*

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The role of n-p pairing correlations in N=Z nuclei is of particular interest due to the fact that neutrons and protons are occupying the same orbitals. As a consequence the n-p pairing becomes as important as the like-nucleons pairing (nn, pp) [1]. Moreover, np pairs can couple to S=0 T=1 or to S=1 T=0 giving rise to a competition between different types of correlations. The empirical effects of this competition should be enhanced in odd-odd nuclei as suggested by the reappearance of a pairing energy gap. In this sense, T=0 states have been found to be lower in energy than T=1 states for A<40 nuclei in agreement with HFB calculations that favour T=0 against T=1 pairing. However, from recent experiments, the ground states of the heavier mass odd-odd N=Z nuclei seem to favour T=1, in agreement with earlier predictions based on extrapolated masses.

Thus, the energy difference between T=1 and T=0 states ($\Delta E = \Delta E_{T=1} - \Delta E_{T=0}$) in these nuclei may constitute a sensitive probe for the role of isovector and isoscalar pairing correlations. Such differences have been estimated by Satula and Wyss [2] using a mean field model including T=0 and T=1 pairing correlations .

We have recently populated the high spin states of odd-odd N=Z nuclei in the mass A∼70 region with the purpose to determine this pairing structures and thus to understand how this competition take place. This research has led to the identification for the first time of the ^{70}Br [3] and to the extension of ^{66}As.

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COLLECTIVE EXCITATIONS OF SUPERFLUID NEUTRON-RICH NUCLEI: CONTINUUM RPA IN COORDINATE-SPACE HARTREE-FOCK-BOGOLIUBOV THEORY

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The superfluidity exhibits special properties for weakly bound neutrons in unstable nuclei [1] because of the extended low-density area around the nuclear surface and the coupling to continuum states. Collective excitations such as pygmy dipoles may be strongly influenced as is pointed for the classical halo nucleus ^{11}Li [2]. To allow theoretical analysis for heavier systems, we have formulated a continuum RPA that is fully consistent with the coordinate-space Hartree-Fock-Bogoliubov description of the superfluid ground states [3]. The theory incorporates not only the one-neutron escaping process but also the two-neutron emission channel.

The theory theory has been applied to a simple model in order to demonstrate new features of the method, with emphasis on effects of superfluidity on collective excitations. Here the model consists of the Woods-Saxon potential for the mean-field and the Skyrme-type delta force as the particle-hole residual interaction, and the density-dependent delta force as the pairing interaction. The HFB equation for the ground state and the linear response equation for the excited states are solved in the coordinate-space radial mesh. The selfconsistency in the pairing channel is satisfied well.

The analysis has been done for monopole, dipole and octupole excitations of neutron-rich oxygen isotopes reaching the drip-line nucleus ^{24}O. The low-lying quadrupole excitations that has a strong neutron dominance is produced by the pairing correlations. The particle-particle RPA correlation brought by the delta pairing interaction has large effect. In the dipole mode, a significant increase of E1 strength near the neutron threshold is obtained. It has a character, at least partly, of the pygmy dipole mode. A large sensitivity of this mode to the density-dependence of the pairing interaction is predicted and discussed in detail.

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BETA DECAY STUDIES OF NUCLEI NEAR ^{32}Mg*

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Despite having a closed N=20 neutron shell, ^{32}Mg has been shown to be highly deformed; the energy of the first excited 2^+ state is anomalously low [1,2], while the reduced matrix element is large indicating a strong quadrupole deformation [3,4]. ^{33}Al differs from ^{32}Mg by the addition of a single proton and, unlike ^{32}Mg, has not been well-studied. By studying the beta decay of ^{33}Al and ^{33}Mg information regarding the structure of nuclei near ^{32}Mg can be obtained.

Using the Coupled Cyclotron Facility at the National Superconducting Cyclotron Laboratory, both ^{33}Al and ^{33}Mg have been produced following the fragmentation of a 140 MeV/nucleon beam of ^{40}Ar in a beryllium target. These isotopes were separated using the A1900 fragment analyzer and implanted in a double-sided silicon strip detector; this detector was also used to observe the subsequent beta decays. Two large germanium detectors were used to detect beta-delayed gamma rays.

By directly correlating implant and decay events, half-life curves and correlated gamma-ray spectra have been obtained for each species. These results, and their implications on the low-energy structure of the daughter nuclei, will be discussed.

*This work supported in part by the National Science Foundation, Grant PHY-95-28844.

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COULOMB EXCITATION OF STABLE EVEN-EVEN XENON NUCLEI FROM $A = 124$ TO 134*

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A series of Coulomb-excitation experiments on $A = 124$ to 134 even-even xenon isotopes was recently performed at the ATLAS facility at Argonne National Laboratory. The xenon isotopes represent a particularly interesting region of the nuclear chart in that they form an extended chain of stable isotopes. They exhibit a slow transition from vibrational level structures close to the $N = 82$ neutron shell closure (^{136}Xe) to the relatively well-deformed ($\beta_2 \approx 0.2$) γ-soft nuclei ^{124}Xe and ^{126}Xe. Using Coulomb excitation, we were able to study in a consistent way the non-yrast level systematics of these xenon nuclei through this transitional region. We are particularly interested in probing the 2^+ mixed-symmetry configurations [1] that are present at relatively low energies in these xenon nuclei. Candidate 2^+ mixed-symmetry states were previously observed in ^{126}Xe [2] and ^{128}Xe [3]; however, our data adds significantly to the previous experiments as well as result in the identification of previously unobserved mixed-symmetry states in the other even-even Xe nuclei that were studied.

To perform these experiments, xenon beams were accelerated by ATLAS to 4.3 MeV/nucleon and directed to our experimental setup, which consisted of a ^{58}Ni target surrounded by six 32-fold segmented germanium detectors of the Michigan State University germanium array and a large-area four-quadrant PPAC. The germanium counters were placed around the target to yield an approximate 6% photopeak efficiency at 1.3 MeV and have a segment opening angle about 10°. The PPAC is placed such that it covered the full angular scattering range of the xenon nuclei.

*This work is supported by the Department of Energy under grant W-31-109-ENG38 and the National Science Foundation under grants PHY-9724299, and PHY-9875122, PHY-0110253.
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DECAY OF A HIGH-K ISOMER IN ^{254}No BY γ AND ELECTRON SPECTROSCOPY*

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The heaviest nuclei are stabilized against fission by shell effects. Hence the accuracy of theoretical predictions of superheavy elements depends on the correct proton and neutron shell structures. 2-quasiparticle states provide information on the single particle energies and on the pair gap. The primary aim of the present work was to determine the properties of a reported [1] 2-qp isomer ($T_{1/2}$ = 0.28sec) in ^{254}No.

The experimental study of nuclei with Z$\geq$ 102 are difficult due to their low production cross sections. Even in the quiet environment at the focal plane of a recoil seperator, such as the FMA at Argonne, the small number of nuclei yield a decay rate much smaller than the background rate. Therefore, new techniques have to be developed to study the isomeric decays of these nuclei through delayed γ rays, alphas and electrons.

^{254}No was populated by the reaction ^{208}Pb(^{48}Ca,2n) with 220 MeV, 50-pnA beam from ATLAS. Evaporation residues were identified by (M/Q) in the FMA and by gating on a ΔE-TOF 2D matrix. ΔE is the energy loss in the focal plane PPAC and TOF the time of flight between the PPAC and a micro channel plate detector. After traversing these detectors, $\sim$ 1000 ^{254}No residues were implanted into a Si PIN diode, one of five detectors in a box array, which detected electrons and α's and also served as an electron calorimeter. The γ rays were detected in two clover Ge detectors and two LEPS's, closely packed to maximize the solid angle.

Prompt $\gamma-\gamma$ and $e-\gamma$ coincidences, which occurred within 0.6 sec of ^{254}No implantation, give preliminary indication of a $\sim$ 0.4s isomer. A 941-keV γ-ray has been observed in coincidence with the 214-keV $8^+ \rightarrow 6^+$ transition of the ground state band and with an electron sum energy between 10 and 519 keV (the excitation energy of the 8^+ state [2]). The 941 keV γ-ray is a candidate for the $8^- \rightarrow 8^+$ isomeric transition, which would yield an energy of 1.460 MeV for a $K^\pi = 8^-$ isomer (K^π inferred from the decay scheme and the expected single-particle orbitals). Data on $e-e$ coincidences are currently being analyzed.

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ROTATION OF LONG-LIVED INTRINSIC STATES IN STABLE AND NEUTRON-RICH YTTERBIUM ISOTOPES VIA DEEP-INELASTIC EXCITATION REACTIONS *

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The A ~ 170–180 mass region of prolate-deformed nuclei is replete with long-lived multi-quasiparticle states which arise from configurations that have large angular-momentum projections, K, on the nuclear symmetry axis. The occurrence, characterisation and decay of these "K-isomers" continue to challenge our understanding of the interplay of intrinsic and large-amplitude collective rotational motion in deformed nuclei. Pushing the boundaries of our existing knowledge to neutron-rich nuclei in this mass region necessitates the use of very heavy-ion beams to initiate deep-inelastic-transfer reactions. The results of such a study undertaken at the *iThemba*** Laboratory for Accelerator Based Sciences (LABS) are outlined below.

Beams of ^{136}Xe ions were delivered by the Separated Sector Cyclotron (SSC) of *iThemba* LABS at an energy of 750MeV with a maximum intensity of ~1pnA. The beams were directed onto Au-backed enriched targets of ^{176}Yb and ^{174}Yb with nominal thicknesses of ~2-3mg/cm^2, located at the centre of the AFRODITE gamma-ray array. At the front of the target(s), the beam energy was ~15% above the Coulomb barrier. Events were recorded when at least 3 (2 of which had to be clovers) of the 15 germanium detectors (7 clovers and 8 4-way segmented LEPSes) fired within ~200ns of one other, referenced to the RF of the SSC.

A preliminary analysis is nearly complete for the ^{176}Yb data and results thus far include the observation of a number of nuclei populated via transfer reactions, in particular ^{177}Yb for which a revised band based on the 7/2$^+$[633] ground-state neutron is suggested. Also of interest is the observation of transitions from the beam-like nucleus ^{138}Ba, which suggests that its target-like partner, ^{174}Er was populated too. This isotope of erbium is 4 neutrons richer than the heaviest stable case, ^{170}Er, but definite candidates for transitions in ^{174}Er remain to be found. Moreover, it would be expected to possess the $K^\pi = 8^-$ two-quasineutron state that is ubiquitous to the N = 106 isotones in this region, including the target, where the half-life of this state is ~12seconds. Indeed, a candidate for the band based on this long-lived state in ^{176}Yb has been found and offers the possibility of an independent characterisation of the two-quasiparticle configuration from the inband branching ratios. The analysis of the ^{176}Yb data is continuing and has commenced for the measurement made with the ^{174}Yb target.

