ENAM'04

The Exotic Nuclei and Nuclear Masses conference can trace its origins to the 1950s and 1960s with the Atomic Mass and Fundamental Constants (AMCO) and the Nuclei Far From Stability (NFFS) series of conferences. Held jointly in 1992, the conferences officially merged in 1995 in Arles, France where the First International Conference on Exotic Nuclei and Atomic Masses was held. Since this beginning, subsequent conferences have been held at Bellaire, Michigan (1998) and Hämeenlinna, Finland (2001). The Fourth Conference will be at Callaway Gardens in Pine Mountain, Georgia USA and is organized by the Physics Division at Oak Ridge National Laboratory.

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Sunday Morning
Session 1
Masses

Sunday Morning 1 - Masses

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Conference organization enam04@phy.ornl.gov	ORNL	Welcome
Wapstra, Aaldert wapstra@nikhef.nl	NIKHEF	Mass spectrometry and reaction- and decay-energies
Lunney, David lunney@csnsm.in2p3.fr	CSNSM-IN2P3/CNRS	The latest trends in the ever-surprising field of mass measurements
Jokinen, Ari ari.s.jokinen@phys.jyu.fi	University of Jyvaskyla	Ion manipulation and precision measurements at JYFLTRAP
Goriely, Stephane sgoriely@astro.ulb.ac.be	Universite Libre de Bruxelles	Recent progress in mass predictions
Bachelet, Cyril bachelet@csnsm.in2p3.fr	CSNSM	A new high precision binding energy for the halo nuclide ^{11}Li
Hausladen, Paul hausladenpa@ornl.gov	ORNL	Mass measurements using "household appliances"
Stoitsov, Mario stoitsovmv@ornl.gov	ORNL	Large-Scale HFB Calculations for Deformed Nuclei with the Exact Particle--Number Projection
Delahaye, Pierre pierre.delahaye@cern.ch	CERN/ISOLDE	Recent developments of the radioactive beam preparation with the Penning trap REXTRAP
Name/email	**Institution**	**Title**

Mass spectrometry and reaction- and decay-energies

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In December 2003, a full collection of atomic masses, AME2003, was published, based on an evaluation of experimental masses. This evaluation compared to the preceding one of 1995 (AME95) contains data obtained in several new ways.

Along the line of stability, use of Penning traps resulted in new data of unprecedented precision. Especially welcome were the data obtained with this method, but also new ones with a classical mass spectrometer, that allowed to get rid of a difficulty with earlier measurements of the masses of the stable mercury isotopes.

Penning trap methods and also the Schottky mass spectrometry method yielded data for very proton-rich nuclides, less precise but very welcome. Investigations of nuclear reaction energies in the same region, up to proton-unstable nuclides, yielded data for α-decay series. In several cases, data were then obtained on chains of isomers in such series. In some cases it became clear that earlier measurements thought to apply to ground-states in reality belong to upper isomers.

Recently, the relevant authorities accepted the evidence for the discovery of element 110 so that a name could be proposed. Similar evidence for elements 111 and 112, already discussed in our 1995 evaluation, may soon be recognized too. This may be more difficult for the evidence on elements 114 and 116 discussed in the 2003 evaluation; and more so for that on elements 113 and 115 that could not yet be included there.

The latest trends in the ever-surprising field of mass measurements

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The binding energy of the nucleus, from its mass, continues to be of capital importance - not only for various aspects of nuclear physics itself, but for other branches of physics as well. For example, extremely accurate masses are required in weak-interaction studies that test the Standard Model and in astrophysics, masses play an crucial role in the orientation of the models required to understand explosive stellar nucleosynthesis.

The number of dedicated, mass-measurement programs is increasing worldwide with recent results reflecting experimental achievements worthy of admiration. This review will describe the modern experimental techniques dedicated to the particularly challenging task of measuring the mass of exotic nuclides and make detailed comparisons in order to present future projects in a critical perspective.

Though tremendous improvements in experimental sensitivity and production techniques have been made, the masses of many exotic nuclei of interest will certainly remain unmeasured for many years to come, leaving no choice but to resort to theory. Thus, the interplay between theory and experiment is crucial and new measurements far from stability are now used as diagnostics in the development of new microscopic mass models (see the presentation by S. Goriely). If extrapolation to the drip lines remains an existential issue, at least a veritable articulation now exists between theory and experiment.

This presentation will build on a recent article published in *Reviews of Modern Physics* 75 (2003) 1021-1082.

Ion manipulation and precision measurements at JYFLTRAP*

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JYFLTRAP operating at the ion guide isotope separator (IGISOL) is a multi-trap apparatus comprising an RFQ ion cooler and buncher coupled to purification and high-precision Penning traps. Such a combination provides a unique opportunity for precision measurements of atomic masses of radioactive refractory isotopes. The purification trap and the precision trap are both situated inside the 7 T superconducting solenoid. In the course of commissioning the JYFLTRAP facility, the operation was demonstrated in a series of experiments on radioactive ions [1]. This included successful tests of the isobar separation and mass measurements both with the purification and the precision traps. A typical mass resolving power of 10^5 was obtained in these studies, which allows direct mass determination of exotic isotopes with an improved accuracy compared to indirect methods.

The purification trap was applied to the mass spectroscopy of refractory fission products in the Zr-Pd region. Masses of neutron-rich Zr-isotopes from ^{96}Zr to ^{104}Zr were measured with a relative accuracy of $5\mathrm{x}10^{-7}$. The mass determination of these isotopes implies disagreement between our data and the recent mass compilation [2]. However, the obtained two-neutron separation energies show a strong local correlation in relation to the shape change and shape coexistence between N=58 and 60. The obtained accuracy is presently being improved by using the precision trap in a time-of-flight mode. In this contribution we will report our recent measurements on the masses of refractory fission products, such as the Zr and Mo chains. The data will be compared to various theoretical models and connection to underlying nuclear structure will be discussed.

The most stringent requirement for mass determination is set by weak interaction studies. Assuming that the half-life and branching ratios are well known, a high accuracy of the Q_{EC}-value of super allowed beta-decay is needed for a precise determination of the ft-value. This results in an accurate measurement of the vector coupling constant G_v. In turn this leads to a determination of V_{ud}, the up-down matrix element of the Cabbibo-Kobayashi-Maskawa Matrix (CKM). The obtained information tests the Conserved Vector Current hypothesis, the unitarity of the CKM and physics beyond the standard model. With this in mind a program has been started to measure the Q_{EC} value of ^{46}V, which has the largest uncertainty in Q_{EC} among the nine well studied T_Z=0 cases [3]. It is worth noticing that vanadium is one of the refractory elements only available at IGISOL. Furthermore, it is planned to start investigations on some T_Z=-1 nuclei in the $18 \leq A \leq 42$ mass range. Such measurements can test nuclear structure corrections and therefore help to increase the overall accuracy of the CKM tests, which is one of the fundamental tests for the standard model.

The JYFLTRAP facility provides a unique approach for these studies because the parent and daughter nuclei can be produced simultaneously in the same experiment. Thus most of the systematical errors are canceled or are of negligible size resulting in a very good accuracy of relative mass difference. During the first experiments with the precision trap, the statistical uncertainty could be pushed down to the 10^{-8} level, while systematical errors dominate the overall uncertainty. The latter can be improved by systematical studies of the operational parameters of the trap. Error analysis, systematic studies of the trap performance and opportunities for high-precision studies will be reviewed and the recent results will be discussed.

[1] V. Kolhinen et al., Nucl. Instr. Meth. (2004), in press.
[2] G. Audi et al., AME2003, Nucl. Phys. A 729, 337 (2003).
[3] J. Hardy and I. Towner, Hyp. Int. 132, 115 (2001), and private communication (2004).

* This work has been supported by the European Union within the NIPNET RTD project under the contract no HPRI-CT-2001-50034 and by the Academy of Finland under the Finnish Center of Excellence Programme 2000-2005 (project number 44875).

Recent progress in mass predictions

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We review the latest efforts devoted to the global prediction of atomic masses. Special attention is paid to the new developments made within the Hartree-Fock-Bogolyubov (HFB) framework. So far, about 10 HFB mass tables based on different parametrizations of the effective interactions in the Hartree-Fock and pairing channels have been published. We analyze their ability to reproduce experimental masses as well as other additional known properties such as giant resonances. The possibility to derive within the HFB framework a universal effective interaction that can describe all known properties of the nuclei (including their masses) and of asymmetric nuclear matter is critically discussed. Finally, the HFB mass tables are compared with the three other modern mass formulas, i.e., the FRDM of Möller et al. [1], the KUTY model of Koura et al. [2], and the model of Duflo & Zuker [3]. In addition to considering the quality of their respective fits to the data of the Atomic Mass Evaluation of December 2003, we also compare their extrapolations out towards the neutron drip line.

[1] P. Möller *et al.*, At. Data Nucl. Data Tables **59**, 185 (1995).

[2] H. Koura *et al.*,, Nucl. Phys. **A674**, 47 (2000)

[3] J. Duflo and A. P. Zuker, Phys. Rev. C **52**, R23 (1995).

A new high precision binding energy for the halo nuclide ^{11}Li

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The halo nucleus ^{11}Li is a perfect illustration of a three-body system. It is described as two correlated neutrons in the field of a ^{9}Li core, but it continues to pose a fundamental challenge to nuclear theory. The two-neutron separation energy, derived from the mass, is a critical input parameter to modern three-body halo models.

The mass of ^{11}Li (8.75 ms) and ^{11}Be (13.6 s) have been measured with MISTRAL, a spectrometer well suited to the measurement of very short-lived nuclides, using a tantalum foil target coupled with the Laser Ion Source of the ISOLDE facility. The new measurement of ^{11}Li is seven times more precise than the value with the dominant weight in the 1995 mass evaluation. Moreover, we find the mass more bound by 75 keV compared to the mass previously used in the adjusment of models. Though small, this represents a sizable shift in the two-neutron separation of 25%. To make us sure of the value found, the mass of the ^{11}Be has been measured and be found nearly equal with the past one and its precision has been improved by a factor near of two.

The MISTRAL experiment (Mass measurements at ISOLDE/CERN with a Transmission RAdiofrequency spectrometer on Line), determines the mass of short-lived nuclides by measuring their cyclotron frequency in a homogeneous magnetic field [1]. The ISOLDE beam is injected directely in the spectrometer alternately with a stable beam reference. The measurement duration corresponds only to time-of-flight of the ions in the 1m diameter magnet, the rapidity of this on-line method allows us to measure the nuclides around some ms of half-life. With a resolving power up to 10^5, we can reach a relative mass uncertainty of a few 10^{-7} for a production rate of ~1000 ions/s.

Recent results using nuclear field theory that include core polarization give binding energies for ^{11}Be and ^{12}Be within a few percent. For ^{11}Li, their results [2] was higher than given by other models. As it turns out, their calculation is in excellent agreement with our higher S_{2n}. It permits to have a better idea of the weight of $(s_{1/2})^2$ and $(p_{1/2})^2$ ground-state configuration [2,3] and has an influence on the calculation of its neutron-neutron root-mean-square distance and constrains the location of the virtual state in ^{10}Li to below 50 keV [4].

[1] D.Lunney et al, Phys. Rev. C **64**, 054311 (2001).
[2] R.A. Broglia et al, in Proceedings of the International Nuclear Physics Conference 2001, edited by E. Norman et al 746 (2002).
[3] N. Vinh Mau, J.C. Pacheco, Nucl. Phys. A **607** , 163 (1996).
[4] M.T. Yamashita, L. Tomio, T. Frederico, Nucl. Phys. A **735** , 40 (2004).

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Mass measurements using "household appliances" *

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Despite the difficulties inherent in mass measurements far from stability, including vanishing production, vanishing signal to background and, because of shrinking lifetimes, the vanishing time scale on which measurements must be made, mass measurements of neutron-rich fission fragments including $^{77-79}$Cu and $^{83-86}$Ge were performed at the Holifield Radioactive Ion Beam Facility with a simple setup of general-purpose beam-diagnostic detectors. The setup, which consists of a position-sensitive MCP and an ion chamber mounted near the focus of the analyzing magnet of the 25 MV tandem electrostatic accelerator, allowed us to measure mass differences between known- and unknown-mass constituents of isobarically mixed beams of accelerated fission products produced with the ISOL technique.

The idea behind these measurements is simply that, after postacceleration, the components of the beam are dispersed at the focal plane of the analyzing magnet in proportion to their mass differences. A high-resolution measurement of the position combined with unambiguous determination of the atomic number of each ion is then sufficient to measure the mass differences between unknown- and known-mass components of the beam. In this way, the characteristics of the HRIBF beams, that is, electrostatically accelerated and isobarically mixed, are used to maximum advantage. The advantage of accelerated beam, making robust independent measurement of Z possible, has allowed us to measure masses for nuclides, including ^{79}Cu and ^{86}Ge, whose halflives are less than 0.2 seconds and whose production constitutes a part in one billion of the total fission yield.

This initial setup, without purpose-built detectors, and without being able to measure at the focus of the analyzing magnet, yielded a resolution of 3 MeV and a mass accuracy of about 500 keV, determined largely by the error in extrapolating from known-mass isobars. The mass data, near doubly-magic ^{78}Ni and near the N=50 waiting point isotones of the r-process, suggest that isotopes of Ge and Cu within a few neutrons of the most recently evaluated masses are more bound than the systematics by as much as 1 MeV [1].

[1] G. Audi *et al.*, Nucl. Phys. **A729** (2003) 337.

*This work was supported by the U. S. Department of Energy under contracts DE-AC05-76OR00033 and DE-AC05-96OR22464.
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Large-Scale HFB Calculations for Deformed Nuclei with the Exact Particle–Number Projection *

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Modern nuclear structure theory is rapidly expanding from the description of phenomena in stable nuclei toward regions of exotic short-lived nuclei far from stability. Stringent constraints on the microscopic approach to nuclear dynamics, effective nuclear interactions, and nuclear energy density functionals, are obtained from studies of the structure and stability of exotic nuclei with extreme isospin values, as well as extended asymmetric nucleonic matter. Hartree-Fock-Bogoliubov (HFB) method is a reliable tool for a microscopic self-consistent description of nuclei, which can be used in the context of the density functional theory.

We solve the HFB equations by using the Transformed Harmonic Oscillator (THO) basis [1-3], which allows for a correct asymptotic behavior of single-quasiparticle wave functions. The method combines the advantages of using the harmonic oscillator basis and those of using the spacial coordinates. It is adopted for performing massive calculations for many axially deformed nuclei including those which are weakly bound.

Recent theoretical advances in the large-scale HFBTHO calculations of nuclear ground-state properties [4] will be presented with the emphasis on the exact particle number projection. The applicability of the widely used Lipkin-Nogami procedure will be discussed together with the analysis of the particle number projection after variation, the influence of different Skyrme functionals and predictions of properties of exotic nuclei close to the particle drip lines [5].

[1] M.V. Stoitsov, P. Ring, D. Vretenar, G.A. Lalazissis, Phys. Rev. **C58**, 2086 (1998).
[2] M.V. Stoitsov, W. Nazarewicz, S. Pittel, Phys. Rev. **C58**, 2092 (1998).
[3] M.V. Stoitsov, J. Dobaczewski, P. Ring, S. Pittel, Phys. Rev. **C 61** (2000) 034311
[4] M.V. Stoitsov, J. Dobaczewski, W. Nazarewicz, S. Pittel, D.J. Dean, Phys. Rev. **C68** (2003) 054312
[5] Mass tables available at http://www.fuw.edu.pl/ dobaczew/thodri/thodri.html

*This work was supported in part by the U.S. Department of Energy under Contract Nos. DE-FG02-96ER40963 (University of Tennessee), DE-AC05-00OR22725 with UT-Battelle, LLC (Oak Ridge National Laboratory), and DE-FG05-87ER40361 (Joint Institute for Heavy Ion Research); and by the National Nuclear Security Administration under the Stewardship Science Academic Alliances program through DOE Research Grant DE-FG03-03NA00083, by the Polish Committee for Scientific Research (KBN); and by the Foundation for Polish Science (FNP).

Recent developments of the radioactive beam preparation with the Penning trap REXTRAP*

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At ISOLDE/CERN, REX-ISOLDE [1] is delivering a post-accelerated radioactive ion beam of energy up to 2.2 MeV to nuclear structure and astrophysics experiments. This installation consists of three stages: a Penning trap REXTRAP used for the beam preparation, the REXEBIS which realizes the charge breeding of the ions, and a LINAC consisting of different resonant cavities. Within REXTRAP [2,3], the motions of the radioactive ions are cooled down by collisions with a buffer gas in a presence of an intense magnetic field. The ions are grouped together in bunches and ejected in pulsed mode towards the EBIS. The beam preparation is needed for a good overall transport efficiency of REX-ISOLDE.

Three major developments tracks are actually pursued at REXTRAP. The first is the study of charge exchange of noble gases ions with the buffer gas. The knowledge of the charge exchange cross sections at thermal velocities of such cooled ions is especially needed for the developments of new cooling devices for fission fragments. These so-called "ion-catchers" are actually under study in several laboratories in Europe and over-seas. The second investigation concerns the ion cooling method. The current "sideband cooling" method consists in applying a quadrupolar excitation field at the cyclotron frequency of the ions in the transverse plane of the trap. A new method, the so-called "rotating wall cooling" spins up the ion cloud in order to compress the ion cloud radially by means of the Lorentz force. From recent experimental results this methods seems to be advantageous for the manipulation of intense radioactive beams, overcoming the difficulties of handling high space charges inside the trap. Lastly, the injection of AlF^+ and $SeCO^+$ molecules inside REXTRAP has been successfully tested for the acceleration of Se^+ and F^+ ions by REX-ISOLDE. In the case of $SeCO^+$, it was possible to break the molecule in Se^+ ions and neutral CO. For both beams, the molecule could be kept with a good efficiency. In that latter case we expect the molecule break-up within REXEBIS then a quite efficient charge breeding of Se and F elements. This method opens up opportunities for new accelerated contaminant free beams. Up-to-date experimental results concerning these three research and development topics will be presented.

[1] D. Habs et al., Hyp. Int. **129**(2000)43
[2] P. Schmidt et al., Nucl. Phys. A **701**(2002)550
[3]: F. Ames et al., submitted to NIM A

*This work was supported by the European commission within the NIPNET RTD network under contract number HPRI-CT-2001-50034

Sunday Morning Session 2 Radioactivity

Sunday Morning 2 - Radioactivity

Name/email	Institution	Title
Mantica, Paul mantica@msu.edu	NSCL/Michigan State University	Beta-Decay Studies of Neutron-Rich Nuclei
Grzywacz, Robert grzywacz@phy.ornl.gov	University of Tennessee	The structure of nuclei near ^{78}Ni from isomer and decay studies
Grawe, Hubert h.grawe@gsi.de	GSI	Shell Structure from ^{78}Ni to ^{100}Sn: Implications for Nuclear Astrophysics
Karny, Marek karny@mimuw.edu.pl	Warsaw University	Beta Decay Studies near ^{100}Sn
Millener, John millener@bnl.gov	Brookhaven National Laboratory	Beta decays of ^{8}He, ^{9}Li, and ^{9}C
Ogloblin, Alexey aoglob@dni.polyn.kiae.su	Kurchatov Institute	Study of cluster radioactivity mechanism by extremely deep sub-barrier fusion
Rotureau, Jimmy rotureau@ganil.fr	GANIL	Microscopic Theory of the Two-Proton Radioactivity
Tripathi, Vandana tripathi@nucmar.physics.fsu.edu	Florida State University	Low-energy level structure of neutron rich Na isotopes approaching the "Island of Inversion"
Volya, Alexander volya@phy.fsu.edu	Florida State University	Nuclear pairing and Coriolis effects in proton emitters
Mazzocchi, Chiara mazzocch@mail.phy.ornl.gov	University of Tennessee	Beta-delayed gamma and neutron emission near the double shell closure at ^{78}Ni
Name/email	**Institution**	**Title**

Beta-Decay Studies of Neutron-Rich Nuclei*

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Significant progress on the study of beta-decay properties of very neutron-rich nuclides has been made in recent years, and can be attributed in part to the following: increases in primary beam intensities at radioactive beam facilities; advances in the separation of an isotope of interest from other beam contaminants; and the implementation of new and more sensitive detection methods. The advancement of beta-decay studies into the so-called "terra incognita" region of the chart of the nuclides promises many rewards, including improved understanding of both the nucleon-nucleon effective interactions employed in current nuclear structure models, which can be more thoroughly tested by examining variations of gross nuclear properties over a wider range of isospin, and the astrophysical rapid neutron capture process. Characteristics of the beta decay, as well as the structure of the resulting daughter nuclei populated following the decay, can shed light on new nuclear structure features that are predicted to occur in nuclei with low neutron separation energies. Beta-decay half-lives, Q values, and delayed neutron emission probabilities of neutron-rich nuclei are also important nuclear physics input parameters for network calculations attempting to reproduce r-process abundances.

For this talk, attention will focus on the measurement of beta-decay properties of neutron-rich nuclides along the expected neutron shell closures at $N = 20$, 28, 50 and 82. Recent results from studies performed at radioactive beam facilities in the US and abroad will be reviewed, and discussed in view of the potentially dynamic nature of neutron single-particle states in nuclei having extreme neutron-to-proton ratios.

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*This work was supported in part by the National Science Foundation grant PHY-01-10253.

The structure of nuclei near ^{78}Ni from isomer and decay studies

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Understanding of nuclei with very large neutron excess requires development of increasingly complex many body models. The half-century old nuclear shell model, a very successful tool describing properties of nuclei, is undergoing the period of revival [1], enabled by the availability of the computing power. The predictive power of the calculations has to be tested by experiments on nuclei with large proton-neutron asymmetry. Magic nuclei are the best benchmarks.

The shell model structure of the neutron rich Z=28 nuclei has been investigated by the study of ^{68}Ni produced in the multinucleon transfer reaction, see Ref.[2]. Evidence for N=40 shell closure was found. Since then, the use of fragmentation reactions made it possible to study more exotic nuclei toward ^{78}Ni and along N=40.

Several experiments on neutron-rich nuclei Z≈28 and $40 < N < 50$ has been performed using fragmentation reactions of ^{86}Kr beam at intermediate energies at Ganil[3-7] and NSCL[8-10] facilities using high acceptance fragment separators to select nuclei of interest. Detection systems sensitive to beta and gamma radiation enabled spectroscopy of states populated in deexcitation of short lived isomers and after beta decay. A variety of other gamma-spectroscopy methods have been applied to study the property of these nuclei [11-13]. These sensitive measurements provided among other results the first observation of the energies of the lowest excited states in the magic nickel nuclei from ^{70}Ni to ^{76}Ni. Neutron-rich iron and cobalt nuclei were studied, indicating the onset of deformation [7]. The shell-model framework applied in the case of ^{68}Ni could not satisfactorily reproduce the measured properties of the more exotic nickel nuclei [14], for example the disappearance of 8^+ seniority isomer in ^{72,74}Ni and its reappearance in ^{76}Ni. Recently this observation found an explanation in new shell-model calculations [15]. The overview of recent experimental results will be given and remaining open questions will be discussed.

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Shell Structure from ^{78}Ni to ^{100}Sn : Implications for Nuclear Astrophysics

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The shell structure of ^{100}Sn as inferred from prompt and delayed γ-ray spectroscopy with multi-detector γ-arrays in-beam and at ISOL and in-flight separators shows close resemblance to ^{56}Ni one major shell lower. The results of large-scale shell model calculations employing realistic interactions derived from effective NN potentials by G-matrix theory will be confronted with experimental evidence from β-decay and in-beam data with emphasis on seniority and spin-gap isomers, highlighting the rôle of core excitations. Key examples from recent experiments are ^{94,95}Ag and ^{98}Cd.

The dominant monopole interaction of the spin-flip partners $\pi g_{9/2} - \nu g_{7/2}$ in N=50,51 isotones below ^{100}Sn is echoed in the $\pi f_{5/2} - \nu g_{9/2}$ pair of nucleons, which is decisive for the N=50 shell gap in ^{78}Ni. The persistence of the N=50 shell and the weakness and extreme locality of the N=40 shell in ^{68}Ni can be traced back to monopole driven migration of selected single particle orbits. Recent experimental data on ^{70,72,76}Ni, ^{78}Zn and ^{67}Fe give evidence for this scenario.

The implication of these strong monopole shifts for the shell quenching in neutron-rich N=50,82 isotones invoked to explain astrophysical r-path abundances is discussed.

Beta Decay Studies near ^{100}Sn

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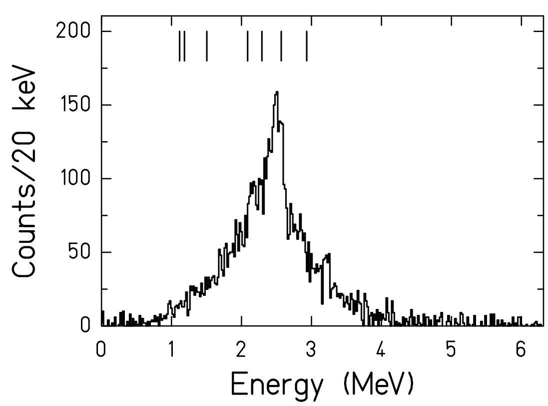
The doubly closed-shell ^{100}Sn nucleus and its neighbours provide a sensitive test ground for the nuclear shell model. In this region β decay is dominated by the $\pi g_{9/2} \rightarrow \nu g_{7/2}$ Gamow-Teller transition. Properties of β decay of several nuclei in the ^{100}Sn region have been investigated in the quest to solve the 'quenching' puzzle. This paper reports on recent decay studies of ^{104}Sn, ^{102}Sn (for the decay studies of odd-mass Sn isotopes see a contribution by M.Kavastyuk et al.). The measurements were performed at the GSI on-line mass separator using a chemically selective ions source, a Total Absorption Spectrometer (TAS), and cluster and clover germanium detectors for high-resolution γ-ray spectroscopy combined with an array of silicon detectors for recording β particles.

For the decays of ^{104}Sn and ^{102}Sn, $\beta - \gamma - \gamma$ coincidences collected with the high-resolution setup helped to deduce a true β-strength distribution from TAS measurements. The decay schemes, constructed on the basis of the high resolution data, confirm and extend previous measurements for ^{104}Sn [1] but differ in the case of ^{102}Sn [2] with respect to the number of γ-transitions observed, level positions and proposed ^{102}In ground-state spin assignment.

The figure presents the β-gated TAS spectrum measured for the ^{102}Sn decay. The vertical lines above the spectrum represent suggested level positions as derived from the high-resolution data. Counts above 3 MeV reveal the same decay constant as the main peak and therefore indicate a non-zero ^{102}Sn β-decay feeding to ^{102}In levels (above 2 MeV) which were not observed with the high resolution (low efficiency) detectors.

Detailed information on the data analysis as well as a comparison of the experimental results to theoretical predictions will be presented. The results obtained in an attempt to measure the β-decay of ^{100}Sn will also be discussed.



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Beta decays of ^{8}He, ^{9}Li, and ^{9}C *

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The beta decays of ^{8}He, ^{9}Li, and ^{9}C all exhibit low-energy transitions with large B(GT) values indicating that the spatial quantum numbers of the final states have a large overlap with those of the initial state. This is evident in the supermultiplet basis with a labelling scheme [f]LSJT.

In the case of ^{8}He decay, the initial $0^+;2$ state is mainly [22] ^{1}S. Of the four predicted 1^+ states of ^{8}Li below 10 MeV, the first three have mainly [31] symmetry (mixed ^{1}P, ^{3}P, ^{3}D) and the uppermost [22] ^{3}S. The first three owe their β-decay strengths to small admixtures of [22] symmetry. The fourth state, near $E_x = 9$ MeV, accounts for most of the Gamow-Teller (GT) sum rule and a small [31] symmetry admixture accounts for the observed β-delayed triton (and neutron) emission [1]. I will show how this works out quantitatively. For example, the predicted width of the ~ 9 MeV state is ~ 1 MeV.

In the case of ^{9}Li and ^{9}C decay, the initial $3/2^-;3/2$ state is mainly [32] ^{2}P. The low-energy states of ^{9}Be and ^{9}B have mainly [41] symmetry and therefore small GT matrix elements. Large GT values can occur for [32] ^{2}P and [32] ^{4}P final states (two $1/2^-$, two $3/2^-$, and one $5/2^-$). Such states owe their widths to small admixtures of [41] symmetry components. The strongest predicted GT transition strength is for the $5/2^-$ level, identified at $E_x = 11.81$ MeV in ^{9}Be and $E_x = 12.16$ MeV in ^{9}B. Theoretically, there should be strong transitions to one $3/2^-$ and one $1/2^-$ state at slightly lower excitation energy. The difficult analyses of the $\alpha + \alpha +$ N spectra [2,3,4] have concentrated the strength in the $5/2^-$ level ($3/2^-$ in [2]) which results in a spectacular asymmetry in the B(GT) values for ^{9}Li and ^{9}C decay [3,4]. I will analyse what is known about states with predominately [32] symmetry in ^{9}Be and ^{9}B and present predictions for energies, decay modes, widths, and GT strengths.

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*This work was supported by the U. S. Department of Energy under contracts DE-AC02-98-CH10886.

Microscopic Theory of the Two-Proton Radioactivity

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Nuclear decays with three fragments in the final state are very exotic processes. The two-proton (2p) radioactivity is an example of such a process which can occur for even-Z nuclei beyond a proton drip line : if the sequential decay is energetically forbidden by pairing correlations, a simultaneous 2p decay becomes the only possible decay branch. In spite of long lasting efforts, no fully convincing experimental finding of this decay mode has been reported (see however data on 2p radioactivity of the ground state of ^{45}Fe [1] and of the second excited 1_2^- state of ^{18}Ne [2]). Recently, we have developed a theory of 2p radioactivity which is based on the extension of Shell Model Embedded in the Continuum (SMEC) [3,4] for the *two-particle* continuum. The configuration mixing in this theory is calculated microscopically and the asymptotic states are obtained in the S-matrix formalism [4].

The Hilbert space is divided in three subspaces : Q, P and T. In Q subspace, A nucleons are distributed over (quasi-)bound single-particle (qbsp) orbits. In P, one nucleon is in the non-resonant continuum and A-1 nucleons occupy qbsp orbits. In T, two nucleons are in the non-resonant continuum and (A-2) are in qbsp orbits. The coupling between Q, P and T subspaces changes the 'unperturbed' Shell Model (SM) Hamiltonian in Q into the effective Hamiltonian :

$$H_{QQ}^{(eff)} = H_{QQ} + H_{QT}G_T^+(E)H_{TQ} + \left[H_{QP} + H_{QT}G_T^+(E)H_{TP}\right]\tilde{G}_P^{(+)}(E)\left[H_{PQ} + H_{PT}G_T^{(+)}(E)H_{TQ}\right] \quad (1)$$

where : $\tilde{G}_P^{(+)}(E) = \left[E - H_{PP} - H_{PT}G_T^{(+)}(E)H_{TP}\right]^{-1}$ is the Green's function in P modified by the coupling to T, and $G_T^{(+)}(E) = [E - H_{TT}]^{-1}$ is the Green's function in T. In the above equations, H_{PP} , H_{TT} are the unperturbed Hamiltonians in P, T subspaces, respectively, and H_{QP}, H_{PQ} , H_{PT}, H_{TP} are the corresponding coupling terms between Q, P, and T subspaces. The second term on the r.h.s of eq. (1) describes a 'pure' diproton emission, and the third term describes the modification due to the mixing of sequential 2p, diproton and 1p decay modes.

In solving SMEC problem with $H_{QQ}^{(eff)}$, the radial single-particle wave functions in Q and the scattering wave functions in P and T are generated by a self-consistent procedure starting with the average potential of Woods-Saxon type with the spin-orbit and Coulomb parts included, and taking into account the residual coupling between Q, P and Q, T subspaces. This procedure yields new orthonomalized wave functions in Q, P and T and new self-consistent potentials for each many-body state in Q [3]. SM effective interaction is used in H_{QQ}. The residual couplings H_{QP}, H_{PT} between different subspaces are given by the contact force including the spin exchange term.

In this contribution, we shall present microscopic analysis of different 2p decay modes from 1_2^- state of ^{18}Ne.

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Low-energy level structure of neutron rich Na isotopes approaching the "Island of Inversion"

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At N >> Z the disappearance of the familiar shell closures due to the spin orbit coupling and their reappearance as harmonic oscillator magic numbers is a burning question, which is strongly related to the dilute neutron density and the decoupling of proton and neutron motion in weakly bound systems. One of the striking examples is the erosion of the N=20 shell closure for Z=10-12, the so called ***island of inversion***, a region of unexpectedly high deformation. This inversion has been attributed to the strong residual interaction between the promoted neutrons and valence protons, interactions between the promoted neutrons and shifts in single particle energies resulting in the intruder *fp*-shell configuration dominating the ground state wave functions [1]. The evolution of these intruder configurations as a function of neutron number forms an interesting study and is an important input to state of the art shell model calculations. In this regard we report the low energy levels ^{27}Na(T_Z=5/2), ^{28}Na (T_Z=3) and ^{29}Na (T_Z=7/2) to understand the transition from the proposed N=16 sub-shell closure to the disappearance of the traditional N=20 shell gap. These nuclei were populated in the beta-decay of ^{27,28,29}Ne isotopes produced in the fragmentation of a 140 MeV/nucleon ^{48}Ca beam at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University. Prior to this study, limited information existed about the excited states in the exotic Na isotopes [2]. The high efficiency of the SeGA array coupled to the beta counting system at NSCL allowed us to observe many new beta-delayed gamma-ray transitions in these nuclei. A preliminary analysis suggests that the lowest ½$^+$ state in ^{29}Na lies lower than expected, which could be a sign of the approach to the island of inversion. Detailed results of the experiment along with shell model predictions incorporating both normal and intruder configurations will be presented.

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Nuclear pairing and Coriolis effects in proton emitters*

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Proton radioactivity is not only a fascinating phenomenon, but describing it is also a significant challenge to theory. As nuclear structure and nuclear reaction theories become more entangled in studies of nuclei far from stability, the development of theoretical approaches that can handle the combination of structure and decay phenomena becomes essential.

From the point of view of nuclear structure models [1], proton radioactivity is a very slow and exclusively single particle process. This permits a perturbative approach to the decay, e.g. in this limit the decay and virtual excitations into the continuum have little effect upon the internal nuclear structure. Thus the entire problem is reduced to a determination of the spectroscopic factor. This simplification is what permits the direct study of the coupling between the collective internal states and the scattering states; a key step in the development of nuclear structure models that include the continuum. It has been shown [2] that deformation and nuclear pairing are essential ingredients in proton radioactivity, as well as the change of these collective properties in the transition from parent to daughter system.

In this work we extend the ideas of Fiorin *et al.* [3], where a quasiparticle description of proton emitters was first used. We implement a more general Hartree-Fock-Bogoliubov approach to describe the rotating mean field, and to include pairing correlations in a self-consistent manner. The Hamiltonian consists of a deformed Woods-Saxon potential which is perturbed by the Coriolis term and the pairing interaction. The resulting many-body problem is solved in a quasiparticle mean-field approximation, and the coupling between quasiparticles and real protons in the decaying states determines the spectroscopic factors. Since the procedure is fully self-consistent, this approach does not require an explicit introduction of Coriolis attenuation terms. We demonstrate our method using the deformed proton emitter ^{141}Ho as an example, where decays both to the ground and first excited state of the daughter ^{140}Dy have been recently observed. By changing the relative strengths of the Coriolis terms and the pairing terms in the Hamiltonian, we explore the impact of the collective deformation and nuclear superconductivity and their interplay on the proton decay spectroscopic factors.

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*This work was supported by the U. S. Department of Energy, Office of Nuclear Physics, under contracts DE-FG02-92ER40750 and W-31-109-ENG-38.

Beta-delayed γ and neutron emission near the double shell closure at ^{78}Ni *

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Nuclear structure in the vicinity of the double shell closure at Z=28, N=50 has garnered increased interest over the last years. The large neutron excess in this region is expected to affect the nucleon-nucleon interaction and new phenomena as changes to the traditional shell gaps and magic numbers are predicted to be manifest [1]. These nuclei lie in a region of interest for nuclear astrophysics, since they are predicted to take part in r-process nucleosynthesis. Therefore β-delayed neutron emission close to ^{78}Ni is particularly interesting. Its investigation can provide information on the Gamow-Teller β-strength distribution and on the branching ratios. These are astrophysically-important, serving as input parameters to r-process network calculations. Several experimental studies based on fragmentation reactions have been performed for nuclei approaching ^{78}Ni [2-4] and a new theoretical description was recently developed [5].

In the present contribution we report on the investigation of the decay of neutron-rich Co and Ni isotopes. The experiment was performed at the National Superconducting Cyclotron Laboratory at Michigan State University. The nuclides studied were produced by fragmentation of 140 A·MeV ^{86}Kr beam in a ^{9}Be target, separated using the A1900 spectrometer, and implanted into a double-sided silicon strip detector. Ion implants and their subsequent β decays were observed in this detector and correlated in software. The implantation detector was surrounded by the SeGA array of germanium detectors to enable observation of both implant- and decay-coincident γ rays.

The analysis of β-delayed γ rays provided the first identification of β-delayed neutron emission in very neutron-rich cobalt isotopes. Results from the β decay of $^{71-73}$Co and neutron-rich Ni isotopes will be presented in detail and compared to theoretical predictions.

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*This work was supported in part by the NSF Grant PHY-01-10253 and by the DOE Grant DE-FG02-96ER40983.
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Sunday Afternoon Session Moments & Radii

Sunday Afternoon - Moments & Radii

Name/email	Institution	Title
Neyens, Gerda gerda.neyens@fys.kuleuven.ac.be	K.U. Leuven	Recent Results from Moment Measurements in the N=8, N=20 and N=40 Neutron Rich Regions
Billowes, Jon j.billowes@man.ac.uk	University of Manchester, Department of Physics and Astronomy	Developments in laser spectroscopy at the Jyvaskyla IGISOL
Mueller, Peter pmueller@anl.gov	Argonne National Laboratory	Laser Spectroscopic Determination of the He-6 Charge Radius
Kowalska, Magdalena kowalska@cern.ch	CERN	Laser and Beta-NMR spectroscopy on neutron-rich magnesium isotopes
Villari, Antonio villari@ganil.fr	GANIL	Reaction cross section measurements of neutron-rich exotic nuclei in the vicinity of the closed shells N=20 and N=28
Utsuno, Yutaka utsuno@nsbox.tokai.jaeri.go.jp	Japan Atomic Energy Research Institute	Anomalous magnetic moment of ^{9}C and shell quenching in exotic nuclei
Kiselev, Oleg O.Kisselev@gsi.de	Mainz University	Investigation of nuclear matter distribution of the neutron-rich He isotopes by proton elastic scattering at intermediate energies
Noertershaeuser, Wilfried W.Noertershaeuser@gsi.de	GSI Darmstadt	Measurement of the Charge Radius of ^{8,9}Li The last step towards the determination of the Charge Radius of ^{11}Li
Koller, Noemie nkoller@physics.rutgers.edu	Rutgers University	First g factor measurement using a radioactive 76Kr beam.
Bingham, Carrol cbingham@utk.edu	University of Tennessee	First 2+ excited state g-factor studies on heavy Te isotopes using the Recoil-in-Vacuum method with the system CLARION plus Hyball at HRIBF
Hass, Michael michael.hass@weizmann.ac.il	Weizmann Institute of Science	Parity Non-Conservation in the gamma Decay of Polarized 17/2- Isomers in ^{93}Tc
Werner, Volker vw@ikp.uni-koeln.de	University of Cologne	Alternative interpretation of E0 strengths in transitional regions
Sumikama, Toshiyuki sumikama@riken.jp	Heavy Ion Nuclear Physics Lab., RIKEN	G-Parity Irregular Term in the Weak Nucleon Current Extracted from the Alignment Correlation Term in the Mass A = 8 System
Name/email	**Institution**	**Title**

Recent Results from Moment Measurements in the N=8, N=20 and N=40 Neutron Rich Regions*

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for the E314, E438 and E322 collaborations at GANIL and the IS389 and P-183 collaborations at ISOLDE-CERN.
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Electromagnetic moments of exotic nuclei in regions of shell closures provide an ideal tool to test the stability of the shell closure and to deduce information on the single particle and collective properties of the nuclei. An intense research program, to study the ground state g-factors and quadrupole moments of neutron rich nuclei around the disappearing N=8 and N=20 shell closures is going on at GANIL (Caen, France) and at ISOLDE-CERN. Precision values for the ground state nuclear moments are measured using β-Nuclear Magnetic and Quadrupole Resonance methods on spin-polarized radioactive beams. At GANIL, the collaboration is using also spin-aligned isomeric beams to investigate the g-factor and structure of isomeric states based on the intruder $\nu g_{9/2}$ orbital in nuclei with less than N=40 neutrons. Gyromagnetic factors of isomeric states have been measured with the Time Differential Perturbed Angular Distribution method.

At GANIL a spin-polarized or spin-aligned radioactive beam is produced and in-flight selected via the high-resolution LISE fragment separator [1], while at ISOLDE the radioactive beams are spin-polarized by a collinear interaction with a circularly polarized laser beam of the proper frequency, provided by the COLLAPS set-up of the Mainz group [2].

Results from precision measurements on the ^{9,11}Li quadrupole moments [3] will be discussed in terms of the halo neutron configuration (related to breakdown of N=8 shell closure) and the g-factors of ^{31,32,33}Al [4,5] will be presented and discussed in terms of weakening of the N=20 shell closure and intruder state admixture into the ground state wave functions. Results from a g-factor measurement of the $9/2^+$ isomeric state in the N=35 nucleus ^{61}Fe will be discussed in terms of an onset of deformation in the neutron rich region below Z=28 [6].

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* This work was supported by the FWO-Vlaanderen (Belgium), the IAP P5/07 project of the OSTC-Belgium, the INTAS 00463 project , the BMBF (Germany), and the IHRP Programmes of EU at GANIL and ISOLDE.