* This work supported by the National Research Foundation of South Africa.

** *Xhosa-Zulu* word meaning "*hope for the future*".

GIANT RESONANCES IN THE CONTINUUM STUDIED WITH ABSORBING-BOUNDARY-CONDITION METHOD

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Advances in radioactive beams enable us to study drip-line nuclei as weakly bound quantum systems. Since excitation spectra above the particle-emission threshold are continuum spectra, theoretical analysis requires continuum wave functions. The random-phase approximation (RPA) with Green's function technique [1] is a simple method to investigate a response in the continuum. However, the applicability was rather limited, namely the method is applicable only to spherical systems. Recently, we have developed methods of calculating the excitation spectra and transition densities for systems with no spatial symmetry [2].

Using techniques of the time-dependent Hartree-Fock (TDHF) theory in real time and real space [3], we explicitly solve the time-dependent equation in the three-dimensional (3D) real space in real time. The problem was that, if we try to describe the continuum wave functions properly, we need to calculate the TDHF states in a huge 3D space. This is impractical. Instead, we show that the continuum effect can be effectively taken into account by introducing a complex Absorbing Boundary Condition (ABC). We shall show that the TDHF with ABC is an efficient method to calculate response functions.

The same method was already applied to photoabsorption spectra of molecules. It is found that the continuum can be well approximated with the ABC if the complex potential satisfies a certain criterion [2]. The idea is also applicable to scattering problems and provides a practical method of solving the Lippmann-Schwinger equation [4].

In this presentation, we discuss properties of excited (resonance) states embedded in the continuum and their reactions for deformed drip-line nuclei. Fig. 1 is an example of our calculation.

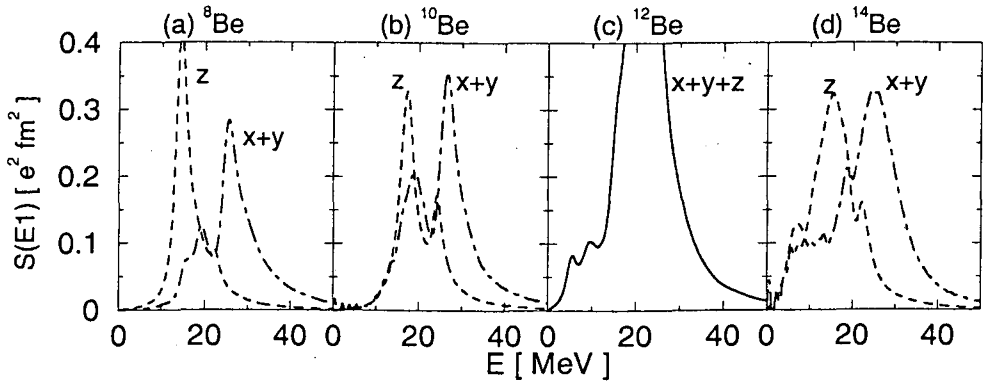

Figure 1: Dipole responses in Be isotopes. x, y, and z indicate the direction of dipole field, where the z-axis is taken as the symmetry axis for ^{8,10,14}Be.

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TRIAXIAL SUPERDEFORMATION IN ^{170}Hf*

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Minima in the nuclear potential energy surface with a large quadrupole deformation ($\epsilon \approx 0.4$) and with a substantial triaxiality ($|\gamma| \approx 20°$) had been predicted theoretically for a long time in the A=165 mass region. In recent years, this region of triaxial superdeformation has also been established experimentally. Rotational bands with large moments of inertia have been found in ^{163}Lu to ^{167}Lu and ^{168}Hf; for some of them the large deformation has been confirmed by lifetime measurements. Experimental proof of the triaxiality is the occurrence of the wobbling mode which was discovered for the first time in ^{163}Lu in a recent EUROBALL experiment [1].

Theory predicts the triaxial superdeformed (TSD) minima to be most pronounced in the Hf isotopes, while experimentally the corresponding bands appear to be stronger in the Lu isotopes. For a search for TSD bands in ^{170}Hf, high-spin states in this nucleus have been populated in the reaction ^{124}Sn(^{50}Ti, 4n) at 216 MeV at the VIVITRON accelerator. Gamma-ray coincidences have been measured with the EUROBALL spectrometer. A preliminary analysis of the data revealed the band shown in Fig.1 which has similar characteristics as the TSD bands in neighbouring ^{168}Hf. In addition, the previously known normal-deformed (ND) bands have been extended to substantially higher spins and several new ND bands have been found.

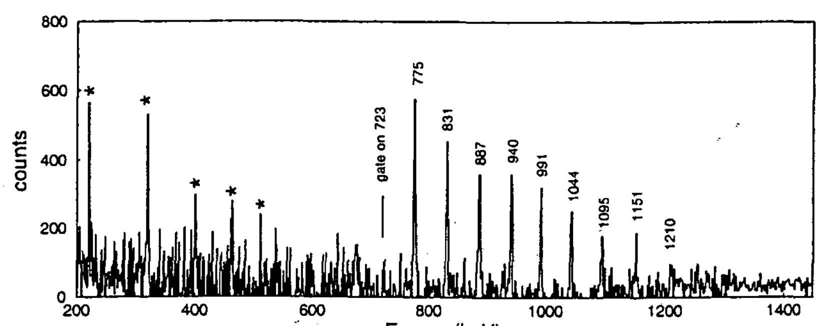

Figure 1: Double-gated γ-ray coincidence spectrum of a new TSD band in ^{170}Hf; first gate on the 723 keV-transition, second gate from a list of all other transitions in the band. ND transitions are marked with a * symbol.

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PROMPT ROTATIONAL STRUCTURES IN NEUTRON-RICH $^{180,181,182}Hf$ *

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Hafnium nuclei have long been considered to be classic examples of rigid axial prolate rotors. Recent theoretical calculations for neutron-rich hafnium nuclei [1], however, predict competition and changing dominance between three different potential energy minima along the yrast line as a function of angular momentum. Prolate collective rotation at low spins yield to intrinsic high-K band-heads at intermediate spins, while at the highest spins, oblate collective rotation is predicted to be the most efficient mode of generating angular momentum. Our continuing investigations in the A~180 region have resulted in significant new information on long-lived K-isomers ($t_{1/2}$ >1μs) in the intermediate spin region for neutron-rich hafnium nuclei [2,3]. The experiments utilized inelastic excitation and transfer reaction mechanisms to populate high-K isomers using heavy beams such as uranium on ^{180}Hf targets, the heaviest stable isotope of hafnium. The first experiments were backed-target experiments with pulsed beams, and focused primarily on the decay of high-K isomers measured during the beam-off periods between pulses.

Our most recent experiment focuses on the study of prompt structures and short-lived isomers in these nuclei. The nuclei were populated via inelastic and transfer reactions using a 750 MeV ^{136}Xe beam from the LBNL 88" cyclotron incident on a thin 410 μg/cm^2 ^{180}Hf target backed by 40 μg/cm^2 carbon. The emitted γ-rays were detected with GAMMASPHERE in conjunction with CHICO [4], a compact, position-sensitive, heavy-ion detector that can detect and distinguish between beam-like and target-like fragments using time-of-flight techniques. Reconstruction of the particle kinematics allows event-by-event Doppler corrections for the fast rotational transitions emitted by nuclei recoiling out of the target.

All rotational structures observed previously in $^{180,181,182}Hf$, built on both low-K and high-K bandheads, have been extended to higher spins and rotational frequencies, with the ground state bands extended to $J^\pi=18^+$, $37/2^-$ and 14^+, respectively. Cranked shell model and total Routhian surface calculations have been performed to understand the intriguing systematics of quasiparticle alignments in N=108 and 110 isotones. The new results provide a comprehensive map of the evolution of potential energy minima for near-yrast excitations in neutron-rich hafnium nuclei.

*This work supported in part by the Department of Energy and the National Science Foundation.

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THE NUMBER OF UNRESOLVED ROTATIONAL BANDS IN THE TRIAXIAL STRONGLY DEFORMED POTENTIAL WELL OF ^{163}Lu*

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Rotational bands with large deformation have been observed in several nuclei in the Z~71, N~92 region. The recent observation of a one phonon wobbling excitation [1], and possibly a two phonon excitation [2], is the first firm experimental evidence of the triaxiality of these states. Using the ^{139}La(^{29}Si,5n)^{163}Lu reaction at 152 MeV, high-spin properties of the triaxial strongly deformed potential well in ^{163}Lu at excitation energies above resolvable bands have been investigated. Gated $E_{\gamma 1} - E_{\gamma 2}$ spectra display clear ridges with moments of inertia corresponding to those observed for the discrete strongly deformed bands. The analysis of count fluctuations in the $E_{\gamma 1} - E_{\gamma 2}$ spectra is based on the fact that there is a limit to the number of possible decay paths available to the γ-cascades [3]. A fluctuation analysis of the TSD ridges yields a number of 2-step paths of ≈ 40 and ≈ 20, when gating on triaxial strongly or normally deformed bands, respectively. These results show that a potential well at large deformation coexists with the normally deformed well, and indicate a mixing between states in the two wells at higher excitation energy.

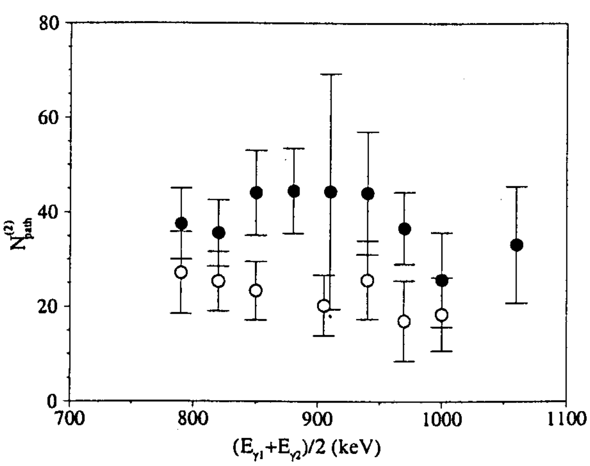

Figure 1: The number of two-step paths along the TSD ridge in the TSD gated matrix (filled circles) and ND gated matrix (open circles).