Developments in laser spectroscopy at the Jyväskylä IGISOL

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A programme of collinear laser spectroscopy measurements on radioistopes has been running at the IGISOL isotope separator facility in Jyväskylä. The collaboration involves the universities of Birmingham, Manchester and Jyväskylä. Optical isotope shifts and hyperfine structures are measured with good precision in a Doppler broadening-free technique. Analysis of the data allows the nuclear static moments and mean square charge radii to be deduced.

In recent years the programme has greatly benefited from the installation of an ion beam cooler-buncher in the mass separated line which improves the emittance and energy spread of the beam. The device can also be used to bunch the ion beam and new laser techniques have been developed which takes advantage of this ability.

The recent work of the collaboration will be reviewed. This includes collinear laser spectroscopy of Zr, Ce and Y radioisotopes, and measurements of two 8^- isomers in ^{130}Ba and ^{176}Yb. The development work with a collinear resonance ionization spectroscopy method will also be presented.

Laser Spectroscopic Determination of the ^{6}He Charge Radius*

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Laser spectroscopic measurements of atomic isotope shifts offer unique access to probe the nuclear charge distribution of short-lived isotopes. Here we present a new high-resolution technique based on laser spectroscopy of single atoms in a magneto-optical trap (MOT). The isotopes of interest are ^{6}He ($t_{1/2}$ = 807 ms) and ^{8}He ($t_{1/2}$ = 119 ms), which exhibit a loosely bound neutron halo around a ^{4}He like core. Charge radii measurements of these isotopes will provide corroboration for their halo structure and test theoretical models of light nuclei. In particular, they will probe the high isospin part of the three-nucleon force.

The atomic structure of helium can be calculated very precisely, which is in this case a precondition for extracting the difference in nuclear charge distribution. The isotope shifts are dominated by the mass effect, causing shifts of tens of GHz. The contribution of the change in charge radii is only on the order of 1 MHz. Consequently, the isotope shifts have to be measured with an error much smaller than 1 MHz and nuclear masses have to be accurately known to calculate the mass effect.

Measurements on ^{6}He and ^{8}He require an on-line experiment with extremely high sensitivity and selectivity. To achieve this a MOT setup has been constructed for trapping helium using the closed 2s $^{3}S_{1}$ – 2p $^{3}P_{2}$ transition at 1083 nm out of the metastable triplet state. The metastable atoms are populated in a RF driven discharge source and decelerated in a Zeeman slower for efficient trapping. The overall trapping efficiency is on the order of 10^{-8}. Single atom detection and isotope shift measurements are performed using the 2s $^{3}S_{1}$ – 3p $^{3}P_{2}$ transition at 389 nm.

In a recent on-line run with the MOT setup at the ATLAS facility at Argonne single atoms of ^{6}He were successfully trapped and detected at a rate of up to 200 atoms per hour. This number agrees well with the rate expected from the overall trapping efficiency and the ^{6}He production rate at ATLAS of about 10^{6}/s. The spectroscopic precision achieved for determining the line center of the ^{6}He transition was better than 100 kHz. Furthermore, off-line tests were conducted with the stable isotopes ^{4}He and ^{3}He. Measurements of the fine structure splitting in ^{4}He and the ^{4}He – ^{3}He isotope shift yielded an accuracy of better than 100 kHz for the MOT results. While data analysis is still in progress, the final uncertainty on the nuclear charge radius of ^{6}He based on existing data is expected to be around 1%. First results will be presented.

*This work was supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. W-31-109-ENG-38.

Laser and β-NMR spectroscopy on neutron-rich magnesium isotopes*

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The standard nuclear shell model fails to explain well the properties of neutron-rich nuclei in the region of proton numbers between 10 and 12 and neutron numbers around 20. This so-called "island of inversion" consists of nuclei which exhibit large deformation, which is interpreted in the shell-model context as a disappearance of N = 20 shell gap between the sd and fp shells. Therefore fp intruder configurations appear at low excitation energies or even become ground states. In order to develop and test an extended shell-model description, data on the experimental observables of nuclei lying in this region are of high importance.

For this purpose an experiment has been set up to measure nuclear spins, magnetic dipole and electric quadrupole moments of the short-lived neutron-rich magnesium isotopes ^{29}Mg, ^{31}Mg and ^{33}Mg. The isotopes are produced at ISOLDE, CERN by proton-induced fragmentation in a UC_2 target and ionised by stepwise excitation in the laser ion source. After acceleration to 60 keV the ion beams are delivered to the setup for collinear laser spectroscopy and β-NMR spectroscopy. Nuclear spin polarisation, required for β-NMR measurements, is achieved by optical pumping with circularly polarised UV laser light at the resonance wavelength of 280 nm. Next, the ions are implanted into suitable cubic or non-cubic crystals and β-decay asymmetry is measured. Observation of this asymmetry as function of the Doppler-tuned optical excitation frequency reveals the hyperfine structure of the ions in the 3s $^2S_{1/2} \rightarrow$ 3p $^2P_{3/2}$ resonance transition. With the laser frequency tuned to the HFS component giving most polarization, the frequency of an RF field in the coil around the crystal is scanned in order to induce nuclear magnetic resonance between different m_I levels, observed as a disappearance of the β-decay asymmetry. By combining the results of the HFS and the NMR measurements, the spin, the magnetic dipole moment and the electric quadrupole moment of the isotope of interest may be deduced.

Preliminary information from first measurements about the involved spins and magnetic moments will be discussed. The observed asymmetries of up to 6% will allow us to achieve higher accuracy and to determine the quadrupole moments from the interaction with the electrical field gradient at the lattice site of the implanted nuclei.

* Work supported by BMBF, Germany, FWO-Flanders, Belgium and IHRP Programme of EU.

Reaction cross section measurements of neutron-rich exotic nuclei in the vicinity of the closed shells N=20 and N=28

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The study of exotic nuclei, especially the so-called magic nuclei, is of great interest to understand the structure and to study the magicity and exoticity of nuclei far from stability. This can be accomplished through the investigation of the evolution of shell structures and matter distributions. At high energy, recent measurements of the interaction cross-section revealed the existence of a new magic number – N=16 – [1] which appears only in very neutron-rich nuclei. Also, from the correlation between the interaction cross-section and separation energy, the anomalous structure, such as halo and skin, could be studied. Moreover, new measurements of interaction cross section at high-energy shows the existence of skin effect in the structure of Na and Mg isotopes [2].

In this context, a new measurement of reaction cross section at intermediate energy was performed at GANIL. The nuclei of interest were produced, in a wide range of neutron-rich nuclei (from N to Ar), by the fragmentation of a 60.3 MeV/nucleon ^{48}Ca primary beam on a ^{181}Ta production target. Using a direct method, where the Silicon detector can play a role of an active target [3], the mean energy integrated reaction cross section was deduced for such exotic nuclei.

Assuming that the energy dependence of the reaction cross section is well described by the parametrization of S.Kox [4], the reduced strong absorption radius is extracted and compared to other results from literature. We present, for the first time, **the results of 19 new radius measurements** in this very exotic region. By the isotopic, isotonic and isospin dependence, the evolution of the strong absorption reduced radius is studied according to the excess of neutrons. According to this analysis, the existence of a new halo effect is proposed to the nuclei of ^{35}Mg and ^{44}S. Also, a quadratic parametrization is proposed for the nuclear radius as a function of the isospin in the region of closed shells N=8 and N=28. This parametrization permits to study the evolution of the radii according to the excess of both neutrons and protons, and to give indications on the existence of such structure anomalies like halo.

In parallel, a Glauber type calculation has been applied to the available. By introducing modifications such as the contribution of profile function and Coulomb repulsion effects in the trajectory of the incident particle, it is shown that this model is also reliable at intermediate energy. Indeed, combining our new measurements at intermediate energy with the high-energy data, we were able to disentangle the effects of the nuclear size (root mean square radii) and the matter distribution (diffusivity) for several isotopes in the region studied. In particular, the behaviour of neutron rich sodium and magnesium isotopes will be shown.

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Anomalous magnetic moment of ^{9}C and shell quenching in exotic nuclei *

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The magnetic moment of ^{9}C, measured for the first time by Matsuta *et al.* [1], is a quite anomalous value, since a very large isoscalar spin expectation value $\langle\sigma\rangle = 1.44$ is deduced by using that of its mirror nucleus ^{9}Li. Here, the mirror symmetry between these two ground states is assumed. This large spin value may reflect either a specific feature of the effective interaction not well taken into account so far or a certain breaking of the mirror symmetry. But a quantitative agreement with the experiment has not been reported yet.

Recently, it has been pointed out in [2] that the shell structure in neutron-rich nuclei varies to a large extent from that of the stable ones, originated from the spin-isospin properties of the nucleon-nucleon interaction. This varying shell gap was investigated in detail in the $N \sim 20$ region with the Monte Carlo shell model calculation [3]. The shell gap in open-shell nuclei is defined with the so-called effective single-particle energy (ESPE) [3] including some effects from the two-body interaction through the monopole interaction. As previous studies have not sufficiently taken this "shell evolution" into account, we examine in the present work [4] how it affects the anomalous magnetic moments of the ^{9}C-^{9}Li pair.

We first fix the effective $N = 8$ shell gap on the basis of the p-sd shell-model calculation empirically to reproduce experimental excitation energies of the abnormal parity states of $N = 7$ isotones. Since no corresponding state has been observed for the Li ($Z = 3$) isotope, the ESPE of Li isotopes is determined by extrapolating the ones of the $Z = 4$-6 isotopes. As a result, it turns out that the $N = 8$ shell gap for $Z = 3$ is rather narrow, but the ground state of ^{9}Li is still dominated by the p-shell configurations. Thus, as far as the mirror symmetry is assumed, the isoscalar spin value of the ^{9}C-^{9}Li pair is still a normal one around 1.

Because the ^{9}C is a loosely-bound nucleus with $S_p = 1.3$ MeV, its proton single-particle energies, particularly the $1s_{1/2}$, can be shifted from the neutron ones of ^{9}Li owing to the Thomas-Ehrman effect. The amount of the shift is estimated from the experimental one of a surrounding pair and the Woods-Saxon potential. We then shift the single-particle energies of ^{9}C from those of ^{9}Li, and examine the change of the magnetic moment. Consequently, an agreement with the experiment is obtained by the shift near the estimate given above. This agreement is closely related to a large $2p$-$2h$ mixing by about 40% for the ground state of ^{9}C: due to the mixing a large fraction of the orbital angular momentum is carried by the valence protons, driving the magnetic moment positively. This kind of the Thomas-Ehrman effect can be referred to as "Thomas-Ehrman mixing" changing the component of the many-body wave function, in contrast to the ordinary "Thomas-Ehrman shift".

In this conference, we will report on this subject in detail.

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*This work was supported in part by Grant-in-Aid for Young Scientists (14740176) from the Ministry of Education, Culture, Sports, Science and Technology.

Investigation of nuclear matter distribution of the neutron-rich He isotopes by proton elastic scattering at intermediate energies

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The study of neutron-rich light nuclei near the drip line has attracted much attention as they exhibit a particular nuclear structure, namely an extended distribution (so-called halo) of the valence neutrons surrounding a compact core. Elastic proton scattering at intermediate energies is known as a suitable technique for exploring the nuclear matter distributions in the stable nuclei. It was successfully used at GSI also for the radioactive nuclei ^{6,8}He [1,2] and ^{6,8,9,11}Li [3]. The experimental technique of inverse kinematics was applied using radioactive beams with energies close to 700 MeV/u. The method has been proven to be very effective for measuring the differential cross sections and deriving the nuclear matter distributions in the halo nuclei, such as ^{6}He, ^{8}He and ^{11}Li, with the aid of the Glauber multiple scattering theory. The measurements have been performed in the small momentum transfer region and have yielded valuable information on the nuclear sizes and radial structure of the overall nuclear matter density distributions. A high-pressure hydrogen-filled ionization chamber was used as the target and detector for the recoiling protons. Recently, a novel experimental approach has been accomplished with the aim to deduce the differential p^{6,8}He cross sections at a higher momentum transfer close to the expected first diffraction minimum. The major difference with respect to the previous experiments was that instead of the active gaseous target a liquid hydrogen target was used, combined with a proton recoil detector. The experimental arrangement allowed for a very low-background data taking. The differential cross sections have been evaluated using several phenomenological parameterizations for a nuclear matter distribution. In addition, a model-independent analysis with a help of a Sum-Of-Gaussians method has been performed, which is the standard method for the investigation of nuclear charge distributions from electron scattering data [4]. The values of the nuclear sizes and the radial structure of the total nuclear matter, core and halo density distributions in ^{6}He and ^{8}He will be presented. The measured differential cross sections have been also used for probing density distributions as predicted by various microscopic theories. The comparison of the data with the latest calculations will be shown.

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Measurement of the Charge Radius of ^{8,9}Li – The last step towards the determination of the Charge Radius of ^{11}Li*

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Almost twenty years ago, Tanihata *et al*. [1] discovered the large interaction radius of ^{11}Li in nuclear reactions and interpreted it as a long tail in the matter distribution due to the weakly bound neutrons of ^{11}Li. This model was supported by many other experiments and established a new phenomenon of nuclear structure close to the neutron drip-line: neutron halos – compact nuclei surrounded by a diffuse, far reaching cloud of one or more neutrons. More nuclei with halos (neutron and proton halos) have been discovered over the last two decades and many of their properties investigated. But, so far, nuclear models lack information about the interaction between the weakly bound neutrons and the protons inside the compact core. To obtain a more complete picture, a measurement of the rms charge radius of halo nuclei is highly desirable. Laser spectroscopic determination of the isotope shifts in a chain of isotopes is the standard tool to investigate changes of charge radii [2], but it has not yet been applied to any halo nucleus. The reason is that the neutron drip line has been reached only for very light elements, for which the volume shift is very small, only on the order of 10^{-4} – 10^{-5} of the overall shift. Thus, an accurate mass shift calculation must be combined with a very precise measurement of the isotope shift. Additionally, small production yields for these short-lived exotic isotopes require very sensitive detection methods.

We present the first measurements of isotope shifts for ^{8,9}Li, performed at the on-line mass separator at GSI Darmstadt. Resonance ionization mass spectroscopy on a thermal atomic beam of radioactive lithium isotopes measured the isotope shift in the 2s $^2S_{1/2} \rightarrow$ 3s $^2S_{1/2}$ two-photon transition. Comparison with recent mass shift calculations [3] allowed determination of the ^{8,9}Li charge radii. It was found that the charge radius decreases monotonically from ^{6}Li to ^{9}Li. This method will soon be used to measure the charge radius of the halo nucleus ^{11}Li.

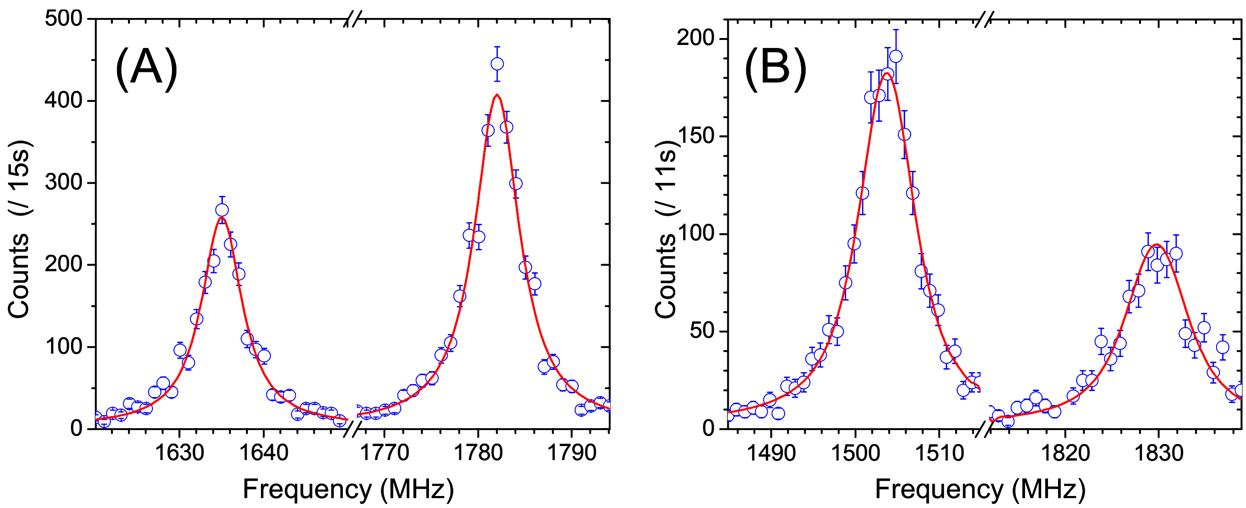

FIG. 1. Resonance Signals of ^{8}Li (A) and ^{9}Li (B)

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First g-factor measurement isong a radioactive ^{76}Kr beam *

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The first measurement of a magnetic moment of a short lived excited state of ions produced as a radioactive beam has been carried out by applying projectile Coulomb excitation in inverse kinematics combined with the transient field technique. The $T_{1/2}$ = 14.8 h ^{76}Kr beam was both produced and accelerated by the re-cyclotron technique at the Lawrence Berkeley 88-Inch Cyclotron. Three production and acceleration cycles yielded six hours of beam on target with peak counting rates of 10^8 particles/sec. About 5.6 x 10^4 particle-γ coincidence events were recorded. The resulting g factor, $g(^{76}\mathrm{Kr};2_1^+) = +0.37(11)$ was obtained by direct comparison to the known $g(^{78}\mathrm{Kr};2_1^+)$ factor value measured under the same kinematic conditions. The potential and limits of this technique will be discussed.

*This work was supported by the U. S. National Science foundation and the U. S. Department of Energy.

Parity Non-Conservation in the γ Decay of Polarized $17/2^-$ Isomers in ^{93}Tc *

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Parity nonconservation (PNC) in bound nuclear systems is a unique probe for the weak interaction part of the nuclear Hamiltonian [1,2]. However, it has been studied in the past in only a few cases and virtually no experimental information has been added in the last several years. The $17/2^-$ - $17/2^+$ parity doublet in ^{93}Tc presents an excellent opportunity of detecting a non-zero PNC effect together with meaningful shell model calculations [3]. The present work is a continuation of our previous experiments [3], where a 3-σ effect has been observed, using an improved experimental setup. The high-rate ^{93}Tc isomeric beam was produced at the UNILAC at GSI by the ^{45}Sc(^{52}Cr, 2p2n)^{93}Tc reaction. The upgraded velocity-filter (SHIP) separated and transfered the ^{93}Tc $17/2^-$ isomers to the focal-plane area where they were polarized using an array of sixteen, 30 $\mu g/cm^2$ thick collodion-carbon foils tilted by 70° with respect to the isomer beam direction. The direction of the polarization was changed periodically by rotating the foils by 180°. The ^{93}Tc isomers were subsequently implanted in a perturbation-free Pb stopper and the decay γ rays were detected with higher efficiency compared to [3], in two Compton-suppressed GSI clover Ge detectors placed at 0° and 180° with respect to the induced polarization. Digital electronic modules for signal processing in the data acquisition system were used, allowing for high count rates with minimal dead time and for the add-back option in the off-line analysis of the γ spectra from the collected events. Standard double ratios [3] were formed in order to provide a measurement of the ensuing 0° - 180° asymmetry of the 751 keV $17/2^-$ - $13/2^+$ M2/E3 transition from ^{93}Tc that is independent of the relative efficiency of the detectors, and of the beam-current fluctuations. The "null-asymmetry" effect was defined by using other γ transitions depopulating the $17/2^-$ isomer as well as γ-rays from ^{93,94}Ru, ^{92,94}Mo and ^{92}Tc.
A detailed analysis is currently in progress and the results will be presented and discussed.

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*This work was partly supported by Israel-Germany MINERVA foundation.

Alternative interpretation of E0 strengths in transitional regions *

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A strong rise of E0 transition strengths between the first excited 0^+ state and the ground state is predicted in shape transitional regions within the Interacting Boson Model (IBM) [1]. This rise matches well existing data and is not connected to a large mixing amplitude between both states. Moreover, a coherence of amplitudes in the wave functions causes the strong transition.

While in vibrational nuclei the E0 strength is small, it remains large when passing the phase transitional region towards deformed nuclei, due to a subtle interplay of annihilation and coherence of parts of the wave functions. This predicts a strong E0 transition between the 0_2^+ state, which is usually identified with the β-vibrational band-head, and the ground state in well-deformed rotors. Therefore, a large E0 strength does not inevitably hint at a large mixing amplitude beween two states, but can also be attributed to the transitional or rotational character of a given nucleus. Nevertheless, knowledge on such transitions is scarce and a confirmation of the IBM predictions affords more data on E0 transitions in deformed nuclei. Large E0 strengths are also predicted between $J \neq 0$ members of the ground state and the β-vibrational band which may be experimentally easier accessible.

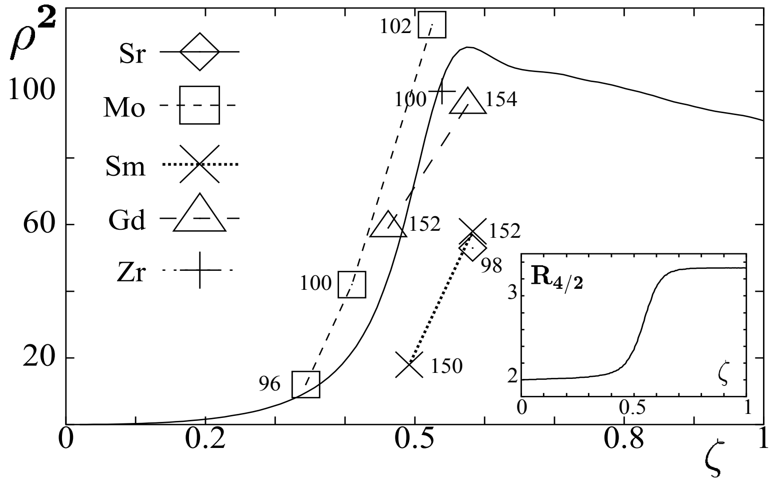

FIG. 1. Empirical $\rho^2(E0; 0_2^+ \rightarrow 0_1^+)$ values (from [2]) for nuclei around A=100. The IBM-1 parameter ζ (ζ=0 for the U(5) vibrator, ζ=1 for the SU(3) rotor) was set to reproduce the $R_{4/2} = E(4_1^+)/E(2_1^+)$ ratio for each nucleus, χ is fixed to $-\sqrt{7}/2$. The solid curve gives the qualitative behavior of ρ^2 calculated for the whole range of ζ in the IBM, set to an arbitrary scale that meets the data points, for N=10 bosons. Comparison with the calculated $R_{4/2}$ shows that the strong rise in E0 strength appears just in the parameter range of the vibrator-rotor shape phase transition.

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*This work was supported by the DFG under contract number Br799/11-1, the BMBF by grant number 06MT190, and by the USDOE under grant number DE-FG02-91ER-40609.

G-Parity Irregular Term in the Weak Nucleon Current Extracted from the Alignment Correlation Term in the Mass $A = 8$ System

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The G parity holds in the nuclear β-decay process, if the strong interaction exactly holds SU(2) symmetry. So that, the G-parity irregular term in the weak nucleon current, which is the induced tensor term, allows us to know how much the fundamental symmetry is broken in nuclei. The induced tensor term may give, for instance, the difference between the up and down quarks in the usual nuclei. For the mass $A = 8$ system, the β-α angular correlation was observed in 1980 by McKeown et al. to test the existence of the induced tensor term[1]. However, due to the contribution from the second-forbidden matrix elements, it is difficult to extract the induced tensor term only from the β-α angular correlation. To extract purely the induced tensor term, in the present study, the alignment correlation terms in the β-ray angular distributions of the spin aligned ^{8}Li and ^{8}B were precisely determined.

A deuteron (^{3}He) beam with the 3.5 MeV (4.7 MeV) was provided by the Van de Graaff accelerator at Osaka University. The ^{8}Li (^{8}B) nuclei were produced through the reaction ^{7}Li(d,p)^{8}Li, (^{6}Li(^{3}He,n)^{8}B), and the nuclear polarization was produced by selecting the recoil angle of the reaction product. The polarized nuclei were implanted in the single crystal of Zn (TiO_2), which was placed in an external magnetic field $H_0 = 2.3$ kOe (600 Oe) to maintain the polarization and to manipulate the nuclear spins by use of the RF magnetic field. The obtained polarization was converted into the positive and negative alignments applying the NMR technique. The β-ray energy spectra from the aligned nuclei were precisely observed.

The alignment correlation terms were extracted from the mirror pair ^{8}Li and ^{8}B, and the difference is shown as a function of β-ray energy in Fig. 1, together with the β-α angular correlation [1]. The average of these two kinds of difference data is given by the sum of the induced tensor term and the weak magnetism without the forbidden matrix elements. The obtained average was well reproduced only by the weak magnetism [2], which suggests that the induced tensor term is very small for the mass $A = 8$ system.

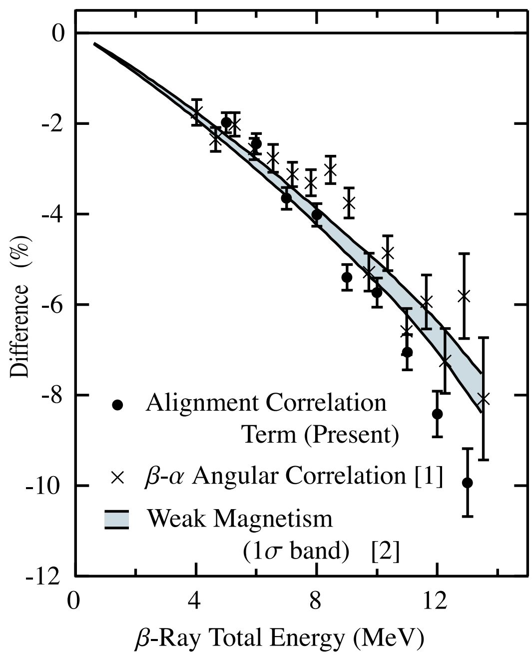

FIG. 1: Difference of the alignment correlation terms and that of the β-α angular correlation [1] between the mirror decays. The average of two differences was well reproduced only by the weak magnetism [2] without the induced tensor term.

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Monday Morning
Session 1
Dripline
&
Clusters

Monday Morning 1 - Dripline & Clusters

Name/email	Institution	Title
Kanada-En'yo, Y. yoshiko.enyo@kek.jp	High Energy Accelerator Research Organization (KEK)	Cluster structure in stable and unstable nuclei
Marques, Miguel marques@lpccaen.in2p3.fr	LPC-Caen	Multineutron clusters (experimental perspective)
Pieper, Steven C. spieper@anl.gov	Argonne National Laboratory	Can modern nuclear hamiltonians tolerate a bound tetraneutron?
Datta Pramanik, Ushasi ushasi@anp.saha.ernet.in	Saha Institute Of Nuclear Physics	Study of Exotic Nuclei near the Neutron Drip Line
Nakamura, Takashi nakamura@ap.titech.ac.jp	Tokyo Institute of Technology	Breakup Reactions of Halo Nuclei
Tajima, Naoki tajima@quantum.apphy.fukui-u.ac.jp	Department of Applied Physics	Continuum effects on the pairing in neutron drip-line nuclei studied with the canonical-basis HFB method
Thoennessen, Michael thoennessen@nscl.msu.edu	Michigan State University	Current Status and Future Studies Along the Proton Dripline
Uusitalo, Juha juha.uusitalo@phys.jyu.fi	University of Jyvaskyla	Alpha-decay studies using the JYFL gas-filled recoil separator RITU
Vretenar, Dario vretenar@phy.hr	University of Zagreb	Relativistic mean-field models with density-dependent couplings
Name/email	**Institution**	**Title**

Cluster structure in stable and unstable nuclei

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Cluster structure in light stable nuclei has been studied for a long time. Recent studies of unstable nuclei revealed that cluster structure may exist also in unstable. In neutron-rich nuclei, a variety of cluster structure has been suggested.

In neutron-rich Be isotopes, the appearance of 2α-cluster cores and He-He resonances in neutron-rich Be isotopes has been discussed in many theoretical studies [1-5]. On the experimental side, cluster states in the excited states have been suggested in the He-He breakup reactions [6,7]. In the AMD study on Be isotopes [3,5], it was found that the single-particle wave functions of the valence neutrons in the low-lying bands are associated with molecular orbits, while the molecular resonant features appear in the highly excited states. Two kinds of molecular features, 'molecular orbital' and 'molecular resonant' features are described as follows. The molecular orbital structure of Be isotopes is composed by 2α and valence neutrons which move around both the two α clusters. In other words, the picture of the molecular orbitals is based on the single-particle orbits of valence neutrons in the mean-field given by the 2α core. On the other hands, molecular resonant structure is characterized by inter-cluster motion in the 2-body clustering. In the theoretical studies on Be isotopes [1-3,5] with cluster models and AMD, the systematics of cluster structure of low-lying states in neutron-rich Be are described by molecular orbitals. On the other hand, the theoretical calculations in Ref.[3,4] showed that the molecular resonant states appear in the highly excited states, which correspond to the experimental measurements[6,7].

It should be noted that the valence neutrons play important roles in these cluster structure in neutron-rich Be. One should remind that the 2α clustering was already well known in the stable nuclei, ^{8}Be and ^{9}Be. When we consider the cluster states in neutron-rich Be in association with those in stable Be nuclei, it is found that, with the increase of the neutron number, a variety of cluster structure appears based on the cluster structure of stable nuclei. In this sense, recent progress of cluster study of stable nuclei will be very helpful in order to research cluster aspects in other unstable nuclei. For instance, 3α states in excited states of ^{12}C motivate us to investigate cluster structure in neutron-rich C isotopes. A 3α condensation(gas-like dilute state) has been suggested recently to appear in ^{12}C(0_2^+) [8,9]. A linear chain structure is also an interesting subject in C isotopes [10]. Cluster aspect must be important still in heavier nuclei such as *sd*-shell nuclei. It is suggested that the cluster aspect appears in largely deformed states and molecular resonances in stable *sd*-shell nuclei.

Thus, clustering is one of the fundamental features in stable and unstable nuclei as well as the mean-field aspect. Both of two features, 'cluster' and 'mean-field' are essential in systematic study of unstable nuclei.

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Multineutron clusters (experimental perspective)

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Neutral nuclei have been searched for since the early 1960s. After a long series of experiments and calculations, there is an overall consensus: experimentally, no one has been able to create and detect multineutrons [1]; theoretically, they should not exist according to our present knowledge of the nuclear interaction [2].

I will briefly review the different classes of experiments and present a new approach to the problem based on breakup reactions of beams of very neutron-rich nuclei. The first application of this technique to the breakup of a ^{14}Be beam into ^{10}Be and 4 neutrons revealed 6 events consistent with the formation of a bound tetraneutron [3].

The description of these data by means of an unbound tetraneutron resonance, and the detection of bound multineutrons through processes other than elastic scattering on protons, will be also dicussed [4]. I will conclude with the experiments that have been undertaken or are being planned at GANIL in order to confirm this observation with ^{12,14}Be and ^{8}He beams, as well as other techniques that are being considered.

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Can Modern Nuclear Hamiltonians Tolerate a Bound Tetraneutron? *

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In the last decade, the Green's function Monte Carlo (GFMC) method has been developed into a powerful tool for calculations of light nuclei (so far up to $A = 12$) using realistic two-nucleon (NN) and three-nucleon (NNN) potentials. GFMC starts with a trial wave function that is obtained via variational Monte Carlo (VMC) and projects out excited state contamination to, in principle, obtain the true ground-state wave function for the given Hamiltonian. In practice the method obtains ground and low-lying excited state energies with an accuracy of 1–2%. A review of the nuclear VMC and GFMC methods up to $A = 8$ may be found in Ref. [1]; $A = 9,10$ results are in [2]. By using the Argonne v_{18} NN potential (AV18) and including two- and three-pion exchange NNN potentials, a series of model Hamiltonians (the Illinois models) were constructed [3] that reproduce energies for ~45 states in $A = 3$–10 nuclei with rms errors of 0.6–1.0 MeV. Preliminary calculations of ^{12}C have been made.

In a recent application [4] of this method, I showed that it does not seem possible to change modern nuclear Hamiltonians to bind a tetraneutron without destroying many other successful predictions of those Hamiltonians. This means that, should a recent experimental claim of a bound tetraneutron be confirmed, our understanding of nuclear forces will have to be significantly changed. Most of this talk will be devoted to reviewing this result.

On the other hand, computations of artificial neutron drops can be used to indirectly study large, neutron-rich, nuclei. These drops are collections of neutrons interacting via a realistic Hamiltonian with the addition of an artificial external well. Studies of spin-orbit splitting and pairing gaps have been made for systems of 2–14 neutrons.

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*This work was supported by the U. S. Department of Energy, Nuclear Physics Division, under contract No. W-31-109-ENG-38.

Study of Exotic Nuclei near the Neutron Drip Line

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The availability of fast radioactive beams provides unique opportunities for detailed investigations of nuclei along and beyond the drip lines. The study of properties of nuclei far off stability is not only important for the understanding of the effective nuclear forces, but it also concerns astrophysical phenomena such as Supernovae or, e.g., the r- and rp-processes.

In the present contribution, results will be discussed from recent measurements of Coulomb and nuclear breakup of light neutron-rich nuclei in the A~20 region. The experiments were performed at GSI, Darmstadt, using the LAND setup. Radioactive beams were produced at the FRS by fragmentation with energies around 600 MeV/u. From the coincident measurement of fragment, neutrons, and γ-rays after breakup on Pb and C targets, the excitation energy prior to decay is reconstructed by utilizing the invariant mass method.

From the γ-ray coincidence measurement, differential cross sections for Coulomb breakup can be derived for individual core states populated, giving access to the ground state single-particle properties of the projectile. Coulomb breakup in conjunction with γ-ray spectroscopy was established as a spectroscopic tool first for exotic carbon nuclei (1). In a similar manner, neutron rich B, O, and F isotopes have been analyzed. The results will be presented and compared to those obtained by different methods like, e.g., transfer and knockout reactions.

Proton removal reactions from neutron-rich nuclei have been used to populate ground and excited states in even more neutron-rich nuclei including continuum states. Recent results including proton removal from B isotopes populating the unbound ^{13}Be will be discussed.

In astrophysical scenarios like, e.g., the hot CNO cycle, or r- and rp-processes, capture cross-sections are important. The direct measurement of these cross-sections, however, is often very difficult since unstable nuclei are involved and the cross sections are small, on the order of nb or pb. Alternatively, capture cross sections might be extracted from the inverse process, which can be studied in the Coulomb breakup reaction. Capture cross sections obtained by this indirect method using high-energy secondary beams will be presented. The limitations, advantages, and disadvantages in the direct and indirect measurements will be discussed.

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Breakup Reactions of Halo Nuclei

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We present the recent experimental results of Coulomb and nuclear breakup of halo nuclei, ^{11}Be, ^{11}Li, ^{14}Be and ^{17}B, studied at the RIPS radioactive beam facility at RIKEN.

In the first part we present on the one-neutron halo nucleus ^{11}Be. One of the intriguing manifestations of neutron halo phenomena is a huge E1 strength just above the neutron decay threshold. Our previous Coulomb dissociation experiment on ^{11}Be [1] and ^{19}C[2], clearly showed that this large E1 strength is attributed to the direct breakup mechanism. Owing to this simple picture, the Coulomb dissociation of the halo nucleus can become a powerful tool to probe exclusively the halo ground state, whose wave function is related directly to the $B(E1)$ spectrum. However, this simple reaction mechanism may require a revision due to the possible higher order effects and the contribution of the nuclear breakup. We have recently revisited the Coulomb dissociation of ^{11}Be at 69 MeV/u with about 30 times more statistics than the previous experiment. This experiment aims at clarifying those effects by combining the excitation energy spectrum with the scattering angle of the reaction. We have found that the higher order effects can be well controlled by selecting the forward scattering angle, and that this effect is, in fact, very small. We could extract the spectroscopic factor of the ground state of ^{11}Be more precisely by this method.

The nuclear breakup of ^{11}Be by the carbon target at 67 MeV/u was then studied. By reconstructing the excitation energy and the scattering angle, we have observed two discrete resonances. The angular distribution for these resonances are consistent with ΔL=2 excitation. The comparison between the Pb target and C target data will be also discussed in terms of the reaction mechanism.

We will also report on the more recent Coulomb and nuclear breakup experiments on two-neutron halo nuclei, ^{11}Li, ^{14}Be, and ^{17}B, all of which have been measured in a kinematically complete way. In this study we have observed an intermediate state of ^{10}Li, ^{13}Be and ^{16}B. We also show n-n correlation, E1 strength distribution for these nuclei to discuss the low-lying E1 excitation of 2n halo nuclei.

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Continuum effects on the pairing in neutron drip-line nuclei studied with the canonical-basis HFB method

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In nuclei near the neutron drip line, the pairing correlation among the neutrons involves significantly the continuum (positive-energy) part of the Hartree-Fock (HF) single-particle states. In principle, there is no difficulty to treat such nuclei with the Hartree-Fock-Bogoliubov (HFB) method, which is the framework to incorporate the pairing correlation into mean-field approximations. In practice, however, such nuclei are difficult to treat if one uses the usual method to solve the HFB, which uses the quasiparticle states to express the HFB ground state. The quasiparticle HFB method can be applied to spherical nuclei [1,2] but its application to deformed nuclei is not feasible. The difficulty originates in the huge number of quasiparticle states, most of which are spatially dislocalized continuum-spectrum states.

Mathematically, HFB ground states can be expressed in the form of the BCS variational function. The single-particle states in this expression are localized. They are called the canonical basis (orbitals). The canonical-basis HFB method [3,4] enables one to obtain the canonical orbitals without knowing the quasiparticle states. It can be applied to deformed neutron-rich nuclei.

The canonical-basis HFB method was originally introduced for spherical nuclei in [3]. I implemented the method for deformed nuclei [4]. For this purpose, I improved the efficiency of the gradient method under constraint of orthogonality between canonical orbitals. I also found the necessity of momentum dependence for the contact pairing interactions if one employs completely coordinate-space representations (like three-dimensional Cartesian mesh, unlike the radial mesh).

In quasiparticle HFB method, the canonical orbitals are obtained from the density and thus people have not noticed the existence of a more direct relation to the Hamiltonian. The present canonical-basis formalism discloses this relation. Namely, highly excited canonical orbitals are roughly the bound eigenstates of the pairing Hamiltonian. It is not the HF Hamiltonian which generates them. Resonances of the HF Hamiltonian are groundless approximations to the canonical basis. This finding makes the understanding of the continuum shell effect much more transparent.

In this paper we extend the formulation and the computer program of the canonical-basis HFB method so as to cover the full Skyrme energy density functional. (Compared with Ref.[4], restriction to symmetric nuclei is removed and the spin-orbit and Coulomb forces are taken into account.) A three-dimensional Cartesian mesh representation is employed to express the single-particle wavefunctions without assuming any spatial symmetries. The mesh representation is adequate to describe spatially extended single-particle states such as neutron-halo orbitals. The time-reversal symmetry is imposed in such a way that the canonical pair of single-particle states are the time reversal state of each other. The necessary computing time per a gradient step is only several times as long as the old program [4].

I will show the results for light even-even nuclei on the neutron drip line and discuss how the continuum affects the pairing when the Fermi level becomes very shallow. Special attention will be paid to the low-lying positive energy canonical-basis orbitals. A systematic study of the spatial extension of these orbitals will enable us to conclude the relative importance between the increase of the radius due to small binding energy and the anticipated pairing anti-halo effect.

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Current Status and Future Studies Along the Proton Dripline*

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Most of the interest for the observation of new isotopes is concentrated along the neutron dripline, because the neutron dripline has only been reached up to oxygen and there hundreds of new isotopes left to be discovered. In contrast it is commonly believed that most of the isotopes along the proton dripline have been observed. However, this is not entirely correct. Although it is true that the proton dripline, defined as $S_p = 0$ has been reached for many isotopes, the exact location of the proton dripline beyond magnesium is actually only known for a few elements. In addition, due to the increasing Coulomb barrier many long-lived isotopes beyond the dripline exist that have not been observed. RIA will be able to produce well over 200 new isotopes at and beyond the proton dripline, with approximately another 100 which will be even out of reach of RIA.
The current knowledge of nuclei along the proton dripline will be presented and the large discovery potential for future experiments will be discussed.

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*This work was supported by the National Science Foundation Grant No. PHY-01-10253.

Alpha-Decay Studies Using the JYFL Gas-filled Recoil Separator RITU*

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The JYFL gas-filled recoil separator RITU [1] at Jyväskylä Accelerator Laboratory has been used intensively for α-decay studies of heavy neutron-deficient nuclei for about ten years. Most of these studies have been performed in the translead region at the extreme limit of nuclear existence. The low production yields due to the strong fission competition have demanded high performance from the separator system and from the focal plane detector system used in these studies.

In the present work α decay hindrance factors HF and reduced widths δ^2, determined according to Rasmussen [2], have been used to obtain structure information of the decaying states. In the lead region the multiproton-multihole intruder states and the occurrence of shape coexistence have been investigated using the α decay as a spectroscopic tool [3, 4]. In addition the vicinity of the proton drip line has offered the possibility to study proton-unbound systems and even to search for direct proton emission [5-7]. While in the lead region the proton drip line crosses the magic proton number 82, in the uranium region the drip line crosses the magic neutron number 126. One of the recently investigated isotopes has been the semi magic nucleus ^{218}U for which two α decaying isomeric states were observed [8]. In addition to the structural information the present α-decay studies have given a lot of valuable information for the mass evaluations [9].

During RITUs ten years of operation time about twenty new α decaying isotopes have been identified in the translead region. In addition numerous α-decay studies have been performed on already known isotopes yielding much improved precision for the measured decay properties. An overview of the α-decay studies performed for the translead nuclei employing the gas-filled recoil separator RITU at Jyväskylä will be given.

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*This work was supported by the Academy of Finland under the Finnish Centre of Excellence Programme 2000-2005 (Project No. 44875, Nuclear and Condensed Matter Physics Programme at JYFL).

Relativistic mean-field models with density-dependent couplings

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The framework of relativitic self-consistent mean-field models has been extended to include effective Lagrangians with density-dependent meson-nucleon vertex functions. When compared to standard relativistic effective interactions with nonlinear meson-exchange terms, the density-dependent meson-nucleon couplings provide an improved description of asymmetric nuclear matter and isovector properties of finite nuclei. The relativistic Hartree-Bogoliubov model has been employed in studies of ground-state properties of spherical and deformed nuclei [1,2]. This model represents a significant improvement in the relativistic mean-field description of the nuclear many-body problem and, in particular, of exotic nuclei far from β-stability. The improved isovector properties of the effective interaction in the *ph*-channel, and the unified description of mean-field and pairing correlations in the Hartree-Bogoliubov framework, offer a unique possibility for accurate studies of nuclei with extreme ground-state isospin values and with Fermi levels close to the particle continuum.
Effective density-dependent interactions have also been employed in relativistic (Q)RPA calculations of giant resonances [3], and in a microscopic analysis of the nuclear matter compressibility and symmetry energy [4]. The comparison of the calculated excitation energies with the experimental data on the giant monopole resonances restricts the nuclear matter compression modulus of structure models based on the relativistic mean-field approximation to $K_{\rm nm} \approx 250 - 270$ MeV. The isovector giant dipole resonance in ^{208}Pb, and the available data on differences between neutron and proton radii, limit the range of the nuclear matter symmetry energy at saturation (volume asymmetry) of these effective interactions to 32 MeV $\leq a_4 \leq$ 36 MeV.

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Study of cluster radioactivity mechanism by extremely deep sub-barrier fusion

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Though the phenomenon of cluster radioactivity is known about 20 years its mechanism still remains an open problem in many aspects. Different theories describe it either as an adiabatic "fission-like" process or as a sudden two-step "alpha-decay-like" (cluster) one. The difficulty is that all of them reproduce the measured decay probabilities quite well. However, different models predict completely different shapes of the potential barrier. "Cluster-type" barriers normally are much narrower than the "fission-type" ones, and their increased penetrability is compensated by the small values of the spectroscopic factors. So, the possible key for solving the problem is getting independent information about the barriers, especially on their internal parts. The study of the inverse processes, fusion or elastic scattering, which are sensitive to the nucleus-nucleus potentials can help in the selection of the theoretical models (see, e.g., [1])

We present in this paper the results of very recent experiment on extremely deep sub-barrier fusion of ^{22}Ne + ^{208}Pb → ^{230}U. Investigation of the cluster decay products fusion leading to the compound nucleus with measured partial time of life (^{230}U → ^{22}Ne + ^{208}Pb) has been performed for the first time. The 4π-array of solid-state track detectors was used. The fission cross-section (exhausting that of fusion) of the ^{230}U compound nucleus has been measured down to 10^{-5} mb, what is by 4-5 orders lower the values obtained in traditional fusion experiments. Similar experiments performed by Kurchatov - JINR collaboration on fusion and near-barrier elastic scattering in ^{12}C, ^{16}O + ^{208}Pb systems (compound nuclei ^{220}Ra and ^{224Th} correspondingly) are analyzed as well.

The barrier shapes strongly differ from those predicted by fission-like models of cluster radioactivity and are typical for "alpha-decay-like" models. Cluster decay probabilities calculated in the frame of "alpha-decay-like" models using the penetrabilities of the obtained barriers and the theoretical spectroscopic factors well reproduce either the experimental value (for ^{230}U) or theoretical predictions [2] (for ^{220}Ra and ^{224}Th). The conclusion is that cluster decays of the light actinide nuclei with A ~ 220 – 230 proceed according to the alpha radioactivity scenario. The touching point of the decay products lies inside the barrier providing necessary condition to formation of quasimolecular configurations.

On the other hand, emission of much heavier clusters, probably, proceeds via fission-like scenario. We showed that the abnormally large diffuseness parameters observed in some analysis of fusion reactions (e.g., ^{58}Ni + ^{58}Ni → ^{116}Ba [3]) correspond to the barrier shapes close to those predicted by fission-like model [4]. This is in accordance with our previous conclusion [1] that the transition between "alpha-decay-like" processes and 'fission-like" ones take place at the masses of the emitted fragments A ~ 35.

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Monday Morning
Session 2
Nuclear
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Monday Morning 2 - Nuclear Astrophysics

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Clark, Jason jclark@physics.umanitoba.ca	Argonne National Laboratory / University of Manitoba	Understanding the rp-Process with the Canadian Penning Trap Mass Spectrometer
Kratz, Karl-Ludwig kl.kratz@uni-mainz.de	University of Mainz	Recent Nuclear Structure Studies of R-Process Nuclei in the ^{132}Sn Region
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Hirsch, Jorge hirsch@nuclecu.unam.mx	Universidad Nacional Autonoma de Mexico	Bounds on the presence of quantum chaos in nuclear masses
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Name/email	**Institution**	**Title**

Amazing Developments in Nuclear Astrophysics*

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The time since ENAM ’01 is short by astrophysical standards, but this period has seen some exciting progress in the area of experimental nuclear astrophysics. New results have been obtained from facilities both large and small, with stable and exotic beams. In the process, we’ve learned a great deal about stellar structure and evolution. However, much remains to be done. This talk will highlight a few of many notable results obtained since ENAM ’01 and will attempt to place them into an astrophysical context. In the process, it may be possible to see where the field is heading and what we might anticipate over the next three years.

*This work was supported by the U.S. Department of Energy under contracts DE-AC05-76OR00033 and DE-FG02-97ER-41041.

Understanding the rp-Process with the Canadian Penning Trap Mass Spectrometer*

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The Canadian Penning Trap (CPT) mass spectrometer at the Argonne National Laboratory is designed to make precise mass measurements of nuclides with short half-lives. Since the previous ENAM conference, many significant improvements to the apparatus were implemented to improve both the precision and efficiency of measurement, and now more than 60 radioactive isotopes have been measured with half-lives as short as one second and with a precision ($\Delta m/m$) approaching 10^{-8}.

The CPT mass measurement program has concentrated so far on nuclides of importance to astrophysics. In particular, measurements have been obtained of isotopes along the rp-process path, in which nuclides are created through a series of rapid proton-capture reactions. An x-ray burst is one possible site for the rp-process mechanism which involves the accretion of hydrogen and helium from one star onto the surface of its neutron star binary companion. Mass measurements are required as key inputs to network calculations used to describe the rp-process in terms of the abundances of the nuclides produced, the light-curve profile of the x-ray bursts, and the energy produced. This paper will present the precise mass measurements made all along the rp-process path with particular emphasis on the "waiting-point" nuclides ^{68}Se and ^{64}Ge, and discuss the implications of these results.

*This work was supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. W-31-109-ENG-38, and by the Natural Sciences and Engineering Research Council of Canada.

Recent Nuclear Structure Studies of R-Process Nuclei in the ^{132}Sn Region

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Meteoritic and astronomical observations, such as the solar-system r-process residuals ($N_{r,\odot} = N_\odot - N_s$) or the recent r-process signatures in ultra-metal-poor halo stars, witness the interplay between shell-structure very far from β-stability and the appropriate environments for rapid neutron-capture nucleosynthesis.

Recent experiments in the ^{132}Sn region at CERN-ISOLDE, including detailed decay spectroscopy on the classical "waiting-point" nucleus ^{130}Cd, as well as the identification of $^{130}Ag_{83}$, $^{133}Cd_{85}$, $^{135}In_{86}$ and $^{138}Sn_{88}$, have revealed a number of nuclear structure surprises, the most important one being the experimental confirmation of N=82 shell-quenching.

Consequences for the build-up and shape of the A$\simeq$130 $N_{r,\odot}$-peak will be presented. Related constraints on the r-matter flow through the A$\simeq$195 $N_{r,\odot}$-peak up to the A$\geq$260 fission region will be given, and the applicability of the long-lived actinides ^{232}Th and ^{238}U as cosmochronometers will be discussed.

First half-life measurement of the doubly-magic r-process nucleus ^{78}Ni *

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The half-life of the doubly-magic nucleus ^{78}Ni has been measured for the first time at the Coupled Cyclotron Facility at the National Superconducting Cyclotron Laboratory (NSCL). Doubly-magic nuclides, as well as nuclides in their vicinity are important benchmarks for nuclear theory. In addition, ^{78}Ni is a waiting point in the astrophysical r-process. The measured half-life therefore directly enters r-process model calculations.
In the same experiment, we performed for the first time half-life measurements for ^{77}Ni, ^{73}Co, ^{74}Co, and ^{75}Co. For ^{75}Ni and ^{76}Ni we obtained greatly improved half-lives. β-delayed neutrons were also detected for some nuclides. We compare the new results with various theoretical predictions, and discuss possible implications for r-process nucleosynthesis.

*This work was supported by NSF grants PHY 02-16783 (Joint Institute for Nuclear Astrophysics) and PHY 01-10253, and the Alfred P. Sloan Foundation (H.S.)

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The Trojan-Horse Method for Nuclear Astrophysics

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The direct measurement of cross sections of astrophysical interest is very difficult for charged-particle reactions at low energies due to the Coulomb barrier that leads to a strong suppression of the reaction rates. Indirect (or surrogate) approaches like the Coulomb dissociation method [1,2] or the method of asymptotic normalization coefficients (ANC) [3,4] have been developed in order to determine the astrophysical S factor for radiative capture reactions. The Trojan-horse (TH) method [5] has been proposed to extract the energy dependence of the S factor for reactions without a photon.

In the TH method the astrophysically relevant reaction $A + x \to C + c$ is replaced by the TH reaction $A + a \to C + c + b$ with three particles in the final state where a spectator b is attached to the nucleus x to form a Trojan horse $a = b + x$ in the initial state. The cross sections of the two reactions can be related with the help of nuclear reaction theory. The TH reaction can be considered as an inelastic transfer reaction to the continuum. The relevant T-matrix element is calculated in a distorted wave Born approximation where the S-matrix elements of the (inverse) two-body reaction enter [6,7].

In an TH experiment quasi-free scattering conditions are chosen where the momentum transfer to the spectator is small. Under these kinematical conditions the direct transfer dominates the reaction mechanism. Depending on the nucleus to be transfered (mainly protons, neutrons, deuterons, and alpha particles), the Trojan horse a with a large probability of clustering into x and b is selected (e.g. ^{2}H, ^{6}Li, ^{7}Li). Even with high energies around or above the Coulomb barrier in the entrance channel of the three-body reaction low relative energies in the three-body reaction can be reached. The two nuclei C and c are detected in the final state of the TH reaction under quasi-free scattering angles.

Basic features of the THM become clear already in an even simpler modified plane-wave approximation. Here, the cross section factorizes into (1) a kinematic factor, (2) a momentum distribution $|W|^2$, and (3) a modified two-body reaction cross section $d\sigma^{TH}/d\Omega$ similar to a plane-wave impulse approximation. The amplitude W is closely related to the wave function of the nucleus x inside the Trojan horse a in momentum space. The width of $|W|^2$ and the allowed momentum transfer defines the range of accessible relative energies in the two-body reaction around a quasi-free energy that is given by simple kinematical considerations. The suppression of the cross section at low energies in the two-body reaction is compensated by additional momentum-dependent factors in $d\sigma^{TH}/d\Omega$. As a consequence the cross section of the TH reaction remains finite even at energy zero of the astrophysically relevant reaction and the Coulomb barrier is effectively removed. From the experimental TH cross section the energy dependence of the astrophysical S factor can be extracted. It has to be normalized to direct data measured at higher energies in order to determine absolute cross sections. Since the S factor extracted in the TH method is not affected by electron screening, a comparison to direct data at very small energies allows to extract the screening potential that can be compared to theoretical estimates.

In this contribution the theoretical foundation of the TH method is discussed and examples of recent applications are presented.

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Bounds on the presence of quantum chaos in nuclear masses *

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Though great progress has been made in the challenging task of measuring the mass of exotic nuclei, theoretical models are necessary to *predict* their mass in regions far from stability [1]. The simplest one is that of the liquid drop model (LDM). It incorporates the essential macroscopic terms, which means that the nucleus is pictured as a very dense, charged liquid drop. The finite range droplet model (FRDM) [2], which combines the macroscopic effects with microscopic shell and pairing corrections, has become the *de facto* standard for mass formulas. A microscopically inspired model has been introduced by Duflo and Zuker (DZ) [3] with good results. Finally, among the mean-field methods it is also worth mentioning the Skyrme-Hartree-Fock approach [4].

These mass formulas can calculate and predict the masses (and often other properties) of as many as 8979 nuclides, but it is in general difficult to match theory and experiment (for all known nuclei) to an average precision better than about 0.5 million electron volts (MeV) [1]. The question of the remaining mass deviations observed in the nuclear mass formulas is addressed in [3] from a novel perspective. It was proposed that there might be an inherent limit to the accuracy with which nuclear masses can be calculated, due to the presence of chaotic motion inside the atomic nucleus [5].

Here we take a second look at this proposal using the relations between neighbouring nuclei, known as the Garvey-Kelson (GK) relations [6]. The comparison between the mass deviations found in three of the global methods (LDM, FRDM, DZ) and our GK studies is presented in the table, for all nuclei with measured masses and $A \geq 16$.

TABLE I. The mass rms deviations $\sigma_{\rm rms}$, in keV, for LDM, FRDM, DZ and GK calculations.

LDM	FRDM	DZ	GK
3447	669	346	86

We conclude that chaotic components in nuclear masses, as suggested in [5], if they exist at all, are rather small, less than 100 keV (or about one part in 10^6).

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*This work was supported in part by the Conacyt, Mexico, and DGAPA-UNAM.

New ^{19}Ne Resonance Observed Using an Exotic ^{18}F Beam*

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The rates of the ^{18}F(p,α)^{15}O and ^{18}F(p,γ)^{19}Ne reactions in astrophysical environments are important for determining the synthesis of the long-lived radioisotope ^{18}F in novae and the extent through which heavy elements are produced through the reaction sequence ^{18}F(p,γ)^{19}Ne(p,γ)^{20}Na(p,γ)^{21}Mg ... in X-ray bursts [1,2]. These reaction rates are uncertain, however, because of the uncertain level structure of ^{19}Ne above the proton threshold at E_x = 6.411 MeV. Despite numerous studies, there still exist ~8 levels in the mirror nucleus, ^{19}F, for which analogs have not been observed in ^{19}Ne in the relevant excitation energy range E_x = 6.4 - 7.6 MeV [3]. To search for these missing levels, we have made the first measurement of the ^{18}F(p,p)^{18}F excitation function over the entire energy range of interest for astrophysics. A 24-MeV ^{18}F beam was stopped in a thick polypropylene CH_2 target. Scattered protons from the ^{1}H(^{18}F,p)^{18}F reaction were detected in a double-sided silicon strip detector. The ^{18}F(p,p)^{18}F excitation function was extracted in the energy range $E_{c.m.}$ = 0.3 - 1.3 MeV by measuring the proton energy spectrum as a function of angle and making a small correction for energy loss in the target. From an *R*-Matrix analysis of our data (see Fig. 1), we have identified and extracted the properties of a newly observed ^{19}Ne level at E_x = 7.420 ± 0.014 MeV, which is most likely the mirror to the $J^{\pi} = 7/2^{+}$ ^{19}F level at 7.56 MeV. We have also found a significant discrepancy with a recent compilation [4] for the properties of a ^{19}Ne state at E_x = 7.500 MeV. Finally, we have set upper limits on the proton widths of ^{19}Ne levels that are still missing. The experimental technique, analysis, and astrophysical implications will be presented.

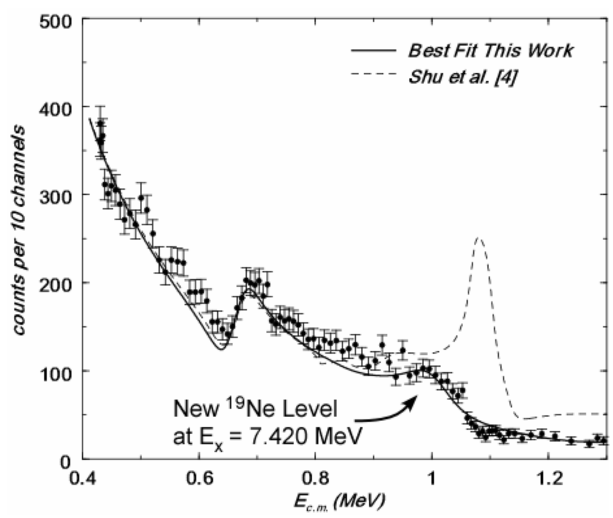

FIG. 1. The ^{18}F(p,p)^{18}F excitation function obtained at 12º along with the best *R*-Matrix fit.

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*Research sponsored, in part, by the Laboratory Directed Research and Development Program of Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U.S. Department of Energy under Contract No. DE-AC05-00OR22725.

Pycno-nuclear reaction rates between neutron rich nuclei*

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Pycno-nuclear reactions are of importance for nucleosynthesis at high density conditions in the deeper layers of accreting white dwarf and neutron star envelopes. Up to recently the pycnonuclear reaction formalism has mainly been developed and applied to the $^{12}C+^{12}C$ reaction in white dwarfs [**?** **?**]. However, in the case of accreting neutron stars electron capture processes can convert the ashes of rp-process driven nucleosynthesis to drip line nuclei in the carbon to magnesium range [**?**]. Pycno-nuclear reactions between these isotopes can provide a new heat source in the neutron star envelope. To model the possible consequences for the neutron star crust and to identify possible observables for such processes the pycno-nuclear reaction rates between light neutron rich nuclei need to be determined. Therefore, the asymptotic behavior of fusion cross section at very low energies is a critical issue for obtaining these rates. Recently a parameter-free model for the nuclear interaction was developed, based on the effects of the Pauli nonlocality [**?**], and the fusion process has been obtained in the context of the barrier penetration model (BPM) using the following effective barrier curvatures [**?**]:

$$\hbar\omega_{\ell eff} = \begin{cases} \hbar\omega_\ell & \text{for } \mu \leq 8 \text{ a.m.u.} \\ \hbar\omega_\ell \left[1 + \lambda(\mu - 8)\right] & \text{for } \mu \geq 8 \text{ a.m.u.} \end{cases} \quad (1)$$

Using $\lambda = 0.1$, the BPM describes with good precision the global behavior of the experimental data in a very wide energy range. We will extrapolate the calculations towards the neutron drip line and will demonstrate a rapid enhancement of the fusion cross section with increasing neutron number. The consequences for the pycno-nuclear reaction rates will be discussed in the frame-work of a modified fusion model [**?**].

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* This work was supported by the National Science Fundation under contracts NSF-PHY-0216783 and FAPESP.

Filling in the Gaps for Odd-A Sb Isotopes from Shell to Shell: A Systematic Perspective of Low-Energy Excitations

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Experimental data for odd-A Sb isotopes provides a variety of theoretical testing grounds for both the behavior of the shell model for single particle excitations near ^{100}Sn and ^{132}Sn; and the interacting boson fermion model for mid-shell Sb isotopes which have high-energy collective structures. For heavy odd-A Sb nuclei that approach the neutron drip-line, recent studies at ISOLDE, CERN, have utilized the technology of a resonance ionization laser ion source to identify all states in neutron-rich ^{135}Sb below 2.0 MeV predicted by the shell-model [1,2]. Level structure for neutron-deficient odd-A Sb isotopes has recently been reported for ^{109}Sb [3]; and new ^{111,113}Te β^+-decay studies performed at Argonne National Laboratory have also revealed information regarding new states in ^{111}Sb and clarified previous ambiguities of the spin and parities of levels in ^{113}Sb [4]. Now that most of the positions and J^π assignments of low-spin levels below 2.0 MeV present in ^{109}Sb to ^{135}Sb are established (FIG. 1), the focus of this paper is to discuss trends and deviations of the systematics of the odd-A Sb states that approach the N=50 closed shell in ^{100}Sn past the N=82 closed shell of ^{132}Sn.

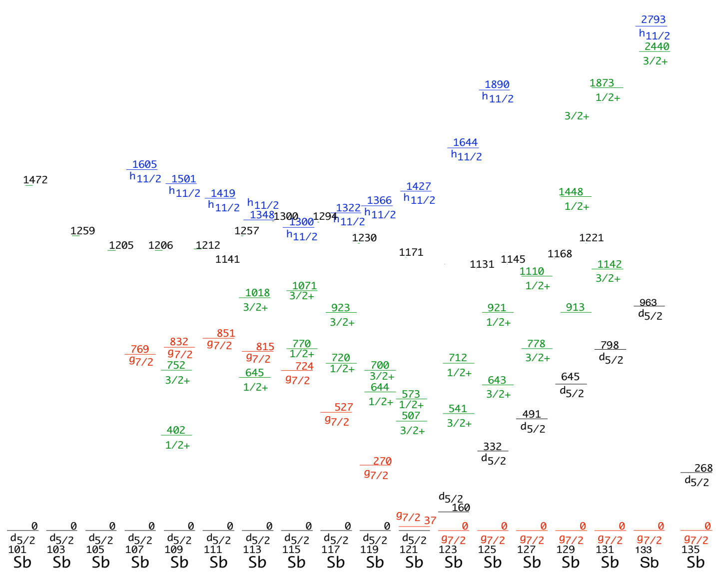

FIG. 1 Low-energy level systematics for odd-A Sb isotopes from 101Sb to 135Sb.

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Monday Afternoon Session Heavy & Superheavy Elements

Monday Afternoon - Heavy Elements & Fission

Name/email	Institution	Title
Ackermann, Dieter d.ackermann@gsi.de	Gesellschaft fuer Schwerionenforschung & Johannes Gutenberg-University Mainz	Beyond Darmstadtium
Utyonkov, Vladimir utyonkov@sungns.jinr.ru	Joint Institute for Nuclear Research	New elements from Dubna
Gaeggeler, Heinz heinz.gaeggeler@psi.ch	Paul Scherrer Institut	Chemical studies of transactinides
Greenlees, Paul ptg@phys.jyu.fi	University of Jyvaskyla	In-beam and decay spectroscopy of transfermium elements
Trotta, Monica Monica.Trotta@na.infn.it	INFN-Sezione di Napoli	Fusion hindrance and quasi-fission in ^{48}Ca induced reactions: implications for SHE production
Denysov, Vitali v.denisov@gsi.de	GSI / KINR	Entrance-channel potentials between nuclei. u-catalysis of superheavy element production. Magic number for ultraheavy region.
Eeckhaudt, Sarah sarah.eeckhaudt@phys.jyu.fi	JYFL	In-beam gamma-ray spectroscopy of ^{254}No
Sieja, Kamila kama@kft.umcs.lublin.pl	Maria Curie-Sklodowska University	Ground State Properties of Heaviest Elements in Mean Field Models
Name/email	**Institution**	**Title**

Beyond Darmstadtium

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The search for superheavy elements has yielded exciting results for both the "cold fusion" approach with reactions employing Pb and Bi targets and the "hot fusion" reactions with ^{48}Ca beams on actinide targets [1-4]. In recent years the accelerator laboratories in Berkeley, Dubna and Darmstadt have been joint by new players in the game in France with GANIL, Caen, and in Japan with RIKEN, Tokyo. The latter yielding very encouraging results for the reactions on Pb/Bi targets which confirmed the results from GSI [5]. Beyond the successful synthesis interesting features of the structure of the very nuclei like the hint for a possible K-isomer in ^{270}Ds [6] or the population of states at a spin of up to 22 h in ^{254}No [7] give a flavour of the exciting physics we can expect in the region at the very extreme upper left of the nuclear chart. To get a hand on it a considerable increase in sensitivity is demanded from future experimental set-ups. High intensity stable beam accelerators, mass measurement in ion traps and mass spectrometers, as well as the possible employment of unstable neutron rich projectile species, initially certainly only for systematic studies of reaction mechanism and nuclear structure features for lighter exotic neutron rich isotopes, are some of the technological challenges which have been taken on.

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New elements from Dubna*

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In previous experiments in which superheavy nuclei close to the predicted neutron magic number N=184 were synthesized, we used the complete-fusion reactions of target and projectile nuclei having the largest available neutron excess: ^{244}Pu+^{48}Ca [1], ^{248}Cm+^{48}Ca [2], and ^{249}Cf+^{48}Ca [3]. In all of these cases, the observed α-decay chains of parent isotopes of elements 114, 116, and 118 were terminated by the spontaneous fission (SF) of previously unknown descendant nuclei with Z=110 [1,2] or 114 [3]. Thus, the method of genetic correlations to known nuclei has limited application in this region for the identification of the parent nuclides. In the present experiments, we identified masses of evaporation residues using the characteristic dependence of their production cross sections on the excitation energy of the compound nucleus (thus defining the number of emitted neutrons) and from cross bombardments, i.e., by varying mass number of the target nuclei which changes the relative yields of the xn-evaporation channels. Both of these methods have been successfully applied in former experiments for the identification of unknown artificial nuclei.

We have studied the excitation functions of the reactions ^{238}U(^{48}Ca, 3-4n), ^{242}Pu(^{48}Ca, 2-4n), and ^{244}Pu(^{48}Ca, 3-5n). The maximum cross sections for the evaporation of 2-5 neutrons in these complete-fusion reactions were measured to be in the range of 0.5 pb to 5 pb. We also report on the observation of new isotopes of element 116, ^{290,291}116, produced in the ^{245}Cm+^{48}Ca reaction with cross sections of about 1 pb. A discussion of self-consistent interpretations of all observed decay chains originating from the parent isotopes ^{282,283}112, $^{286\text{-}289}$114, ^{290,291,293}116, and ^{294}118 is presented. The decay properties of the new isotopes of even-Z elements are compared with those of previously known heavy nuclei and predictions of the macroscopic-microscopic theory.

For the neighboring odd-Z elements, especially their odd-odd isotopes, the probability of α-decay with respect to SF should increase due to hindrance for SF. For such odd-Z nuclei one might expect longer consecutive α-decay chains terminated by the SF of relatively light descendant nuclides ($Z \leq 105$). The decay pattern of these superheavy nuclei is of interest for nuclear theory. In the course of a series of α-decays, the increased stability of nuclei caused by the predicted spherical neutron shell N=184 (or perhaps N=172) should gradually become weaker for descendant isotopes. However, the stability of these nuclei at the end of the decay chains should increase again due to the influence of the deformed shell at N=162. For these investigations, we chose the fusion-evaporation reaction ^{243}Am+^{48}Ca, leading to isotopes of element 115. With 248-MeV ^{48}Ca projectiles, we observed three similar decay chains consisting of five consecutive α decays, all detected in time intervals of about 20 s and terminated at a later time by SF. At the higher bombarding energy of 253 MeV, we registered a different decay chain of four consecutive α decays detected in a time interval of about 0.5 s, also terminated by SF. The decay properties of these synthesized nuclei are consistent with consecutive α-decays originating from the parent isotopes of the new element 115, ^{288}115 and ^{287}115, produced in the 3n- and 4n-evaporation channels with cross sections of about 3 pb and 1 pb, respectively.

The experiments were carried out at the U400 cyclotron with the recoil separator DGFRS at FLNR, JINR.

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*This work has been performed with the support of the Russian Ministry of Atomic Energy and grants of RFBR No. 01-02-16486, 03-02-06236 and 04-02-17186. Much of the support for the LLNL authors was provided through the U.S. DOE under Contract No. W-7405-Eng-48.

CHEMICAL STUDIES OF TRANSACTINIDES

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Chemical investigations are currently possible with elements that have isotopes with half-lives of at least one second. Thanks to the increased nuclear stability at atomic number 108 (Hs) and neutron number 162 (with rather long-lived nuclides in this region) our knowledge on chemical properties could be extended to elements with atomic numbers above 105 (Db). In addition, the recent discovery claims from FLNR in Dubna to have observed rather long-lived spherical superheavy elements in ^{48}Ca induced fusion reactions with actinide targets opened up additional perspectives to extend chemistry even further to atomic number 114. The main purpose of chemical studies is, of course, to deepen our knowledge on the basic principles that govern the periodic table, both experimentally and theoretically. Of special importance are relativistic effects that are expected to significantly influence the electronic energy levels of heaviest elements.

However, chemical separation techniques may also be used to study nuclear properties of new nuclides or to position the atomic numbers of new decay chains observed in on-line separator experiments.

In recent years, mostly gas phase techniques have been applied to study, for the first time, the chemical properties of Sg (Z=106) [1], Bh (Z=107) [2] and Hs (Z=108) [3]. In addition, two attempts have been made to study the chemical properties of element 112 that yielded the fascinating indication for a behaviour like a gaseous metal [4,5].

The separation techniques include isothermal gas chromatography (OLGA: On-Line Gas chemistry Apparatus [6]) and thermochromatography (IVO: In-situ Volatilization and On-line detection [7]). In a recent experiment a modification of the IVO technique was applied to study surface chemical reactions of HsO_4 [8].

Such experiments also resulted in the discovery of several new isotopes, e.g. ^{267}Bh [9] or ^{270}Hs [10].

Moreover, the chemical study of hassium with the isotope ^{269}Hs as tracer enabled the confirmation of the discovery claim of element 112 from GSI since the decay chain of ^{277}112 passes through this isotope [11]. Finally, experiments are presently performed at FLNR in Dubna to confirm the discovery of element 115 from the ^{48}Ca+^{243}Am reaction by chemically isolating the long-lived daughter Db (Z=105) [12].

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In-beam and decay spectroscopy of transfermium elements

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In recent years, a wealth of new spectroscopic data has been obtained in studies of transfermium nuclei. At the focal planes of efficient recoil separators, the “traditional” alpha-decay spectroscopic techniques have been augmented with systems capable of coincident gamma and conversion-electron measurements. The data obtained allow the determination of excitation energies, lifetimes and spins/parities of the levels involved to be made with much greater accuracy than previously possible. Recent work in this field has been led by the GSI group performing experiments using the velocity filter SHIP (see [1] for a review).
The focal plane data have been complemented with high-spin data from in-beam gamma- and electron-spectroscopic measurements made possible through use of the Recoil-Decay Tagging (RDT) technique. Since 1998, when the ground-state rotational band of ^{254}No was observed for the first time using GAMMASPHERE coupled to the FMA [2], the structures of ^{250}Fm, ^{251}Md, ^{252,253,254}No and ^{255}Lr have been investigated in in-beam measurements (see, for example [3]). At JYFL, these studies have been centred around the gas-filled separator RITU [4], in conjunction with various Ge arrays (JUROSPHERE, SARI and JUROGAM) and the conversion-electron spectrometer, SACRED [5,6]. The focal plane of RITU has recently been upgraded with the addition of the U.K. Universities GREAT spectrometer [7]. Another important part of the GREAT project is the triggerless Total Data Readout (TDR) acquisition system, which is now in use at JYFL.
The structure information gleaned from these studies provides valuable input to theoretical investigations of the region. They allow constraints to be placed on the various theoretical models, and yield information on the properties of the mean field far from stability. Of particular interest are the studies of odd-mass nuclei, which may allow the ordering and excitation energies of the single-particle orbitals in the region to be determined.
A brief overview of the experimental techniques used, and highlights from the most recent experiments will be presented.

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Fusion hindrance and quasi-fission in ^{48}Ca induced reactions: implications for SHE production

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A research program is currently being performed in Legnaro with the aim of understanding which are the main ingredients (e.g. mass asymmetry, fissility, target deformation, shell effects…) playing a role in the onset of quasi-fission reactions. Such reactions compete with complete fusion at near barrier energies in the case of collisions between massive nuclei and can lead to a large hindrance for fusion [1,2], therefore affecting the probability of producing superheavy elements (SHE) [3].

In this framework, fusion-fission and fusion-evaporation cross sections have been measured in a large energy range for the ^{48}Ca+^{168}Er, ^{154}Sm reactions. The comparison of the reduced evaporation data for such reactions and for collisions induced by light projectiles (^{12}C, ^{16}O) leading to the same compound nuclei ^{216}Ra* and ^{202}Pb* puts in evidence a fusion hindrance for the ^{48}Ca induced reactions, which is consistent with a noticeable contribution coming from quasi-fission events observed in the mass-energy distribution of fission fragments [4]. The asymmetric mass distribution of the quasi-fission component has been explained in terms of shell effects, favouring the population of closed shell fission fragments [3]. The onset of quasi-fission in the ^{48}Ca+^{168}Er reaction has been recently confirmed by a large anisotropy observed in the angular distribution of mass-asymmetric fission fragments. The comparison of ^{48}Ca+^{154}Sm with preliminary data on ^{48}Ca+^{144}Sm (see FIG.1) and ^{40}Ca+^{154}Sm suggests that the target deformation plays a role in the onset of the quasi-fission mechanism.

Implications for SHE production will be discussed.

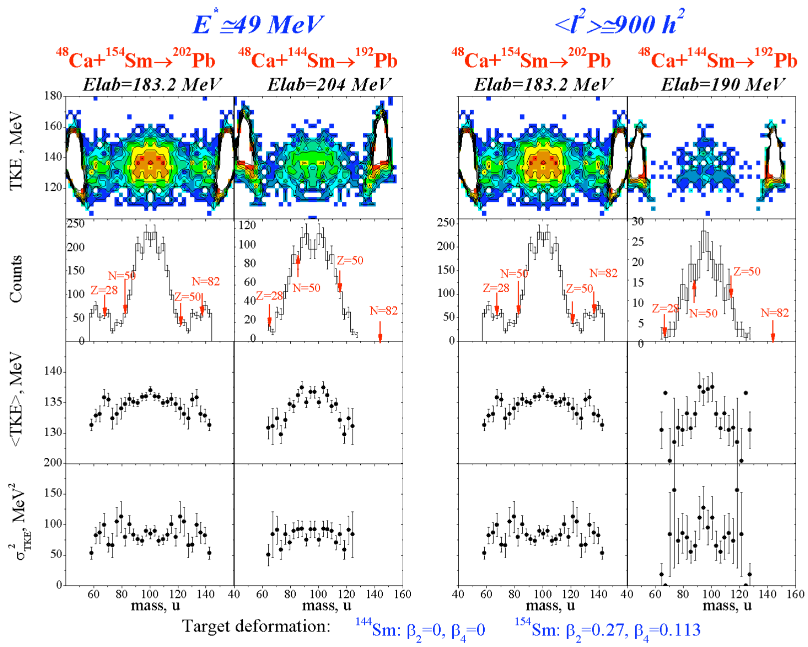

FIG. 1. TKE-Mass distribution, mass yield, average TKE and TKE variance vs. mass of fission fragments for ^{48}Ca+^{154,144}Sm at the same excitation energy (left panels) and average square angular momentum (right panels).

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Entrance-channel potentials between nuclei. μ^--catalysis of superheavy element production. Magic number for ultraheavy region.

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The knowledge of interaction potential between nuclei is very important for evaluation of cross section of various nuclear reactions. The accurate evaluation of the potential barrier and capture well is especially important for the production of superheavy elements (SHEs) in nucleus-nucleus fusion reaction. For heavy-ion reactions leading to SHEs, the interaction potentials for the distances around the touching point is systematically studied in the frozen-density approximation. The potential energy is evaluated in the Thomas-Fermi approximation extended to second-order gradient contributions. The (frozen) density of projectile and target nuclei are obtained from Hartree-Fock-BCS calculations for various Skyrme forces. The resulting semi-microscopic potentials (SMPs) between the nuclei for different reactions leading to SHEs are considered in detail. The barrier and pocket energies, as well as the neutron separation energies are discussed in detail for symmetric and asymmetric, even-even and even-odd, spherical-spherical and spherical-deformed projectile-target combinations, and in particular in relation to successful reactions in the synthesis of SHEs. The isotopic dependence of the SMP is studied.

The most shallow interaction pockets are obtained for collisions of approximately equal nuclei. The deepest pockets result for very asymmetric projectile-target combinations, which have successfully been used in hot fusion reactions. The pockets, obtained for cold fusion reactions, are intermediate between those for hot and symmetric fusion reactions. These pockets are expected to be essential for the fusion process, such that for very shallow or vanishing pockets the capture processes is strongly suppressed.

The entrance-channel SMPs between the light- and medium-weight nuclei are also discussed. Unfortunately, the semi-microscopic approach is not so convenient for various practical applications due to cumbersome numerical calculations. Therefore we choose 119 spherical or near spherical nuclei along the β-stability line from ^{16}O to ^{212}Po and perform calculations of the interaction potentials between all possible nucleus-nucleus combinations in the semi-microscopic approximation. We evaluate potential for any nucleus-nucleus combinations at 15 distances between nuclei around the touching point. By using database for 7140 ion-ion potentials at 15 points each, we find an analytical expression for the nucleus-nucleus potential. The potentials obtained by means of the analytical expression well agree with semi-microscopic one. The barrier heights and radii of barrier evaluated by using analytical expression for various nucleus-nucleus systems well coincide with empirical the ones [1].

It is shown that μ^- bound with light projectile induces the SHE production in nucleus-nucleus collisions. It is easy to understand qualitatively a influence of muon μ^- on the SHE fusion process, if we recollect that the wave function of $1s$ state of μ^- in a very heavy nucleus is located inside the nucleus. Therefore, negatively-charged muon inside heavy nucleus should effectively reduce the Coulomb repulsion between protons. Due to this the forces, inducing fission of compound nucleus and preventing fusion of two nuclei should decrease. Consequently, the SHE formation probability should rise due to μ^-.

Proton and neutron shell corrections are calculated for nuclei with proton numbers in the range $76 \leq Z \leq 400$ along the β-stability line described by Green's approximation [2]. The shell corrections are evaluated for Woods-Saxon nucleon mean field with spin-orbit, Coulomb and pairing interactions. Proton and neutron magic numbers are determined for ultraheavy nuclear region. α-decay half-lifes and fission barriers of double-magic nuclei $^{298}114_{184}$, $^{472}164_{308}$, $^{616}210_{406}$ and $^{798}274_{524}$ are estimated.

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In-beam gamma-ray spectroscopy of ^{254}No

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Knowledge of the structure of very heavy elements is essential for the development of mean field theories which predict nuclear properties far from stability. Important input comes from the study of transfermium nuclei, the heaviest systems which can be studied using in-beam spectroscopy.

Recent developments in spectrometer and acquisition techniques at JYFL made progress in the study of these transfermium nuclei possible. The new Ge array JUROGAM, an array of 43 Compton-suppressed HPGe detectors, has been installed at the target position of the gas-filled recoil separator RITU [1]. The focal plane of RITU has been upgraded with the addition of the GREAT spectrometer [2]. Installation of the new digital Total Data Readout [3] acquisition system improved the data processing.

An experiment has been performed with this new setup to study ^{254}No and improve previously obtained results [4]. This nucleus can be produced via a fusion-evaporation reaction of a ^{48}Ca beam and a ^{208}Pb target with a cross section of 2 μbarn. The selective recoil-decay tagging technique [5,6] allows the gamma-rays of interest to be unambiguously identified from the dominant fission background.

Preliminary analysis has shown the presence of new transitions in the rotational band built on the ground state of ^{254}No as well as indications for non-yrast states. These new data will be presented.

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Ground State Properties of Heaviest Elements in Mean Field Models

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Spontaneous fission half-lives studied in the framework of macroscopic-microscopic models are sensitive to both parts of the energy. It is very important to determine ground state properties of known nuclei to a very good accuracy to predict masses and half-lives of the heaviest elements. The recently developed Lublin-Strasbourg Drop model (LSD) [1] with parameters fitted for 2766 presently known nuclei (rms=0.698) seems to be the best choice for the macroscopic part of the energy. The results of previous calculations of masses with the LSD and the δ-pairing interaction for rare-earth nuclei [2] are in a good agreement with experimental data [3].

The δ-pairing force used in this type of calculations leads to matrix elements (and therefore pairing energies) similar to those obtained with the Gogny-type pairing interaction [4] being additionally relatively simple in the numerical treatment. It was shown that using the δ-pairing force instead of a schematic seniority force affects significantly spontaneous fission half-lives of e.g. Fermium isotopes [5].

In the present work masses of the heaviest elements are calculated in the macroscopic-microscopic method based on a few macroscopic models including the LSD, Woods-Saxon potential [6] and the δ-pairing force and are compared to those obtained in selfconsistent RMF+BCS calculations. A variety of fits of the pairing strengths is tested in order to reproduce ground state properties (masses, pairing gaps, radii, *etc.*) and to assure the proper dependence of fission barriers and mass parameters on deformation. Spontaneous fission half-lives are determined in the dynamical fission model [7] in a four dimensional space of β deformations.

An excerpt of results for nuclear mass deviations for refitted liquid drop (RLD) [1] is displayed in Fig. 1.