* Work supported by EU, TMR:(contract no. ERBFMGECT980145)

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FRONTIERS OF K-ISOMERS IN THE MASS A∼130 REGION*

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In nature, the longest lifetimes observed for K-isomeric states have been found to be in the mass A∼180 region [1], which is a region rich in multi-quasiparticle states (in both even and odd-mass nuclei). As a consequence of the charge independence of the nuclear force, similar features might be expected in the mass A∼130 region. Indeed, $K^\pi=8^-$ isomeric states built on the coupling of the $7/2^+[404]\otimes9/2^-[514]$ neutron orbits have been observed in the even-even N=74 isotones, from $^{140}_{66}$Dy [2] to $^{128}_{54}$Xe [3], with half-lives ranging from $\sim10^{-3}$ ($^{130}_{56}$Ba) to $\sim10^{-9}$ s ($^{128}_{54}$Xe). However, there is not yet any evidence for higher seniority K-isomers in the A∼130 region nor indeed for lifetimes on the scale of the 31 years measured in ^{178}Hf [1]. Moreover, in the odd-even N=74 isotones, there is a limited amount of information on 3-qp states, where only $^{131}_{57}$La shows evidence of isomerism with a $J^\pi=21/2^-$ isomeric state built on the $5/2^+[413]$ proton orbit and the $7/2^+[404]\otimes9/2^-[514]$ neutron orbits, with a half-life of 38(2) ns being observed [4]. In the lighter N=74 isotones, shorter lifetimes would be expected as the Z=50 closed shell approaches, following the loss of deformation, and thus, purity of the K quantum number. This is not observed experimentally for the even N=74 isotones and has been explained in terms of two-band mixing for $Z\geq56$ [5].

In order to focus on the lighter N=74 isotones which are known to be γ-soft in the ground state [6], $^{126}_{52}$Te, $^{127}_{53}$I and $^{128}_{54}$Xe have been studied at the Australian National University facility. Indeed, the rather short lifetime observed for the $K^\pi=8^-$ isomeric state in ^{128}Xe has been explained in terms of the negative parity states observed below the isomeric state [7]. Decay schemes have been built for these nuclei and calculations based on the configuration constrained method [8] have been performed in order to calculate 2-qp excitation energies and energy potential surfaces. The new information obtained will reveal the limits of K-isomerism.

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CONTRIBUTION TO THE INVESTIGATION OF THE NUCLEAR PHENOMENA WITH IMPROVEMENTS IN DETECTOR TECHNOLOGY

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The observation of new scientific phenomena requires necessarily the development of new detection apparatus. In most of cases we have reached the detection limit with current detectors designed to investigate the physics of exotic nuclei or other domains in nuclear structure.

The gamma detector arrays are still based on Germanium detector due to their high resolving power (energy resolution and photopeak efficiency). The simple solution to improve, at the same time, the photopeak efficiency and energy resolution is to locate the individual interaction gamma-ray points in order to correct γ-ray spectra by electronic and computer treatments. Such computations allow a Doppler broadening reduction but also a γ-ray path rebuilding (Tracking), and so the expected the resolving power increases. The current detectors have to be highly segmented to perform the best correction. Different kind of detectors attract the physicists, some prefer to work with coaxial detector to benefit from the high intrinsic efficiency whereas others prefer to use stacks of planar detectors providing a high granularity.

During many years, detectors were developed to fit the physicist wishes with coaxial detectors (4-fold segmented Clover detector, encapsulated segmented detectors ...) as well as planar detector technology with thin contact development allowing the realisation of charged particles telescopes or Compton camera.

A presentation of the state of the art in this area will be given.

SIDE-FEEDING PATTERN INVESTIGATION IN NEAR-MAGIC Gd NUCLEI*

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A new approach for the investigation of continuum γ-cascades has been developed. It is based on precise simulations of entry state distributions as well as side-feeding γ-ray cascades by Monte-Carlo methods using a few characteristic parameters for fitting simultaneously different types of experimental data: 1) Statistical distributions of γ-ray cascades like multiplicity, sum energy, relative intensities of transitions in the observed cascades, etc. 2) γ lineshapes in the DSA technique, sensitive to the time distributions of the population of high-spin levels by side-feeding cascades.

High spin γ-spectroscopic data from the $^{114}Cd(^{36}S,xn)^{144,145,146}Gd$ (E=182 MeV) and $^{100}Mo(^{48}Ti,xn)^{143,144,145}Gd$ (E=215 MeV) reactions, measured with the γ spectrometer GASP at LNL [1, 2] have been used for the extraction of γ-multiplicity distributions and the evaluation of critical input angular momenta. DSA lineshape studies have been performed for the $28^+ \rightarrow 26^+$ transition of ^{144}Gd populated in the $^{114}Cd(^{36}S,6n)^{144}Gd$ reaction. The analysis of the experimental data (Fig. 1) shows in particular that in the case of the near-magic Gd isotopes:

a) Magnetic rotational bands play an important role in the formation of the side-feeding cascades and give a significant contribution to the multiplicity;

b) In the high-spin region, where superdeformed bands (SDB) become yrast the deexitation in the continuum region proceeds through many SDB in comparison to normal deformed bands.

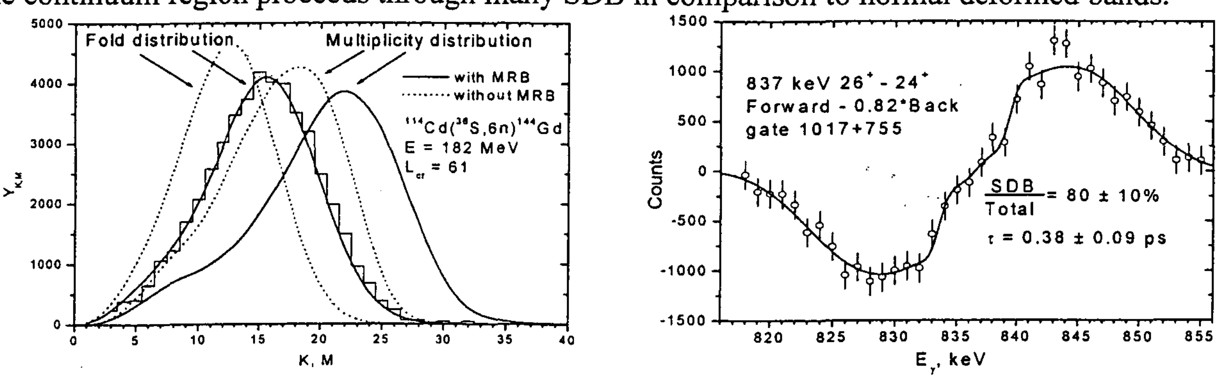

Figure 1 **Left**: Experimental (histograms) and calculated fold and multiplicity distributions for a gate on the 712 keV transition in ^{144}Gd. Solid and dotted lines are calculated with and without taking into account magnetic rotational bands (MRB) in the continuum. **Right**: Spectrum obtained by subtracting a spectrum for the 144^0 ring from that of the 36^0 ring. The result of a two-parameter fit is illustrated. SDB/Total is the relative deexitation probability through SDBs with Qo=14 eb as compared to the full value including normal deformed stretched E2 bands (Qo=4 eb) in the high-spin region (I>26 ħ).

*Partly supported by IB of BMBF at DLR under the WTZ contract RUS 99/191

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BACKGROUND SUBTRACTION IN E_γ^N COINCIDENCE DATA.

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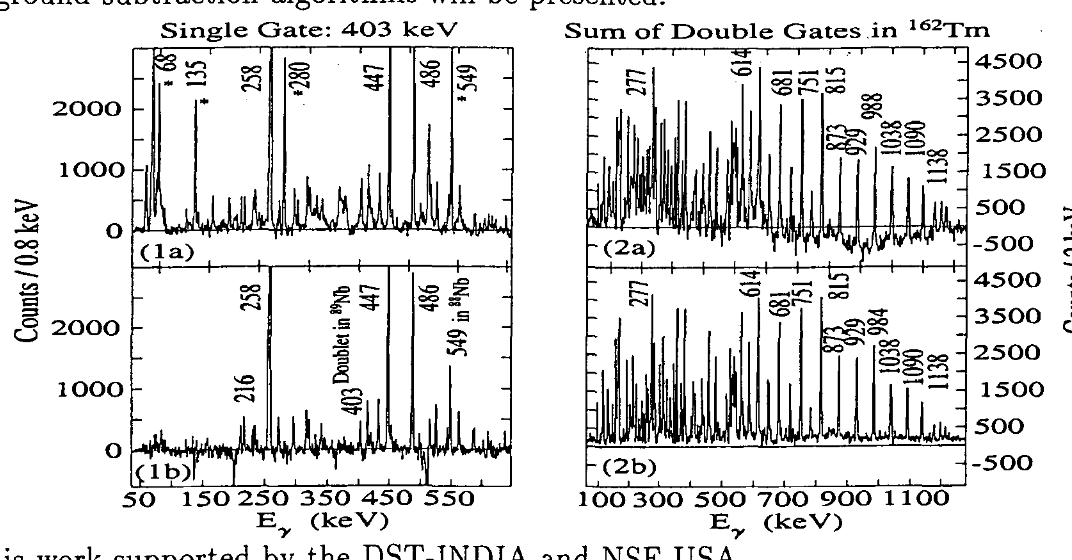
RADWARE and earlier methods as described in Ref. [1] extract photopeak coincidences directly from E_γ^N histograms for the (HI, $xn\gamma$) data. The present method extends these algorithms to improve the genuine photopeak coincident events of interest. However, one has to minimize over subtraction of uncorrelated γ rays originating from the Coulomb excitation of the backing or target material and strong reaction channels. These γ rays are in prompt coincidence with the genuine γ cascades.

Figs. (1a) and (1b) illustrate the gated spectrum (from the $E_\gamma - E_\gamma$ matrix) with a gate on the 403 keV transition from the reaction $^{31}P(^{68}Cu, xn\gamma)^{88,89}Nb$, and obtained by subjecting the data to conventional background subtraction techniques and the present method, respectively. In Fig (1a), we do find peaks originating from the uncorrelated γ-rays (the stronger uncorrelated transitions are marked with '*'). As seen from the Fig (1b), the present method did not subtract the 403 keV transition (this transition is a doublet of ^{89}Nb), and in case of 549 keV transition belonging to ^{88}Nb, it made free from the overlap of back ground transition from gold backing.

We have also extended our method to a higher fold coincidence data set. The results are illustrated in Fig (2a & 2b). The algorithms have been implemented in our in-house data sorting program *IUCSORT* and these methods and the program are compatible with RADWARE[2]. The algorithms developed and the detailed results vis-a-vis the prevailing background subtraction algorithms will be presented.



+ This work supported by the DST-INDIA and NSF-USA.

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IDENTIFICATION OF THE $K^\pi = 25^{(+)}$ STRUCTURE IN ^{182}Os.

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The ^{150}Nd(^{36}S,4n) reaction was used with the GAMMASPHERE spectrometer at the Lawrence Berkeley Lab. in order to establish the structures built upon the $K^\pi = 25^{(+)}$ isomeric state in ^{182}Os. This $130 \pm 20ns$ isomer has been the subject of many experiments because of its apparent violation of the K-selection rule [1]. One of its decay transitions, a 1061.6 keV dipole γ ray is apparently responsible for a change of 25 units in K as it connects the isomer ($K = 25$) with the ground-state band ($K \approx 0$). In order to more fully understand this violation we have used the GAMMASPHERE spectrometer to establish the structures on top of the isomer. These structures show very different behaviour to those normally associated with the collective rotation of a high-K multiquasiparticle configuration in this mass region. The reasons for this difference in behaviour above the $K^\pi = 25^{(+)}$ isomeric state will be discussed with in the framework of the tilted-axis cranking model and provide possible evidence that the high-spin nuclear angular momentum is generated by nuclear vibrations.

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HIGH SPIN STATES IN ^{114}Xe: BUILDING A BRIDGE BETWEEN THE MASS 110 AND 130 REGIONS*

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Superdeformed (SD) nuclei in the mass 130 region were initially believed to be driven solely by the occupation of $\nu i_{13/2}$ intruder orbitals from the N_{osc}=6 shell [1]. This was consistent with the original observation of a strongly populated (5%) SD band in ^{132}Ce (N=74) [2], while only recently have SD bands been found for $N \leq 72$ [3]; this work did however show that the presence of holes in the $\pi g_{9/2}$ orbital, which originates below the Z=50 spherical shell gap, are just as important in forming SD shapes in $Z \sim 58$ nuclei; superdeformation still persists as the neutron Fermi surface falls well below the $\nu i_{13/2}$ intruder orbitals [4]. The $\pi g_{9/2}$ holes are also a crucial ingredient of smoothly terminating bands seen in $A \approx 110$ nuclei with $Z \approx 50$ [5].

New results have been obtained for $^{114}_{54}$Xe, populated with the 230-MeV ^{58}Ni(^{58}Ni,2p) reaction at Argonne National Laboratory. GAMMASPHERE was used in conjunction with the MICROBALL charged-particle detector in order to select evaporation residues of interest. The yrast band of this nucleus has been greatly extended by fourteen transitions to a spin of $52\hbar$ and shows high-spin features consistent with smooth band termination. This band represents the first firm evidence for a core-excited (6-particle, 2-hole) proton configuration above Z=53 involving two $\pi g_{9/2}$ holes. Results of cranked Nilsson-Strutinsky calculations predict a deformation of $\varepsilon_2 \approx 0.30$ for the band, much larger than the ground-state deformation of ^{114}Xe. This demonstrates the shape-driving aspect of holes occupying a strongly upsloping ($\partial E/\partial \varepsilon_2 > 0$) orbital and explains the connection between mass 110 terminating bands and mass 130 SD bands ($\varepsilon_2 \approx 0.35$). The SD bands, with a larger valence space, can accommodate more spin before termination is reached; for instance, the yrast SD band in ^{132}Ce is expected to terminate at $I^\pi = 78^+$, $22\hbar$ higher than that predicted (56^+) for the new band in ^{114}Xe. The present results for Z=54 advances the bridge between these two structural features in the two mass regions.

* This work supported by the UK EPSRC, and US NSF and DOE.

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TERMINATING STRUCTURES AND LIFETIME MEASUREMENTS IN ^{87}Nb

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Two experiments have been performed using the ^{32}S(^{58}Ni, $3p$) reaction at 135 MeV with GAMMASPHERE and the MICROBALL to study the high-spin structure of the transitional nucleus ^{87}Nb. The first experiment using a thin target provided a considerable extension and refinement of the level and decay scheme, as well as firm spin assignments from DCO ratios. Sub-picosecond lifetimes were measured in the second backed-target experiment using the Doppler-shift attenuation method. The lifetimes imply a rather modest average deformation of $\epsilon_2 \sim 0.1$, but with considerable variation from state to state. Strong alternations were observed in the $B(M1)$ strengths of transitions between some pairs of bands. The experimental results were compared with calculations performed within the configuration-dependent shell-correction approach using a cranked Nilsson potential. The calculations generally reproduce the irregularities in the band structure and plunging Q_t values, explaining them as reflections of the underlying microscopic shell structure leading to band terminations. For example, band termination is indicated in the figure by the rise in $E - E_{ld}$ at high spin coupled with a simultaneous drop in Q_t.

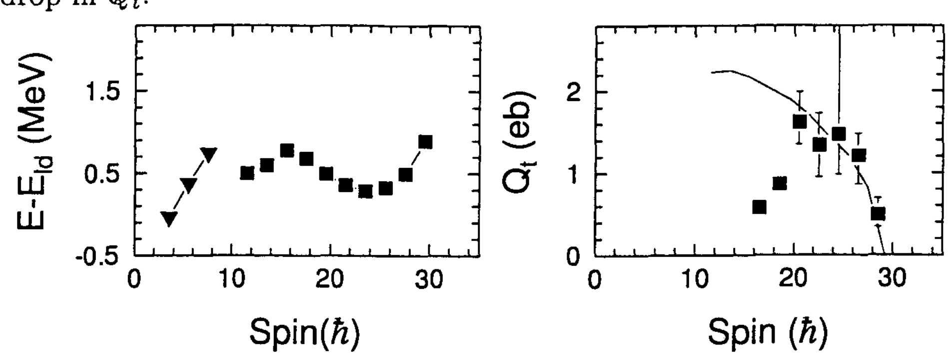

Figure 1: Left: The observed states with $\pi = +$, $\alpha = -\frac{1}{2}$ are plotted against spin with the energy of a "standard" rigid rotor subtracted. Right: Q_t values for the transitions between these states are plotted against spin along with the CNSM predictions.

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THE ORIGIN OF THE DOUBLET BANDS OBSERVED IN A~130 NUCLEI

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The spectroscopic study of neutron defficient nuclei in the A~130 mass region undertaken recently in various laboratories around the world, revealed the existence of nearly degenerate doublet $\Delta I = 1$ bands in odd-odd nuclei. Calculations in the framework of the 3D tilted axis cranking (TAC) model explain the doublet bands as result of the existence of chirality in the intrinsic frame of the nucleus [1]. Extensive investigations to search for doublet bands have been performed in the odd-odd nuclei surrounding the ^{134}Pr nucleus where such bands were first identified [2] and where the degeneracy of the doublet bands is best realized [3]. In this context, we also found two $\Delta I = 1$ bands with the same parity and almost degenerate levels in ^{128}Pr [4], which suggested that they might be a pair of chiral sister bands. However, detailed 3D TAC and two-quasiparticle+rotor model calculations including the residual interaction between the odd proton and odd neutron show that the two bands belong to the pseudospin doublet $[3\tilde{2}1]$. In both calculations it turned out to be impossible to achieve the observed small level spacing. The question rises if this is not a hint of a hidden symmetry related to pseudospin.

Another question related to the same topic is the possible existence of doublet bands in even-even or odd-even triaxial nuclei. Possible candidates for such structures were very recently identified in Nd nuclei and their interpretation in terms of pseudospin or chiral doublets will be discussed.

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Beta decay of exotic nuclei close to ^{100}Sn: ^{94}Ag and ^{100}In

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The double shell closure at $N = Z = 50$ is a favourable study ground for the residual proton-neutron interaction, the single-particle energies and the Gamow-Teller (GT) strength, offering the following particularly interesting features: 1. High-spin states in nuclei close to a major shell closure may receive extra binding energy due to the large overlap of proton and neutron orbitals in particle-particle (*pp*) and hole-hole (*hh*) configurations, giving rise to spin-gap isomers. In analogy to ^{52}Fe [1] and ^{95}Pd [2], where the maximum aligned configurations of 12^+ and $21/2^+$ are isomeric and undergo β decay, experimental evidence has been found for (7^+) and $I \geq 17$ isomers in ^{94}Ag [3].

2. The strong monopole shift in $\pi\nu$ pairs of spin-orbit partners as $\pi g_{9/2}\nu g_{7/2}$ decreases the $\nu d_{5/2}\nu g_{7/2}$ spacing with filling of the $\pi g_{9/2}$ orbital towards ^{100}Sn [4,5]. Thus, the competing *ph* multiplets $[\pi g_{9/2}^{-1}\nu d_{5/2}]$ and $[\pi g_{9/2}^{-1}\nu g_{7/2}]$ determine the spin of the low-lying states in the odd-odd ^{100}Sn neighbour, i.e. ^{100}In, and shed light on details in the proton-neutron residual interaction. Beta decay studies of ^{100}In were performed at the GSI mass separator and the results, including spin and parity assignments, will be discussed and compared with large scale shell-model calculations [6].

3. By comparing the GT strength distributions measured in the total absorption spectrometer (TAS) with the calculations, a hindrance factor of 3.1(4) for the total GT strength is obtained, which agrees well with a value expected for the super-GT resonance of ^{100}Sn [7].

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SEARCH FOR EXCITED SUPERDEFORMED BANDS IN ^{197,198}BI

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In order to have access to intrinsic orbitals which will not be reached until the discovery of superheavy elements and the knowledge of their first excited states, a study of excited superdeformed (SD) bands in the ^{197,198}Bi nuclei is under analyze. In addition, from the experimental point of view very little is known about the superdeformation phenomenon beyond Z=82.

Excited high-spin states in ^{197,198}Bi isotopes were populated by the ^{184}W(^{19}F,xn)^{197,198}Bi reactions at a beam energy of 114 MeV during six days supplied by the VIVITRON accelerator at the Institut de Recherches Subatomiques Strasbourg. The γ-rays were detected with the EUROBALL IV spectrometer comprising an innerball of 210 BGO crystals and 71 Ge detectors which represent 239 Ge individual crystals [1].

In more details, one of the low-lying configuration of the super-heavy isotopes unknown at present which would be accessible is the $\pi[770]1/2$ orbital coming from the spherical (N=7)$\pi 1j_{15/2}$ shell never observed up to now. Theoretical microscopic calculations concerning the ^{198}Po nucleus and using the SLy4 effective interaction within the cranked HFB formalism are done presently by our group to have a better idea of the configurations of the ^{197}Bi nucleus without and with rotation.