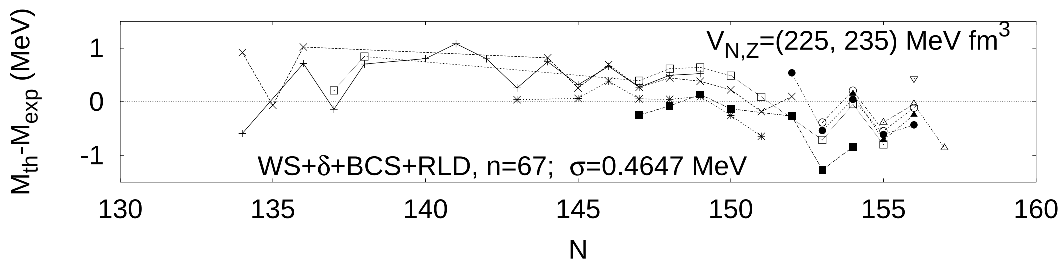

Figure 1: Theoretical and experimental mass differences (MeV) for 67 heaviest elements in RLD + Woods-Saxon + δ-pairing BCS model vs. neutron number N. The rms deviation $\sigma = 0.465$MeV

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Tuesday Morning
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Tuesday Morning 1 - Nuclear Structure

Name/email	Institution	Title
Scheit, Heiko h.scheit@mpi-hd.mpg.de	Max-Planck-Insitut fuer Kernphysik	Coulomb Excitation of Neutron-Rich Beams at REX-ISOLDE
Yamada, Kazunari nari-yamada@riken.jp	RIKEN	The First Measurement of Reduced Transition Probabilities for First 2^+ Excited State in ^{46}Cr, ^{50}Fe, and ^{54}Ni
Wiedenhoever, Ingo iwiedenhover@physics.fsu.edu	Florida State University	Investigation of Shell Structure in ^{42}Si
Sagawa, Hiro sagawa@u-aizu.ac.jp	University of Aizu	Deformation and Electromagnetic Moments of Light Exotic Nuclei
Pakarinen, Janne janne.pakarinen@phys.jyu.fi	University of Jyvaskyla	Probing the Three Shapes of ^{186}Pb in In-beam Measurement
Ideguchi, Eiji ideguchi@cns.s.u-tokyo.ac.jp	University of Tokyo	Study of high-spin states in ^{48}Ca region induced by secondary fusion reactions
Agrawal, Bijay bijay@shlomo.tamu.edu	Texas A&M University	Breathing mode energy and nuclear matter incompressibility coefficient within relativistic and nonrelativistic models
Baktash, Cyrus baktash@phy.ornl.gov	Oak Ridge National Laboratory	Evolution of Collectivity and Monopole Shifts in Neutron Rich Nuclei
Draayer, Jerry draayer@lsu.edu	Louisiana State University	Extended pairing model for strongly deformed nuclei
Yamagami, Masayuki yamagami@riken.jp	RIKEN	Collective excitations induced by pairing anti-halo effect
Iwasaki, Hiro hiwasaki@phys.s.u-tokyo.ac.jp	University of Tokyo	Intermediate-energy Coulomb excitation of the neutron-rich Ge isotopes around N=50
Name/email	**Institution**	**Title**

Coulomb Excitation of Neutron-Rich Beams at REX-ISOLDE

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The REX accelerator at the ISOLDE facility at CERN was built as a pilot experiment to demonstrate a novel technique to trap, bunch, charge breed and accelerate radioactive, exotic isotopes produced by the ISOLDE facility [1]. The commissioning of the accelerator was largely completed in 2002 and first physics experiments were performed in 2003. With the principle proven and due to its successful operation REX became a CERN user facility at the end of 2003.

The main experimental device operated in conjunction with the REX accelerator is the high-purity Germanium γ spectrometer MINIBALL [2]. Due to the sixfold electric segmentation of the outer detector electrodes and fully digital electronics the array features excellent granularity, energy resolution and rate capability.

The first experiments using MINIBALL at the REX accelerator focused on the structure of light neutron-rich nuclei. In particular Coulomb excitation and single-nucleon transfer reactions were used to study the collective and single-particle structure of neutron-rich Na and Mg isotopes [3,4]. Indeed, even though it was already discovered almost 30 years ago that the neutron-rich isotopes ^{31,32}Na are more tightly bound than expected, the unusual properties of the Na and Mg isotopes near the $N = 20$ shell closure are still the subject of strong theoretical and experimental investigation. Detailed experimental spectroscopic information is scarce and some results even contradict each other. For example, the published $B(E2; 0_{gs} \rightarrow 2^+)$ values for ^{30,32}Mg differ by as much as a factor of two [5-7]. The aim of our experiments is to study these nuclei by applying standard nuclear physics tools, such as (safe) sub-barrier Coulomb excitation and single-nucleon transfer reactions.

After shortly introducing the REX-ISOLDE facility and the MINIBALL array I will present first results on the above mentioned experiments and comment on the status and perspectives of MINIBALL at REX-ISOLDE.

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The First Measurement of Reduced Transition Probabilities for First 2^+ Excited State in ^{46}Cr, ^{50}Fe, and ^{54}Ni

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The proton-rich ^{46}Cr, ^{50}Fe, and ^{54}Ni nuclei have been studied by intermediate-energy Coulomb excitation in inverse kinematics. The reduced transition probabilities $B(\mathrm{E2}; 0^+_{\mathrm{g.s.}} \rightarrow 2^+_1)$ were measured for the first time. The excitation energy of the 2^+ state in ^{54}Ni was also determined from the γ-ray spectrum. This measurement completes the systematics of $B(\mathrm{E2}\uparrow)$ for the even-even nuclei of $T = 1$ pairs from $Z = 20$ to 28 region.

The experiment was performed at the RIKEN Accelerator Research Facility. A primary beam of 95 AMeV ^{58}Ni was used for bombarding a 0.34-mm-thick nickel target, and projectile fragments were selected by RIKEN Projectile-Fragment Separator. The fraction of each secondary beam was enhanced by about 10 times with the help of a newly constructed RF deflector system [1]. Secondary beams of ^{46}Cr and ^{50}Fe were focused on a 224 mg/cm^2 thick lead target, and a ^{54}Ni beam, on a 189 mg/cm^2 thick lead target. We measured de-excitation γ-rays in coincidence with the scattered particles using a new detector array DALI2 [2] consisting of 116 NaI(Tl) scintillators.

Figure 1 shows the plots of $B(\mathrm{E2}\uparrow)$ and energy of the first 2^+ states for the known even-even $T_z = -1$ nuclei from $Z = 20$ to 28 region. This result well represents the effect of proton shell closure in the vicinity of $Z = 20$ and 28, where the B(E2) values are decreased and E(E2) values are increased. We examined the behavior of the $Z = 28$ shell closure by comparing the $B(\mathrm{E2}\uparrow)$ values of nickel, chromium, and iron isotopes. In order to investigate the collectivities from a different view point, the ratio of neutron and proton multipole matrix elements $M_\mathrm{n}/M_\mathrm{p}$ were determined by combining known spectroscopic information of their mirror nuclei [4]. These results will be presented. Comparisons of the present results and theoretical calculations will also be discussed.

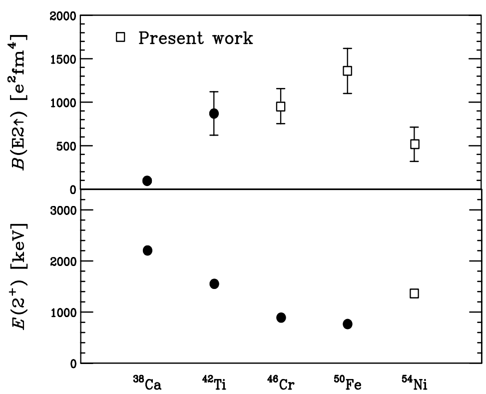

FIG. 1. $B(\mathrm{E2}\uparrow)$ and energy of the first 2^+ excited state for even-even $T_z = -1$ nuclei from $Z = 20$ to 28 region. Adopted values from [3] are indicated by filled circles.

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Investigation of Shell Structure in ^{42}Si

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The modification of magic numbers and the shell structure of very neutron-rich systems is one of the most intriguing subjects to be studied with present and future exotic beam facilities. In particular, the development of the N=28 shell closure in very neutron-rich systems has attracted a great deal of experimental and theoretical attention. In a SMMC study, Dean et al [1] concluded that the N=28 shell closure is "reasonably robust" and should persist in ^{42}Si. Regarding the proton shell structure, a study of the ^{48}Ca(d,^{3}He) reaction [2] indicates, that in ^{48}Ca, the gap between the proton $d_{5/2}$ and $s_{1/2}$ orbitals is quite large, which indicates a possible magic number for Z=14 in very neutron-rich nuclei. Both arguments together would suggest a doubly-magic character for ^{42}Si. In contrast to this argument, Werner *et al.* [3] predict that ^{42}Si has a strong oblate deformation and that the N=28 shell closure vanishes, as do Rodríguez-Guzmán, Egido and Robledo [4].

In order to investigate the character of ^{42}Si, we performed an experiment using a ^{44}S beam, generated in fragmentation of 140 MeV/u ^{48}Ca. The primary beam was delivered by the Coupled-Cyclotron Facility at the NSCL, and the secondary ^{44}S beam was selected with the A1900 fragment separator and delivered to the target position of the S800 spectrograph, where secondary reactions occurred. The secondary reaction products were characterized with the focal plane detectors of the magnetic spectrograph. Coincident γ rays were detected with the segmented Germanium array, SeGA, surrounding the S800 target position.

We observed two-proton knockout from the ^{44}S beam populating the ground state and excited states of ^{42}Si. Two aspects of this experiment allow us to study the character of the underlying shell-structure in ^{42}Si: The direct reaction character of two-proton knockout [5] allows to compare the observed cross-section to calculations using the eikonal-approach and, thus, estimate the number of valence protons present in the ^{44}S wave function. The second aspect lies in the observation of γ–rays to classify the collectivity and character of the excited nuclear states of ^{42}Si, thereby investigating the persistence of the N=28 shell gap. The results of this ongoing investigation will be presented.

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Deformations and Electromagnetic Moments of Light Exotic Nuclei

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We study the ground state and excited states of several isotopes using microscopic models. A deformed Hartree-Fock (HF) + BCS model with Skyrme interactions is performed to study the isotope dependence of deformation properties of C, N and Ne isotopes as a manifestation of Jahn-Teller effect. It is shown that shallow deformation minima appear in both the oblate and the prolate sides in ^{16}C, ^{17}C and ^{19}C having almost the same binding energies [1]. We discuss also shell model calculations to study magnetic moments, electric dipole and quadrupole transitions of B, C, N and Ne isotopes. We show clear empirical evidence of the isospin dependence of the effective charges of quadrupole moments in B isotopes in both proton and neutron drip line nuclei [2]. It is also pointed out that the isotope dependence of quadrupole moments and magnetic g-factors in the odd C isotopes will be useful to find out the deformation and unknown spin-parities of the ground states of these nuclei. Calculated electric quadrupole transitions between the first 2^+ states and the ground states of C and Ne isotopes are also compared with experimental data and found in quantitative agreement.

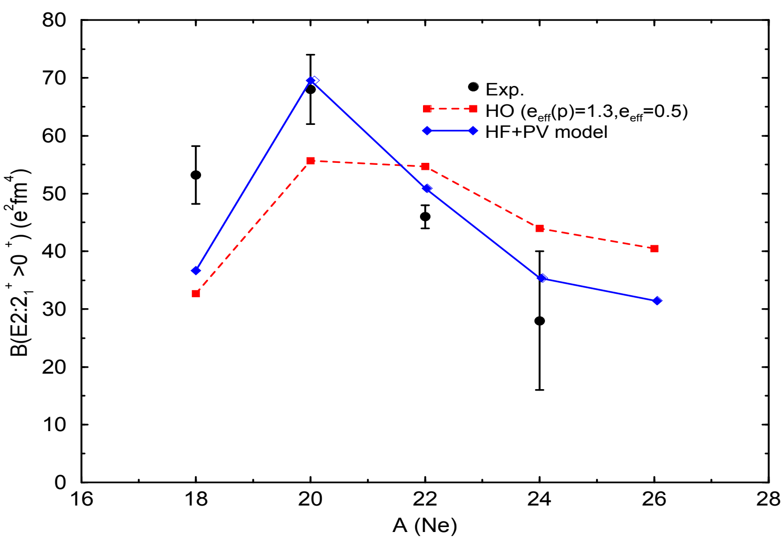

FIG. 1. Electric quadrupole transitions of Ne isotopes. The solid line is obtained by using the core polarization charges of microscopic Hartree-Fock and particle-vibration coupling model [2], while the dashed line is the results of constant effective charges with harmonic oscillator wave functions. The shell model wave functions are calculated with Warburton-Brown effective interaction.

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Probing the Three Shapes of ^{186}Pb in In-beam Measurement *

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One of the recent highlights in studies of exotic nuclei has been the discovery of three possible shapes of the ^{186}Pb nucleus in the vicinity of its ground state [1]. In the 0^+ ground state the ^{186}Pb nucleus is spherical. It is unique that two first excited states of ^{186}Pb identified in alpha-decay studies have also been found to be 0^+ states and associated with oblate and prolate deformation.

An yrast prolate rotational band in ^{186}Pb observed in earlier in-beam experiments confirms the existence of the low-lying prolate potential energy minimum [2]. It would be important to confirm the existence of the oblate minimum by observing a rotational band based on the oblate 0^+ state.

Detailed studies of ^{186}Pb have so far been very difficult as it can be produced in fusion evaporation reactions with cross-sections of the order of only 100 microbarn. By employing the joint-European JUROGAM array at the RITU gas-filled separator and the GREAT focal-plane spectrometer at JYFL we performed a Recoil-Decay-Tagging in-beam gamma-ray experiment for ^{186}Pb. High statistics gamma-gamma coincidence data were collected from the ^{106}Pd(^{83}Kr,3n)^{186}Pb reaction enabling us to identify the yrast prolate band and a new non-yrast band. Properties of this new band and its relation to nuclear shapes will be discussed.

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*This work was supported by the EU-IHR-ARI-RTD project EXOTAG under contract HPRI-CT-1999-50017

Study of high-spin states in ^{48}Ca region induced by secondary fusion reactions

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Studies of high-spin states in atomic nuclei by in-beam gamma-ray spectroscopy have provided detailed information on the nuclear structure. In such studies, high-spin states are achieved mostly through a fusion reaction using a combination of a stable-isotope beam and a stable-isotope target, since large angular momentum can be brought to the nucleus of interest in the reaction. However, nuclei produced in the fusion reaction are limited, in many cases, to the proton-rich side relative to the β-stability line. By utilizing a neutron-rich beam in the fusion reaction, nuclei will be produced in the neutron-rich side and the region available for high-spin studies will be largely expanded. Especially, in the ^{48}Ca region, nuclei can not be formed by fusion reaction because it is most neutron-rich Ca isotope. There, onset of collective excitation is expected due to the presence of deformed shell gaps in Z=20 and N=28 [1].

In order to actualize the method, experiments to produce low-energy secondary beams ($\sim$5MeV/nucleon), which is indispensable for inducing the fusion reaction, were performed at the RIKEN accelerator research facility. Neutron-rich secondary-beams, ^{37}P and ^{46}Ar, were produced at the RIPS Facility [2] in RIKEN by the fragmentation reactions of ^{40}Ar and ^{48}Ca primary-beams (63 MeV/nucleon), respectively, impinging on a thick ^{9}Be target. The energy of the secondary beam was lowered by using an Al wedge-shaped degrader at first momentum dispersive focal plane (F1) and a rotatable degrader placed at the second focal plane (F2). The secondary beams were transported to the final focal plane (F3) and irradiated on the secondary ^{9}Be target 10μm thick. By the secondary fusion reactions, ^{9}Be(^{37}P, xn)$^{46-x}$K and ^{9}Be(^{46}Ar, xn)$^{55-x}$Ti, high-spin states of these isotopes were investigated. The intensities of the secondary beams at F3 were about 1.0×10^{5} counts per second. Gamma rays from the secondary reaction were measured by using the CNS Ge array (GRAPE) [3], which is comprised of 18 segmented planar Ge detectors.

In the conference, experimental results obtained by the above two experiments will be presented.

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Breathing mode energy and nuclear matter incompressibility coefficient within relativistic and nonrelativistic models *

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The knowledge of the equation of state (EOS) of infinite nuclear matter (INM), is very important for understanding properties of nuclei, structure of neutron stars, supernova explosion and heavy-ion collisions. To extend our knowledge on the EOS around the saturation point, an accurate value of the INM incompressibility coefficient K is needed. Recently [1], very accurate measurements are carried out for the centroid energy E_0 of the isoscalar giant monopole resonance (ISGMR), also referred to as the breathing mode. Theoretically, the most sensitive probe to determine the value of K is the microscopic mean-field based random phase approximation (RPA). The value of K can be estimated by comparing the measured values of E_0 for the several nuclei with the ones obtained in the RPA. We review the current status of K as deduced from data on E_0.

At present, the non-relativistic Hartree-Fock (HF) -based RPA calculations for the ISGMR, with Skyrme and Gogny interactions, predict a value of K = 210 - 220 MeV. Recent relativistic mean field RPA (RRPA) calculations for the ISGMR yield a value of K = 250 - 270 MeV. This dependency of 10 - 20% in the value of K are quite significant in view of the good accuracy of 2 - 3% in the current experimental data for E_0. We will present results of our investigation resolving this discrepancy in the value of K.

1. We have generated parameter sets for Skyrme interaction, having K of about 260 MeV and yielding E_0 close to the experimental values, by fitting the same experimental data as considered for determining the parameters of an effective Lagrangian adopted in RRPA.

2. We provide for the first time accurate assessments of the consequences of violations of self-consistency in the HF-RPA theory as commonly used to calculate the energy E_0 of the nuclear breathing mode. We show that the uncertainties δE_0 introduced by various components contributing to self-consistency violations are large but have different signs. Surprisingly, our results for the ^{90}Zr and ^{208}Pb nuclei for several Skyrme type effective nucleon-nucleon interactions indicate that the net uncertainty ($\delta E_0 \sim 0.3$ MeV) is comparable to the experimental one.

In the view of the results of our investigation we may conclude that at present we have that $K = 230 \pm 20$ MeV.

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*This work was supported in part by the US Department of Energy under grant # DOE-FG03-93ER40773.

Evolution of Collectivity and Monopole Shifts in Neutron Rich Nuclei*

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It has been predicted that, near neutron drip line, diffused surface densities may produce a shell structure that resembles that of a harmonic oscillator with only a spin-orbit term [1]. This entails dramatic changes in the shell structure and collectivity of weakly bound nuclei. Although at present neutron drip line has been reached for only light elements, it is not too soon to develop a set of sensitive probes that could be used to discern the predicted structural changes in neutron-rich nuclei. In this abstract, we show evidence that: (a) quadrupole collectivity of the first 2^+ states (as a percentage of sum rule) *decreases steadily* across isotopic chains, and (b) the observed shifts in effective single-particle energies around ^{132}Sn may be traced to spin-isospin interactions (i.e., monopole drift) and are not due to a change in *L.L* or *L.S*, as has been recently suggested [2].

Quadrupole strength of first 2^+: It has long been assumed that the Grodzins rule, which states that (scaled) products of E(2^+).B(E2) are nearly constant, is obeyed reasonably well. A comprehensive review of the available data, however, clearly demonstrates that this product, which may be expressed as a percentage of energy-weighted sum rule, decreases steadily as a function of *N* for each isotopic chain. The decrease is *not* correlated with shapes, and persists even when we traverse from prolate to spherical, and back to strongly prolate deformations. The product decreases most steeply near magic numbers. Qualitatively, this trend may be attributed to the increasingly larger contributions of neutrons to the wave functions of 2^+ states in more n-rich nuclei. Division of the scaled E(2^+).B(E2) products by neutron separation energies results in a more constant behavior; thus producing a more reliable tool to predict B(E2) from the known E(2^+) values.

Evolution of effective single-particle energies near ^{132}Sn: Recent studies of the low-lying states in *sd* nuclei have indicated emergence of large shifts in the familiar shell gaps and the corresponding magic numbers at *N*=8 and 20 in n-rich nuclei. These shifts have been successfully reproduced in shell-model calculations by the Tokyo group [3], which trace their origin to strong attraction between $d_{5/2}$-$d_{3/2}$ spin-isospin partners. Similar effects have also been observed for the $\pi f_{5/2}$ configurations across n-rich isotopes of Cu, as well as for $\nu g_{7/2}$ orbitals in *proton-rich* *N*=51 isotones as their $g_{9/2}$ partner orbitals get filled. Similar effects are also expected in the ^{132}Sn region, where $g_{7/2}$-$g_{9/2}$, $d_{3/2}$-$d_{5/2}$, and $g_{7/2}$-$h_{11/2}$ spin-isospin partners may be occupied in isotopic and isotonic chains of semi-magic nuclei at *N*=81,83 and *Z*=49, 51. It is, therefore, crucial that we recognize and separate the changes in effective single-particle energies that are due to monopole shifts from the more exotic effects that might arise from diffused boundaries and modifications in the *L.L* or *L.S* terms in the potential.

We can draw the following conclusions from the available data for semi-magic nuclei with *Z*=49,51 and *N*=81,83:

(1) Many of the low-lying states (*e.g.,* $1/2^+$, $3/2^+$ in Sb, or $9/2^-$, $11/2^-$, $5/2^-$ and to some extent $3/2^-$ and $13/2^+$ states in *N*=83 isotones) receive significant contributions from the 2^+ and 3^- phonons in their corresponding cores.

(2) The energies of the $\pi g_{7/2}$ particles in Sb and $\nu h_{11/2}$ hole states in *N*=81 isotones are strongly affected by the $\pi g_{7/2}$x $\nu h_{11/2}$ attractive force (about 160 keV drop in $\pi g_{7/2}$ energy for each additional pair of $\nu h_{11/2}$). Therefore, changes in the effective energies of $\pi g_{7/2}$ relative to other orbitals do not point to exotic effects (*e.g.,* a change in *L.S* strength [2]), unless the monopole shifts have been accounted for.

(3) A comparison of the experimental data for neutron orbitals above and below ^{132}Sn with the calculated binding energies using several variations of the Skyrme force indicates that these forces *overestimate L.S and underestimate L.L splittings* in this region [4]. A similar study of *L.L* and *L.S* strengths is underway for other doubly-magic nuclei.

It is very instructive to investigate if use of additional spectroscopic data in semi-magic nuclei could help define some of the poorly-constrained parameters in these forces, thus resulting in a better agreement with data. An exploratory effort in this direction is under consideration [4].

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[3] T. Otsuka *et al.,* Phys. Rev. Lett. **87**, 082502 (2001).
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* Oak Ridge National Laboratory is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 with the U.S. Department of Energy.

EXTENDED PAIRING MODEL FOR STRONGLY DEFORMED NUCLEI

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A mean-field plus an extended pairing interaction Hamiltonian with many-pair correlation terms is proposed for describing well-deformed nuclei [1]. Eigenvalues of the model can be determined by solving a single transidental equation. The results shows that even through the extended pairing includes many-body interactions, the one- and two-body terms continue to dominate the dynamics for small values of the pairing strength. However, as the strength of the pairing interaction grows, the higher-order terms grow in importance and ultimately dominate. A numerical study of even-odd mass differences in the $^{154-171}$Yb isotopes demonstrates the applicability of the theory.

1. Feng Pan, V. G. Gueorguiev, and J. P. Draayer, Phys. Rev. Lett. **92** (2004) 112503.

Collective excitations induced by pairing anti-halo effect

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Low-frequency collective vibrational excitations in neutron drip line nuclei are one of the most interesting subjects in nuclear structure physics. Naively we expect low-frequency vibrational modes associated with low-density neutron matter (neutron skin and halo). A famous one is soft dipole mode. However it is a fundamental question whether such collective modes can really appear in loosely bound nuclei.

Vibrational excitations are represented as coherent superposition of 1p-1h states. In stable nuclei, because the Fermi energies are deep, 1p-1h states between tightly bound single-particle states having similar spatial characters only contribute, and these 1p-1h states concentrate around the nuclear surface. Around neutron drip line, by contrast, 1p-1h states between tightly bound , loosely bound, resonance, and non-resonant continuum states contribute. Because each single-particle state has different spatial extent, 1p-1h states among them have different spatial characters. Therefore it is a non-trivial problem whether vibrational modes can be realized as a result of coherency between such 1p-1h states.

In this study, important features of low-frequency collective vibrational excitations in neutron drip line nuclei are discussed [1]. We emphasize that pairing anti-halo effect in the Hartree-Fock-Bogoliubov (HFB) theory [2] plays crucial roles to realize collective motions in loosely bound nuclei. We study the spatial properties of one particle - one hole (1p-1h) states with/without selfconsistent pairing correlations by solving simplified HF(B) equations in coordinate space. Next, by performing Skyrme-HFB plus selfconsistent quasiparticle random phase approximation (QRPA) we investigate the first 2^+ states in neutron rich Ni isotopes. Three types of calculations, HFB plus QRPA, resonant BCS plus QRPA (no pairing anti-halo effect), and RPA are compared.

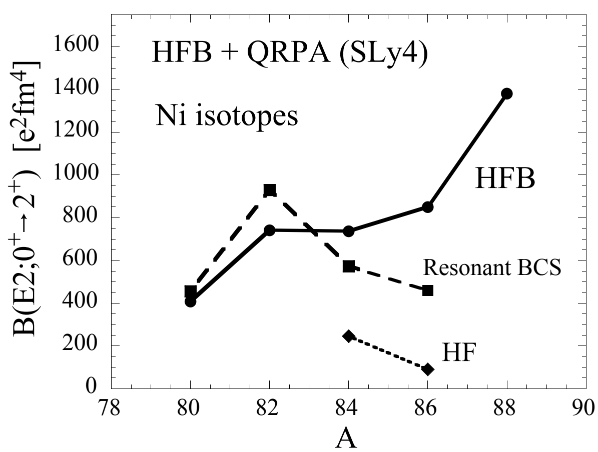

Figure 1: The $B(E2)$ values and the excitation energies of the first 2^+ states in neutron rich Ni isotopes calculated by HFB plus selfconsistent QRPA, resonant BCS plus QRPA (no pairing anti-halo effect), and RPA with Skyrme SLy4 force.

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Intermediate-energy Coulomb excitation of the neutron-rich Ge isotopes around N=50

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We have studied intermediate-energy Coulomb excitation of the neutron-rich Ge isotopes around N=50 using radioactive-ion (RI) beams of $^{78-82}$Ge incident on Pb and C targets. Among the various reactions employed in the γ-ray spectroscopy with intermediate-energy RI beams [1–6], Coulomb excitation affords unique opportunities for measuring both energies and transition probabilities B(E2) for the low-lying 2^+ states. A particular interest of the present work is focused on systematic trends of quadrupole collectivity of the neutron-rich nuclei in the vicinity of the N=50 shell closure. In addition, the two-step excitation at an intermediate energy has also been studied to examine a possible access to higher excited states.

The experiment was performed at the RIPS facility in RIKEN. The secondary beams of the Ge isotopes were produced using a ^{86}Kr primary beam accelerated up to 63 AMeV by the RIKEN Ring Cyclotron (RRC) incident upon a 66.2-mg/cm^2-thick ^{9}Be target. The linear accelerator complex of the RFQ+RILAC+CSM scheme was used as an injector to RRC, which facilitated an intense ^{86}Kr beam with a maximum beam intensity of 100 pnA. Particle identification of the incident beams, which contained various isotopes around $A\sim80$, was performed by measuring magnetic rigidity, time-of-flight (TOF), and energy loss (ΔE) information. The secondary beams were transported to the experimental area, where a Pb (or C) target was set to excite the projectiles. The subsequent γ transitions were measured by the DALI2 array, which is composed of 158 NaI(Tl) scintillators. Scattered particles were detected and identified by a Si telescope and a NaI(Tl) calorimeter, which provided energy-loss (ΔE) and E information, respectively. The Si telescope consisted of 16 silicon detectors, while the NaI(Tl) calorimeter consists of 132 NaI(Tl) crystals. The E information was also useful to identify the different charge states contained in the incident beams.

Figure 1 shows the γ-ray energy spectra obtained in coincidence with $^{78-82}$Ge. The measured energies of the low-lying E2 states and corresponding B(E2) values will be presented and discussed in relation to the N=50 magicity far from stability. The experimental results on the two-step excitation applied for the $0^+ \to 2^+ \to 4^+$ transition of ^{76}Ge will also be presented.

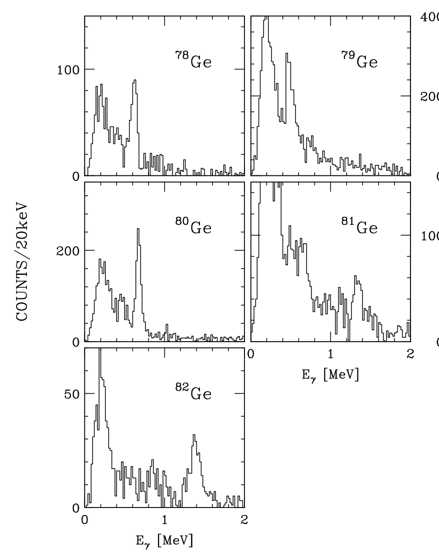

FIG. 1. Doppler-corrected γ-ray energy spectra in the $^{78-82}$Ge+Pb scattering.

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Tuesday Morning
Session 2
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Tuesday Morning 2 - Nuclear Structure

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Gadea, Andres Andres.Gadea@lnl.infn.it	INFN-Laboratori Nazionali di Legnaro	First results of the CLARA-PRISMA setup installed at LNL
Becker, Frank f.becker@gsi.de	GSI Darmstadt	Status of the RISING project at GSI
Ekman, Jorgen jorgen.ekman@nuclear.lu.se	Lund University	News on Mirror Nuclei in the sd and fp Shells.
Satula, Wojtek satula@fuw.edu.pl	University of Warsaw	Cranking in isospace: applications to neutron-proton pairing and the nuclear symmetry energy
Hamilton, Joseph j.h.hamilton@vanderbilt.edu	Vanderbilt University	Evidence for Soft Chiral Vibrations in ^{106}Mo
Fortunato, Lorenzo fortunat@pd.infn.it	INW-Instituut voor Nucleaire Wetenschappen	Soft triaxial solution of the Bohr hamiltonian in the vicinity of $\gamma=\pi/6$ and its extension to the sector $0<\gamma<\pi/3$
Keyes, Kirstine kirstine.keyes@paisley.ac.uk	University of Paisley	High Spin Studies of Neutron-Rich Nuclei Produced in Deep Inelastic Reactions
McCutchan, Libby elizabeth.ricard-mccutchan@yale.edu	Yale University	^{132}Te and single-particle density dependent pairing
Corradi, Lorenzo corradi@lnl.infn.it	INFN-LNL, Laboratori Nazionali di Legnaro	Multinucleon transfer reactions studied with the spectrometer PRISMA
Terasaki, Jun jterasak@physics.unc.edu	University of North Carolina at Chapel Hill	Skyrme-QRPA Calculations of Multipole Strength in Exotic Nuclei
Nakatsukasa, Takashi takashi@nucl.ph.tsukuba.ac.jp	University of Tsukuba	Unrestricted TDHF studies of nuclear response in the continuum
Name/email	**Institution**	**Title**

First results of the CLARA-PRISMA setup installed at LNL

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The successful installation, at LNL (Legnaro), of the setup consisting of CLARA [1], an array of 25 Clover (EUROBALL type) Ge detectors, placed at the target position of the PRISMA[2] magnetic spectrometer, has been completed at the beginning of 2004 (see Fig.1).

As a consequence of the CLARA array granularity (100 Ge crystals), photopeak efficiency (≈3%) and the PRISMA large acceptance (≈80 msr, and 20% $\Delta p/p$), the setup has become an excellent tool to investigate the structure of neutron rich nuclei, populated in multinucleon transfer reactions and deep inelastic collisions with stable beams. It is also suitable to study non-yrast states, with relatively simple structure, populated through few nucleon transfer reactions with heavy ions.

PRISMA allows the identification of the reaction products opening the possibility to go further away from stability in comparison with previous experimental activities using the aforementioned reactions.

The setup has been commissioned in the first three months of the year and since March is full operational. Five experiments had been performed, with beams delivered by the LNL tandem and the ALPI linac.

In the present contribution the main features of the setup as well as the outcome, from the preliminary analysis of some experiments, will be described. The results of the 82Se (515MeV) + 238U multinucleon transfer reaction, populating nuclei in the region with N≈50, will be discussed, focusing on the evolution of the nuclear structure at the N=50 shell closure.

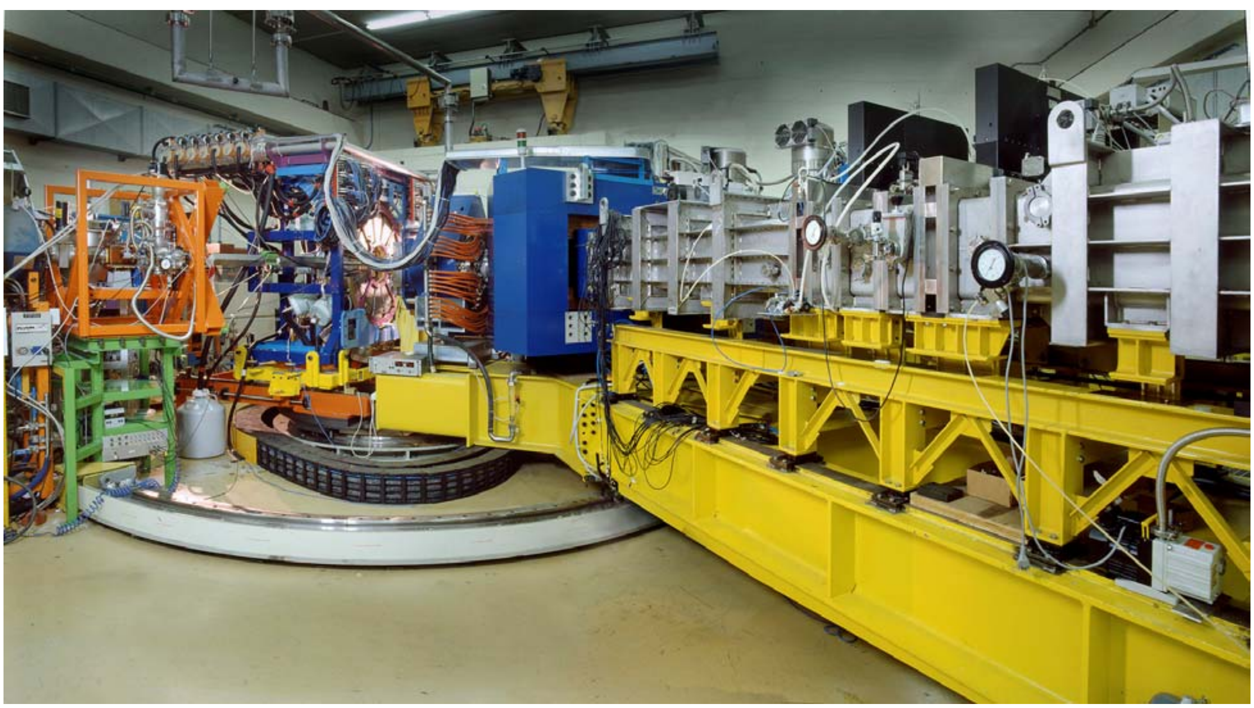

FIG. 1. The CLARA-PRISMA setup

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[2] A.Gadea et al., Eur. Phys. Jour. A20 (2004) 193

Status of the RISING project at GSI

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The RISING setup (*R*are *IS*otope *IN*vestigations at *G*SI) [1, 2] consists of the fragment separator FRS and an array of EUROBALL Ge-Cluster detectors together with BaF_2 detectors (HECTOR) placed at the final focus of the FRS. The SIS/FRS facility [3] provides secondary beams of unstable rare isotopes produced via fragmentation reactions or fission of relativistic heavy ions. These unique radioactive beams have sufficient intensity to perform gamma-ray spectroscopy measurements. In the first campaign fast beams at ~ 100 A·MeV were used for relativistic Coulomb excitation and secondary fragmentation experiments. Coulomb excitation at intermediate energy is a powerful spectroscopic method to study low-spin collective states of exotic nuclei. It takes advantage of the large beam velocities and allows the use of thicker secondary targets. Unwanted nuclear contributions to the excitation process are excluded by selecting reactions with an extremely forward scattering angle, corresponding to a large impact parameter. Contrary to Coulomb excitation, fragmentation reactions at the secondary target are a universal tool to produce exotic nuclei in rather high spin states. Besides being an excellent tool to investigate radioactive fragments up to higher spin states, fragmentation reactions provide a selective trigger, particularly suppressing the huge background of purely atomic interaction events.

The RISING setup is optimised to study the following subjects of exotic nuclei: the shell structure of doubly magic nuclei such as ^{56}Ni and ^{100}Sn and their vicinity, the evolution of shell structure towards extreme isospin, the investigation of shapes and shape coexistence around the N~Z line and the N=Z mirror symmetry, as well as collective modes, for instance the giant dipole resonance (GDR) in proton deficient nuclei (N>>Z).

In a first campaign in 2003 three experiments on Coulomb excitation and one on secondary fragmentation were performed. In all Coulomb excitation experiments a gold target was used while in the secondary fragmentation experiment a ^{9}Be target was placed at the final focal plane of the FRS.
In a pilot experiment a primary ^{84}Kr beam was used. The aim was to investigate the feasibility of Coulomb excitation measurements under the best beam conditions. The $2^+ \rightarrow 0^+$ transition in ^{84}Kr was used to study particle-gamma angular correlations and the impact parameter dependence at relativistic energies.
Two relativistic Coulomb excitation measurements with secondary beams were performed to measure B(E2) values of the first excited 2^+ state. Excitation of ^{56}Cr was applied in order to investigate the shell structure of nuclei with extreme isospin. In the case of ^{56}Cr the secondary beam was produced by fragmentation of a primary ^{84}Kr beam. In the second experiment fragmentation of a primary ^{124}Xe beam produced the secondary ^{108,112}Sn beams. The measurement of the electromagnetic transition probability in the neutron deficient nucleus ^{108}Sn gives insight in the nuclear structure near the heaviest N=Z nucleus ^{100}Sn. It is a sensitive test of E2 correlations related to core polarization. The already measured B(E2) value in ^{112}Sn serves as a normalisation.
The secondary fragmentation reaction was applied to study the mirror pair ^{53}Mn/^{53}Ni. The identification of the so far unknown first excited states in ^{53}Ni provides information on isospin symmetry and Coulomb effects at a large proton excess as well as a rigorous test of the shell model. A secondary beam of ^{55}Ni and ^{55}Co was produced by the fragmentation of a primary ^{58}Ni beam. The fragmentation of the secondary beams produced many exotic nuclei, inter alia the nuclei of interest ^{53}Mn and ^{53}Ni.
The present RISING setup will be described and the first results will be discussed.

[1] http://www-aix.gsi.de/~wolle/EB_at_GSI/rising.html
[2] H.-J. Wollersheim et al., submitted to NIM A
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News on Mirror Nuclei in the *sd* and *fp* Shells.

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The isospin T is a good quantum number under the fundamental assumptions of charge symmetry and charge independence of the strong force, which imply that the proton and neutron can be viewed as two different states of the same particle, the nucleon. However, it has long been expected and recently been shown [1] that a small part of the nucleon-nucleon interaction adds to the Coulomb force in violating the isospin symmetry. Isospin breaking effects can be studied in pairs of mirror nuclei, in which the number of protons and neutrons are interchanged. The experimental studies so far have been concentrated to the $1f_{7/2}$ shell, i.e., nuclei between ^{40}Ca and ^{56}Ni. In this contribution we present novel results on mirror nuclei in the *sd* and *fp* shells, which to a large extent call for interpretations that go beyond the traditional picture:

1) Excited states have recently been identified in ^{35}Ar. A comparison with the mirror nucleus ^{35}Cl shows two remarkable features: (i) A surprisingly large energy difference for the $13/2^-$ states, in which the electromagnetic spin-orbit term — hitherto overlooked — is shown to play a major role and (ii) a very different decay pattern for the $7/2^-$ states which provides direct evidence of isospin mixing [2].

2) The $A = 51$ mirror nuclei ^{51}Fe and ^{51}Mn have been studied previously, but only in terms of Mirror Energy Difference (MED) diagrams of the yrast $1f_{7/2}$ sequence. Recently, the lifetimes of the yrast $27/2^-$ states have been measured using the Cologne plunger coupled to the GASP Ge array [3]. These results allow for a precise determination of the effective charges, or ultimately the isospin-vector component of the polarization charges. In addition, core excited states have been identified in the $T_Z = -1/2$ partner ^{51}Fe following two Gammasphere experiments [4]. This observation makes it possible to construct MED diagrams for this class of states for the first time. Comparison with predictions from shell-model calculations will be presented.

3) Excited states in the $T_Z = -1/2$ nucleus ^{61}Ga [5] have been identified following an HRIBF experiment using the CLARION Ge array coupled to the Recoil Mass Separator (RMS). ^{61}Ga thus represents one of the heaviest $T_Z = -1/2$ nuclei where excited states are known. From the same experiment preliminary data on excited states tentatively assigned to the $T_Z = -1$ nucleus ^{62}Ge will be presented. In both the $A = 61$ and $A = 62$ mirror nuclei, particle excitations from the $2p_{3/2}$ orbit to the $1f_{5/2}$ orbit are present in the excitation scheme, which allows the study of the influence of electromagnetic spin-orbit effects and radial effects on the resulting MED diagrams. The experimental results also indicate the presence of particle decaying states in the weakly bound ^{61}Ga nucleus.

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[2] J. Ekman *et al.*, Phys. Rev. Lett. **92** (2004), in press.
[3] R. du Rietz *et al.*, to be published.
[4] J. Ekman *et al.*, to be published.
[5] L-L. Andersson, E. Johansson *et al.*, to be published.

Cranking in isospace: applications to neutron-proton pairing and the nuclear symmetry energy*

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The proper treatment of the isospin degree of freedom is crucial for our understanding of low-energy nuclear structure. We shall present selected applications of the iso-cranking technique which represents the lowest order approximation to the isospin projection after variation and, due to its internal simplicity, offers a very intuitive understanding of the basic physics mechanisms underlying phenomena like isoscalar pairing or the nuclear symmetry energy. We will briefly discuss the role and the response of the isovector and isoscalar pair fields to this generalized rotation [1]. In particular, we will focus our attention on the microscopic structure of the nuclear symmetry energy (NSE) within the Skyrme-Hartree-Fock (SHF) method [2]. We will demonstrate, that the NSE origins in part from the discreteness of the single-particle levels characterized by the mean spacing $\sim \varepsilon$ which is governed essentially by the isoscalar mean-potential. In addition, we will discuss the influence of non-localities on the second component of the NSE, the part related to the isovector mean-potential. This part, in spite of the complexity of the Skyrme isovector potential, can be characterized essentially by a single number, the strength of the effective $\sim \frac{1}{2}\kappa\hat{T}^2$ interaction, with surprisingly high accuracy, see Fig. 1. Finally we will discuss the mass-dependence of the NSE, Fig. 1, as well as the possible impact of our results on self-consistent mass calculations based on Skyrme forces.