In addition, the observation of M1 transitions connecting signature-partner SD bands would enable us to increase our knowledge of the magnetic properties in rotating very deformed nuclei. Our previous results [2] appeared as the third evidence of the surprising lack of quenching obtained for neutron SD orbitals in ^{193}Hg, ^{193}Pb and ^{197}Pb contrary to the results obtained for the proton SD $\pi[642]5/2$ orbital in ^{191}Tl, ^{193}Tl and ^{195}Tl. Experimental results have been compared with the theoretical predictions of the $R = \frac{g_K - g_R}{Q_o} K$ ratio done for odd Hg and Pb nuclei with collective gyromagnetic ratios g_R calculated within the Inglis Cranking approximation, using HF+BCS calculations [3]. Data based on a new proton orbital based on the $\pi[514]9/2$ orbital, as expected for ^{197}Bi, will bring us crucial information concerning the magnetic properties in the SD well.

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HUNTING FOR TILTED ROTORS AND TRIAXIALITY IN FISSION FRAGMENTS*

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Among the odd-A fission fragments studied in GAMMASPHERE, EUROGAM, and other large γ-detector arrays there are definite indications of softness toward triaxiality in many cases.[1]

Also it has been suggested that tilted-rotor bands may also show up in fission-fragment gamma spectra.[2] The best hunting grounds and criteria for tilted rotors [3] will be discussed. Our preferred single-particle level diagrams in a spheroidal potential are those in Fig. 1 of ref. [4].

I am much indebted to my colleagues in the GANDS2000 collaboration, listed in ref. [2], for acquisition and analysis of the ^{252}Cf spontaneous fission data on which this talk is mainly based.

*This work supported by U.S. Department of Energy under Contract DE-AC03-76SF00098 with Lawrence Berkeley National Laboratory.

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LIFETIMES IN THE YRAST AND AN OCTUPOLE–VIBRATIONAL SUPERDEFORMED BAND IN ^{196}Pb[a]

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Lifetimes have been measured for states in the yrast (band 1) and an excited octupole-vibrational superdeformed band (band 2) in ^{196}Pb using Doppler–shift methods. High–spin states in ^{196}Pb have been populated in the ^{170}Er(^{30}Si,4n) reaction at the VIVITRON accelerator at IReS. Centroid shifts and line shapes of transitions in γ–ray coincidence spectra measured with the EUROBALL spectrometer have been analyzed. The transition quadrupole moments deduced from these data for the yrast and the excited superdeformed band agree within the experimental uncertainties. This result shows that the excited band is not built on different deformation–driving orbitals compared to band 1. It is compatible with previous evidence for an octupole–vibrational excitation of band 2 and its signature partner, band 3.

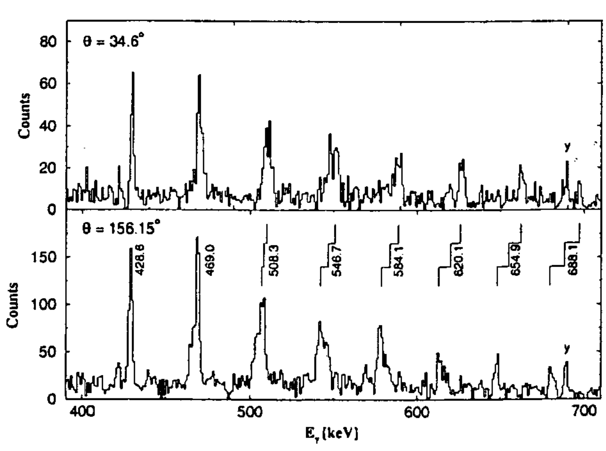

Figure 1: Triple–gated background–subtracted spectra of the yrast SD band 1 from the ring of forward detectors (upper panel) and the ring of backward detectors (lower panel).

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STARS – a new auxiliary detector for Gammasphere

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STARS (Silicon Telescope Array for Reaction Studies) is a highly segmented particle detector using the ΔE-E technique for identifying reaction products. The detector is mainly geared toward transfer reactions. Two different geometries have been realized:

- a lamp-shade geometry, where eight telescopes form a ring covering forward angles between 30 and 60 degrees. Each telescope is divided into eight radial strips giving an angular resolution of some 3.75 degrees. Two and two telescopes are bussed together strip-wise. The energy resolution of the detectors are in the order of 250 keV; p, d, t, τ and α particles can be discriminated. The front detectors are 150 μm thick and the end detectors 2 mm, giving a useful range for protons between 4 and 20 MeV and for α particles between 16 and 75 MeV. The distance from the target is approximately 4–5 cm.
- a planar geometry using large annular detectors. These detectors are divided into 48 rings on one side (1.1 cm innermost radius and 3.5 cm outermost radius, thus having 0.5 mm wide segmentations), and 16 segments on the other side. Two and two rings and segments are bussed together, giving 1 mm wide rings and eight segments. The front detector is again 150 μm thick and the end detector 1 mm, giving a useful range for protons between 4 and 13 MeV and for α particles between 16 and 53 MeV. The distance from the target can be varied up to some 20 cm. The distance between front and end detectors can be made large in order to allow for track reconstruction. The detectors can be mounted at forward or backward angles.

While the lamp-shade geometry allows for detection of several particles simultaneously, this can lead to ambiguous results in the planar geometry. Results of the first test experiment of the lamp-shade geometry will be discussed. Further development of the planar geometry will involve the replacement of the Si end detector by an array of CsI crystals to increase the stopping power and the useful energy range for light particles, especially hydrogen isotopes. It is also planned to develop a target gas-cell in order to be able to study reactions in inverse kinematics with heavy stable or radioactive beams.

COMPARITIVE QUADRUPOLE MOMENTS OF TRIAXIAL SUPERDEFORMED STATES IN ^{163,164,165}Lu*

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In the mass region around A=165 a large number of rotational bands have been discovered over the past few years which are associated with the calculated potential energy minima with large deformation and large triaxiality. Experimental proof of the triaxiality is the occurrence of the wobbling mode which was found for the first time in ^{163}Lu [1]. In this contribution we report on lifetimes of states in the yrast triaxial superdeformed bands of ^{163}Lu, ^{164}Lu and ^{165}Lu, determined in a Doppler-shift attenuation-method experiment.

High-spin states in ^{163,164,165}Lu were populated in the ^{124}Sn(^{45}Sc,xn) reaction, the ^{45}Sc beam of 217 MeV being provided by the 88-Inch cyclotron at LBNL. The target consisted of a 1 mg/cm^2 ^{124}Sn foil and a 13 mg/cm^2 thick Au backing. The Sn and Au foils were separated by a 240 μg/cm^2 thick Ta layer. Gamma-ray coincidences were measured with the Gammasphere spectrometer array. For ^{163}Lu and ^{165}Lu fractional Doppler shifts F(τ) were analysed. For the weaker TSD band in ^{164}Lu the spectra measured with the Ge detectors at different angles to the beam direction were shifted using calculated F(τ) values for a range of quadrupole moments. The F(τ) values which resulted in the summed spectrum with the best peak to background ratio were adopted.

The transition quadrupole moments derived from the fractional Doppler shifts are $Q_t=7.4^{+0.7}_{-0.4}$ and $6.0^{+1.2}_{-0.2}$ b for TSD bands 1 in ^{163}Lu and ^{165}Lu, respectively. The quadrupole moment for TSD band 1 in ^{164}Lu lies between these two values. These values are somewhat smaller than the calculated quadrupole moment [2] of 9.5 b for the minimum with $\epsilon = 0.38$ and $\gamma = 20^0$. For the minimum with negative γ, a quadrupole moment of 11.5 b is calculated. Thus, our experimental results show that the yrast TSD bands are associated with the minima with positive γ deformation.

Since all three quadrupole moments were derived from the same experiment, the relative values are very reliable, even if the absolute values might be subject to larger uncertainties. It is therefore interesting to observe that the quadrupole moments decrease with increasing neutron number. This trend is not reproduced in the calculations, which may be due to an insufficient knowledge of the positions of the deformation-driving orbitals in this mass region.

* Supported by BMBF, Germany and the Danish Science Foundation

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DOES THE PHENOMENON OF ANTIMAGNETIC ROTATION EXIST IN NUCLEI?*

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The phenomenon of magnetic rotation is now well established in near-spherical nuclei in the light lead and cadmium/tin regions (see refs [1,2]). In these so called shear structures the angular momentum is generated by the gradual alignment of long neutron and proton spin vectors with the total angular momentum vector, I, which lies at some angle to the principle axis. A particularly distinguishing feature of such structures is the large B(M1) values for the M1 transitions, which decrease rapidly as the spin increases.

It has been suggested [1] that a different type of shears band could exist in weakly deformed nuclei, where both of the blades of the shears are formed from the spin vectors from the same type of particle, ie two proton (or neutron) blades. Here, the angular momentum is expected to be generated by the simultaneous closing of the two shears blades with one of the principle axes, along which lies a fixed vector contribution from aligned neutrons (or protons) A regular sequence of energy levels should still result from the closing blades, but the decay will now occur via electric quadrupole transitions rather than by strong M1 transitions, since the mean-field will once again have both rotational and reflection asymmetry and the cranking axis coincides with the principal axis. Such structures, if they exist, have been termed "antimagnetic" in analogy with the concept of antiferromagnetism.

One of the best regions to look for this effect is predicted to be in the light Cd isotopes. Recent work in ^{100}Pd [3] has provided the first tentative evidence for the presence of this new mode of excitation in nuclei, however, no lifetime measurements were made, hence, the existence of the phenomenon could not be firmly established. In the present work we will report the latest results of lifetime measurements in the yrast positive parity bands in ^{106,108}Cd and compare the deduced B(E2) and quadrupole moment values with the predictions of principal axis TAC calculations and with the results of cranked Nilsson-Strutinsky model calculations, the latter of which have been used very successfully to interpret the configurations of smoothly terminating bands in this mass region. The evidence for the existence of antimagnetic rotation in these nuclei will be explored.

*This work supported by the UK EPSRC and the US DoE.

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3 S. Zhu *et al.*, Phys Rev. C 64 (2001) 041302(R)

TRIAXIALITY VERSUS AXIAL SYMMETRY IN ODD-ODD NUCLEI

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An important similarity between an axially symmetric ($\gamma = 0°/\ 60°$) rotor and a triaxial ($\gamma = 30°$) rotor with irrotational flow moment of inertia relies on the fact that, only for these values of γ, two out of the three principal-axis moments of inertia are equal. These are the moments of inertia for the axes perpendicular to the symmetry axis in the axial case, or those for the short and the long axes in the triaxial case. As a consequence, the Hamiltonian for a $\gamma = 30°$ triaxial rotor with the intermediate axis being the effective symmetry (quantization) axis has the same structure as that for an axially symmetric rotor, despite geometrical differences in shape. The difference between these rotors is in the value of the third moment of inertia. For the axial case, the moment of inertia for the symmetry axis is zero; as a consequence, collective rotation is not allowed about this axis. For the triaxial ($\gamma = 30°$) case, however, the moment of inertia for the intermediate axis is the largest and rotation about this effective symmetry axis is thus favored. This observation has important consequences for nucleon-rotor coupling. The general Hamiltonian for odd-odd nuclei can be separated into the rigid-rotor part which follows an $I(I+1)$ dependence, the $\vec{R} \cdot \vec{j_\pi}$, $\vec{R} \cdot \vec{j_\nu}$, $\vec{j_\pi} \cdot \vec{j_\pi}$ Coriolis terms, and the interaction part, which describes nucleon-rotor and nucleon-nucleon coupling. This interaction part is often approximated by a quadrupole deformed potential well. The potential well is invariant under rotation by 180° with respect to the principal axes ($R_i(\pi)$ signature symmetry, $i = x, y, z$); eigenstates of one of these signature operators can then be chosen to diagonalize the interaction Hamiltonian. The most familiar example comes from the coupling of a single nucleon to an axially symmetric rotor with the eigenstates of $R_x(\pi)$ selected and with the x-axis coinciding with the rotor angular momentum. Because of this fact, a direct correspondence exists between the intrinsic eigenstates of signature and the eigenstates of total angular momentum in the laboratory reference frame; the Coriolis terms do not mix signature eigenstates. This leads to the well known signature classification scheme and selection rules for $M1$ transition rates, which are enhanced and hindered between the states of the opposite and the same signature, respectively. This signature classification and the above correspondence breaks down as the shape of the rotor deviates from axial symmetry. An extremely simple situation arises, however, for particle-hole coupling with a $\gamma = 30°$ triaxial rotor. It can be shown that a correspondence between the intrinsic $R_x(\pi)$ signature eigenstates and the laboratory eigenstates of the total angular momentum is retained (signature mixing occurs between $\gamma = 0°/60°$ and 30°). This results from the fact that the $R_x(\pi)$ eigenstates have the angular momenta oriented perpendicular to the rotation (intermediate) axis. Moreover for particle-hole coupling, the single particle angular momenta are nearly perpendicular, which characterizes the chiral geometry. The Coriolis terms for these nearly orthogonal angular momenta vectors are necessarily small resulting in only minor perturbations of the intrinsic eigenstates when transformed to the laboratory reference frame, which is manifest in the energy spectra. Odd-even spin staggering of the $B(M1)$ strength is another result. The experimental data for the chiral doublet bands in the mass $A \sim 130$ region will be addressed following these concepts.

QUASICONTINUUM *g* FACTORS AND THE COMPLETE DISCRETE SPECTROSCOPY

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The *g* factors of high-spin states depend mainly on the relative contributions of aligned protons and/or neutrons. An average high-spin *g* factor in the discrete bands and the damping region of the continuum can be measured by the transient-field technique. Such measurements, mainly in the rare-earth region, indicate a dominant role for neutron configurations at spins between about 20ħ and 40ħ. In contrast, recent measurements on the Pt isotopes near mid-shell have demonstrated the importance of both aligned protons and neutrons at spins near 20ħ [1].

In this presentation, the experimental data will be reviewed and connections between the observed quasicontinuum *g* factors and features of the discrete spectroscopy will be explored. It will be shown that there are strong correlations between the observed quasicontinuum *g* factors and features in the discrete spectroscopy. The reasons for these correlations will be discussed. Two examples are presented in the figure. The g factors for the discrete bands, calculated using a generalization of the Dönnau-Frauendorf formalism, are shown as dotted lines. A smoothed average of these values (thick lines) is in agreement with the experimental [1,2] quasicontinuum *g* factors. The arrows indicate the approximate spins at which pairs of neutrons and protons align.

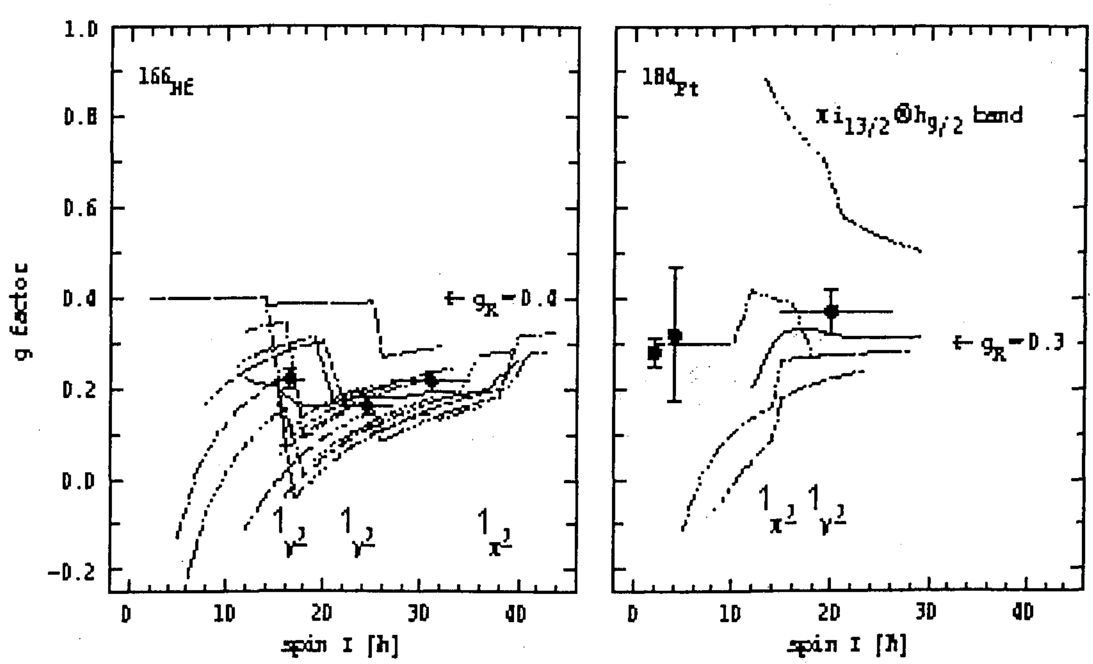

Figure 1. Experimental and calculated *g* factors in ^{166}Hf and ^{184}Pt.

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THE TRIPLE DEGENERACY IN THE PSEUDOSPIN PAIR AND THE SPIN PAIR LEVELS IN THE RELATIVISTIC MEAN FIELD

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The pseudospin pair-levels in the axially symmetrically deformed nuclei are for the levels with $[N, n_z, \ell_z]\Omega$ and $[N, n_z, \ell_z{+}2](\Omega{+}1)$, if we use the asymptotic quantum number $[N, n_z, \ell_z]\Omega$ to identify the deformed single-particle state. These two levels are also labelled by $[N, n_z, \tilde{\ell}_z]\Omega$ and $[N, n_z, \tilde{\ell}_z](\Omega + 1)$ with the use of $\tilde{\ell}_z = \ell_z + 1$. On the other hand, the spin pair-levels are for $[N, n_z, \ell_z]\Omega$ and $[N, n_z, \ell_z](\Omega + 1)$. If we use the cylindrical coordinates (ρ, φ, z) in the Dirac equation with the axially symmetrically deformed potential, the eigenfunction has two amplitudes for each of the upper and lower components, i.e. totally four amplitudes. Thus, we compare eight amplitudes for the pair-levels. The equations for the pseudospin pair-levels become the same form as those of the spin pair-levels at the limit where the potential derivatives are zero. However, the centrifugal terms of four amplitudes among eight components in the pseudospin pair-levels have pseudo $\tilde{\ell}_z$, while those in the spin pair-levels have natural ℓ_z. When both of the pseudospin and the spin symmetries are well satisfied, there appears triple degeneracy. The relativistic mean-field calculation over ^{154}Sm gives [400]1/2, [402]3/2 and [402]5/2 levels as such a candidate, although the pseudospin pair-levels has 0.18 MeV energy splitting and the spin pair-levels 1.397 MeV. We adopt the same parameter set as in our previous work [1] where good agreement in the absolute values of four amplitudes with $\tilde{\ell}_z$ is found for the pseudospin pair-levels of [400]1/2 and [402]3/2. The numerical results shown in Fig. 1 are for the eight amplitudes in the spin pair-levels of [402]3/2 and [402]5/2. We find a very good agreement in the absolute values of solid and dotted lines both for the upper and lower components.

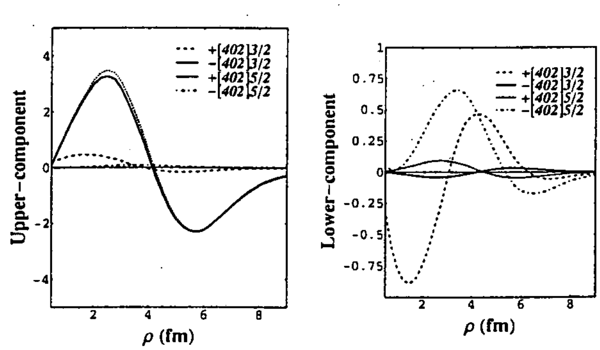

Figure 1: The upper components (left panel) and lower components (right panel) for spin doublet as a function of ρ at $z = 1$ fm. The dashed and the solid lines are for [402]3/2, and the dot-dashed and the dotted lines are for [402]5/2. The solid and dotted lines are for the amplitudes with ℓ_z in the centrifugal term.