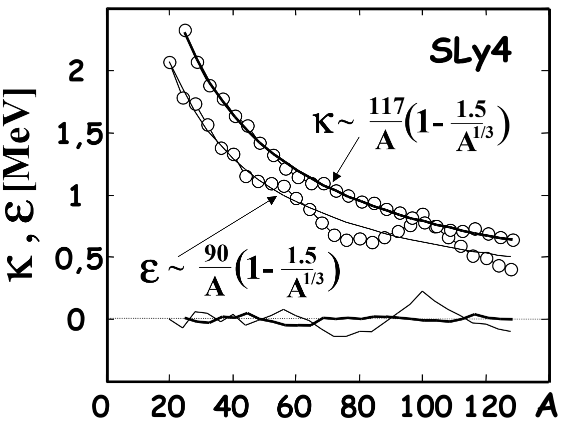

FIG. 1: Contributions to NSE due to the isoscalar $\sim\varepsilon$ and isovector $\sim\kappa$ mean SHF potentials. Calculated points are marked with open dots. Solid lines show smooth average trends and their deviations from the calculated curves. Average mass dependence of ε and κ is given in the figure.

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* This work was supported by the Polish Committee for Scientific Research and by the Göran Gustafsson Fundation.

Evidence for Soft Chiral Vibrations in ^{106}Mo

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High spin states in neutron-rich ^{106}Mo nuclei were investigated by detecting the prompt γ-rays in the spontaneous fission of ^{252}Cf with Gammasphere. Several new quasiparticle bands are observed in both nuclei. Two pairs of ΔI=1 bands in ^{106}Mo are found to have all the characteristics of a new class of chiral doublets. Chiral bands with two sets of ΔI=1 bands can occur in well deformed triaxial nuclei when the angular momentum has substantial components on all three principal axes of the triaxial density distribution. Examples of chiral band pairs are found in odd-odd nuclei around Z=59 and N=75 and predicted around Z=43, N=65 [1] associated with the angular momentum of high j proton particles and neutron holes. Chirality is a geometrical concept that derives only from the orientation of the angular momentum with respect to the triaxial shape [1], which is by no means restricted to odd-odd nuclei. To demonstrate the general nature of chirality, it is important to find chiral sister bands with different quasiparticle composition. Here we report the first observation of a pair of chiral vibrational sister bands (Fig. 1). Tilted axis cranking calculations support the chiral assignment and indicate that the chirality is generated by only the neutrons. The calculations also indicate that the two bands which correspond to the zero and one phonon chiral vibration should have exactly the decay pattern where one band decays out to the one phonon γ-vibrational band and the other decays out to two phonon γ-vibrational band as in Fig. 1. This different mechanism, which generates the chirality here, as compared to known cases, helps establish the general nature of the concept.

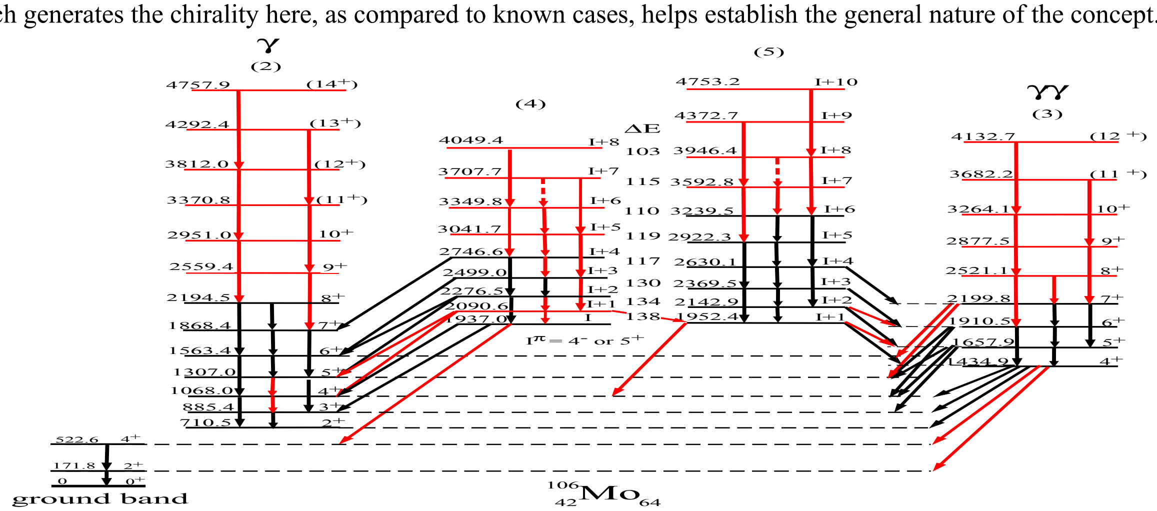

FIG. 1. Decay patterns of chiral bands into γ and γ- γ bands in ^{106}Mo.

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Soft triaxial solution of the Bohr hamiltonian in the vicinity of $\gamma = \pi/6$ and its extension to the sector $0 < \gamma < \pi/3$

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A solution of the stationary Schrödinger equation

$$H_B \Psi(\beta, \gamma, \theta_i) = E \Psi(\beta, \gamma, \theta_i)\,,$$

for the Bohr collective hamiltonian, $H_B = T_\beta + T_\gamma + T_{rot} + V(\beta, \gamma)$ is presented for the $\beta-$soft, $\gamma-$soft triaxial rotor making use of a harmonic potential in γ and Coulomb-like and Kratzer-like potentials in β:

$$V(\beta, \gamma) = V_1(\beta) + \frac{V_2(\gamma)}{\beta^2}\,,$$

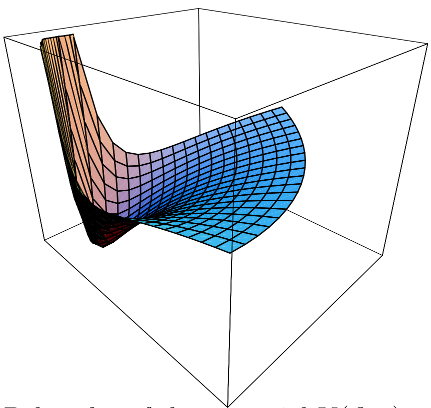
with

$$V_1(\beta) = \frac{\hbar^2}{2B_m}\left(-\frac{A'}{\beta} + \frac{B'}{\beta^2}\right), \qquad V_2(\gamma) = \frac{\hbar^2 C'}{2B_m}(\gamma - \gamma_0)^2\,.$$

The above Schrödinger equation is separable and can be solved in the vicinity of $\gamma_0 = \pi/6$, thus providing a paradigm for the spectrum of soft triaxial rotors.
It has been shown [1] that, while the $\gamma-$angular part in the present case gives rise to a straightforward extension of the rigid triaxial rotor energy in which now an additive harmonic term appears, the inclusion of the β part results instead in a non-trivial expression for the energy spectrum:

$$\epsilon(n_\gamma, n_\beta, L, R) = \frac{A^2/4}{\left(\sqrt{9/4 + B + \omega_{L,R,n_\gamma}} + 1/2 + n_\beta\right)^2}\,,$$

with $\omega_{L,R,n_\gamma} = \sqrt{C}(2n_\gamma + 1) + L(L+1) - \frac{3}{4}R^2$. In this case the projection of the angular momentum on the 1-axis, R, is a good quantum number. The negative anharmonicities of the energy levels with respect to a simple rigid model are in qualitative agreement with general trends as obserbed in experimental data. A tentative application to the spectrum of ^{192}Pt is proposed.
Recently it has become possible to extend these results to soft triaxial rotors with any asymmetry in the sector $0 < \gamma < \pi/3$ by means of a group theoretical approach based on the su(1,1) algebra.



Polar plot of the potential $V(\beta, \gamma)$ with minimum in $\gamma_0 = \pi/6$.

The components of the moment of inertia are defined here, neglecting fluctuations in the $\gamma-$variable, as

$$A_\kappa = \frac{1}{4\sin^2(\gamma_0 - 2\pi\kappa/3)}\,.$$

This model contains in total 3 parameters (2 from the two potentials and one of the above components, or alternatively γ_0) and provides a simple model for the interpretation of collective spectra of a large number of nuclei that do not posses axial symmetry.
This extension automatically generates the particular results obatined above when $\gamma_0 = \pi/6$.

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High Spin Studies of Neutron-Rich Nuclei Produced in Deep Inelastic Reactions*

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The neutron-rich Na and Mg nuclei around the N=20 shell closure have attracted intense international interest both in experimental and theoretical investigations. In the present work, high spin states of neutron-rich nuclei were populated in deep inelastic reactions using a beam of ^{26}Mg at 160MeV incident on a ^{150}Nd target of thickness 700μm/cm^2.

The reaction was carried out using the EUROBALL IV array of escape-suppressed Ge detectors. The good resolving power of EUROBALL IV was further increased by combining it with the Binary Reaction Spectrometer, BRS, for the detection of projectile-like fragments. The BRS detector allows full reconstruction of the kinematics of the binary reaction by supplying information relating to the energy, Z and the (θ,φ) coordinates of the projectile-like fragments. Moreover, the BRS allows crucial Doppler corrections of the gamma-ray spectra to be performed.

*This work was supported by the E.P.S.R.C.

^{132}Te and single-particle density dependent pairing *

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Recent experiments in the A=130 region, especially Coulomb excitation studies, have revealed very interesting aspects of nuclear structure on the neutron-rich side of stability [1]. These experimental results have motivated new microscopic calculations [2].

The nucleus ^{132}Te was populated in β^- decay and studied through γ-ray coincidence spectroscopy with the CLARION array [3] at the Holifield Radioactive Ion Beam Facility (HRIBF). The new data has led to a significantly revised γ-decay scheme. Many new transitions were placed, and new levels proposed. A number of previous placements were found to be inconsistent with the new high quality coincidence data. Several previously proposed levels were shown not to exist. Some of these changes also appear in the unpublished work of Ref. [4].

Important changes to the level scheme consist of a number of new, likely 2^+, states below 2500 keV. Our results allow a test of very recent quasiparticle random phase approximation calculations [2] with a density dependent pairing force that accounts for the anomalous violation of the Grodzins rule above N = 82 in the Te isotopes. A comparison of the energies of the 2^+ states with those predicted in the calculations of Ref. [2] shows very good agreement. The correct number of low lying 2^+ levels is predicted and at approximately the observed energies.

Another important result is the removal of a 3^- state at 2280 keV. This fact in turn removes an incompatibility of the low lying negative parity states with possible shell model configurations and leads to a simple interpretation of their structure.

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Multinucleon transfer reactions studied with the spectrometer PRISMA

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The role played by pair modes degrees of freedom in multinucleon transfer processes is an interesting aspect of low energy heavy-ion reactions (see Ref. [1] and references therein for the last review on the subject). In inclusive measurements performed with high resolution magnetic spectrometers [2], multineutron and multiproton transfer channels have been identified, and possible signatures of pair transfer modes have been searched for by studying the behaviour of the differential and total cross sections. In the recently studied $^{40}Ca + ^{208}Pb$ system [3] the Q-value distributions provide additional interesting information. The two neutron pick-up channel shows a selective population of excitation energy region in ^{42}Ca close to the pairing vibrational states previously identified in light ion reactions. With the new large solid angle magnetic spectrometer PRISMA [4] coupled to the gamma array CLARA [5], it is now experimentally possible to measure the transfer strength to specific final states with high efficiency. Valuable information about the structure of those states can be derived from the study of their decay modes. Future possibilities include the probing of E0 transitions of highly excited 0^+ levels via different experimental approaches. A discussion will be presented on recent multinucleon transfer studies performed with spectrometers and on the ongoing experiments with PRISMA to elucidate the role played by the various degrees of freedom in the population of specific transfer channels.

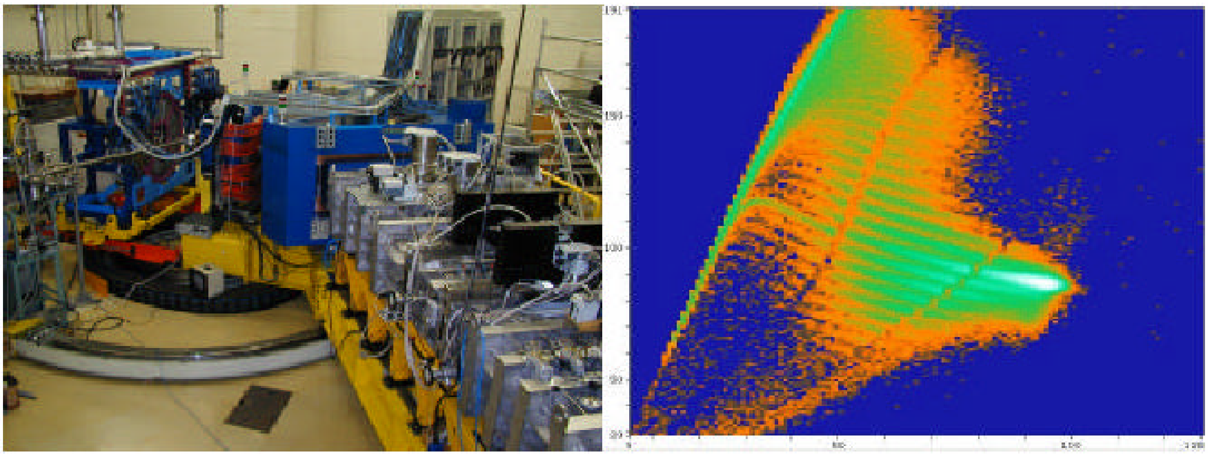

FIG. 1. Left : a picture of the PRISMA spectrometer in its present configuration coupled to the CLARA gamma array. Right : example of a DE (y-axis)-E (x-axis) matrix recently obtained in the reaction $^{64}Ni + ^{238}U$ at E_{LAB}=400 MeV and at the grazing angle of 64^0. The most intense "band" corresponds to Z=28, A=64. One observes proton stripping channels and proton pick-up channels mixed with fission events (lower and higher Z, respectively).

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[5] A.Gadea et al., Eur. Phys. J. A **20**, (2004)

Skyrme-QRPA Calculations of Multipole Strength in Exotic Nuclei

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Drip-line nuclei display collective properties that are sometimes different from those in stable nuclei. Here we study their dynamical properties, using Skyrme Hamiltonians that were developed to reproduce static properties near stability. We use a code that we recently developed to solve the quasiparticle random phase approximation (QRPA) equations for even-even spherical nuclei in the "canonical basis", which includes continuum states. The code allows us to study both low-lying vibrations and giant resonances of nuclei near the drip-lines.

After discussing the code's accuracy, we systematically examine $J^\pi = 1^-$ and 2^+ strength functions in the Ca, Ni, and Sn isotopes. FIG. 1 shows an example: isoscalar 1^- strength functions in two drip-line Sn isotopes. The strength increases significantly and the peak energy moves down dramatically as the neutron number increases.

This work was supported in part by the U.S. Department of Energy under Contract Nos. DE-FG02-96ER40963 (University of Tennessee), DE-AC05-00OR22725 with UT-Battelle, LLC (Oak Ridge National Laboratory), and DE-FG05-87ER40361 (Joint Institute for Heavy Ion Research); DE-FG02-97ER41019 (University of North Carolina); and by the National Science Foundation Contract No. 0124053 (U.S.-Japan Cooperative Science Award)

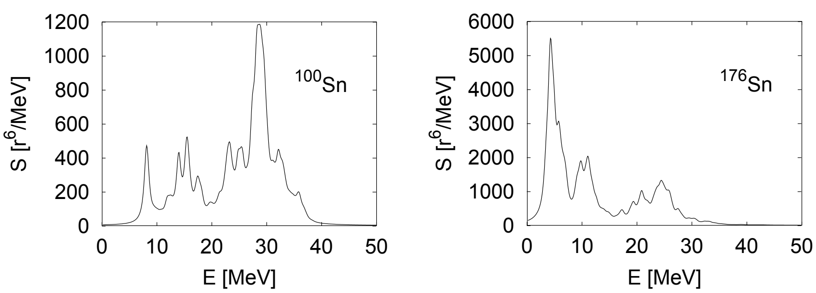

FIG. 1. Isoscalar dipole strength functions for ^{100,176}Sn, calculated with the Skyrme parameter set Skm* and a mixed density-dependent pairing force [1].

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Unrestricted TDHF studies of nuclear response in the continuum

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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 continuous, 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 [2,3].

Using techniques of the time-dependent Hartree-Fock (TDHF) theory in real time and real space, 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 continuum response functions. The same method was successfully applied to photoabsorption spectra of molecules [2]. It is found that the continuum can be well approximated with the ABC if the complex potential satisfies a certain criterion. The ABC has also been proved to be useful for description of breakup reactions in weakly bound nuclei [4].

In this presentation, we discuss properties of ground and excited (resonance) states embedded in the continuum for spherical and deformed nuclei. We show here an example of our calculation with SGII force (Fig. 1). In Fig. 1 (a), a result of the box boundary condition (BBC), $\psi(\mathbf{r}) = 0$ at $r = 20$ fm, is also shown by a thin line. Comparing ABC and BBC results, we see a strong damping according to the particle escape. The BBC calculation must exhibit number of spurious peaks in strength distributions after the Fourier transform from time to energy. The calculated ground state of a stable nucleus, ^{24}Mg, is well-deformed and the $E1$ resonance peak shows a deformation splitting (Fig. 1 (b)). In neutron-rich nuclei, we find a significant broadening of resonance peaks as well as a low-lying soft-dipole peak. We also discuss effects of the time-odd components in the Skyrme energy functional upon nuclear dynamics.

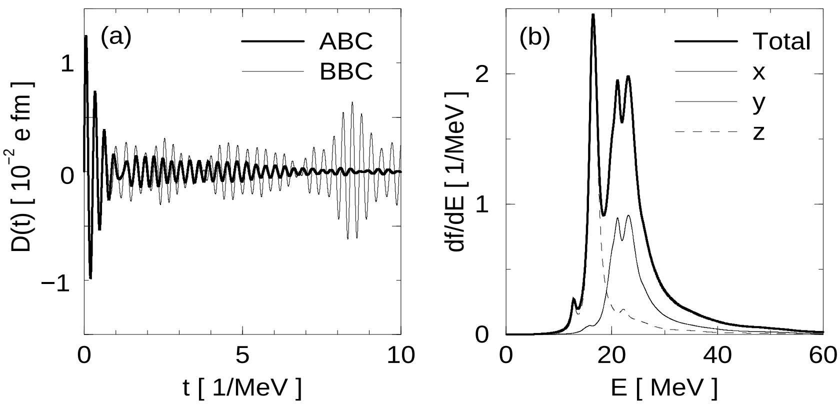

FIG. 1. Time evolution of electric dipole moment parallel to the symmetry axis with and without the continuum for ^{24}Mg; ABC (thick) and BBC (thin line), respectively. (b) Calculated $E1$ oscillator strength distribution in ^{24}Mg.

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Tuesday Afternoon Session Reactions

Tuesday Afternoon - Reactions

Name/email	Institution	Title
Loveland, Walt lovelanw@onid.orst.edu	Oregon State University	Fusion Studies with RIBs
Gade, Alexandra gade@nscl.msu.edu	Michigan State University	Spectroscopic factors in exotic nuclei
Catford, Wilton W.Catford@surrey.ac.uk	University of Surrey	First experiments on transfer with radioactive beams using the TIARA array
Mittig, Wolfgang mittig@ganil.fr	GANIL	Reactions induced beyond the dripline at low energy by secondary beams
Sakai, Hide sakai@phys.s.u-tokyo.ac.jp	University of Tokyo	First experiment of ^{6}He with polarized proton target
Raabe, Riccardo riccardo.raabe@fys.kuleuven.ac.be	K.U. Leuven	Fusion and other reactions around the barrier with weakly bound nuclei: ^{6}He + ^{238}U
Boutachkov, Plamen pboutach@nd.edu	University of Notre Dame	Doppler shift as a tool for studies with RIBs and spectroscopy of ^{7}He through isobaric analog states in ^{7}Li
Bonaccorso, Angela bonac@df.unipi.it	INFN	Unbound exotic nuclei studied by transfer to the continuum and projectile fragmentation
Roussel-Chomaz, Patricia patricia.chomaz@ganil.fr	GANIL	Study of the ground state wave function of ^{6}He via 2n transfer reaction ^{6}He(p,t)alpha
Name/email	**Institution**	**Title**

Fusion Studies with RIBs*

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One of the interesting aspects of the study of nuclear reactions induced by radioactive beams is the study of fusion using n-rich radioactive projectiles or halo nuclei. Various authors have suggested that there will be significant enhancements to the fusion cross sections for n-rich projectiles due to a lowering of the fusion barrier and the possible excitation of the soft dipole mode. They have further speculated that the use of these projectiles might lead to the successful synthesis of new or superheavy nuclei. For the halo nuclei, there are the competing effects of the enhanced fusion associated with the weakly bound halo nucleons and the effects of projectile breakup.

In the first generation of experiments on fusion enhancement with neutron-rich projectiles carried out in the late 1990s, we found [1] evidence for significant fusion enhancement in the reaction of $^{32,38}S$ with ^{181}Ta . We concluded that the fusion enhancement seen with the ^{38}S projectile was due to a lowering of the fusion barrier of 5.9±0.4 MeV in going from ^{32}S to ^{38}S in rough agreement with the systematics of the isospin dependence of the fusion barrier height. No evidence was found for any enhancement apart from this simple shift in barrier height as seen in Figure 1 where the reduced excitation functions for the two systems ($^{32,38}S$ + ^{181}Ta) are shown. Similar results were found in other investigations. [2] All of these studies were restricted to phenomena occurring well above the fusion barrier (due to the low radioactive beam intensities) and were not able to probe the sub-barrier region where many of the most interesting effects are thought to occur. In the pioneering work of Kolata, et al. [3] on the fusion of the nucleus ^{6}He with ^{209}Bi, large fusion enhancements were found near or below the barrier that were interpreted in terms of a ^{4}He transfer/breakup channel acting as a doorway state to fusion. In the interaction of the halo nucleus ^{11}Be with ^{209}Bi, no enhancement is observed. [4]

Second-generation radioactive beam facilities (such as HRIBF, and the CCF), with higher intensities of n-rich and halo beams, have opened up the possibility of extending the previous studies into the sub-barrier region to look for new phenomena. The recent result of Liang et al [5] seems to fulfill this promise. In a study of fusion in the reaction of ^{132}Sn with ^{64}Ni, an enhanced sub-barrier fusion cross section was found that exceeded that expected from the shift in the fusion barrier due to the n-rich projectile. Attempts to explain the observations using coupled channel calculations were not successful although the possibility of contributions from neutron transfer channels has not been fully evaluated. We are currently attempting to extend this result to systems where significant fusion hindrance might occur to determine the isospin dependence of fusion hindrance.

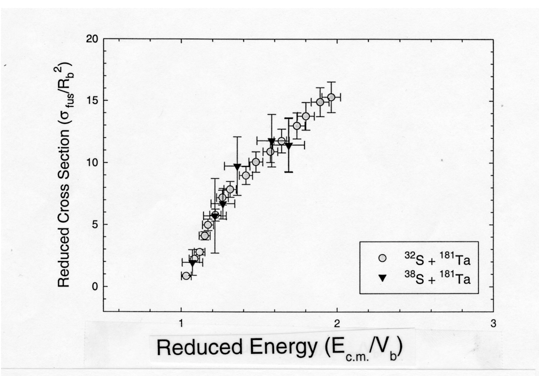

FIG 1. Reduced excitation function for the reaction of $^{32,38}S$ with ^{181}Ta [1].

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*This work was supported by the U.S. Department of Energy under grant DE-FG06-97ER41026

Spectroscopic factors in exotic nuclei

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The nuclear shell model pictures deeply-bound states as fully occupied by nucleons. At and above the Fermi sea, configuration mixing leads to occupancies that gradually decrease to zero. Correlation effects [1] (short-range, soft-core, long-range, and coupling to vibrational excitations) are beyond the effective interactions employed in shell model and mean-field approaches. The picture given above will be modified depending on the strength of the correlations. In stable nuclei a reduction of $R_s = 0.6 - 0.7$ with respect to the shell model has been established from $(e, e'p)$ data [2].

The question on the situaton beyond the valley of β-stability arises. At rare-isotope accelerators, very deeply and weakly bound exotic nuclei become accessible. The experimental approach to assess the occupation number of single-particle orbits in exotic nuclei are one-nucleon removal reactions at intermediate beam energies. The measured spectroscopic factor C^2S relates to the occupation number of the orbit involved [3]. Recent work at the NSCL has demonstrated that the spectroscopic factors deduced from knockout reactions are in agreement with the electron-scattering results [4].

Experiments close to stability and far out towards the drip lines have been performed at the Coupled Cyclotron Facility of the National Superconducting Cyclotron Laboratory at Michigan State University using NSCL's large-acceptance fragment separator A1900 and the high-resolution S800 magnetic spectrograph partly in conjunction with γ-ray spectroscopy. Results covering a wide range of nucleon separation energies across the nuclear chart will be presented and compared [5,6].

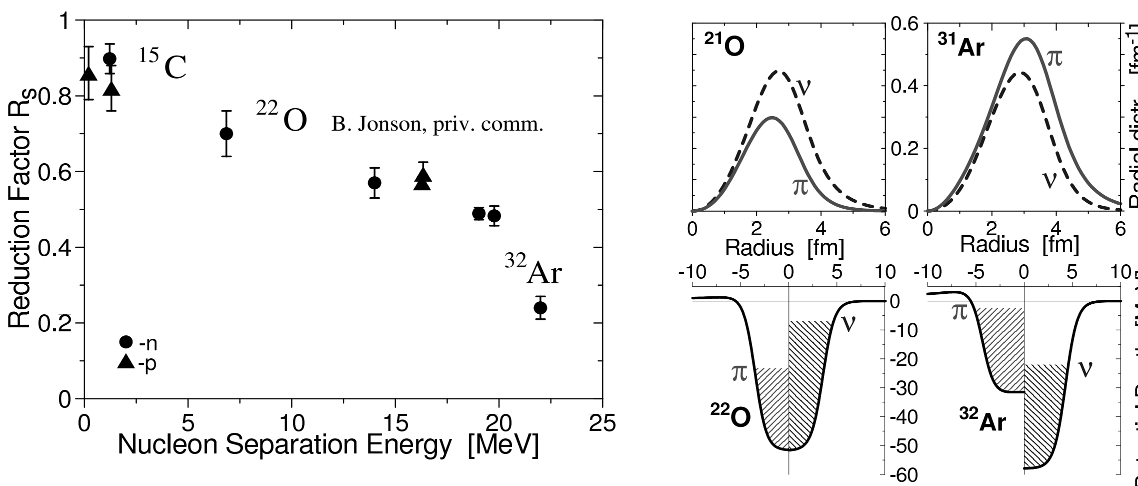

FIG. 1. Reduction in occupancy with respect to shell model as function of nucleon separation energy and differences in the radial distributions for isotones with widely different proton numbers. Figures taken from [5].

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First Experiments on Transfer with Radioactive Beams using the TIARA Array*

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Nucleon transfer reactions induced by radioactive beams can be studied with various approaches [1,2] and in the case of the classic single-nucleon reactions such as (d,p) or (d,t)/(d,^{3}He) the experimental design is strongly influenced by the decidedly inverse kinematics. The resolution for the excitation energies of final states is limited by target and kinematical effects, and is much poorer than for normal kinematics. For this reason, gamma-ray detection offers attractive supplementary information, although it brings with it certain challenges in terms of efficiency (important because of low radioactive beam intensities) and Doppler broadening (since the gamma-ray is emitted by the particle moving at the beam velocity). One of the first dedicated set-ups for this type of experiment is the TIARA silicon strip array [2,3] combined with the EXOGAM segmented germanium array. Together they comprise a highly compact, position sensitive particle array with 90% of 4π coverage, mounted inside a cubic arrangement of four segmented gamma-ray detectors in very close geometry with 67% of 4π active coverage.

The structure of ^{25}Ne has been studied via the (d,p) reaction. A pure ISOL beam of 10^5 sec^{-1} of ^{24}Ne at 10 MeV/A was provided by the SPIRAL facility at GANIL. This bombarded a $(CD)_2$ target of 2 mg/cm^2. The ^{25}Ne was detected at the focal plane of the VAMOS spectrometer where it was separated from the (intercepted) direct ^{24}Ne beam according to magnetic rigidity. Reaction protons were detected with little background over the 88% of 2π covered by TIARA backwards of $90°_{lab}$ (equivalent to $\theta_{cm} = 45°$), and with some background due to (d,d) reactions forward of 90°. Four resolved peaks were recorded between $E_x = 0$ and 4 MeV. The data confirm and extend the results from a multinucleon transfer study using the (^{13}C,^{14}O) reaction [4]. Further analysis is underway using the energies of coincident gamma-rays (which were recorded at 1 MeV with 17% FEP efficiency). The reactions ^{24}Ne(d,d′)^{24}Ne, ^{24}Ne(d,t)^{23}Ne and ^{24}Ne(d,^{3}He)^{23}F were recorded simultaneously and analysis of these is also underway.

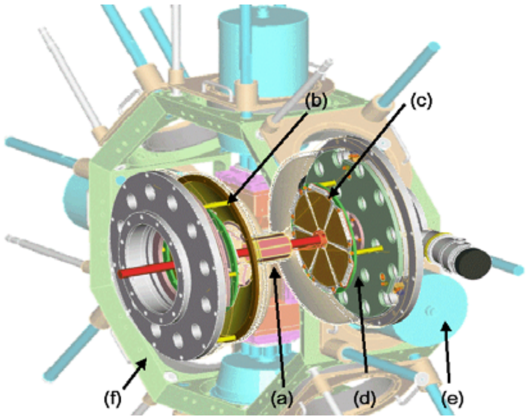

FIG. 1. A schematic cutaway drawing of the TIARA array shown inside a background image of the surrounding 4 detectors from EXOGAM: (a) Si barrel, (b) forward annular Si, (c) backward annular Si, (d) target selection wheel, (e) Ge dewar, (f) EXOGAM support. The central rod represents the beam, which enters from the right of the figure.

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*This work is supported by the UK EPSRC under research grants GR/N38510/01, GR/N38558/01 and GR/N38565/01.

Reactions induced beyond the dripline at low energy by secondary beams

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The low to medium energy acceleration of radioactive beams opens up specific possibilities for the study of nuclear reactions and nuclear structure. This energy domain is particularly well suited for the study of direct transfer reactions and resonant scattering. The study of nuclei far from stability interacting with simple target nuclei, such as protons, deuterons, ^{3}He and ^{4}He implies the use of inverse kinematics. The kinematics, together with the low intensities of the beams call for special techniques([1]). We tested a new detector, in which the detector gas is the target, an active target. This allows in principle a 4π solid angle of the detection, and a big effective target thickness without loss of resolution. The detector developped, called Maya, used isobutane C_4H_{10} as gas in the first experiment, and other gases are possible. The multiplexed electronics of more than 1000 channels allows the reconstruction of the events occurring between the incoming particle and the detector gas atoms in 3D. A first experiment with this detector was performed with an incoming beam of ^{8}He at 3.9MeV/n and the detector was filled with 1atm of isobutane. With this gas density, the beam was stopped in the detector, and thus the energy domain between the incident energy and zero energy was covered. The 3 dimensional determination of the trajectories needed a quite important development of software [2]. As an example we will show some results of the ^{8}He(d,p) reaction. The angular distributions were obtained for maximum energy down to about 2MeV/n. They were analysed using the code Fresco, with a standard optical potential. Experimental uncertainties of the absolute cross section are of the order of 30% due to efficiency of the reconstruction algorithm. The optical model introduces another uncertainty in the evaluation of this reaction. Nonetheless, the angular distributions agree well, and a spectroscopic factor $C^2S=3\pm1$ is obtained in the analysis. This is close to a simple shell model estimation where one expects $C^2S=4$ for 4 nucleons in the $p_{3/2}$ shell. On figure 1 the angle integrated cross section as a function of energy is shown. The experimental data were integrated using the Fresco angular distributions renormalized on the experimental data.

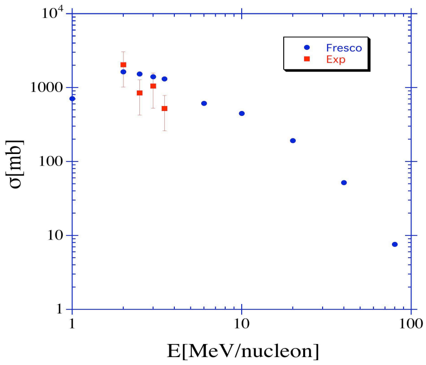

FIG. 1. Angle integrated cross section for the ^{8}He(p,d)^{7}He$_{gs}$ reaction. The theory is given for $C^2S=4$.

As can be seen, the cross section is very high, reaching 1barn in the energy domain of the present experiment. It is the first time that this effect predicted [3] was observed to our knowledge. The good agreement between the theory and experiment shows that even at this low energy the direct reaction mechanism is dominant. Elastic scattering and the (p,t) reaction were observed simultaneously. A preliminary analysis of the elastic scattering shows that it is possible to assign a spin to the ground state of ^{9}He by the observation of the isobaric analog state in ^{9}Li.

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First experiment of ^{6}He with polarized proton target

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Measurements of polarized proton scattering on stable nuclei have continuously yielded basic key information on nuclear structure as well as nuclear reaction mechanism. It is particularly interesting and important to extend such polarization measurements to unstable nuclei.

Since the scattering experiments with an unstable beam are performed under the inverse kinematic condition, a detection of low energy particles emitted to large angles which correspond to small angles in normal kinematic condition is inevitable. A choice is to use the well established polarized proton gas target. However low intensity of unstable beam with thin gas target makes it impossible to carry out the measurement. Thus the thick polarized proton target is needed such as a polarized *solid* proton target (PSPT). Though a conventional PSPT is inconvenient, since it requires a strong magnetic field (> 2 T) as well as a low temperature (< 1 K). The strong magnetic field and the cryogenic materials of the target surroundings prevent the low energy particles coming out from the target region.

We have developed a new spin PSPT which overcomes those drawbacks of conventional ones. Our target can be operated under a low magnetic field of 0.08 T and a high temperature of 100 K. The basic principle to polarize a proton is a pulsed dynamic nuclear polarization (DNP) method [1]. An aromatic material (host), naphthalene, doped with pentacene is optically pumped to attain an alignment of electron population in triplet state of pentacene which is subsequently transferred to the proton polarization by using the integrated solid effect. We have achieved the proton polarization of about 36% with a relaxation time of about 22 hours in the off-line test experiment [2].

The first polarization asymmetry measurement [3] was performed by the unstable beam of ^{6}He with 71 MeV/u produced by RIPS at RIKEN. For this reaction, the cross sections were measured for $\theta_{\rm cm} = 20° - 50°$ [4]. The cross section and the polarization asymmetry (=target polarization×analyzing power) were measured for $\theta_{\rm cm} = 40° - 80°$ which covers the second diffraction peak of cross sections. The polarized target with estimated polarization of about 20% with a size of 1 mm thick with 14 mm diameter was bombarded by the ^{6}He beam of 10^5 particles/sec.

The magnitude and its angular dependence of cross sections are almost identical with those of $\vec{p}+{}^6$Li scattering at 72 MeV by R. Henneck et al. [5], indicating similar interaction potentials for both nuclei. However, it is very surprising to find that the observed polarization asymmetry shows a remarkable difference between the $\vec{p}+{}^6$He and $\vec{p}+{}^6$Li scatterings. The polarization asymmetry changes the sign from a positive value at $\theta_{\rm cm} = 40° - 50°$ to the negative value at $\theta_{\rm cm} = 60°$ degrees for $\vec{p}+{}^6$He, while it increases rapidly from the small positive value to the large positive value for the same angular range in case of $\vec{p}+{}^6$Li. This peculiar behavior of $\vec{p}+{}^6$He can be roughly understood by the difference of the spin-orbit potentials. The optical potential analysis shows that the spin-orbit potential for ^{6}He locates outside further by about 0.8 fm compared to that for ^{6}Li, which could be due to the neutron skin characteristic to the ^{6}He nucleus.

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Fusion and other reactions around the barrier with weakly bound nuclei: $^{6}He + ^{238}U$

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The fusion reaction of two heavy ions at energies around and below the Coulomb barrier is governed by quantum tunneling. The probability of tunnelling varies strongly with the structure of the system and the intrinsic degrees of freedom. Already for stable systems, it was observed that the coupling of the relative motion of the colliding nuclei with intrinsic excitations and with other reaction channels can enhance the fusion cross section [1]. In halo systems, such as ^{6}He, ^{11}Li, ^{11}Be, strong variations of the fusion are expected. An enhancement is predicted due to an effective reduction of the potential barrier, induced by the abnormal neutron density. The presence of a large fraction of the dipole strength at low excitation energy is also expected to enhance the fusion cross section. More controversial is the role of the weak binding: according to the different pictures, a strong break-up channel may either enhance [2] or inhibit the fusion process [3]. The experimental data obtained so far [4] are not conclusive about this point.

We present here new data for the $^{6}He + ^{238}U$ fusion cross section at energies around and below the Coulomb barrier. The measurements were performed at the Cyclotron Research Centre of Louvain-la-Neuve, using the fission process as signature for fusion. In the same experiment a strong two-neutron transfer channel was identified. The new data show no enhancement of the fusion cross section below the Coulomb barrier with respect to simple model predictions. The comparison with coupled-channel calculations points to an effect due to the breakup channel. This picture is also confirmed by recent measurements where the $^{7}Li + ^{238}U$ and $^{7,9}Be + ^{238}U$ cross sections are compared.

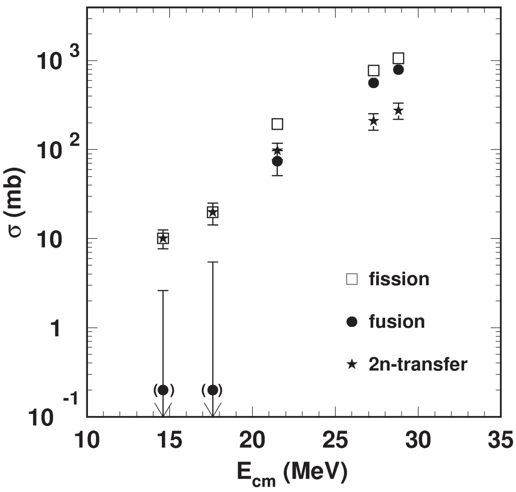

FIG. 1. Fission, fusion and 2n-transfer cross sections for the system $^{6}He + ^{238}U$.
At the lower energies only upper limits are given for the fusion cross section.

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Doppler shift as a tool for studies with RIBs and spectroscopy of ^7He through isobaric analog states in ^7Li *

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Studies of exotic nuclei with radioactive beams require applications of new measurement techniques. We propose a new method to measure the total cross-section for formation of compound system as a function of excitation energy for neutron rich exotic nuclei. The technique uses the (p,n) reaction to populate isobaric analog states of the nucleus of interest [1]. We have used the Doppler shift of a gamma ray emitted from the heavy reaction product to tag the reaction channel and measure the velocity distribution of the reaction products. We applied this technique to the study of the structure of ^7He.

The ^7He nucleus is particle unbound with respect to neutron decay and until recently only the ground state was known [2], new-excited states of this system were reported in references [3,4,5,6]. We studied the structure of ^7He through its isobaric analog states in ^7Li(T=3/2). These states were populated through ^6He(p,n)$^6Li^*(E_{ex} = 3.56$ MeV) reaction. We will discuss the technique, which has been used for first time in the study of exotic nuclei and the implementations of the new results.

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*This work was supported by the U.S. National Science Foundation under contract 02-030099.

Unbound exotic nuclei studied by transfer to the continuum and projectile fragmentation.

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The properties of unbound exotic nuclei such as ^{10}Li and ^{13}Be are of fundamental importance in the understanding of two neutron halo nuclei like ^{11}Li and ^{14}Be [1]-[8].
From the experimental point of view they have been studied by several methods. One of them is projectile fragmentation [9]-[13] in which ^{11}Li and ^{14}Be have undergone nuclear breakup following which the core plus one neutron have been detected in coincidence. Another method is transfer to the continuum [14]-[16] in which a beam of ^{9}Li or ^{12}Be has interacted on a deuteron target and the projectile plus one neutron relative energy spectrum has been reconstructed.
We have developped two models [17]-[18] to study these reactions based on time dependent perturbation theory and an exact quantum mechanical treatment of the final state interaction between the neutron and the core via an optical potential. It is shown that the two methods give rise to sligthly different measured quantities and therefore the extraction of stucture information has to be dealt with care.

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Study of the ground state wave function of ^{6}He via 2n transfer reaction $^{6}He(p,t)\alpha$

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The ^{6}He nucleus is now currently used as one of the benchmark nuclei to study the halo phenomenon and 3-body correlations [1], especially because the alpha-core can very well be represented as inert. However, in order to have a complete and detailed description of the ^{6}He wave function, the question arises whether the only contributions are the cigar and di-neutron configurations, where only ^{4}He and 2-n clusters intervene, or if some t+t clustering is also present.

In the case of the ^{6}Li nucleus, it was shown that it was possible to have considerable α +d and ^{3}He+t clustering at the same time, and the importance of both configurations was studied by analyzing angular distributions of the $^{6}Li(p,^{3}He)^{4}He$ reactions [2].

Following the same ideas, we measured recently at GANIL the complete angular distribution for the $^{6}He(p,^{3}H)^{4}He$ with the SPEG spectrometer and the MUST array, with a special emphasis on the most forward and backward angles which could not be measured in a previous experiment performed at JINR Dubna [3]. The results of the data analysis of this experiment will be presented, which show that the t+t contribution is very small compared to expectations of different theoretical models [4,5,6].

This work was financially supported by the IN2P3-Poland cooperation agreement 02-106.

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Wednesday Morning Session 1

Fundamental Symmetries & Applications

Wednesday Morning 1 - Fundamental Symmetries & Applications

Name/email	Institution	Title
Jungmann, Klaus jungmann@kvi.nl	KVI	Fundamental Symmetries and Interactions
Behr, John behr@triumf.ca	TRIUMF	Weak Interaction Symmetries with Atom Traps
Engel, Jonathan engelj@physics.unc.edu	University of North Carolina	Time-Reversal Violation in Heavy Octupole-Deformed Nuclei
Hardy, John hardy@comp.tamu.edu	Texas A&M University	Superallowed 0^+-to-0^+ beta decay and CKM unitarity: A new overview including more exotic nuclei
Kiefl, Rob kiefl@triumf.ca	University of British Columbia	Low Energy Polarized Radioactive Nuclei: Applications in Condensed Matter
Name/email	**Institution**	**Title**

Fundamental Symmetries and Interactions

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Nuclear Physics offers a variety of possibilities to investigate fundamental symmetries in nature and to study properties of the known fundamental forces in physics and searches for possible new ones. A review will be given which will include tests of the standard model and suggested extensions. Among the topics covered will be the properties of fundamental fermions, discrete symmetries and the exploitation of well established known interactions to determin constants of basic importance.

Weak Interaction Symmetries with Atom Traps *

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We use laser trapping and cooling techniques with a table-top sized apparatus to precisely test the Standard Model of the weak interaction. Beta-decaying atoms are held in a 1 mm-sized cloud using a magneto-optical trap. By measuring the momentum of the β^+ and the daughter nucleus, we can reconstruct the ν momentum. The Standard Model predicts the angular distribution of the neutrinos with respect to the positrons, and by testing for deviations we search for new interactions, in particular interactions involving exchange of spin-0 bosons. We have pioneered these techniques [1] at the Isotope Separator and Accelerator facility at TRIUMF [2], and now are learning to polarize the nuclei, to test whether parity is fully violated in the weak interaction, and to test time-reversal symmetry.

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*This work was supported by the National Research Council of Canada through TRIUMF and by the Natural Sciences and Engineering Research Council of Canada.

Time-Reversal Violation in Heavy Octupole-Deformed Nuclei *

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A nonzero atomic electric-dipole moment (EDM) at a level not far from current experimental limits would signify time-reversal violation from outside the Standard Model. EDM's are enhanced in atoms that have octupole-deformed nuclei. I report careful self-consistent mean-field calculations of the time-reversal-violating nuclear "Schiff moment" — the quantity that induces an atomic EDM — in several odd-A octupole-deformed nuclei, some of which can be produced at RIA. The self-consistent mean fields in odd-A nuclei include important effects of core polarization. The results of the calculations are encouraging for EDM experiments in the light actinides.

Accurate calculations are also needed for Schiff moments in ordinary spherical and quadrupole-deformed nuclei, so that limits on extra-Standard-Model physics can be extracted from ongoing EDM measurements in the associated atoms. I describe work in progress on this more general problem.

*This work was supported by the U. S. Department of Energy under contracts DE-FG02-97ER41019.

Superallowed 0^+-to-0^+ beta decay and CKM unitarity: A new overview including more exotic nuclei*

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Currently, the most demanding test of the unitarity of the Cabibbo-Kobayashi-Maskawa (CKM) matrix is provided by nuclear beta decay. Precise measurements of superallowed beta-decay transitions between analog 0^+ states are used to determine G_V, the vector coupling constant; this, in turn, yields V_{ud}, the up-down element of the CKM matrix. The most precise beta-decay data available for obtaining V_{ud} are the *ft*-values for nine 0^+-to-0^+ transitions, which have been established to a precision of ~0.1% or better; these transitions span a wide range of nuclear masses from ^{10}C, the lightest parent, to ^{54}Co, the heaviest. As anticipated by the Conserved Vector Current hypothesis, CVC, all nine yield consistent values for G_V, but the value of V_{ud} derived from their average leads to a more surprising result. The value of V_{ud} from these nuclear decays is, by far, the most precisely known element of the CKM matrix and, when combined with V_{us} and V_{ub}, the other top-row elements, it leads to the most demanding test available of the unitarity of that matrix. Strikingly, existing data do not confirm unitarity but show a 2.3-sigma deviation [1]: *viz* $V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 0.9968$ (14). Since CKM unitarity is a fundamental pillar of the Electroweak Standard Model, this discrepancy could indicate the need for new physics, a possibility that has stirred considerable activity directed at arriving at a more statistically definitive result.

Since the V_{ud} uncertainty is dominated by uncertainties in the small theoretical correction terms applied to the data, the focus of this recent work on superallowed beta decay has been to test and refine the nuclear-structure-dependent corrections. A consistent set of calculated corrections now exists [2] for the nine superallowed transitions currently measured to high precision, and also for a number of additional superallowed transitions in more exotic nuclei not previously accessible to exacting experiments. New experiments are beginning to achieve the precision required on these previously inaccessible transitions: for example, in the decays of ^{22}Mg, ^{34}Ar, ^{62}Ga and ^{74}Rb [3]. Only the ^{22}Mg and ^{34}Ar transitions have so far provided a good test of the structure-dependent corrections, but soon one can expect meaningful comparisons between experiment and theory over a wide range of new cases. Some improvement in the precision of V_{ud} can be expected to follow and, with comparable activity underway in improving the value of V_{us}, we can anticipate a more definitive result for unitarity within a few years.

We have just completed a new survey and overview of world data on superallowed 0^+-to-0^+ beta transitions including not just the nine cases previously considered, but also eleven more from T=1 parents: even-even $T_z = -1$ nuclei from ^{18}Ne to ^{42}Ti; and odd-odd $T_z = 0$ nuclei from ^{62}Ga to ^{74}Rb. Hundreds of references published over five decades have been incorporated. The results will be described and suggestions given as to where new experimental measurements are most urgently required.

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*This work was supported by the U.S. Department of Energy under contract DE-FG03-93ER40773 and by the Robert A. Welch Foundation.

Low Energy Polarized Radioactive Nuclei: Applications in Condensed Matter *

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Conventional nuclear magnetic resonance (NMR) is a powerful technique for probing the local electrical and magnetic properties of materials. However, NMR typically requires a large number(10^{18}) of nuclear spins to generate a signal. Consequently it is most widely used in studies of bulk materials. A much greater sensitivity can be achieved with nuclear methods such as β-NMR, where the nuclear polarization is detected through beta-decay. β-NMR has been used extensively to measure nuclear moments of unstable isotopes. There are also interesting applications in condensed matter. For example it can be used to simulate the diffusion and reactivity of an isolated impurity in a semiconductor or to study the behaviour of an atom on a surface.

At the TRIUMF ISAC facility we have recently created a low energy polarized $^8Li^+$ beam which presents new opportunites in condensed matter research. In particular, the method is well suited for studies of nano-structures and ultra-thin films where conventional NMR is difficult due to the small number of host nuclear spins. The implantation energy of the $^8Li^+$ ions can be varied in the range 0.1 keV to 30.0 keV, corresponding to a mean depth of a few nm up to 200 nm. The scientific applications of such depth profiling β-NMR are similar to those associated with low energy muon beams. However, the positive muon and a radioactive nucleus are very different probes and thus provide complementary information. Spectrometers for β-NMR and zero field beta detected nuclear quadrupole resonance have recently been commissioned at ISAC. We report here results from the first experiments and discuss future directions for the program.

*This work was supported by the NSERC, TRIUMF and the Canadian Institute for Advanced Research

Wednesday Morning
Session 2

RIB
Production
&
Applications

Wednesday Morning 1 - Fundamental Symmetries & Applications

Name/email	Institution	Title
Jungmann, Klaus jungmann@kvi.nl	KVI	Fundamental Symmetries and Interactions
Behr, John behr@triumf.ca	TRIUMF	Weak Interaction Symmetries with Atom Traps
Engel, Jonathan engelj@physics.unc.edu	University of North Carolina	Time-Reversal Violation in Heavy Octupole-Deformed Nuclei
Hardy, John hardy@comp.tamu.edu	Texas A&M University	Superallowed 0^+-to-0^+ beta decay and CKM unitarity: A new overview including more exotic nuclei
Kiefl, Rob kiefl@triumf.ca	University of British Columbia	Low Energy Polarized Radioactive Nuclei: Applications in Condensed Matter
Name/email	**Institution**	**Title**

Laser Ionization for the Production and Study of Exotic Nuclei

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Resonant laser ionization is a very selective technique that has recently been implemented at different target -ion source systems of on-line isotope separators [1]. These laser ion sources are not only interesting to produce exotic nuclei in an efficient and element, sometimes isomer, selective way but they can under certain conditions be used to probe specific properties of the nuclei like ground -state or isomeric-state moments and mean square charge radii. A large number of experiments with radioactive beams (including post - accelerated beams) suffer from isobaric contamination in the beam and a way to control or measure the purity of the beam is often a crucial issue. As will be shown in this contribution laser ionization offers this in a very elegant way. It also will be advocated that laser ionization applied in the ion source is a very sensitiv e technique that allows precision laser spectroscopy measurements on nuclei very far from the line of stability.

We will review the different ways resonant laser ionization has been implemented for the production of exotic nuclei, discuss the advantages a nd limitations, and present results from a selection of recent experiments using photo-ionized beams. Amongst them are the identification and production of isomeric pure beams of 70Cu [2], betadecay experiments in the neutron -rich Pb region, Coulomb excit ation experiments of the neutron -rich 74,76Zn isotopes whereby laser ionized beams were post -accelerated and laser spectroscopy experiments down to the very neutron- deficient 1 8 3Pb isotope. In the last part of the presentation the importance of laser ionization for future ISOL - based radioactive ion beam projects like RIA and EURISOL will be discussed.

[1] P. Van Duppen, Nucl. Instr. and Meth. B126 (1997) 66
[2] J. Van Roosbroeck et al., Phys. Rev. Lett. 92 (2004) 112501

Ion manipulation with cooled and bunched beams*

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Ion beam properties are critical to experiments with rare isotopes. The ability to cool transverse motion and energy spread in the beam or modify the time structure of the beam can yield significant improvements in resolution or signal to noise for many types of experiments. This ability, based to a large degree on technical developments from the field of ion trapping, is now a common feature in existing low-energy facilities and will play a central role in a number of next generation radioactive beam facilities.

The techniques used rely on the efficient injection of the ion beam into large acceptance electromagnetic devices that confine and guide the beam in two or three dimensions while energy loss of the ions by collisions with a low-pressure high-purity gas reduces the energy spread and concentrates the beam at the bottom of the confining potential. These new devices (ion coolers, isobar separators, gas catchers and so on) perform multiple tasks ranging from transverse cooling, to bunching and to purification of beams and can now even transform recoils from fission, low-energy nuclear reactions or fragmentation reactions into beams of ISOL-type quality. The basic physics underpinning the operation of these various devices will be introduced in the talk together with the key technical evolutions that have occurred since the previous ENAM conference. Examples of operating devices of the various types will also be given, together with the performance presently achieved and improvements expected in the near future.

*This work was supported by the U.S. Department of Energy Office of Nuclear Physics under contract No. W-31-109-ENG-38.

Recent highlights from ISOLDE@CERN

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The ISOLDE [1] facility is an online mass separator [2] located at CERN providing a large variety of radioactive ion beams. More than six hundred different isotopes from seventy elements are produced at present. The amount of accessible species allows carrying out research on nuclear physics, atomic physics, solid state physics and life sciences.

The radioactive nuclei at ISOLDE are generated by spallation, fragmentation and fusion reactions induced by the CERN PS Booster proton beam of 1.0/1.4 GeV impinging on a thick target. The reaction products are then ionized, mass-separated and transported to different experimental setups, which include high-resolution laser spectroscopy devices, high-precision mass spectrometers, an on-line nuclear polarization setup, spectrometers for emission channeling and angular correlation measurements, a total absorption gamma spectrometer, a HV platform for 200 kV post acceleration, ultra-high-vacuum experimental chambers for surface and several interface studies, and general purpose nuclear spectroscopy setups. The facility holds and extensive physics-driven target and ion source development program, which has helped ISOLDE keep its outstanding international status for more than 35 years.

The recently operational REX-ISOLDE post-accelerator [3] is capable of accelerating the isotopes produced at ISOLDE to energies of up to 3.0 MeV/u by using a charge breeder and a linear accelerator structure. The device has opened up the possibility of nuclear spectroscopy studies by means of transfer reactions and Coulomb excitation of exotic nuclei. The post-accelerator is complemented by a highly segmented Ge array, MINIBALL [4], in conjunction with a compact silicon strip detector, located at the secondary target position.

This presentation will highlight some of the recent ISOLDE scientific achievements and technical developments together with an outlook to the future plans for the facility.

[1] http://www.cern.ch/isolde
[2] E. Kugler, Hyperfine Interact. **129**, 23 (2000)
[3] O. Kester et al., Nucl. Instr. Meth. **B204**, 20 (2003)
[4] J. Eberth et al., Prog. Part. Nucl. Phys. **46**, 389 (2001)

ISOL beams of neutron-rich oxygen isotopes at ISOLDE and SPIRAL*

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ISOL beams of $^{19-22}$O have been produced at ISOLDE. The neutron-rich oxygen isotopes are produced by 1.4 GeV proton-induced reactions in a 50 g/cm^2 standard ISOLDE UC$_x$/graphite target. The oxygen radicals are too reactive to be efficiently released, but by reaction with carbon from the target material volatile CO is formed. The target is connected via a water-cooled transfer line (to retain all non-volatile isobars) to an ISOLDE type FEBIAD ion source where the CO is partially dissociated to form O$^+$, but dominantly ionized as CO$^+$. The yields of the atomic O$^+$ and molecular CO$^+$ beams were measured and a short (~1 h) test run with a ^{12}C^{22}O$^+$ beam allowed to remeasure the beta-gamma decay of ^{22}O [1] with high statistics, showing new beta-delayed gamma transitions.

ISOL beams of neutron-deficient oxygen isotopes had been produced before at SIRa (GANIL) [2]. Recently also neutron-rich oxygen isotopes up to ^{22}O have been produced in the SPIRAL target and ion source system at GANIL. A 77.5 MeV per nucleon ^{36}S beam was fragmented in a thick graphite target, coupled by a cold transfer tube to a multicharged ECR ion source. The yields of the observed radioactive oxygen isotopes, as atomic and molecular ions, will be presented.

An extension towards ^{23,24}O is more difficult, not only due to the lower production cross-section and the very short half-life (increasing the decay losses), but mainly due to the background situation. Atomic ^{23}O$^+$ beams suffer from very intense ^{23}Ne$^+$ background and molecular ^{12}C^{23}O$^+$ beams have strong background from ^{35}Ar$^+$ and multiply charged ^{140}Xe^{4+}. Methods will be discussed to overcome this particular background problem and to generally enhance the beam intensity of the neutron-rich oxygen beams.

[1] F. Hubert et al., Z. Phys. A 333, 237 (1989).
[2] S. Gibouin et al., Nucl. Instr. Meth. B204, 240 (2003).

*This work was supported by the EU-RTD project TARGISOL (HPRI-CT-2001-50033).

First beams of the Radioactive Ions Beam Facility in Brazil (RIBRAS)

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A system consisting of two superconducting solenoids (RIBRAS)[1] for the production of secondary light exotic beams was recently installed at the Pelletron Laboratory of the University of São Paulo, Brazil. The two solenoids are presently installed at one of the beam lines of the 8 MV, Tandem accelerator and, in a later stage, they will be moved to the LINAC pos-accelerator of $10A.MeV$, when operational. The RIBRAS system is similar to the UND-TWINSOL system, with a larger field integral ($5T.m$) and a larger maximum central field ($6.5T$) in order to operate using the higher mass and higher energy primary beams delivered by the LINAC.

Secondary beams of ^{8}Li (E_{lab}=26 MeV) and ^{6}He (E_{lab}=23 MeV) using a (E = 30MeV, $200nA$) ^{7}Li primary beam and a ^{9}Be primary target have been produced with intensities of $10^{5}part/s$ of ^{8}Li and $10^{4}part/s$ of ^{6}He. We performed measurements of elastic scattering angular distributions of ^{8}Li and ^{6}He on ^{51}V and gold targets.

Details of the project, future perspectives and the new data will be presented.

[1] R. Lichtenthäler, A. Lépine-Szily, V. Guimarães, G.F. Lima, M.S. Hussein, Nucl. Instrum. and Methods in Phys. Res. **A505**(2003)612

Nuclear research applied to the transmutation of nuclear waste and the production of radioactive nuclear beams

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Spallation neutron sources are proposed to be used in accelerator driven systems (ADS's) to drive sub-critical reactors, in which long-lived nuclear waste could be burnt [1] or energy produced [2]. Spallation reactions are also considered for the production of intense radioactive nuclear beams using the ISOL technique [3,4]. A common issue to both applications is the design of the spallation targets. A detailed engineering design of these targets needs a precise optimisation of its performances in terms of useful neutron or spallation residues production. In addition a proper assessment of specific problems likely to occur in such systems like radiation damage in target, accelerator window or structure materials or additional shielding due to the presence of high energy neutrons should be considered.

Some of these problems could be investigated using Monte Carlo transport codes, however the last OECD/NEA inter-comparison [5] lead to the conclusion that many improvements of the models are still needed but also that these was a lack of experimental data to validate the codes. During the last years, a wide effort has been made in several laboratories to measure spallation data regarding the production of neutrons [6] and residual nuclides [7]. In this talk we will review the most outstanding experimental programs devoted to characterise spallation reactions and we will discuss their implications in the production of radioactive nuclear beams and in basic nuclear research.

[1] C. D. Bowman, *et al.*, Nucl. Instrum. Methods Phys. Res. A, **320**, (1992), 336
[2] C. Rubia, *et al.*, preprint CERN/AT/95-44(ET), 1995
[3] Report of the Study Group on Radioactive Nuclear Beams, OECD Megascience Forum, 2000
[4] NuPECC Report "Radioactive Nuclear Beam Facilities", April 2000
[5] International Code Comparison for Intermediate Energy Nuclear Data, OECD/NEA, 1995
[6] X. Ledoux, *et al.*, Phys. Rev. C, **57**, (1998), 2375
[7] W. Wlazlo, *et al.*, Phys. Rev. Lett., **84**, (2000), 5736

Wednesday Afternoon Session 1

Dripline & Clusters

Wednesday Afternoon 1 - Dripline & Clusters

Name/email	Institution	Title
Sakurai, Hiro sakurai@phys.s.u-tokyo.ac.jp	University of Tokyo	Spectroscopy on neutron-rich nuclei at RIKEN
Ter-Akopian, Gurgen gurgen@jinr.ru	Joint Institute for Nuclear Research	New Insights into the Resonance States of the Lightest Neutron-Excess Nuclei: 4H, 5H, 7H and 5He
Sarazin, Fred fsarazin@mines.edu	Colorado School of Mines	Halo neutrons and the beta-decay of ^{11}Li
Kanungo, Rituparna ritu@postman.riken.jp	RIKEN	Observation of a two-proton halo in ^{17}Ne
Cortina, Dolores d.cortina@usc.es	Universidad de Santiago de Compostela	Shell structure of the near-dripline nucleus ^{23}O
Stolz, Andreas stolz@nscl.msu.edu	Michigan State University	First Observation of ^{60}Ge and ^{64}Se
Lepine-Szily, Alinka alinka.lepine@dfn.if.usp.br	University of Sao Paulo	Anomalous behaviour of matter radii of proton-rich Ga, Ge, As, Se and Br nuclei
Name/email	**Institution**	**Title**

Spectroscopy on neutron-rich nuclei at RIKEN

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Recent studies on nuclear structure by using radioactive isotope (RI) beams available at the RIKEN projectile-fragment separator (RIPS) [1] are introduced. Special emphasis is given to experiments selected from recent programs that highlight studies for neutron-rich nuclei.

Since the intermediate energy Coulomb excitation method was applied for ^{32}Mg [2], activities of the in-beam gamma spectroscopy with fast RI beams have been expanded with a high growth rate. To step further for more neutron-rich nuclei, we developed a liquid hydrogen target. The use of the target provides the highest reaction rates and significant reduction of background because of the largest number of target nuclei and the absence of gamma-rays originated from target excitation. This target has been used so far at several experiments. One of them is observation of the first 2^+ state of ^{30}Ne via the (p,p') reaction [3]. We observed the gamma line for the transition of $2^+ \rightarrow 0^+$ with an extremely low beam intensity of 0.3 particles per seconds, and determined the energy of the 2^+ state to be 791(26) keV, which is lower than that of ^{32}Mg. The result suggests that ^{30}Ne has a larger collectivity than ^{32}Mg. The other example is to investigate the excited states of ^{34}Si via the (d,d') reaction [4]. The result from gamma-gamma coincidence excludes the 1.193 MeV line as a candidate for the transition from the 2^+ state to the second 0^+ state, as suggested by the work with β-γ spectroscopy.

A large isovector component in the quadruple $2^+ \rightarrow 0^+$ transition of ^{16}C has been found very recently by two experimental approaches based on the in-beam gamma spectroscopy. One is combination of B(E2) measurement [5] and determination of deformation length δ from the (p,p') reaction [6], and the other is use of the Coulomb-nuclear interference method [7]. To obtain the B(E2) value for ^{16}C, the recoil shadow method (RSM) to measure mean lifetime of the 2^+ state was newly developed for fast RI beams, instead of use of the CEX which may suffer from contamination of nuclear reaction for such light nuclei. The measured $B(\mathrm{E2}; 2^+ \rightarrow 0^+)$ value is found to be $\sim$0.3 W.u. and anomalously small, compared with the value empirically predicted by the quantum liquid model. According to Bernstein's prescription, the neutron component in the transition was estimated from the δ value obtained via the (p,p') reaction, and it is found to be very large compared with the proton one. The result of the second approach also suggests that ^{16}C has the similar magnitude of differences between the proton- and neutron-components. The large isovector component appeared in ^{16}C would be a new type of collective motions.

To increase primary beam intensities for RI beam production, a new acceleration scheme was developed at RIKEN, where the RFQ+RILAC+CSM linear accelerator complex is used as an injector. A ^{48}Ca beam was accelerated up to 64A MeV with a maximum intensity of 150 pnA, which is about two orders of magnitudes higher than before. The ^{48}Ca beam was used to explore the limit of existence at N=20$\sim$28, and bringing out three new isotopes, ^{34}Ne, ^{37}Na, ^{43}Si, and evidence on particle instability of ^{33}Ne, ^{36}Na, ^{39}Mg [8]. Based on high intensities available in the new scheme, further studies via the in-beam gamma spectroscopy are now proceeding at the present facility of RIKEN before the RIBF running.

[1] T. Kubo *et al.*, Nucl. Instrum. and Methods B **70** (1992) 309.
[2] T. Motobayashi *et al.*, Phys. Lett. B **346** (1995) 9.
[3] Y. Yanagisawa *et al.*, Phys. Lett. B **566** (2003) 84.
[4] N. Iwasa *et al.*, Phys. Rev. C **67** (2003) 064315.
[5] N. Imai *et al.*, Phys. Rev. Lett. **92** (2003) 062501.
[6] H. J. Ong *et al.*, contribution in this conference; to be submitted.
[7] Z. Elekes *et al.*, Phys. Lett. B **586** (2004) 34.
[8] M. Notani *et al.*, Phys. Lett. B **542** (2002) 49.

New Insights into the Resonance States of the Lightest Neutron-Excess Nuclei: ^{4}H, ^{5}H, ^{7}H and ^{5}He*

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The ^{4}H resonance was investigated in the transfer reactions ^{2}H(t,p)^{4}H and ^{3}H(t,d)^{4}H using liquid targets of deuterium and tritium and 58 MeV triton beam. Recoil protons and deuterons were measured in coincidences with tritons or neutrons from the decay of ^{4}H. Careful considerations were made for the competing processes of final state interaction and quasifree scattering. The data show a peak with resonance parameters E_{res}=3.05±0.19 MeV and Γ_{obs}=4.18±1.02 MeV. The pole of S-matrix corresponding to the physical values of energy and width, E_0=1:99±0.37 MeV and Γ0=2.85±0.30 MeV, has been extracted.

The spectrum of ^{5}H was studied in the ^{3}H(t, p)^{5}H reaction at 58 MeV of laboratory energy for small CM angles of outgoing ^{5}H. The complete kinematical reconstruction of energy and angular correlations among the decay fragments of ^{5}H and the high data statistics allowed one to identify the broad structure in the missing mass spectrum above 2.5 MeV (with several MeV width) as a mixture of $3/2^+$ and $5/2^+$ states. These correlation data also showed that the ^{5}H ground state is located at about 2 MeV. These results thus provide a good support to the experimental observations of Refs. [1,2].

The ^{5}H nucleus was produced also in the reaction ^{2}H(^{6}He,^{5}H)^{3}He studied with a 132 MeV ^{6}He beam. The observed ^{5}H ground state resonance position also confirms the results reported in Refs. [1,2]. All ^{5}He resonances known before were obtained in the reaction ^{2}H(^{6}He,^{5}He)^{3}H. Three ^{5}He resonance states located at E*≈20.0, 21.4 and 24.0 MeV were clearly seen in the decay mode ^{5}He→t+d. These tree resonances did not show up in the decay modes ^{5}He→^{3}He+n+n and ^{5}He→t+p+n. The observation of these decay modes, made for the first time, revealed a new, previously unknown resonance state of ^{5}He lying at excitation of 22.0±0.2 MeV. The estimated resonance width is FWHM=2.8±0.4 MeV. Different considerations support the conclusion that this new resonance is the T=3/2 isobaric analogue state observed in ^{5}He.

The ^{7}H nucleus most likely possesses an unique decay dynamics: the four-neutron emission (or 5-body decay). The estimated decay energy of this nucleus has a large uncertainty making possible a very small decay width of its ground state resonance. In an attempt to observe a long living quasi stable ^{7}H, produced in the reaction ^{2}H(^{8}He,^{7}H)^{3}He, we set an upper limit of 3 nb/sr for the reaction cross section. We utilized a 20.5 MeV/amu ^{8}He beam bombarding a 5.6 cm thick liquid deuterium target, and searched for ^{7}H nuclei moving between 0°−50° CM angles. The obtained cross section limit corresponds to a ^{7}H lifetime less than 1 ns, which allows one to estimate a lower limit of 50−100 keV for the ^{7}H energy above the ^{3}H+4n breakup threshold.

[1] A. A. Korsheninnikov et al., Phys. Rev. Lett., **87**, 092501 (2001).
[2] M. S. Golovkov et al., Phys. Lett. B, **566**, 70 (2003).

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*This work was partly supported by the Russian Foundation for Basic Research (grant No. 02-02-16550) and by INTAS (grant No. 03-51-4496).
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Halo neutrons and the β-decay of ^{11}Li

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The structure of ^{11}Li, a ^{9}Li core surrounded by two distant neutrons (the so-called halo), has been the subject of intense studies. In particular, the β-decay of ^{11}Li is expected to shed light on how the weak interaction affects (and is affected by) the two neutrons composing the halo.
In August 2002, the β-decay of ^{11}Li was investigated at TRIUMF-ISAC with the 8π spectrometer, an array of 20 Compton-suppressed germanium detectors. ^{11}Li was produced by bombarding a 22 g/cm^2 Ta foil with a 500 MeV proton beam. A pure 30.4 keV ^{11}Li beam was extracted from the target and implanted into a Al foil at the centre of the γ-detector array. Most of the β-decay strength is observed to proceed through unbound states in ^{11}Be, which subsequently decay by one-neutron emission to ^{10}Be. This results in the observation of a γ-spectrum dominated by the decay of the excited states in ^{10}Be. As shown in the figure, these transitions exhibit characteristic Doppler-broadened lineshapes.

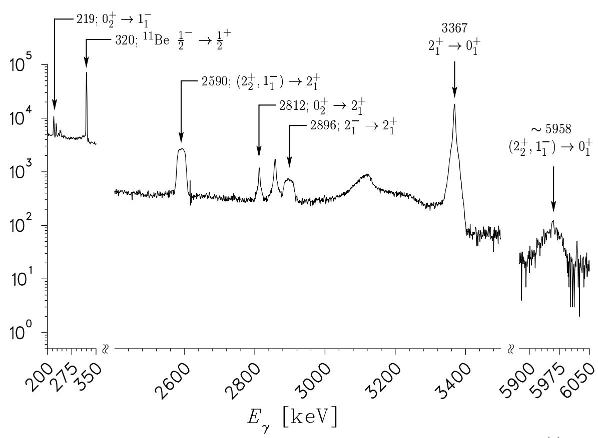

FIG. 1. Compton suppressed γ-spectrum following the β-decay of ^{11}Li. Only the relevant parts that contain the γ transitions observed in ^{10}Be and in ^{11}Be are shown (room background subtracted).

A Monte-Carlo simulation has been developed to analyze the complex shape of the γ-lines observed in this experiment. The results of this analysis, including new lifetime measurements, will be presented. The possibility that one of the two original halo neutrons of ^{11}Li had survived in a halo configuration in an excited state of ^{10}Be will be discussed.

[1] F. Sarazin *et al.*, To be submitted to Phys. Rev. C (2004).

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Observation of a two-proton halo in ^{17}Ne

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The first observation of two-neutron halo, nearly two-decades back, brought about a major revolution in our view of nuclear structure [1]. However, it has been long argued whether a proton halo can exist or not due to presence of the Coulomb barrier. Although, there has been some discussion on possibility of one-proton halo, in ^{8}B [2], so far no two-proton halo nucleus was confirmed to exist. The existence of a two-proton halo despite the Coulomb barrier is extremely interesting from nuclear structure point of view.

The investigation of a two-proton halo in proton drip-line nucleus ^{17}Ne based on a simultaneous study of longitudinal momentum distribution and interaction cross-section will be presented. A rather narrow momentum width (FWHM = 167±17MeV/c) coupled to a large interaction cross-section is suggestive of an evidence for the first two-proton halo [3]. In a ^{15}O+p+p picture of ^{17}Ne, an added confirmation comes from the fact that the momentum distribution of the core ^{15}O is much wider (FWHM ~ 290 MeV/c) [4]. Details on interpretation of these observables leading to the conclusion will be discussed.

It is further interesting to note that the study reveals an enhanced probability of the valence protons in ^{17}Ne occupying the $2s_{1/2}$ orbital. This is in contrast to the mirror partner ^{17}N. It thus gives an evidence of existence of mirror nuclei with different ground state configurations [3].

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[4] H. Jeppessen *et al*, Nucl. Phys. A *(in press)*

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Shell structure of the near-dripline nucleus ^{23}O

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Recent studies in neutron-rich oxygen isotopes near the neutron dripline have shown very exciting issues. ^{24}O [1] with no excited states below 4 MeV is today accepted to be the last bound oxygen isotope reinforcing the idea of the $N = 16$ magic number replacing the $N = 20$ gap for the heavy dripline nuclei [2]. In this context, ^{23}O is a key nucleus to understand the structure of light neutron-rich isotopes. Consequently, it has been subject of interest and several experiments have been dedicated to its study in the last years gaining a new interest because the interpretation of different inclusive experimental results [3,4] yield for different spin and parity assignment for its ground state.

For better understanding of this problem gamma coincidence data are crucial. Therefore, we have performed an experiment at GSI-FRS to distinguish between the ^{22}O $g.s$ contribution to the ^{23}O wave function from any other contribution of ^{22}O excited states. The experiment was dedicated to the study of the nuclear structure evolution when approaching the dripline using the one-neutron breakup of light neutron-rich secondary beams produced by nuclear fragmentation of relativistic ^{40}Ar at 1 GeV/nucleon, on a carbon target.

The exclusive momentum distributions of ^{22}O fragments after one-neutron removal from ^{23}O were measured for the ^{22}O ground state and excited states contributions. From the comparison of experimental momentum distribution for the one-neutron removal channel leaving the ^{22}O core in its ground state to theoretical momentum distributions calculated in an Eikonal model for the knockout process [5] we can conclude that the ground-state spin of ^{23}O is $I^{\pi} = 1/2^{+}$, providing a clear solution to the discrepancy of the ground-state spin and parity assignment of ^{23}O.

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FIRST OBSERVATION OF ^{60}Ge AND ^{64}Se

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The neutron-deficient nuclei ^{60}Ge and ^{64}Se were observed for the first time following the fragmentation of ^{78}Kr. This is the first observation of new proton-rich nuclei below Z=50 in over three years.

A primary beam of 140-MeV/nucleon ^{78}Kr was produced using the Coupled Cyclotron Facility and fragmented in a Be target. The secondary neutron-deficient fragments were separated by the A1900 fragment separator [1] and stopped in a stack of silicon PIN diodes. The fragments were identified by a measurement of energy loss, total energy, and time-of-flight.

^{60}Ge is the last nucleus along the proton dripline lighter than cadmium which is predicted to be bound (S_{2p} = 50 +– 240 keV) by the latest atomic mass evaluation [2] and which has not yet been observed. Theoretical calculations predict ^{60}Ge to be bound with respect to two-proton emission by 167(141) keV [3] and 630 keV [4], while ^{64}Se is predicted not to be bound [2].

From the number of observed events of ^{60}Ge and ^{64}Se the production cross section and lifetime will be estimated. No events of ^{59}Ga and ^{63}As were observed confirming that these nuclei are unbound with respect to proton emission and upper limits of the lifetime can be established.

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*This work was supported by the National Science Foundation Grant No. PHY-01-10253.

Anomalous behaviour of matter radii of proton-rich Ga,Ge,As,Se and Br nuclei

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The recent reaction cross-section measurements are mainly concentrated on the neutron-rich side of the nuclear chart. They have shown evidence for neutron skins and halos close to the drip-line. The proton-rich side is much less studied, mainly due to the restrictions that the Coulomb barrier imposes on the existence of proton skins or halos. The correlation between separation energies and skin effect was found for some neutron-rich and proton-rich nuclei[1]. The correlation of neutron halos with shell effects is also clearly verified for light drip-line nuclei. The goal of this work was to measure nuclear matter radii on the proton-rich side around N$\sim$ Z$\sim$30-36 where anomalous shape transitions were found close to the stability line. Proton-rich isotopes of Ga, Ge, As, Se and Br had their total reaction cross sections (σ_R) measured at $\sim$55 Mev/nucleon. Root-mean-squared matter radii were determined from Glauber model calculations, which reproduced the experimental σ_R values. For all isotopic series a decrease of the r_{rms} was observed as the neutron number increases. At the same time the matter radii show an anomalously strong increase as a function of Z for several isotonic series. There seems to be no correlation with deformation or with proton separation energy, but with shell effects.

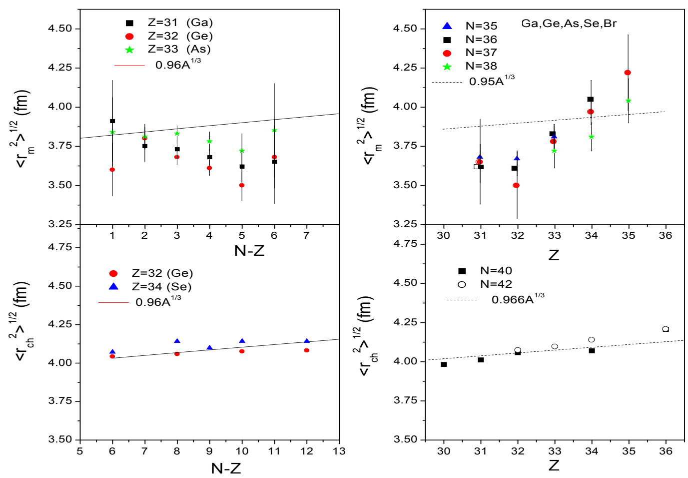

FIG. 1. Upper panels: The variation of the r.m.s. matter radii of the proton-rich nuclides respectively as a function of N-Z and Z, compared to $R = 0.96A^{1/3}$. Lower panels: The same for r.m.s. charge radii of stable nuclides, compared to $R = 0.96A^{1/3}$.

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Wednesday Afternoon Session 2

Astrophysics & Masses

Wednesday Afternoon 2 - Astrophysics & Masses

Name/email	Institution	Title
Heger, Alex alex@ucolick.org alex@ucolick.org	Los Alamos National Laboratory	Nuclear Astrophysics Theory
Martinez Pinedo, Gabriel martinez@ieec.fcr.es	Institut d'Estudis Espacials de Catalunya	Shell-model applications in supernova physics
Yakovlev, Dima yak@astro.ioffe.ru	Ioffe Physical Technical Institute	Pycnonuclear reactions in dense stellar matter
Magierski, Piotr Piotr.Magierski@olimp.if.pw.edu.pl	Warsaw University of Technology	Nuclear structure and dynamics in the neutron star crust
Herfurth, Frank F.Herfurth@gsi.de	GSI	Recent high-precision mass measurements with the Penning trap mass spectrometer ISOLTRAP
Savajols, Herve savajols@ganil.fr	GANIL	New Mass Measurements at the Neutron Drip Line
Name/email	**Institution**	**Title**

Nuclear Astrophysics Theory*

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Nuclear astrophysics comprises determining nuclear properties and reaction rates, both theoretical and experimental, theoretical modeling of astrophysical systems (mostly stars), and observational astronomy, for example of stellar and interstellar/intergalactic abundances and of neutron stars. Key parts of nuclear astrophysics theory are modeling unmeasured nuclear properties and numerical simulations, e.g., of stars, stellar interiors, and stellar evolution. Many of the nuclear properties like reaction rates that are needed for these simulations are not or cannot be easily measured in the laboratory and therefore supplemented by nuclear theory. On the other hand, astrophysical modeling can also help to place limits on the nuclear properties and reaction rates. One past example is ^{12}C(α,γ)^{16}O reaction rate. A key uncertainty, though, in astrophysical modeling that limits the constrains that can be placed on nuclear reaction rates is our limited understanding of turbulent mixing processes in stars. Thus often some ambiguity between constraints on reaction rates and on mixing process exist. Progress on either of these will improve our understand of nuclear astrophysics processes. In this talk I will focus on recent results for nucleosynthesis in stars, including *p*-process and neutrino-process, and of X-ray bursts and their *rp*-process.

*This work was supported by the U. S. Department of Energy under grant W-7405-ENG-36 to the Los Alamos National Laboratory and and the DOE Program for Scientific Discovery through Advanced Computing (SciDAC; DE-FC02-01ER41176).

Shell-model applications in supernova physics

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Progress in nuclear structure calculations have allowed for detailed fully microscopic calculations of weak interaction rates for astrophysical environments, including electron capture rates and neutrino-nucleus scattering cross sections. The resulting rates affect the final evolution of stars with masses exceeding roughly 10 $M_{\odot}$ before they explode as supernova. Previous supernova simulations assumed that during core collapse electron capture occur dominantly on free protons, while captures on heavy nuclei are ignored. We find that rates for electron-capture on nuclei are large enough that they dominate over electron-capture on free protons and produce significant changes in the hydrodinamics of core collapse and bounce. We discuss how theoretical models can be validated using high resolution charge-exchange reactions for the calculation of electron capture rates, and electron-scattering data for the calculation of neutrino scattering cross sections.

Pycnonuclear Reactions in Dense Stellar Matter *

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The main properties of pycnonuclear reactions [1] in stellar matter at densities up to 10^{13} g cm^{-3} are outlined. The physics of nuclear burning, highly unusual atomic nuclei involved, expected reaction rates and energy release rates are discussed [2]. Possible consequences of pycnonuclear burning in the cores of white dwarfs and the inner crusts of neutron stars are considered.

As an application, pycnonuclear burning of matter accreted on a neutron star in a binary system is analyzed. An efficient pycnonuclear burning occurs when accreted matter sinks into the stellar interior under the weight of a newly accreted material and reaches the shell of densities from about 10^{12} g cm^{-3} to about 10^{13} g cm^{-3} in the inner stellar crust (Fig. 1). For typical accretion rates $\dot{M} \sim 10^{-14} - 10^{-9}$ $M_\odot$ yr^{-1} the burning energy produces the deep crustal heating which is sufficient to warm the star. The surface thermal radiation of the star becomes dependent on the poorly known equation of state of supranuclear matter in the stellar core, which gives a method to explore this equation of state. Theoretical calculations of thermal states of transiently accreting neutron stars are compared [3] with observations of accreting neutron stars in soft X-ray transients. Current constraints on the properties of supranuclear matter, inferred from such a comparison, are summarized.

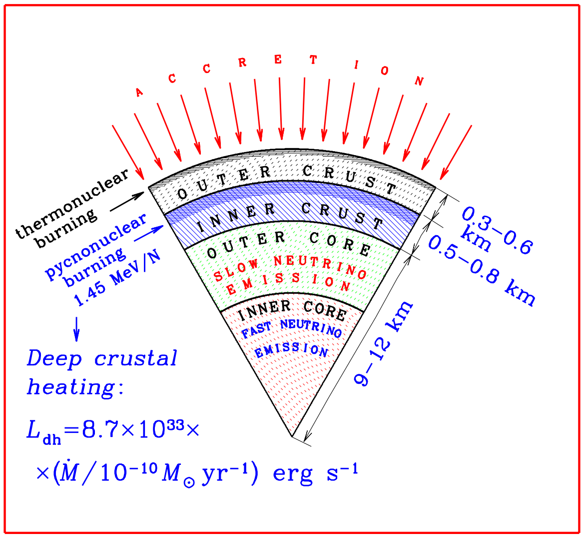

FIG. 1. A schematic drawing of an accreting neutron star of mass $M \sim 1.4\,M_\odot$; $L_{\rm dh}$ is the deep crustal heating power. The main energy release takes place in a tightly shaded shell in the inner stellar crust. This heating enables one to study (poorly known) properties of supranuclear matter in the inner stellar core (which may contain nucleons/hyperons, pion or kaon condensates, or quark matter).