1. K. Sugawara-Tanabe, S. Yamaji and A. Arima, Phys. Rev. **C62** (2000) 054307.

TRIAXIAL SUPERDEFORMED BANDS IN ^{163}Lu

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A theoretical attempt is made to describe the triaxial superdeformed bands observed in ^{163}Lu [1]. We employ the model of a single-j nucleon coupled to an asymmetric rotor described by $H_{\rm rot}$, whose triaxial deformation parameter γ is in common with the single-particle potential $H_{\rm sp}$. Similar scheme has been applied to the normal deformed states of odd-A nuclei [2]. We pay attention to the invariance of the physical state under D_2 symmetry and Bohr's symmetry, and diagonalize the total Hamiltonian $H = H_{\rm rot} + H_{\rm sp}$. The numerical results show that the energy difference between the yrast triaxial superdeformed band (TSD1) and the yrare one (TSD2) is almost constant independent of spin value I as indicated by the experimental data. This fact stands in sharp contrast to the wobbling scheme, where the coefficient of the wobbling Boson number gives a strong spin-dependence in the energy difference. We compare the numerical results of $E^* - AI(I+1)$ as a function of I at $\gamma = 12°$ with the experimental data in Fig. 1. The experimetal branching ratios of $B(E2)^{\rm TSD2\to TSD1}_{\rm out}/B(E2)^{\rm TSD2\to TSD2}_{\rm in}$ are also well reproduced by this solution. We extend our algebraic method taking account of the second order in Boson number [3] to odd-A nuclei by introducing two kinds of Bosons corresponding to $\vec{I}$ and $\vec{j}$. We confirm that the quantum numbers I_z and j_z assigned to the main component in the exact solution agree with the predicted ones from the algebraic method.

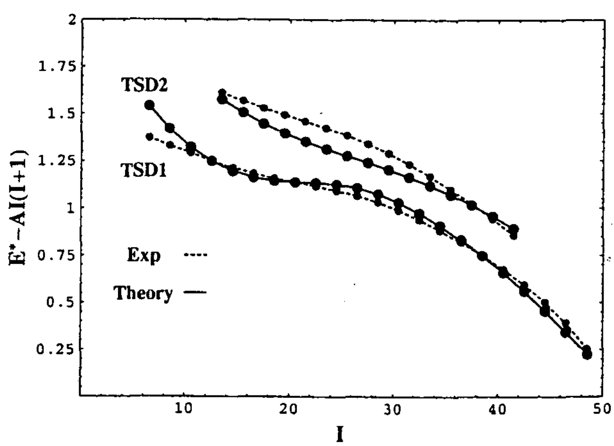

Figure 1: Comparison between the theoretical energies and the experimental data. The larger circles connected by the solid lines correspond to theoretical values, and the smaller circles connected by the dotted lines correspond to experimetal data.

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2. J. Meyer-ter-Vehn, F. S. Stephens and R. M. Diamond, Phys. Rev. Lett. **32** (1974) 1383.
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MASS OF ^{15}F: WEAKENING OF THE Z=8 SHELL?*

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The disappearance of magic numbers for some very neutron-rich nuclei is one of the most important results of the exploration of exotic nuclei. Similarly, these effects should also be present for very proton-rich nuclei. We investigated the proton separation energy as a function of proton number with isospin $T_z = -3/2$ across the Z = 8 shell. A similar study across the N = 8 shell confirmed the vanishing of this shell [1]. The important quantity for evidence for the weakening of the shell effects is the mass of ^{15}F.

At GANIL we measured the mass of the unbound nucleus ^{15}F has been by detecting its decay products ^{14}O and proton and performing a missing mass reconstruction. The value obtained, $\Delta(^{15}\mathrm{F}) = 16.28 \pm 0.18$ MeV is approximately 0.5 MeV lower than the previously adopted value obtained from a multinucleon multitransfer reaction. Proton separation energy systematics taking into account this new value indicate a weakening of the Z = 8 shell closure for $T_z = -3/2$ nuclei. In addition to the ground state three excited states of ^{15}F were observed.

*This work supported in part by the Région Aquitaine and the U.S. National Science Foundation under grant PHY 95-28844.

1. A. Ozawa *et al.*, Phys. Rev. Lett. **84** (2000) 5493.

STUDIES OF ^{235}U BY COULOMB EXCITATION.

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The stucture of the nucleus ^{235}U is of interest from several viewpoints. An early spectroscopic study [1] was motivated to examine Coriolis interactions of bands built on the Nilsson j15/2 multiplet. Bands built on the 3/2, 5/2, 7/2 (the ground state band), 9/2 and 11/2 members were identified. The 3/2 and 11/2 bands probably have a mixed gamma-vibrational character. The 1/2, 13/2 and 15/2 members have never been identified. A motivation for the present work was to extend the earlier study with modern techniques.

γ-γ coincidence techniques work poorly at low spins in ^{235}U; states of interest decay by one-step transitions to low-lying states of the ground band whose subsequent decays are largely converted. Fusion reactions with light contaminants in the target produce floods of high γ-ray-multiplicity cascades. Therefore, γ-γ coincidences make invisible the interesting transitions, whilst enhancing the background.

Experiments with the 8PI Spectrometer proved more successful, because with gating on low total energy, and gamma-ray multiplicity the fusion background was greatly suppressed. A remarkable feature of the data was the strong Coulomb excitation of positive-parity levels. Comparison with a standard Winther-DeBoer code indicated B(E3)-values of approximately 10-15 spu., which is surprisingly high for simple Nilsson states.

We have continued this aspect of the experiment in γ-ray singles with Gammasphere and the University of Rochester CHICO detector system. The ^{235}U target was thick enough to stop the 180 MeV incident ^{40}Ar beam, and CHICO detectors backward of 90 degrees registered scattered ions in coincidence. The spectrum contains approximately 300 resolvable lines in the energy range 150-1700 keV, most of which are assigned to ^{235}U.

This work confirms the earlier observation of strong E3 excitation to the positive parity bands, particularly [624]7/2, [631]1/2, and [622]5/2. The bandhead assignments of ref 1 were also confirmed, and the known bands were excited to higher spin. However, todate we have not assigned the 1/2, 13/2 or 15/2 members of the 15/2 multiplet.

1. F.S.Stephens, M.D.Holtz, R.M.Diamond, and J.O.Newton. Nucl Phys. A115 (1968) 129.

LIFETIMES AND BAND TERMINATIONS IN ^{86}Zr *

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The transitional nucleus ^{86}Zr lies between highly deformed ^{80}Zr and nearly spherical ^{90}Zr. An earlier investigation of its high–spin structure in conjunction with calculations performed within the configuration–dependent shell–correction approach using a cranked Nilsson potential (CNSM) showed evidence of band terminations at the 24^+, 27^-, and 30^+ states [1]. A characteristic feature of band terminations is a rapid drop in collectivity approaching termination. The present work was undertaken to measure transition strengths in ^{86}Zr to examine the evolution of collectivity.

^{86}Zr was populated in the ^{58}Ni(^{32}S,3pn) reaction at 135 MeV using the 88–Inch Cyclotron at LBNL. Recoiling ^{86}Zr nuclei were stopped in a thick Ta backing. Prompt multi–γ coincidences with evaporated charged particles were detected using GAMMASPHERE and the MICROBALL. To improve statistics data from pairs of nearby detector rings were combined and whenever possible lifetimes were measured at each of the four angles 34.95°, 52.81°, 127.19°, and 145.45°. Mean lifetimes of 36 levels in ^{86}Zr were measured using the Doppler–shift attenuation method. In many cases the lineshapes were gated by transitions above the one of interest to eliminate the uncertainties of side feeding.

The transition quadrupole moments Q_t inferred from the measured lifetimes in the yrast positive–parity band are graphed as a function of the spin of the initial state in Fig. 1. The sharp drops in collectivity approaching the 24^+ and 30^+ states support the interpretation [1] of band termination in these configurations.

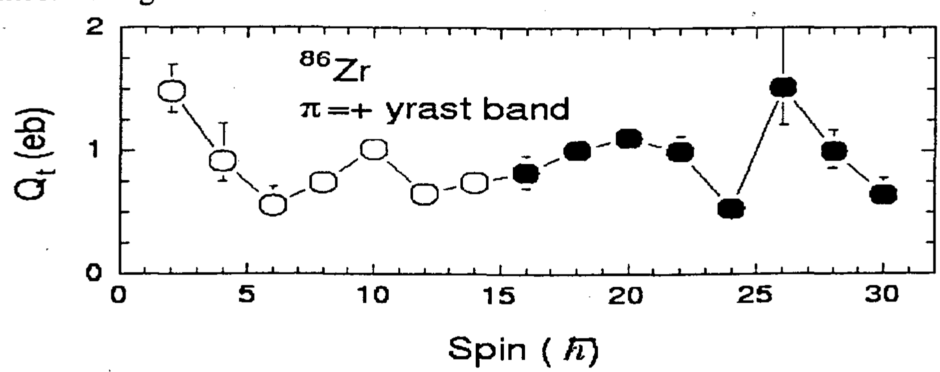

Figure1: The transition quadrupole moment Q_t versus spin in the yrast band. Open circles indicate Q_t values calculated using lifetimes from previous work [2,3].

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MIRROR SYMMETRY IN $^{53}_{27}Co_{26}$ AND $^{53}_{26}Fe_{27}$

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In two recent experiments the large gamma-ray spectrometer array, GAMMASPHERE, was used to identify gamma decays from high-spin states in the mirror-pair nuclei $^{53}_{27}Co_{26}$ and $^{53}_{26}Fe_{27}$. The reaction $^{32}S + ^{24}Mg \longrightarrow ^{56}Ni^*$ at a beam energy of 95MeV was used in the first instance, with reaction channel selection afforded by the FRAGMENT MASS ANALYSER recoil separator and an ion-chamber. In the second instance the reaction $^{32}S + ^{28}Si \longrightarrow ^{60}Zn^*$ at a beam energy of 125MeV was used, with channel selection provided by the MICROBALL light charged particle detector and NEUTRON SHELL neutron detector.

States up to the $f_{\frac{7}{2}}$-shell band termination of $J^\pi = \frac{19}{2}^-$ were identified in both A=53 mirror-pair nuclei, and the Coulomb Energy Difference (CED) was calculated as $Ex(^{53}\mathrm{Co})$-$Ex(^{53}\mathrm{Fe})$ for each level throughout the entire spin range. Changes in the CED will be interpreted in terms of non-collective particle alignment effects. The CED will also be compared to the results of large-scale shell-model calculations in the full-fp valence space. A discussion of the physical significance of the Coulomb Matrix Elements used in the calculations will be presented, and the results of a fit of the measured CED to these Matrix elements will be shown.