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*This work was supported by the Russian Foundation for Basic Research, grants 02-02-17668 and 03-07-90200, and by the Russian Science Support Foundation

Nuclear structure and dynamics in the neutron star crust

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We review the properties of the cold nuclear matter forming the inner crust of neutron stars. Its structure influences various processes associated with the thermal evolution of neutron stars, such as cooling and nuclear burning of accreted matter. The structure of the crust is rather complex and depends strongly on the nuclear density. In the inner crust, due to the high density and pressure, a large fraction of neutrons occupies unbound states. Nuclei which are still present are therefore immersed in a neutron gas and form a crystal lattice stabilized by the Coulomb interaction. We analyze the static properties of such system using the Skyrme-Hartree-Fock + BCS approach with the Coulomb interaction treated beyond the Wigner-Seitz approximation. Our results suggest that at the bottom of the crust the shell effects associated with unbound neutrons play an important role leading eventually to a disordered phase. As a result the complicated phase transition pattern between various exotic nuclear phases (as a function of the density) has been predicted.

The dynamic properties of neutron-proton-electron matter in the inner crust are responsible for its thermal and electric conductivities. Since nuclei are immersed in a superfluid neutron liquid, as they move they bring the fermionic medium into motion as well. As a result the nuclear bare masses are strongly renormalized and the spectrum of the ion lattice vibrations is significantly affected. Consequently the specific heat and the lattice thermal energy of the Coulomb crystal are noticeably modified. Hence the thermal and electric conductivities of the inner crust, governed by the electron-phonon scattering, are changed. There is also a need for consideration of other nuclear degrees of freedom. Since the nuclear matter at these densities is predicted to be strongly paired, the specific heat of the system is significantly lowered at temperatures below 1 MeV. We show however that there is a substantial contribution to the specific heat coming from the nuclear collective degrees of freedom.

Recent high-precision mass measurements with the Penning trap mass spectrometer ISOLTRAP

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Beside half-life and decay mode the mass is one of the gross properties of a nucleus. The mass, explored along isotopic and isotonic chains, helps considerably to improve the understanding of the nucleus by constraining weaknesses in nuclear models, by uncovering nuclear fine structure effects as well as by tracking shell and sub shell closures. Additionally, high-precision mass data of selected nuclides provide important contributions to test the conserved vector current (CVC) hypothesis, the unitarity of the Cabibbo-Kobayashi-Maskawa (CKM) matrix and the isobaric multiplet mass equation (IMME). Mass data are also an important type of nuclear physics data needed in astrophysical nucleosynthesis calculations.

ISOLTRAP is a Penning trap mass spectrometer installed at the online isotope separator ISOLDE/CERN. The continuous ISOLDE ion beam is transfered at 60 keV to the ISOLTRAP set-up, which consists of three main parts: (1), a linear gas-filled radiofrequency quadrupole (RFQ) trap for ion retardation, accumulation, cooling and bunched ejection at low energy, (2), a gas-filled cylindrical Penning trap for isobaric separation, and (3), a hyperboloidal Penning trap in high vacuum for isomeric separation and the mass measurement. The latter is based on the direct determination of the cyclotron frequency $\omega_c = q/m \cdot B$ of a particle of mass m and charge q revolving in a magnetic field of the strength B. To this end an azimuthal radio-frequency field is applied to increase resonantly the ion's radial energy, which is detected using a time-of-flight technique. Presently, ISOLTRAP can reach a relative mass uncertainty of $8 \cdot 10^{-9}$ and has a sensitivity of 100 ions per second and has access to nuclides with half-lives of less than 100 ms [1].

In the last three years the masses of more than 100 nuclei have been measured at ISOLTRAP with a relative mass uncertainty of a few 10^{-8} in most cases. A general overview will be presented with emphasis on some highlights as for instance the mass measurements of ^{32,33}Ar [2], which provided the so far most stringent test of the IMME, and the measurement of ^{74}Rb, the heaviest system studied to test CVC. Other highlights are the unambiguous assignment of three β-decaying isomers in ^{70}Cu using the very high resolving power of the ISOLTRAP spectrometer in combination with selective laser ionization [3] and the mass determination of the rp-process waiting point nucleus ^{72}Kr.

[1] F. Herfurth *et al.*, J. Phys. **B 36**, 931 (2003).
[2] K. Blaum *et al.*, Phys. Rev. Lett. **91**, 260801 (2003).
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New mass measurements at the neutron drip-line

H.Savajols[1], B.Jurado[1], W.Mittig[1], C.E.Demonchy[1], L.Giot[1], M.Rousseau[1], P.Roussel-Chomaz[1], A.Villari[1], A.Khaouaja[1], Y.E. Penionzhkevich[2], S. M. Lukyanov[2], A. Gillibert[3], M. Chartier[4], Z. Dlouhy[5], J.Mrazek[5], D. Baiborodim[5] and A.Lepine-Szily[6]

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The evolution of shell closures far from stability is a subject of much actual debate. Deformations, shape coexistence or variations in the spin-orbit strength as a function of the neutron to proton ratio could provoke the modification of magic numbers. Experimentally, nuclear binding energies are very sensitive to the existence of shells and may provide clear signatures of shells closures. Such measurements (SPEG91[1] and SPEG99[2]) have already given a clear signature of the breaking of the N=20 magicity and have shown a change in shell structure around N=28.

More recently, a new mass measurement experiment (SPEG02[3]) has been performed to extend mass beyond the N=20 shell gap, at the neutron drip-line. As a result, the mass resolution of around 20 neutron-rich nuclei has been improved and the masses of more than 15 neutron-rich nuclei have been determined for the first time. The region covered presents a considerable interest to determine both, the boundary of the island of inversion, responsible for the breaking of the N=20 magicity and to extend mass measurements around N=28.

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[3] H.Savajols et al., E364 GANIL experiment .

Thursday Morning Session 1

Nuclear Structure Theory

Thursday Morning 1 - Nuclear Structure Theory

Name/email	Institution	Title
Vary, James jvary@iastate.edu	Iowa State University	Ab-initio no-core shell model - recent results and future prospects
Ploszajczak, Marek ploszajczak@ganil.fr	GANIL	Shell-Model Description of Weakly Bound and Unbound Nuclear States
Honma, Michio m-honma@u-aizu.ac.jp	University of Aizu	Shell-model description of pf-shell nuclei with a new effective interaction GXPF1
Navratil, Petr navratil1@llnl.gov	LLNL	Ab Initio No-Core Shell Model Calculations Using Realistic Two- and Three-Body Interactions
Piecuch, Piotr piecuch@cem.msu.edu	Michigan State University	Coupled Cluster Calculations of Ground and Excited States of Nuclei
Name/email	**Institution**	**Title**

Ab-Initio No-Core Shell Model — Recent Results and Future Prospects *

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The *ab initio* No-Core Shell Model (NCSM) adopts an intrinsic Hamiltonian for all the nucleons in the system. This Hamiltonian consists of a relative kinetic energy operator, a realistic nucleon-nucleon (NN) interaction, a three-nucleon (NNN) interaction, and electromagnetic pairwise interactions as appropriate. There is no center-of-mass (CM) component and there are no single-particle energies or mean field.

The NN interaction is taken from one of those recently developed to describe the available two-body data. Alternatively, it is taken from a theoretical derivation, such as chiral field theory, that describes a limited range of NN data. These interactions may feature charge-symmetry breaking, may be non-local, and may be highly singular at short distances. Recently obtained NN potentials from inverse scattering theory are also investigated and applied to light p-shell nuclei. The NNN interactions are taken from either meson-eschange theory or chiral field theory.

In order to accommodate the strong short-range correlations, we adopt an effective Hamiltonian approach in which a 2-body or 3-body cluster subsystem of the full A-body problem is solved exactly. From the exact solutions of the cluster subsystem, an effective Hamiltonian is evaluated in a model space appropriate to the no-core many-body application at hand. The full Hamiltonian is then approximated as a proper superposition of these cluster effective Hamiltonians and the no-core many-body problem is then solved in the defined model space [1]. The full Hamiltonian and all the eigensolutions obtained respect the symmetries of the underlying NN and NNN iteractions.

Recent applications include (a) spectra and transition rates in p-shell nuclei; (b) di-neutron correlations in the ^{6}He halo nucleus; (c) neutrino cross sections on ^{12}C; (d) spectra of ^{16}C and ^{16}O; (e) spectroscopy of the $A = 47 - 49$ nuclei; (f) exotic multiple quark systems; plus others that will not be discussed due to time limitations.

Given the rapid progress of the ab-initio NCSM in the last three years, one anticipates additional applications and extensions. It should have continuing impact on developing the nuclear many-body "standard model" including improvements in the NN and NNN interactions. It should contribute high-precision results for the determination of fundamental symmetries in nature such as nuclear double beta decay and the neutrino mass determination. Extensions to scattering theory and to the structure of heavier nuclei are underway. Recently, applications to non-perturbative solutions of quantum field theory have appeared and underscore the potential for cross-disciplinary applications.

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Shell-Model Description of Weakly Bound and Unbound Nuclear States

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Consistent description of weakly bound and unbound nuclei, requires an accurate description of the particle continuum properties when carrying out multiconfiguration mixing. This is the domain of the Gamow Shell Model (GSM) [1,2,3] which is the multiconfigurational shell model with a single-particle (s.p.) basis given by the complete Berggren ensemble [4] consisting of resonant states and the complex non-resonant continuum. We shall present the application of the GSM formalism to the p-shell nuclei in the model space involving both neutron and proton s.p. resonant states calculated from the self-consistent Hartree-Fock method. We shall also report the first successful application of the density matrix renormalization group methods [5,6] in the context of the GSM which allows to find the GSM wave function in model spaces which are inaccessible with standard methods.

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Shell-model description of pf-shell nuclei with a new effective interaction GXPF1

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The nuclear shell model has been one of the most powerful tools for the study of nuclear structure. Owing to recent developments in computational facilities and numerical calculation techniques, most of the pf-shell nuclei are now in the scope of exact $0\hbar\omega$ calculations. The current frontier of such direct calculations is the middle of the pf-shell ($A \sim 60$), where the maximum M-scheme dimension reaches to two billion. Once a suitable effective interaction is given, the shell model can describe various nuclear properties accurately and systematically in a unified framework, covering many nuclei in the model space of interest. It is useful not only for the analysis of experimental data, but also to predict unobserved properties of unstable nuclei.

The success of the shell model crucially depends on the choice of the effective interaction. The effective interaction can in principle be derived in a microscopic way, starting from a realistic nucleon-nucleon potential. However, such microscopic interactions are not necessarily successful in describing experimental data especially for cases with many valence nucleons. For a practical use, we have derived a new effective interaction GXPF1 [1] for full pf-shell calculations, by modifying such a microscopic interaction empirically, taking into account the knowledges from experimental many-body data. The GXPF1 has been tested extensively [2] from various viewpoints such as binding energies, electromagnetic moments, systematics of low-lying states and transitions among them, revealing its predictive power in the wide region of pf-shell space. At the same time, the limitation of its applicability has been suggested near the end of the pf-shell, which is attributed mainly to the effect of intruder configurations. The deviation of shell-model predictions form available experimental data becomes sizable for $N \sim 35$ or larger.

The application to the study of unstable nuclei is one important test of the GXPF1. For example, the structure of $N \sim Z$ nuclei around ^{56}Ni is sensitive to the strong proton-neutron interaction. Contrary to the large energy gap above the $f_{7/2}$ orbit, the ^{56}Ni core is broken relatively easily, producing a low-lying collective band which consists mainly of core-excited configurations. We have shown that the core-excitation is a key to the improvements of the microscopic effective interactions beyond the monopole corrections. Another interesting topic is the shell evolution as a function of the valence nucleon number, especially in neutron-rich nuclei. Since the attractive interaction between the proton $f_{7/2}$ and the neutron $f_{5/2}$ orbits is rather strong, the effective single-particle energy of the latter orbit is sensitive to the occupation of the former orbit and goes up rapidly for smaller Z, which gives rise to a shell gap for $Z \sim 20$. The GXPF1 successfully described/predicted the existence of $N = 32$ shell gap in Cr [3] and Ti [4]. On the other hand, in the recent experiment for ^{56}Ti, the excitation energy of 2_1^+ state was observed to be lower than the prediction of GXPF1 by 0.4MeV, suggesting a narrower energy gap between $p_{1/2}$ and $f_{5/2}$ orbits. Such experimental data provide us with a crucial information for a possible refinement of the GXPF1.

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Ab Initio No-Core Shell Model Calculations Using Realistic Two- and Three-Body Interactions *

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In recent years, construction of accurate nucleon-nucleon potentials and increases in computing power have led to new methods capable of solving the nuclear structure problem for systems of more than four nucleons. In this talk we will describe one of these methods, the *ab initio* no-core shell model (NCSM) [1]. The principal foundation of this approach is the use of effective interactions appropriate for the large, but finite, basis spaces employed in the calculations. These effective interactions are derived from the underlying realistic inter-nucleon potentials by a unitary transformation in a way that guarantees convergence to the exact solution as the basis size increases.

We will discuss convergence tests of the method and nuclear structure results for light nuclei up to $A = 13$ obtained by using several modern nucleon-nucleon potentials, including those derived from the effective field theory. We will highlight our recent study of the parity inversion in ^{11}Be where calculations were performed in basis spaces up to $9\hbar\Omega$ (dimensions reaching 7×10^8).

At present, the *ab initio* NCSM is capable of including the much-less-explored realistic three-nucleon forces [2,3]. An important result of these nuclear-structure studies is the significance of three-nucleon interaction in determining not only the binding energy, but also the excitation spectra and other observables. Consequently, nuclear-structure calculations are becoming a tool in discriminating different three-body interaction models and at the same time can put constraints on the three-body force parameters. As a step in this direction, we improved accuracy of our three-body interaction calculations and obtained results for the p-shell nuclei using the Tucson-Melbourne TM′ three-nucleon interaction [4] with several proposed parameter sets [5].

It is a challenging task to extend *ab initio* nuclear structure approaches to the description of nuclear reactions. For the NCSM, this is in particular true concerning the low-energy reactions relevant for astrophysics. The first step toward this goal is the cluster decomposition of the NCSM eigenstates. We will present results of cluster form factor calculations for light p-shell nuclei, e.g. ^{7}Li$\rightarrow^3$H$+^4$He, ^{6}Li$\rightarrow^4$He$+d$ etc.

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*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. UCRL-ABS-203425.

Coupled Cluster Calculations of Ground and Excited States of Nuclei *

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Physical properties, such as masses and life-times, of very short-lived, and hence very rare, nuclei are important ingredients that determine element production mechanisms in the universe. Given that present nuclear structure research facilities and the proposed Rare Isotope Accelerator will open significant territory into regions of medium-mass and heavier nuclei, it becomes important to investigate theoretical methods that will allow for a description of medium-mass systems that are involved in such element production. Such systems pose significant challenges to existing nuclear structure models. In particular, highly accurate calculations for medium-mass and larger nuclei using the fully microscopic first principles (*ab initio*) description employing the fundamental laws of quantum theory represent an unresolved problem in nuclear physics that awaits a satisfactory, computationally tractable, solution.

The *ab initio* coupled cluster theory [1,2] is a particularly promising candidate for such endeavors due to its enormous success in quantum chemistry. The coupled cluster methods are very promising, since they allow one to study ground- and excited-state properties of nuclei with dimensionalities beyond the capability of present shell-model approaches, with a much smaller numerical effort when compared to the more traditional shell-model methods aimed at similar accuracies. For the weakly bound nuclei to be produced by the proposed Rare Isotope Accelerator it is almost imperative to increase the degrees of freedom under study in order to reproduce basic properties of these systems. Judging by the success of coupled cluster theory in chemistry, it is expected that coupled cluster methods will enable the *ab initio* microscopic calculations for nuclei in the mass 20–50 region.

In this talk, we will discuss our first results of applying the standard and renormalized coupled cluster techniques, which have been previously developed in the context of electronic structure calculations [3-5], to the ^{4}He and ^{16}O nuclei [6]. By comparing the results of coupled cluster calculations with the results of the exact diagonalization of the Hamiltonian in the same model space, we will show that the the quantum chemistry inspired coupled cluster approximations provide an excellent description of ground and excited states of nuclei. The bulk of the correlation effects is obtained with the basic coupled cluster and equation of motion coupled cluster models with singly and doubly excited (i.e. one- and two-body) clusters. The noniterative inclusion of three-body clusters produces the virtually exact description.

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*This work was supported by the U.S. Department of Energy under contracts DE-FG02-01ER15228 (Michigan State University), DE-FG02-96ER40963 (University of Tennessee), DE-AC05-00OR22725 with UT-Battelle, and LLC (Oak Ridge National Laboratory), the Research Council of Norway, the Alfred P. Sloan Foundation (P.P.), and National Science Foundation under Grant No. CHE-0309517 (Michigan State University).

Thursday Morning Session 2

Radioactivity & Nuclear Structure

Thursday Morning 2 - Radioactivity & Nuclear Structure

Name/email	Institution	Title
Pfutzner, Marek pfutzner@mimuw.edu.pl	Warsaw University	Two-proton Emission
Blank, Bertram blank@cenbg.in2p3.fr	CEN Bordeaux-Gradignan	First observation of ^{54}Zn and its decay
Fedorov, Dmitri fedorov@phys.au.dk	Aarhus University	Sequential and/or direct three-body decays?
Robinson, Andrew a.robinson@ed.ac.uk	Univerity of Edinburgh	Recoil-decay tagging study of ^{146}Tm
Radford, David radfordd@phy.ornl.gov	Oak Ridge National Laboratory	Coulomb excitation and transfer reactions with neutron-rich radioactive beams
Varner, Robert varner@phy.ornl.gov	Oak Ridge National Laboratory	Coulomb Excitation Measurements of Transition Strengths in the Isotopes $^{132,134}Sn$
Name/email	**Institution**	**Title**

Two-proton Emission

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Two-proton emission (2p) from nuclear states is a process known since 1983 when it was observed to proceed from exited states populated in the beta decay of ^{22}Al and ^{26}P [1,2]. Later, several other exites states were found to emit two protons, following both the beta decay and nuclear reactions. Decays in all these cases, however, were found to be consistent with a sequence of one-proton emissions proceeding through states in the intermediate nucleus. Similarly, the ground states of ^{12}O, being a broad resonance, was found to emit two protons sequentially via very broad intermediate states [3]. Thus, the intriguing possibility of a decay mechanism in which the diproton (^{2}He) state plays an important role continues to inspire and motivate studies in this field. Recently, a few experimental achievements renewed this interest and brought hopes for a substantial progress.

First is the observation of the 2p decay of the 1^- resonance at 6.15 MeV in ^{18}Ne [4]. Since no states in the intermediate nucleus (^{17}F) are known through which sequential emission could proceed, measurements of the correlations between the two emitted protons are very promising. The question concerning the decay mechanism in this case could not be answered yet due to limited statistics. Even more interesting situation is found in ^{17}Ne [5]. The 2p emission from the excited states of this nucleus was investigated and the proton-proton correlation data suggest the presence of a diproton contribution, seemingly increasing with the increasing excitation energy. Also in this case larger statistics is needed before firm conclusions can be drawn.

The development of projectile fragmentation facilities with the in-flight identification of selected ions allowed a breakthrough in the search for the 2p radioactivity which was predicted to occur in medium-mass even-Z nuclei where due to Coulomb barrier the relevant states are narrow and where the emission of a single proton is energetically forbidden or at least strongly suppressed. In two experiments, one performed at the GSI Darmstadt [6] and another at the GANIL Caen [7], decay of the proton drip-line nucleus ^{45}Fe has been investigated and the first evidence for the ground-state two-proton radioactivity has been found. This discovery opened a new field of spectroscopy of nuclei beyond the proton drip line. New measurements are being planned aiming at the more accurate determination of the ^{45}Fe decay properties – particularly the correlations between the two protons. Experiments on other candidates for the 2p radioactivity, like ^{19}Mg, ^{48}Ni, and ^{54}Zn are in progress.

In the talk, the status of the two-proton emission studies will be briefly summarised with an emphasis on the recent achievements. The experimental results will be compared with the recently refined theoretical models of the 2p decay process [8,9]. Then, the plans and perspectives for the future developments will be presented.

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First observation of ^{54}Zn and its decay

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Two-proton (2p) radioactivity is one of the most exciting new phenomena discovered in recent years in nuclear structure physics. In experiments at the LISE3 separator of GANIL [1] and at the FRS of GSI [2], the decay of ^{45}Fe was studied and it turned out to decay with a branching ratio of about 80% by two-proton emission from its ground state. This was the first case of 2p radioactivity, the decay of a nucleus by 2p emission where a one-proton emission is energetically forbidden.

According to theoretical predictions, other candidates for 2p radioactivity include ^{48}Ni and ^{54}Zn [3,4,5,6]. In a recent experiment at the LISE3 facility, we observed for the first time the $T_z = -3$ nucleus ^{54}Zn and studied its decay branches. The new results will be presented and future perspectives for this research will be discussed.

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Sequential and/or direct three-body decays?

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Weakly bound many-body quantum states are sometimes well described as three-body states [1]. Resonances in both ordinary and dripline nuclei also sometimes have dominating three-body components. Decay into the three constituent clusters are often discussed as sequential or direct processes, respectively loosely defined as either direct population of three-body continuum states or two sequential emissions of one cluster. One three-body resonance can then be dominated by one sequential decay via an intermediate two-body subsystem (not necessarily a resonance). Several paths may be comparable for example via different two-body resonances in the same or different subsystems, or the direct decay is not easily resolved into this type of two-body basis.
We shall use core plus two neutrons, core plus two protons and three alpha particle systems to illustrate different aspects of various decay mechanisms. Full quantum mechanical calculations are compared with simple, but rather accurate, results obtained from tunneling through a one-dimensional effective radial barrier.

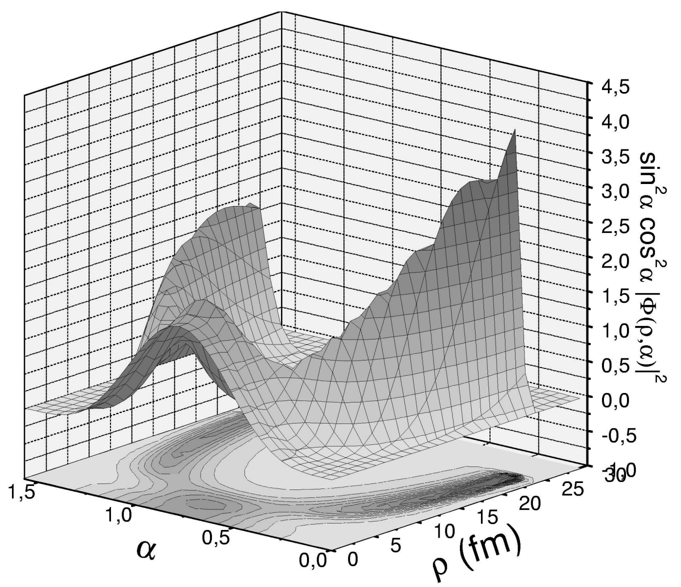

FIG. 1. The probability distribution for the lowest adiabatic potential for the 5/2 resonance of ^{17}Ne as function of hyperradius and the hyperangle α.

The probability distribution of the 5/2 resonance of ^{17}Ne ($^{15}O + p + p$) is shown in the figure as function of the effective radius ρ and the angle α related to the $p -^{15} O$ distance by $\rho \sin\alpha$. As ρ increases the probability concentrates in narrow strips at small and large distances corresponding to one proton close and one proton far away from the ^{15}O-core. This is sequential decay promoted by the strong attraction in the s and d-waves of the $p -^{15} O$ system. However, precisely the same structure is present for the 3/2 resonance of ^{17}Ne where the intermediate two-body resonance of ^{16}F is forbidden by energy conservation. Both structures are similar in the important regions under and just outside the barrier, but the 3/2 decay mechanism is then better described as virtual sequential decay.
The ^{6}He 2^+ resonance has no ^{5}He but a large dineutron, sequential decay component, and is in general better described by direct decay. The WKB tunneling width is larger by almost a factor of two corresponding to destructive interference when the full computation with coupled adiabatic potentials is used. More details for these and other systems will be presented to illustrate when the general model is needed and when one dominating decay mechanism obtained with simpler models is sufficient.

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Recoil-Decay Tagging Study of ^{146}Tm*

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^{146}Tm is an odd-odd proton emitter, lying in the transitional region between predicted deformed and near-spherical shapes. It is potentially a rich source of information regarding the role of the odd neutron in proton decay, since recent work [1] indicates that it emits at least 4 proton groups, with half-lives between 80 and 250 ms. In order to help shed light on the assignment of half-lives to the various groups, we have performed an RDT experiment on ^{146}Tm, using Gammasphere to detect prompt γ-rays tagged by protons observed in a double-sided silicon strip detector located at the focal plane of the FMA recoil mass spectrometer. No previous work on the excited states of ^{146}Tm has been reported. The proton spectrum is shown in the figure. Gamma-ray spectra correlated with proton groups will be presented, and a decay scheme for ^{146}Tm will be discussed.

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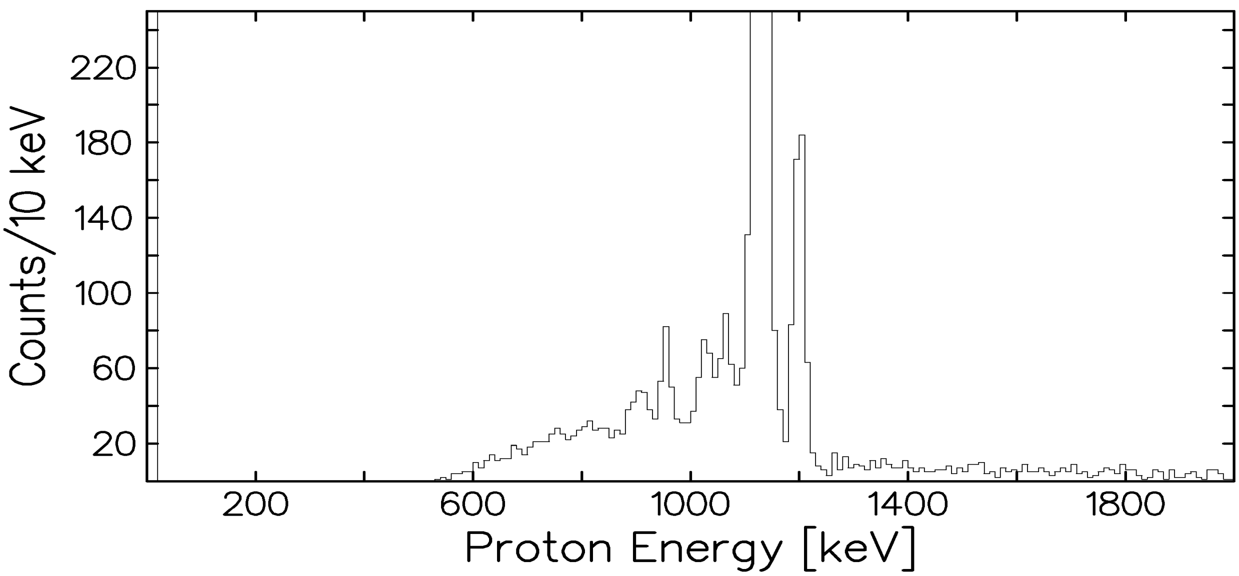

* Work supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. W-31-109-ENG-38

Coulomb excitation and transfer reactions with neutron-rich radioactive beams*

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The Holifield Radioactive Ion Beam Facility (HRIBF) at the Oak Ridge National Laboratory (ORNL) is able to produced high-quality post-accelerated beams of heavy radioactive nuclei from proton-induced fission of uranium. 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.

$B(E2; 0^+ \to 2^+)$ values for even-even $^{126-134}$Sn and $^{132-136}$Te isotopes have been measured by Coulomb excitation in inverse kinematics. Scattered target ions were detected, along with coincident γ rays in the CLARION Ge clover detector array or the ORNL-TAMU-MSU BaF_2 array. The ratio of elastic to inelastic cross-sections gives the excitation probability, and thus the $B(E2; 0^+ \to 2^+)$ value. The results for the Te isotopes [1] were in disagreement with previous shell-model calculations; this disagreement may be related to weak neutron pairing in $N = 84$ isotones near ^{132}Sn. The results for the Sn isotopes were obtained with highly purified Sn beams derived from SnS^+ molecular ions, produced by adding sulfur to the UC target material. The measured values of ~ 1.2 single particle units for ^{130}Sn and ~ 1.4 s.p.u. for ^{134}Sn are some of the smallest values measured for first 2^+ states. The doubly magic ^{132}Sn nucleus shows a relatively large $B(E2)$ value of ~ 7 s.p.u.[2], exhibiting behavior similar to that of ^{208}Pb.

More recently, we have attemted to measure the $B(E2; 0^+ \to 2^+_2)$ and $B(E2; 2^+_1 \to 4^+_1)$ values in ^{136}Te, and performed a pilot experiment on Coulomb excitation of odd-mass nuclides close to ^{132}Sn[3]. A mass-129 beam, comprising mainly ^{129}Te and ^{129}Sb, was excited using a target of ^{50}Ti. The data allows extraction of $B(E2)$ values for transitions between a number of low-lying levels. In addition, $\gamma - \gamma$ coincidence data allowed the identification of at least one new level in ^{129}Te.

The single-neutron transfer reactions ^{9}Be(^{134}Te,^{8}Be)^{135}Te and ^{13}C(^{134}Te,^{12}C)^{135}Te were studied using a ^{134}Te beam on ^{nat}Be and ^{13}C targets at energies just above the Coulomb barrier. One goal of this work was to search for the previously-unidentified $\nu i_{13/2}$ single-neutron level in ^{135}Te. In addition to transitions previously observed[4] in the decay of ^{135}Sb, several new transitions were clearly seen, including a 939 keV transition that populates the $11/2^-$ state at 1180 keV. Carbon-gamma angular correlations unambiguously determine this to be a stretched dipole transition from a strongly-aligned state. We therefore identify a new level at 2119 keV as the $\nu i_{13/2}$ level of ^{135}Te.

The results of these and other measurements will be discussed, together with plans for future experiments with these heavy neutron-rich RIBs.

1. D. C. Radford *et al.*, Phys. Rev. Lett., **88** (2002) 222501.
2. J. R. Beene *et al.*, to be published.
3. C.-H. Yu *et al.*, to be published.
4. P. Hoff, *et al.*, Z. Phys. **A322** (1989) 407.

* Oak Ridge National Laboratory is managed by UT-Battelle, LLC, for the U.S. D.O.E under contract DE-AC05-00OR22725.

Coulomb Excitation Measurement of Transition Strengths in the Isotopes ^{132,134}Sn

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At the HRIBF of Oak Ridge National Laboratory, accelerated beams of neutron-rich nuclei near the double-closed-shell nucleus ^{132}Sn have opened the possibility of systematic study of collective and single particle states in these nuclei. We will report on an experiment optimized to determine the transition probabilities for excitation of the first excited 2^+ state in ^{132}Sn. The large excitation energy (4.04 MeV) and consequent small excitation cross-section, together with the modest beam intensity available makes this a challenging experiment. The preliminary result is B(E2)=$0.14 \pm 0.05 e^2 b^2$. We expect the uncertainty to be reduced substantially in the final result. This result corresponds to a transition strength exhausting about 14% of the isoscalar quadrupole energy weighted sum rule, a value very similar to that of the 4.085 MeV 2^+ state in ^{208}Pb. Recently an unexpectedly small value for the B(E2) of the first excited 2^+ state in ^{136}Te, which is two neutrons beyond the N=82 closed shell, was reported by Radford et al. [1]. The high efficiency and generalized nature of the setup enabled us to also measure the first 2^+ state in the two-neutron nucleus ^{134}Sn. We have determined a value of B(E2)=$0.028 \pm 0.005 e^2 b^2$, which is almost identical to the value recently measured for ^{130}Sn[2], and shows no sign of the asymmetry with respect to the N=82 shell closure exhibited by the Te isotopes. We will discuss the ^{132,134}Sn measurements and the impact of our results on our understanding of nuclear structure near ^{132}Sn.

Oak Ridge National Laboratory is managed by UT-Battelle, LLC under contract DE-AC05-00OR22725 with the U.S. Department of Energy.

[1] D. C. Radford, et al., Phys Rev. Lett. 88, 222501 (2002).

[2] D.C. Radford, et al., Proceedings of CM2002, to be published.

Thursday Afternoon Session

Nuclear Structure

Thursday Afternoon - Nuclear Structure

Name/email	Institution	Title
Bender, Michael mbender@phys.washington.edu	Institute for Nuclear Theory	Microscopic models for exotic nuclei
Paar, Nils npaar@phy.hr	University of Zagreb	Self-consistent relativistic QRPA studies of soft modes and spin-isospin resonances in unstable nuclei
Mach, Henryk Henryk.Mach@studsvik.uu.se	ISV, Uppsala University	New structure information on ^{30}Mg, ^{31}Mg and ^{32}Mg
Thomas, Jeff jeffthom@physics.rutgers.edu	Rutgers University	Single-Neutron Excitations in Neutron-Rich N=51 Nuclei
Michimasa, S. mitimasa@riken.jp	RIKEN	Study of Single-Particle States in ^{23}F using a Proton Transfer Reaction
Reserved for recent results (15 minutes)		
Reserved for recent results (15 minutes)		
Aysto, Juha juha.aysto@phys.jyu.fi	University of Jyvaskyla	Conference Summary
Name/email	**Institution**	**Title**

Microscopic models for exotic nuclei*

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The presentation will give an overview over recent developments on why and how to go beyond self-consistent mean-field methods for the description of exotic nuclei.

Self-consistent mean-field approaches are nowadays a standard tool to describe and explain a manifold of phenomena throughout the chart of nuclei [1]. Recent data on exotic nuclei and exotic phenomena close to stability invite us to re-examine and refine the models. One focus of the ongoing efforts is the parameterization of the effective interaction used for such calculations, and how it is connected to first principles of the strong interaction. The overall quality of the models, however, has already a level where these efforts interfere with missing correlations in the mean-field states.

One strategy to resolve this is to add long-range correlations to the modeling through projection methods and variational configuration mixing with a discretized version of the generator coordinate method (GCM). The same effective interaction is used to generate the mean-field states and to perform the configuration mixing. Applications of the method are twofold. It adds long-range correlations to all observables that are usually addressed with mean-field approaches, for example the systematics of masses. This allows a much more reliable description of transitional nuclei. As a new feature, the method gives also access to (mainly collective) excitations. Such a method allows for a unified description of collective vibrational and rotational motion together with the motion of individual nucleons. Exact particle-number and angular momentum projection allow for the calculation of moments of the nuclear density in the laboratory frame without any further approximations. It also delivers in-band as well as out-of-band transition matrix elements in the lab frame. No assumptions about the evolution of the single-particle states nor any restrictions of the model space of single-particle states have to be put into the calculations. As the full model space of occupied single-particle states is used, no effective charge needs to be introduced. The method has the advantage that its results still can be interpreted in the intuitive picture of the shapes of a nuclear fluid and shells of single-particle states provided by mean-field models. The current implementations of such methods, which still have some symmetry restrictions on the mean-field states, deliver results that demonstrate the descriptive power throughout the chart of nuclei. An efficient approximation scheme for the calculation of ground-state properties has recently been set up [2] and is currently used for a large-scale analysis of quadrupole correlation energies beyond the mean-field level as corrections to mass models.

The presentation will highlight some applications of the method on the spectroscopy of exotic nuclei [3] and the implications of symmetry restoration and configuration mixing on the systematics of nuclear masses [4].

Acknowledgments: The ideas and results presented here were mainly developed in collaboration with G. F. Bertsch (INT and University of Washington, Seattle), P. Bonche (Saclay), T. Duguet (Argonne Natl. Lab.), and P.-H. Heenen (Université Libre de Bruxelles).

[1] M. Bender, P.-H. Heenen, and P.-G. Reinhard, Rev. Mod. Phys. **75** (2003) 121.
[2] M. Bender, G. F. Bertsch and P.-H. Heenen, Phys. Rev. C **69** (2004) 034340.
[3] M. Bender, P. Bonche, T. Duguet, and P.-H. Heenen, Phys. Rev. C (2004) in press. nucl-th/0311090.
[4] M. Bender, G. F. Bertsch and P.-H. Heenen, in preparation.

*This work was supported by the US Department of Energy under Grant DE-FG-06-90ER40561, the PAI-P5-07 of the Belgian Office for Scientific Policy, and through a Marie Curie fellowship of the European community.
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Self-consistent relativistic QRPA studies of soft modes and spin-isospin resonances in unstable nuclei

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The multipole response of unstable nuclei far from the valley of β-stability[1] is analyzed in the framework of the relativistic quasiparticle random-phase approximation (RQRPA), derived in the small amplitude limit of the time-dependent Relativistic Hartree-Bogoliubov (RHB) model [2]. The RQRPA configuration space is based on the RHB canonical single-nucleon basis, including two-quasiparticle pairs formed from the fully or partially occupied states of positive energy in the Fermi sea, and the empty negative-energy states from the Dirac sea. In addition to standard non-linear meson self-interactions, the RQRPA model has also been extended to include effective interactions with explicit density-dependent meson-nucleon couplings [3,4]. The density-dependent interaction DD-ME1 provides an improved description of asymmetric nuclear matter and isovector properties of finite nuclei. The RHB+RQRPA framework is fully self-consistent, i.e. the same effective interactions in the *ph* and *pp* channels, are used both in the RHB calculation for the ground state and in RQRPA residual interaction. This feature is essential for the decoupling of the zero-energy mode which corresponds to the spurious center-of-mass motion, and it also presents a necessary condition to fulfill the sum rules[2].

The RHB+RQRPA model is applied in the analysis of the pygmy dipole resonances in neutron-rich nuclei [2]. The dipole response of very neutron-rich isotopes 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 onset of dipole strength in the low-energy region is due to non-resonant independent single particle excitations of the loosely bound neutrons, whereas in heavier nuclei low-lying dipole states appear that are characterized by a more distributed structure of the RQRPA amplitude. Among several peaks characterized by single particle transitions, a single collective dipole state is identified below 10 MeV, and its amplitude represents a coherent superposition of many neutron particle-hole configurations. The isotopic dependence of the excitation energy of the pygmy resonance has been analyzed and, in particular, its relation to the neutron separation energy [3].

The RHB+RQRPA model with density-dependent meson-nucleon couplings has also been extended to the analysis of charge-exchange modes [4]. For the excitations that involve spin and isospin degrees of freedom, the residual interaction terms are generated by the ρ- and π-meson exchange. Both the T=1 and T=0 pairing channels have been included in the residual interaction, and the effect of pairing on the strength distributions of the isobaric analog resonance (IAR) and the Gamow-Teller resonance (GTR) has been investigated. A new method has been suggested for determining the difference between the radii of the neutron and proton density distributions along an isotopic chain, based on the measurement of the excitation energies of the GTR relative to the IAR [5].

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[3] N. Paar, T. Nikšić, D. Vretenar, and P. Ring, submitted to Phys. Lett. B (2004).
[4] N. Paar, T. Nikšić, D. Vretenar, and P. Ring, submitted to Phys. Rev. C (2004).
[5] D. Vretenar, N. Paar, T. Nikšić, and P. Ring, Phys. Rev. Lett. **91**, 262502 (2003).

New structure information on ^{30}Mg, ^{31}Mg and ^{32}Mg

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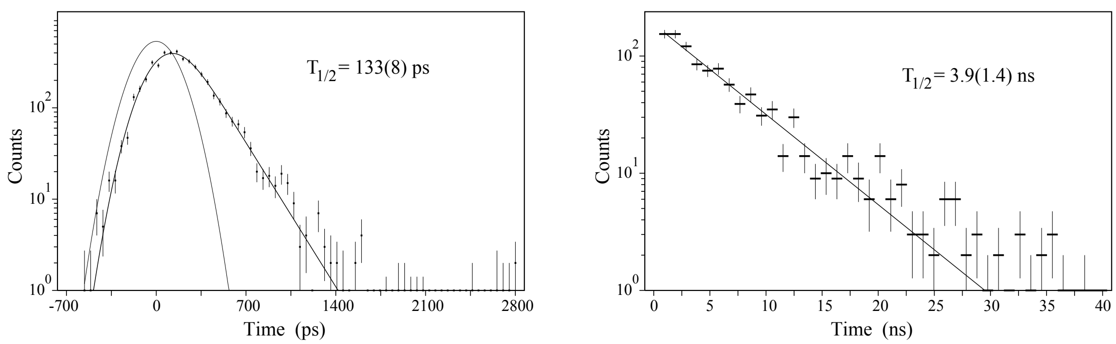
A number of recent experiments using a variety of advanced probes, has been focused on the structure of exotic Mg nuclei and nuclei in their close vicinity. This region is called "the island of inversion" [1,2] where the shell model configurations are strongly rearranged. Despite many experimental attempts on these exotic nuclei there remains a number of issues still to be resolved. Very recently we have performed a series of fast timing measurements using the Advanced Time Delayed $\beta\gamma\gamma(t)$ Method [3] on ^{30,31,32}Mg populated in the beta decay of ^{30,31,32}Na, respectively. These are key nuclei just at the border of "the island of inversion". In particular, the nuclei of ^{30}Mg and ^{31}Mg are expected [1,2] to exhibit coexistence of spherical and intruder configurations, yet it is not clear how to classify the observed excited states at low excitation energy into members of these configurations. Our aim was to obtain new information that would better characterize the excited states in ^{31}Mg and to search for a candidate for the intruder 0^+ state in ^{30}Mg. The second objective of this experiment was to verify information on the excited states in ^{32}Mg populated in the beta decay of ^{32}Na and to measure the half-life of the first excited 2^+ state in ^{32}Mg by a time-delayed method. This state is located at only 885 keV indicating that the ground state in ^{32}Mg is dominated by the intruder configurations.