SHAPE COEXISTENCE AND CONFIGURATION MIXING IN ^{100}ZR*

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Shape coexistence in ^{100}Zr is a well-known phenomenon. However, a consistent description of the configuration mixing between two shapes with very different deformation has not been made. In this work, the B(E2,$2_2^+ \rightarrow 0_2^+$) value in ^{100}Zr has been inferred from the known γ-ray branching ratios between the intraband transition and the interband transitions to members of the ground-state band. The absolute scale of the latter was established under the assumption that adjustments to the interband transitions due to the coupling between the rotation and intrinsic motions can be approximated by a perturbation expansion of angular-momentum dependence. Correction terms up to the second order, which account for the deformation difference between two 0^+ bands, were considered in the description. The intrinsic quadrupole moment for the second 0^+ state at 331 keV is derived to be $Q \approx 1.69$ b from the B(E2,$2_2^+ \rightarrow 0_2^+$) value assuming a rotational relationship. It suggests that the weakly deformed 0_2^+ state coexists with the strongly deformed ground state of $Q \approx 3.37$ b. Configuration mixing between the two 0^+ states has been studied using both the known $E0$ and the intrinsic $E2$ matrix elements derived from this work. A weak mixing of ≈ 7.7 % was found, which is nearly a factor of two lower than suggested by a previous analysis [1]. Quantitative evidence of the energy shift for the ground state, deduced from the systematics of transition energies for the yrast states [2], is consistent with this weak mixing scenario. Near-spherical and well-deformed shapes with the deformation parameter β of ≈ 0.12 and ≈ 0.37, respectively, are identified as the basis states before the mixing takes place.

The main difference between the previous [1] and the current analyses is the inclusion of the intrinsic $E2$ matrix element between the two unperturbed 0^+ states for this work. The current analysis is possible because of the knowledge of the absolute $E2$ strength of the second 2^+ state, which was inferred from the systematics of the interband transitions to members of the ground-state band. The shortcoming of the early analysis is reflected by the discrepancy between the derived energy shift ≈ 47 keV [1] for the ground state and the observed one ≈ 21 keV [2] from the systematics of transition energies for the yrast states. The latter is in good agreement with ≈ 26 keV derived from the current analysis. The introduction of the intrinsic $E2$ matrix element between the two unperturbed 0^+ states is shown to be important for an understanding of the configuration mixing in ^{100}Zr.

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SURROGATE REACTIONS FOR CROSS-SECTION MEASUREMENTS*

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Many nuclear reactions cannot be presently studied because they require very short-lived beams or targets. Even with the eventual advent of a Rare Isotope Accelerator (RIA) facility, reactions on the shorter-lived targets will remain inaccessible. For such measurements, and in the foreseeable future, the only feasible approach may be surrogate reactions that use a stable beam/target combination to form the same compound nucleus and separate the problem into a formation reaction and a decay probability. The challenge in surrogate-reaction measurements is to properly account for differences in initial spin and parity distribution in the compound system between the reaction of interest and its surrogate.

Extending a formalism originally developed to estimate (n,f) cross sections from fission-barrier properties[1,2] by incorporating a detailed treatment of spin distributions, the (n,f) cross section has been deduced for the target nuclei ^{231,233}Th, ^{235,235m,237,239}U, and ^{239,241,243}Pu as a function of neutron energy, using surrogate (t,p) fission-probability data. The present results will be compared to existing measurements of the ^{235,237}U(n,f) and ^{239}Pu(n,f) cross sections. For the remaining nuclei, the target lifetime is too short, and no direct measurements have been performed. For example, the neutron-induced fission cross section on the $T_{1/2} \approx 26$-minute isomer in ^{235}U is interesting because it provides a rare opportunity to study the fission process as it proceeds from states with nearly identical excitation energies ($\Delta E_x = 76.8$ eV) but very different nuclear structure (with Nilsson quantum numbers $7/2^-[743]$ for the ground state, and $1/2^+[631]$ for the isomer). The only direct measurements of the ^{235m}U(n,f) cross section have been performed with thermal and cold neutrons,[3,4] and the values reported in the literature differ significantly. There are no measurements of this cross section at higher neutron energies. The ^{235m}U(n,f) cross section is extracted in the present work for $E_n \leq 3$ MeV.

The surrogate (n,f) cross-section measurements will be presented. The formalism used to relate the (n,f) and (t,p) reactions will be discussed, along with a sensitivity analysis of the technique and extensions to reactions other than neutron-induced fission.

* This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

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LOW-SPIN SIGNATURE INVERSION IN THE $\pi i_{13/2} \otimes \nu i_{13/2}$ BANDS IN ODD-ODD ^{176,178}Ir AND ^{182,184}Au NUCLEI*

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Low-spin signature inversion is a very interesting phenomenon observed in a number of deformed odd-odd nuclei and it has been attracting large experimental and theoretical interests. Up to date, the signature inversion has been systematically observed throughout the chart of nuclides in the $\pi g_{9/2} \otimes \nu g_{9/2}$, $\pi h_{11/2} \otimes \nu h_{11/2}$, $\pi h_{11/2} \otimes \nu i_{13/2}$, and $\pi h_{9/2} \otimes \nu i_{13/2}$ configurations. These bands correspond to the high-j spherical parentage, it is thus a natural assumption that the $\pi i_{13/2} \otimes \nu i_{13/2}$ bands of high-j parentage may present a similar inversion phenomenon. In the past few years, great efforts have been devoted to search for the $\pi i_{13/2} \otimes \nu i_{13/2}$ semi-decoupled bands in odd-odd ^{176,178}Ir and ^{182}Au. As the $\pi i_{13/2} \otimes \nu i_{13/2}$ bands in these three nuclei may locate at higher excitations, we have paid much attention to establish the inter-band transitions from the expected $\pi i_{13/2} \otimes \nu i_{13/2}$ bands to a low-lying 2-quasiparticle band. Several rotational bands with different characteristics have been newly found in each of the nuclei among which the $\pi i_{13/2} \otimes \nu i_{13/2}$ bands in ^{176,178}Ir and ^{182}Au have been identified. The inter-band linking transitions have been established which fix unambiguously the spin and parity of $\pi i_{13/2} \otimes \nu i_{13/2}$ band relative to the other. In this presentation, the experimental details and results of theoretical calculations in the framework of configuration-constrained total Routhian surface and cranked shell model will be given. The low-spin signature inversion in the $\pi i_{13/2} \otimes \nu i_{13/2}$ bands in ^{176,178}Ir and ^{182,184}Au will be discussed.

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SHAPE CO-EXISTENCE AND STRUCTURAL EVOLUTION OF THE YRAST BAND IN ^{157}Yb*

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The high-spin states of ^{157}Yb have been studied via the ^{144}Sm(^{16}O, 3n) reaction at ^{16}O energy of 90 MeV using techniques of in-beam γ-ray spectroscopy. Measurement of γ-γ-t coincidences was performed with 11 BGO (AC)HPGe detectors. Based on the measured results of γ-γ coincidences, γ-ray anisotropies and DCO ratios, the level scheme for ^{157}Yb was established. The low-lying part in the level scheme show a coexistence of slightly oblate and weak prolate deformations. With increasing angular momentum, the $i_{13/2}$ band in ^{157}Yb loses gradually its collectivity with its structure evolving into vibration-like excitations, and finally this band gives way to single particle excitations. The N=87 nucleus ^{157}Yb has been shown to be transitional in two aspects. Not only does ^{157}Yb connect the isotopes (N<87) with spherical or oblate shapes to those (N>87) with pronounced prolate shapes; also exhibit structure features of both groups. The shape co-existence and structural evolution of the $\nu i_{13/2}$ band with increasing angular momentum in ^{157}Yb have been discussed, and the systematic of the $\nu i_{13/2}$ bands in the N=87 odd-A isotones have been compared. The shape evolution of the $\nu i_{13/2}$ bands in the N=87 isotones has been interpreted quite well by the total energy surface calculation. For these isotones, the Fermi level is positioned near the bottom of the $i_{13/2}$ sub-shell. Therefore, the $i_{13/2}$ quasiparticles exert a strong polarizing force that drives the nucleus toward increasing positive γ deformation with increasing angular momentum, and finally reaches the γ=60° noncollective oblate shape. It should be pointed out that the shape evolution of the $\nu i_{13/2}$ band in ^{157}Yb follows generally the systematic of the lighter isotones, but the detailed structure of these $\nu i_{13/2}$ bands is different; the $\nu i_{13/2}$ bands in ^{153}Dy and ^{155}Er display collective rotational behavior up to the terminating states, while the high-lying part of the $\nu i_{13/2}$ band in ^{157}Yb shows a vibration-like structure.

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CANDIDATE CHIRAL BANDS IN THE ODD-A NUCLEUS ^{135}Nd *

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Very interesting and intriguing nuclear structure effects associated with chiral symmetry breaking were predicted by Frauendorf and Meng some time ago for the odd-odd nuclei having triaxial shapes.[1] The resulting "chiral twin" bands have since been reported in several odd-odd nuclei.[2]

This effect has so far been studied, both theoretically and experimentally, only for the odd-odd systems which provide the simplest and most straightforward examples of this symmetry. However, there is no *a priori* reason to believe that this effect does not occur in nuclei in which either the protons or the neutrons (or both) are even-numbered. Indeed, the occurrence of chiral effects in odd-A and even-even triaxial nuclei is an essential feature of the theory proposed by Frauendorf and coauthors; the experimental verification of this prediction has been elusive, however.

We have observed candidate chiral twin bands in the odd-A nucleus ^{135}Nd. Two bands with close excitation energies, as well as direct ΔI=1 and ΔI = 2 links between them have been observed in this nucleus, making them excellent candidates for chiral partners. Detailed results on the ^{135}Nd level scheme will be presented. The corresponding chiral configurations will be discussed on the basis of tilted axis cranking calculations.

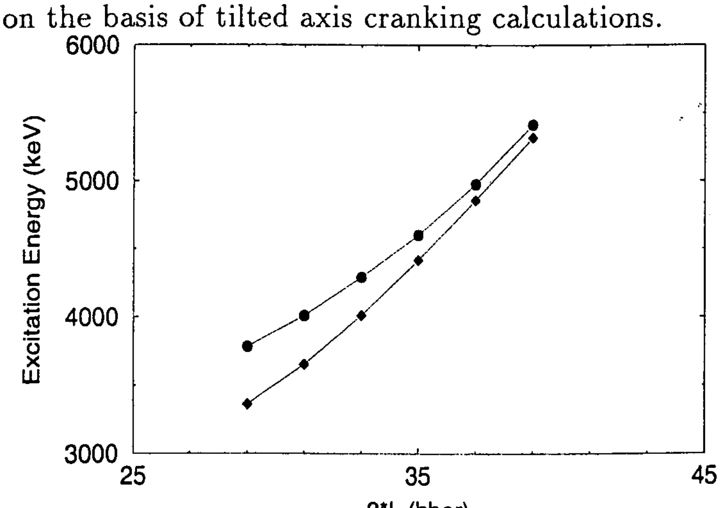

Figure 1: Experimental excitation energies vs. spin for the candidate chiral bands in ^{135}Nd.

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