Although the data analysis is in progress, a number of new results has already been obtained. In particular new states and new level lifetime were determined in ^{31}Mg and ^{32}Mg. Figure 1 presents preliminary half-live values for the 221 keV level in ^{31}Mg and for the 1789 keV state in ^{30}Mg. The relatively short lifetime of the 221 keV state implies that the 170 and 221 keV transitions de-exciting this state are not E2 transitions and if they have any E2 admixture it has to be weak. On the other hand, the long lifetime of the 1789 keV and its decay properties (our data imply no 1789 keV gamma ray de-exciting this state) make it a natural candidate for the intruder 0+ configuration in ^{30}Mg.

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[2] G. Klotz et al., Phys. Rev. C47 (1993) 2502.
[3] H. Mach et al., Nucl. Phys. A523 (1991) 197.

Single-Neutron Excitations in Neutron-Rich $N = 51$ Nuclei *

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The properties of low-lying states in nuclei near the closed shells are key benchmarks in the description of nuclear structure. The low-lying states of neutron-rich nuclei near the closed shells also in uence how heavier nuclei are produced in the astrophysical rapid neutron capture (r-) process. It has been predicted that as the neutron drip-line is approached the familiar strong shell structure is quenched [1], and the resulting uniformly spaced shell levels could better explain the observed patterns of solar r-process abundances [2,3]. With the advent of radioactive ion beams, the low-lying single-particle states in neutron-rich nuclei near the closed shells can be studied.

We have begun a program to measure (d, p) reactions on neutron-rich nuclei, probing the single-particle states near the $N = 50$ closed shell. We have measured the neutron transfer to two $N = 51$ nuclei, ^{83}Ge and ^{85}Se, at the Holi eld Radioactive Ion Beam Facility at Oak Ridge National Laboratory. The measurements were performed in inverse kinematics: isobaric $A = 82$ and $A = 84$ radioactive beams bombarded thin deuterated polyethylene $(CD_2)_n$ targets. Protons from the transfer were detected in a large area silicon detector array in coincidence with heavy recoils detected in a gas- lled ionization counter. This is the rst study of the excited states of ^{83}Ge. The spectroscopic properties of low-lying excitations in ^{83}Ge and ^{85}Se will be compared with properties of more stable N=51 isotones.

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This work was funded in part by the National Science Foundation under contract number NSF-PHY-00-98800; the U.S. Department of Energy under contract numbers DE-FC03-03NA00143 (Rutgers), DE-AC05-00OR22725 (ORNL), DE-FG02-96-ER40955 (TTU), and DE-FG03-93ER40789 (Mines); and the LDRD program of ORNL.

Study of Single-Particle States in ^{23}F using a Proton Transfer Reaction

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We have studied excited states in neutron-rich nucleus ^{23}F using a one-proton transfer reaction onto ^{22}O at 35 MeV/nucleon, an inelastic scattering of ^{23}F at 41.5 MeV/nucleon and a neutron-knockout reaction of ^{24}F at 36 MeV/nucleon. Neutron-rich fluorine isotopes locate in a region connecting sites of exotic nuclear phenomena: the new magic number of N=16 [1] and an island of inversion [2]. Therefore, shell structures in these nuclei are important for understanding nucleon-nucleon interactions causing those phenomena. In order to investigate nuclear shell structure, a one-particle transfer reaction is a good probe because this reaction populates selectively single-particle states. In the present work, we are interested in interactions between neutrons in the $1d_{5/2}$ shell and a proton in the $1d_{3/2}$ shell ($\pi d_{3/2}$-$\nu d_{5/2}$), because it is an inverse situation of interaction between protons in the $1d_{5/2}$ shell and neutrons in the $1d_{3/2}$ shell ($\pi d_{5/2}$-$\nu d_{3/2}$), which is considered to make a large contribution to the shell gap at N=16 [3].

The present experiment was performed at the secondary beam line RIPS in RIKEN Accelerator Research Facility. The secondary beam was a mixture of ^{22}O, ^{23}F and ^{24}F. These particles were produced by fragmentation reaction of 63-MeV/nucleon ^{40}Ar with a ^{9}Be target of 180 mg/cm^2, and were identified event-by-event using energy loss (ΔE) in a beam-line SSD and time-of-flight (TOF) between two plastic scintillators 5 meter apart. The secondary beam bombarded a liquid helium target of 100 mg/cm^2, which was contained in an aluminum cell with two windows of 6-μm Havar foils. Reaction products were detected by a telescope consisting of 9 silicon detectors and 36 NaI(Tl) scintillators. Particle identification of the products were performed by the combination of TOF between the secondary target and the NaI(Tl) scintillator, energy loss in the silicon detector (ΔE) and energy loss in the NaI(Tl) scintillator (E). In order to measure excitation energies of the products, de-excited γ-rays were detected by DALI(II) system, which consists of 150 NaI(Tl) scintillators surrounding the secondary target. Scattering angles of the products were measured by three PPACs. The two of them placed before the secondary target to determine the direction and the hit point of the beam. The other one placed after the target to measure the direction of the product.

We found three candidates for de-excited γ-rays from single-particle states at 2.3, 3.4 and 4.1 MeV by comparing with γ-ray spectra obtained from the three different reactions approaching ^{23}F. Figure 1 shows a level scheme of ^{23}F constructed by multiple γ-ray detections in the proton transfer reaction. We will report the angular momenta and spectroscopic factors of these levels deduced from measured angular distributions.

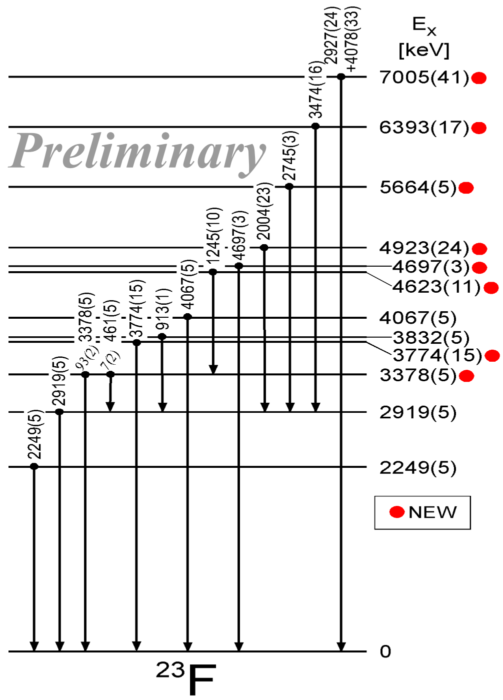

Fig. 1. Gamma-decay scheme in ^{23}F deduced from the proton transfer reaction (^{22}O,^{23}F). Closed circles show the new excited states identified for the first time in the present experiment.

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First 2^+ excited state g-factor studies on heavy Te isotopes using the Recoil-in-Vacuum method with the system CLARION plus Hyball at HRIBF*

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[2]*Department of Physics and Astronomy, University of Tennessee, Knoxville, TN 37996, USA*
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The HRIBF accelerator at Oak Ridge National Laboratory has produced beams of radioactive Te isotopes ^{132,134,136}Te which have been used to measure the B(E2) strengths of excitation of the first 2^+ states in these isotopes [1]. Using a thin [~1 mg/cm^2] carbon foil target and detecting the recoil C ions in the Hyball/Bareball CsI detector array and the de-excitation gamma transition following Coulomb excitation of a 3 MeV per nucleon Te beam in the CLARION array it is straightforward to study the angular distribution of the gamma emission from these states. We have shown that there is strong anisotropy of the gamma decay in the plane normal to the beam as measured with respect to the reaction plane, as well as anisotropy with respect to the beam axis.

Since the Te ions recoil into vacuum from the thin C target, these angular distributions are attenuated through the influence of hyperfine fields present in the recoiling ions. This attenuation is related to the lifetime and g-factor of the de-exciting nuclear state and forms the basis of the 'recoil-in-vacuum' (RIV) method of g-factor measurement [2]. Extraction of unknown g-factors requires calibration of the attenuation through measurements, at the same recoiling Te ion energies, of the attenuated distributions from states of known g-factor and lifetime. In addition the full, unattenuated, anisotropy, corrected for detector solid angle effects, must be known.

We have measured attenuated distributions from the first 2^+ state de-excitations of ^{122,126,130}Te when the Te ions recoiled into vacuum from the same C target, and also the 'unattenuated' distributions from the same isotopes when stopped in a thick [~14 mg/cm^2] Cu backed C [~0.63 mg/cm^2] target.

We will present discussion of the potential of different methods to measure excited state g-factors of short-lived nuclear states using RIBs, emphasizing the ability of the RIV method to yield useful results with extremely weak beams. We will show preliminary evidence of its possible use for levels in odd-A isotopes as well as even-even isotopes. From the measurements described above we will extract a value for the magnitude of the g-factor of the first 2^+ state in ^{132}Te.

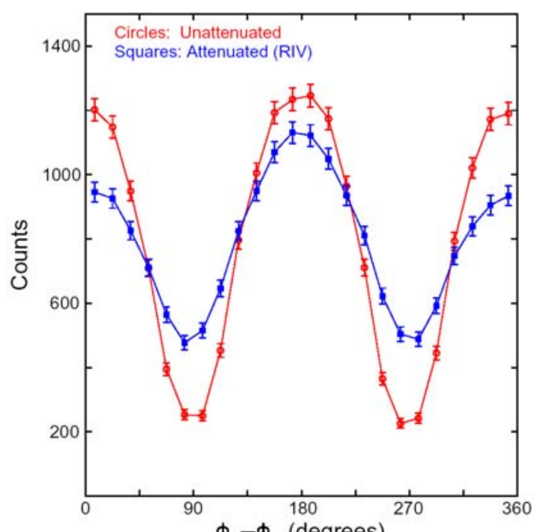

FIG. 1. Unattenuated and attenuated angular distributions measured for first 2^+ state de-excitation in ^{130}Te.

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*This work was supported by the U.S. Department of Energy under contracts DE-AC05-00OR22725 and DE-FG02-96ER40983.

Posters

Atomic Masses

Posters - Masses

Number/Session	Name/email	Institution	Title
1/ Monday	Athanassopoulos, Sotiris sathanas@cc.uoa.gr	University of Athens	New nuclear mass systematics using neural networks
2/ Tuesday	Audi, Georges audi@csnsm.in2p3.fr	CSNSM	Estimates of yet unknown masses
3/ Monday	Beck, Dietrich d.beck@gsi.de	GSI-Darmstadt	Mass measurements of short-lived nuclides of francium and radium with ISOLTRAP
4/ Tuesday	Block, Michael m.block@gsi.de	GSI	The ion trap facility SHIPTRAP - status and perspectives
5/ Monday	Bollen, Georg bollen@nscl.msu.edu	Michigan State University - NSCL	Precision Experiments with Rare Isotopes with LEBIT at MSU
6/ Tuesday	Dilling, Jens jdilling@triumf.ca	TRIUMF	TITAN: Concept and status of a new Penning trap mass spectrometer for short-lived highly charged ions at ISAC
7/ Monday	Guenaut, Céline guenaut@csnsm.in2p3.fr	CSNSM	Is N = 40 magic? The verdict from new, precision mass measurements.
8/ Tuesday	Guenaut, Celine guenaut@csnsm.in2p3.fr	CSNSM	Extending the mass "backbone" to short-lived nuclides with ISOLTRAP
9/ Monday	Gueorguiev, Vesselin vesselin@phys.lsu.edu	Louisiana State University	Extended Pairing Model Applied to Some Heavy Nuclei
10/ Tuesday	Habs, Dieter dieter.habs@physik.uni-muenchen.de	Sektion Physik, University of Munich (LMU)	Penning trap system in Munich
11/ Monday	Izosimov, Igor izosimov@atom.nw.ru	Khlopin Radium Institute	Beta Decay Strength Measurement, Total Beta Decay-Energy Determination and Decay Schemes Completeness Testing by Using the Total Absorption Gamma-Ray Spectroscopy
12/ Tuesday	Janecke, Joachim janecke@umich.edu	University of Michigan	Symmetry energies and the curvature of the nuclear mass surface
13/ Monday	Lunney, David lunney@csnsm.in2p3.fr	CSNSM-IN2P3/CNRS	A MISTRAL spectrometer accoutrement for the study of exotic nuclides
Number/Session	Name/email	Institution	Title

Posters - Masses

Number/Session	Name/email	Institution	Title
14/ Tuesday	Lunney, David lunney@csnsm.in2p3.fr	CSNSM-IN2P3/CNRS	Effects of the pairing energy on nuclear radii
16/ Tuesday	Osborne, Chris c.osborne@mpi-hd.mpg.de	Max Planck Institute for Nuclear Physics	A High Current EBIT for Charge-Breeding of Radionuclides for the TITAN Penning Trap Mass Spectrometer
17/ Monday	Papenbrock, Thomas papenbro@mail.phy.ornl.gov	Oak Ridge National Laboratory / University of Tennessee	Solution of large scale nuclear structure problems by wave function factorization
18/ Tuesday	Ringle, Ryan ringle@nscl.msu.edu	NSCL	The LEBIT 9.4 Tesla Penning Trap System
19/ Tuesday	Rodríguez, Daniel rodriguez@lpccaen.in2p3.fr	LPC-ENSICAEN	Mass measurements on the rp-process waiting point ^{72}Kr
20/ Tuesday	Schwarz, Stefan schwarz@nscl.msu.edu	NSCL / Michigan State University	Commissioning of the ion beam buncher and cooler for LEBIT
21/ Monday	Sharma, Kumar sharma@physics.umanitoba.ca	University of Manitoba	Atomic mass ratios for some stable isotopes of platinum relative to ^{197}Au
22/ Tuesday	Smith, Mathew msmith@triumf.ca	TRIUMF/UBC	Simulation, Construction and Testing of a Gas Filled RFQ Cooler and Buncher for TITAN
23/ Monday	Wang, Yuyan wang@phy.anl.gov	University of Manitoba & Argonne National Lab	Precise Mass Measurements of ^{252}Cf Fission Fragments with The Canadian Penning Trap Mass Spectrometer
24/ Tuesday	Weber, Christine c.weber@gsi.de	GSI	Non-Destructive FT-ICR Detection for On-Line Mass Measurements at SHIPTRAP
25/ Monday	Woehr, Andreas awoehr@nd.edu	University of Notre Dame	The N=Z rp-Process Waiting-Point Nucleus ^{68}Se and its Astrophysical Implication
26/ Tuesday	Yazidjian, Chabouh Chabouh.Yazidjian@CERN.ch	CERN	Commissioning and first on-line test of the new ISOLTRAP control system
Number/Session	**Name/email**	**Institution**	**Title**

New nuclear mass systematics using neural networks*

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Statistical modeling of data sets by neural network techniques is offered as a valuable complement to conventional global modeling of nuclear properties.

In this work, continuing the program established in [1] we use neural networks to develop global nuclear mass models aiming first to determine the degree to which the entire mass table is determined by the existing experimental data, and only the data, and second, to provide reliable predictive models that can be used to forecast mass values away from the valley of stability. The actual predictions for the masses are of great current interest in connection with present and future experimental studies of nuclei far from stability, conducted at heavy-ion and radioactive ion-beam facilities [2]. The results are also useful for such astrophysical problems as nucleosynthesis and supernova explosions.

We use the enriched data base AME03 [3] for learning and validation together with suitable architecture, training algorithm and coding schemes to achieve high performance both in learning and prediction. Our performance is compared to the best of other mass models like the FRDM model of Möller et al. [4] and the HFB2 model of Pearson et al. [5], that are rooted in conventional hamiltonian theory.

Neural network modeling, as well as other statistical strategies based on new algorithms for artificial intelligence, may prove to be a useful asset in the further exploration of nuclear phenomena far from stability.

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* This research has been supported in part by the U. S. National Science Foundation under Grant Nos. PHY-9900173 and PHY-0140316 and by the University of Athens under Grant No. 70/4/3309.

Estimates of yet unkown masses

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The new collection of atomic masses, AME2003, published last December [1], comprises evaluated experimental masses (cf. the presentation by A.H. Wapstra), and also estimates for many still unknown masses. These estimates were obtained in several ways. Examination of previous such estimates, where the masses are now known, shows that the method used, though basically simple, has a good predictive power [2].

The main source of our predictions stem from the observation that the mass surface is very smooth. In the past most estimates were obtained from the derivatives of the mass surface (mainly separation energies). More recently we have exploited also and more extensively the regularity of the mass surface itself.

Since the binding energy varies very rapidly with N and Z, one should subtract a simple function of N and Z from the masses. Practically, we use the results of the calculation of one of the modern models. However, we can use here only those models that provide masses specifically for the spherical part (i.e. forcing the nucleus to be un-deformed). The reason is that the models generally describe quite well the shell and sub-shell closures, and to some extent the pairing energies, but not the locations of deformation. If the theoretical deformations were included and not located at exactly the same position as given by the experimental masses, the mass difference surface would show two dislocations for each shape transition. Interpretation of the resulting surface would then be very difficult. In our work, we currently make use of such differences with models. The plots we have prepared can be retrieved from the AMDC [3].

It is tempting to extend the reasoning above for the deformations, to the shell and sub-shell closures, going back thus to the pioneering work of Weizsäcker [4]. A recent work [5] on the modern fits of the original Bethe and Weizsäcker's formula seems promising in this respect.

The limits for the methods above appear rapidly when going down to low mass numbers where nuclear structures appear and disappear on very short ranges, not to mention vanishing magic numbers. Light neutron-rich masses could be constrained by our knowledge of nuclides being stable or unstable relative to neutron emission. Light proton-rich masses could be derived from the masses of their mirror companions, or from the IMME (Isobaric Multiplet Mass Equation) which showed, up to now, to be fairly well verified. New developments in these directions are in progress.

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Mass measurements of short-lived nuclides of francium and radium with ISOLTRAP

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ISOLTRAP [1,2] is a Penning trap mass spectrometer tailored for on-line mass measurements of short-lived nuclides produced at ISOLDE/CERN [3]. The outstanding feature of ISOLTRAP is the applicability to all elements produced at ISOLDE as well as the accuracy of mass values that can be obtained. Accurate mass values as a function of neutron and proton number serve as a microscope to investigate nuclear structure effects like pairing, the onset of deformation and shell-closures. Furthermore, they provide solid anchorage of α- and β-decay chains as well as for other mass measurements [4,5] far from stability. For this purpose, more than 200 masses have been determined with a typical relative accuracy of $1 \cdot 10^{-7}$. A relative mass accuracy close to $1 \cdot 10^{-8}$ has been achieved for specific nuclides of interest to test fundamental physics [6,7,8 and 9].

Mass measurements on heavy neutron-rich nuclei above ^{208}Pb are supported by multiple interests. Many mass values in this region are unknown although some nuclides have half-lives up to minutes. A profound understanding of this region is required to predict the properties of super-heavy elements. Here, the half-lives for α-decay and spontaneous fission are very sensitive to shell corrections [10]. For the production of super-heavies, it is of primary interest to test those shell corrections around Z = 82, the next heavy shell closure. Furthermore, ^{232}U and ^{232}Th are key nuclei for cosmochronometry [11]. However, exact dating requires the knowledge of the formation of these two nuclides which is especially difficult for the long lived ^{232}Th. An in-depth knowledge of the r-process path and subsequent β-decay towards ^{232}Th is needed. This requires new experimental mass data towards the neutron rich side.

This work extends the previous investigations by ISOLTRAP [12,13] in this region towards the neutron rich side of the valley of beta-stability. Short-lived radio-nuclides of francium and radium have been produced by proton bombardment of an uranium carbide target and subsequent ionization with a hot surface tungsten ion source. With ISOLTRAP, the masses of the short-lived nuclides ^{229,230}Fr and $^{229\text{-}232}$Ra have been measured with a relative accuracy of $1 \cdot 10^{-7}$. The mass values of ^{230}Fr and ^{231,232}Ra were previously unknown and have been determined experimentally for the first time. Furthermore, ^{232}Ra is the heaviest nuclide which has been investigated in a Penning trap ever.

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The ion trap facility SHIPTRAP - status and perspectives

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The ion trap facility SHIPTRAP at GSI Darmstadt has been set up to enable precision experiments on very heavy elements produced in fusion reactions by combining the advantages of an ion trap with the SHIP separator. SHIPTRAP can provide data on different fundamental properties such as masses, half-lives and atomic levels even for super heavy elements. For the complete system including the RFQ buncher and the Penning traps currently the overall efficiency is about 1%.
It is well known that Penning trap mass spectrometers allow for the most precise mass measurements of radionuclides with half-lives down to 100 ms. For mass measurements at SHIPTRAP a double Penning trap system will be used. The trap system was characterized in off-line tests with ^{133}Cs ions. For the purification trap a mass resolving power of $m/\Delta m > 80,000$, sufficient for isobaric purification was obtained. For the measurement trap $m/\Delta m > 860,000$ was demonstrated. At SHIPTRAP the production mechanism and the very low production cross sections of super heavy elements represent an additional challenge compared to other Penning trap facilities. A crucial element in this respect is the gas stopping cell utilized to reduce the energy of the fusion products from a few hundred keV/u to a few eV appropriate for trapping. Hence an extensive test program was performed at the accelerator laboratory in Garching and at GSI. The device is working and the absolute efficiency of the stopping cell together with the extraction RFQ was measured to be about 5% for reaction products in the perpendicular extraction scheme used at GSI. To improve this promising result a more detailed investigation of the loss processes inside the gas cell is necessary. A longitudinal extraction scheme might allow for an efficiency increase because of the simplified matching of the stopped ion distribution to the extraction volume.
A production cross section of 1 μb corresponds to a production rate of about 1 ion/s behind SHIP. Hence, with the current efficiency a mass measurement on such nuclides can be performed with 10^{-7} precision in a few hours beam time. For first mass measurements it is more appropriate to select nuclides with higher production rates to allow for a quick optimization of all components. Therefore measurements in the region near the neutron-deficient lutetium isotopes are planned in 2004. This area is interesting because of its vicinity to the proton dripline, and in particular because of the phenomenon of ground-state proton radioactivity, which was discovered at SHIP. The key parameter is the proton separation energy, which can be derived from atomic masses. Still today, there are many masses in this region which are so far experimentally unknown, for instance the masses of $^{150-152}$Lu and ^{157}Hf.
To access even heavier elements and to allow for a higher precision, the overall efficiency of SHIPTRAP has to be further improved since the production cross sections of super heavy elements drop to about 1 pb for Z=112. In the future additional improvements are possible by more efficient ion detectors or a different detection principle. For long-lived transactinides the non-destructive Fourier transform ion cyclotron resonance technique may be advantageous compared to the generally utilized destructive time-of-flight method since several measurements can be performed with the same ion. This can result in a high gain factor and give access to nuclides with lower production rates. The detection of even single ions requires highly sensitive detection electronics and a cryogenic trap set-up. Such a system is currently being constructed for SHIPTRAP.

Precision Experiments with Rare Isotopes with LEBIT at MSU *

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The Low-Energy beam and Ion Trap Project LEBIT opens the door to a new class of experiments with fragment beams. The Coupled Cyclotron Facility at the NSCL delivers a large range of rare isotopes with high intensities, produced by the in-flight separation method. LEBIT converts these beams into low-energy beams with excellent quality by using gas stopping and advanced ion guiding, cooling, and bunching techniques. The ion stopping, ejection and bunching has been recently demonstrated. The experimental program will start with high precision mass measurements on nuclides along the N=Z line and on neutron-rich isotopes in the vicinity of N=28 in a high-field (9.4 T) Penning trap system. Other experiments envisaged for this ion trap system are in-trap decay studies for precision conversion electron spectroscopy. Provisions are made to extend the experimental activities with LEBIT towards laser spectroscopy and towards post-accelerated beams. The installation of LEBIT is completed and first results are expected until by 2004.

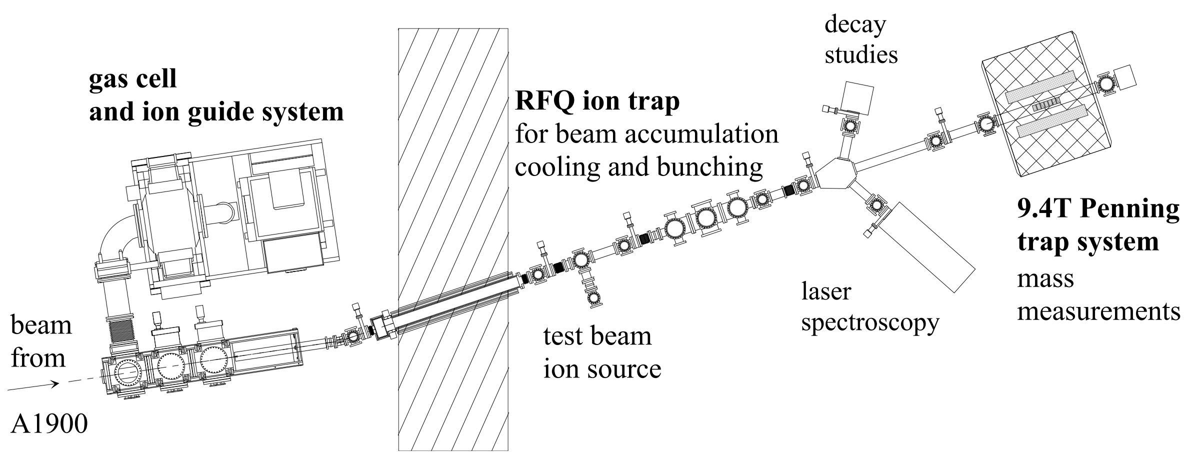

FIG. 1. Layout of the LEBIT facility at the NSCL.

*This work was supported by MSU, NSF and DOE.

TITAN: Concept and status of a new Penning trap mass spectrometer for short-lived highly charged ions at ISAC.

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The TITAN (Triumf's Ion Trap for Atomic and Nuclear science) will employ a gas-filled RFQ cooler and buncher, a charge-breeding EBIT, and a m/q selecting Wien-filter to deliver highly charged ions to the Penning trap for the determination of the mass via the cyclotron frequency. The mass resolution of a Penning trap spectrometer depends directly on the charge state, the magnetic fields, the observation time and the sqrt(N) of the number of detected ions. This translates into three advantages when employing highly charged ions: 1. maintaining sufficient mass resolution for exotic isotopes with low production rates, for example far away from the valley of stability, 2. conserving good mass resolution of very short-lived ($t_{1/2}$□10 ms) isotopes, and 3. reaching the required high mass resolution □m/m □ $1 \bullet 10^{-8}$ for specific isotopes relevant for Standard Model tests or of nuclear astrophysics interest. All three advantages fit very well to ISAC, where the production of exotic isotopes far away of the valley of stability is one of the main goals and yield gain of a factor of 10-50 over other on-line facility has been copiously demonstrated. The TITAN system is presently in the design and construction phase and is partly assembled, with test underway. First on-line mass measurements are planned for 2006.

Is $N = 40$ magic? The verdict from new, precision mass measurements

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Shell closures are fundamental pillars on which nuclear structure rests but we now know them to erode as we explore extreme isospin systems. The first so-called "magic" number to disappear was the $N = 20$ shell closure around Na and Mg and now the $N = 28$ would appear to succumb as well. Like a good magic act, shell closures, having disappeared, can also *reappear* as attested by the cases $N = 16$ and $N = 32$.

Different observables can be used for the analysis of this "magic number migration": excitation energies in even-even nuclei, nuclear level densities, interaction cross-sections and, in the grandest tradition, nucleon separation energies. The latter are particularly sensitive to pairing correlations in the context of superfluidity [1], especially for the case of semi-magic nuclei. As explained in [1], the variation of the two-neutron separation energy (S_{2n}), which is the energy required to extract two neutrons from a nucleus, versus N is smooth where the pairing correlation is present and jagged where it is absent.

The question of superfluidity has been addressed in the difficult case of ^{68}Ni [2], for which a plethora of experimental and theoretical work exists but with no clear consensus on whether this case of ($Z = 28$) $N = 40$ is magic or not. Often, two-neutron separation energies are not smooth due to the propagation of inaccurate decay Q-values. Using the powerful ISOLTRAP mass spectrometer [3], we have made precision mass measurements in the $N = 40$ region for Ni, Cu and Ga isotopes in order to finely map the S_{2n} behavior. The high accuracy of the ISOLTRAP mass measurements also permits us to map out the fine structure of the neutron pairing energy which we have also analyzed for correlations and signatures of closed or open shells.

This contribution will present the results of these new measurements and the analysis of the related quantities in light of superfluidity in order to enable some pronouncement on the status of this mysterious, if not magic number.

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Extending the mass "backbone" to short-lived nuclides with ISOLTRAP

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In the Atomic-Mass Evaluation [1], a backbone of nuclides along the line of stability in a diagram of atomic number Z versus neutron number N is distinguished. For these nuclides the atomic mass values are known with exceptionally high precision. The precision now achieved with Penning traps allows also to improve the precision in our knowledge of atomic mass values along the backbone.

ISOLTRAP [2,3] is a facility using the on-line mass separator ISOLDE, located at CERN, Geneva. This spectrometer was designed for high-precision mass measurement on short lived nuclides. The measurement is based on the determination of the cyclotron frequency of the ions trapped in a magnetic field. This is made with a Penning trap which now allows us to reach an accuracy better than 10^{-8} even for short-lived nuclides, which is by far the most accurate technique for radioactive nuclides.

In an effort to extend the backbone, almost ten nuclides were measured with an uncertainty around 10^{-8} (less than 5 keV for $A = 50$), these high-precision mass measurements were included in the new Atomic-Mass Evaluation published in the end of 2003 [1]. This table is a result of the evaluation of all available experimental data on mass measurements and decay and reaction energies. Evaluation means that every data is compared to the previous one, and also takes into account all the links between the results.

In this contribution we present our new results (figure 1) and comparisons with the previous values. Thanks to our high-precision measurements, in some cases we succeeded to decrease by at least a factor 5 the uncertainty on the mass value, in some other cases we confirm the value.

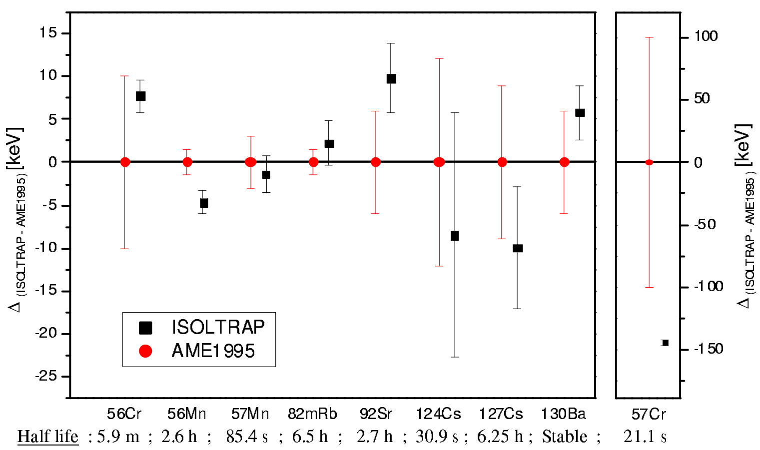

Figure 1: Difference between ISOLTRAP measurement and AME 1995.

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[2] G. Bollen et al., Nucl. Instr.Meth. A 368 (1996) 675.
[3] F. Herfurth et al., Nucl. Instr. Meth. A 469 (2001) 254.

Extended Pairing Model Applied to Some Heavy Nuclei *

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We study binding energies in three isotopic chains ($^{100-130}$Sn, $^{152-181}$Yb, and $^{181-202}$Pb) using the extended pairing model [1] with Nilsson single-particle energies. The exactly solvability of the model means that the pairing strength $G(A)$ required to reproduce the experimental binding energies can be determined uniquely. The valence space consists of the neutron single-particle levels between two closed shells corresponding to the magic numbers 50-82 and 82-126. In all three isotopic chains, $\log(G(A))$ has a smooth quadratic behavior for even as well as odd nucleon number A; $\log(G(A))$ for even and odd A are very similar. Remarkably, $G(A)$ for all the Pb isotopes can also be described by a two parameter expression (see FIG. 1) that is inversely proportional to the dimensionality of the model space.

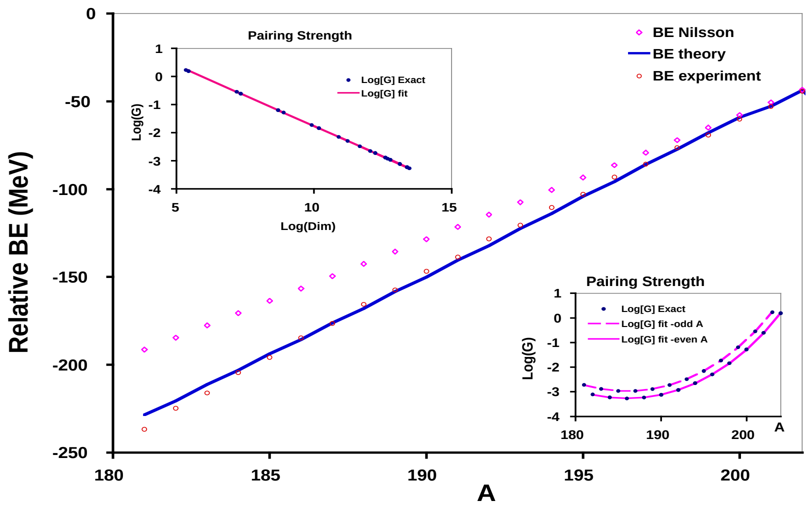

FIG. 1. The solid line gives the theoretical binding energy for the Pb isotopes relative to the ^{208}Pb nucleus. The insets show the fit to the values of G that reproduce exactly the experimental data using a ^{164}Pb core. The lower inset shows the two fitting functions: $\log(G(A)) = 382.3502 - 4.1375A + 0.0111A^2$ for even values of A and $\log(G(A)) = 391.6113 - 4.2374A + 0.0114A^2$ for odd values of A. The upper inset shows a fit to $G(A)$ that is inversely proportional to the size of the model space, $(\dim(A))$, that is valid for even as well as odd values of A: $G(A) = 366.7702/\dim(A)^{0.9972}$. The Nilsson BE energy is the lowest energy of the non-interacting system.

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*Support provided by the U.S. National Science Foundation (0140300), the Natural Science Foundation of China (10175031), and the Education Department of Liaoning Province (202122024).

†On leave from the Institute of Nuclear Research & Nuclear Energy, Bulgarian Academy of Sciences, Sofia 1784. Currently on a NATO research fellowship at the Instituto de Estructura de la Materia, CSIC, Madrid, Spain

Penning trap system in Munich

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The MAFF facility (Munich Accelerator for Fission Fragments) planned at the research reactor FRM-II in Munich is dedicated to produce, cool and accelerate high-intensity neutron-rich radioactive beams.

The experimental activities at MAFF will focus around nuclear spectroscopy studies and nuclear mass measurements. One of the experimental devices serving this purpose will be the ion trap system MLLTRAP [1]. Its main tasks are to decelerate, cool, bunch and purify the radioactive beam and to perform high-precision nuclear mass measurements. Before operating at MAFF, MLLTRAP will be tested at the MLL (Maier-Leibnitz Laboratory) 15 MV Tandem. The experimental on-line assembly will be composed of:

1) a target chamber, where the beam from the MLL Tandem produces, after fusion reaction, radioactive recoil nuclei. They are further separated from the primary beam by the
2) 90 degree beam separation magnet (B about 1 T),
3) a gas stopping chamber for the radioactive ions' deceleration [2] (to eV range), coupled to an RFQ cooler-buncher which injects the ions into
4) an Electron Beam Ion Source (EBIS), to produce highly-charged radioactive ions and inject them into
5) a linear Paul trap. There singly-charged Mg ions will also be stored, and laser-cooled. Subsequently they will serve to sympathetically cool highly-charged ions injected from the EBIS,
6) an ion source producing singly-charged Mg ions,
7) a laser system to (laser-) cool Mg ions inside the linear Paul trap,
8) a double Penning trap system in one superconducting magnet, consisting of the purification Penning trap and the precise mass measurement Penning trap.

This system, due to the use of highly-charged ions, will perform mass measurements of radioactive nuclei with higher precision (below 10^{-9} is expected), than before ($8*10^{-9}$, [3]). It will allow to perform measurements of e.g. the molar Planck constant in collaboration with GAMS (M. Jentschel, ILL).
First phase of the above experiment will be an off-line sympathetic cooling testing assembly. It will consists of:
1) an off-line ion source emitting a stable ion beam of singly-charged Cs and Mg ions,
2) an RF funnel cooler/buncher [4] for an efficient beam cooling,
3) a linear Paul trap, where singly charged Mg ions will be stored and laser-cooled together with Cs ions,
4) a laser system to (laser-) cool Mg ions inside the linear Paul trap which exists from PALLAS [5],
5) a double Penning trap system as described before.

The electrode structure of the Penning trap is ready. The B=7 T superconducting magnet for the Penning trap system has been delivered to LMU in April 2004. The planned test assemblies and the experiments will be presented.

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Beta Decay Strength Measurement, Total β-Decay Energy Determination and Decay Schemes Completeness Testing by Using the Total Absorption γ-Ray Spectroscopy

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The total absorption γ-ray spectroscopy (TAGS) is based on summation of cascade gamma quantum energies in the 4π geometry [1]. The TAGS may be applied for β-decay strength function $S_\beta(E)$ measurement, for total β-decay energy Q_β determination and for decay scheme completeness testing. The combination of the TAGS with high resolution γ-spectroscopy may be applied for $S_\beta(E)$ fine structure study and for detailed decay schemes construction [2-5]. In our experiments we use the total absorption γ-rays spectrometer which consists of the two NaI(Tl) crystals 200mm by 110mm and 200mm by 140mm. The larger crystal has a 70mm by 80mm well into which the nuclei under investigation are supplied and where a Si(Au) detector is install for β-particles detection [4]. Isolating total absorption peaks in the total absorption (TAS) spectrum, one can find the occupancy of the levels *I(E)*, and the strength function $S_\beta(E)$ [1,4]. The end-point energy of TAS spectrum is connected with the total beta decay energy Q_β [3]. The TAS spectrum and $S_\beta(E)$ may be calculated from decay scheme data. For decay scheme construction the high-resolution nuclear spectroscopy methods are using. Compare the TAGS spectroscopy data (TAS spectrum and $S_\beta(E)$) with the data obtained from decay schemes one may estimate the degree of the decay scheme completeness and determine the energies regions where decay scheme is not enough complete.

In this report the measurements and analysis of beta strength fine structure are presented. It is shown that fine structure of beta strength may be essential for delayed processes interpretation. Decay schemes completeness testing by using TAGS spectroscopy is discussed. Demonstrated that for correct application of TAGS spectroscopy it is necessary to have both Z (element) and M (mass) separated sources.

Application of the maximum-likelihood method for total electron capture energy Q_{EC} determination from TAS spectrum is discussed. It is shown that the maximum-likelihood method give more small error than other methods. In the fig.1 the TAS spectrum for ^{156}Ho ($T_{1/2}\approx$56min) and results of it's maximum-likelihood analysis are presented. By using maximum likelihood-method we obtained Q_{EC}=(5.05± 0.02)MeV for ^{156}Ho($T_{1/2}\approx$56min).

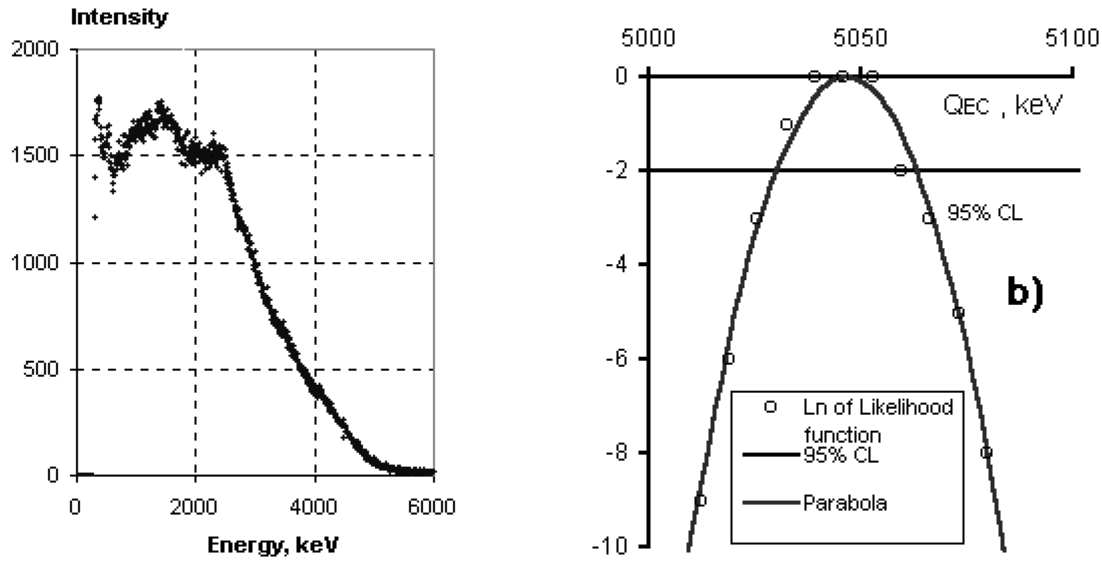

FIG. 1. Experimental TAS spectrum for ^{156}Ho ($T_{1/2}\approx$56min) β^+/EC decay and (b) likelihood function dependence on Q_{EC} parameter for this TAS spectrum .

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Symmetry energies and the curvature of the nuclear mass surface

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The goodness of mass equations is influenced by how well the curvature of the experimental nuclear mass surface is reproduced.

Symmetry energies E_{sym} depend on isospin T and nucleon number A. The isospin dependence is essentially quadratic, and the decrease with increasing A is approximately proportional to $1/A$. The curvature of the mass surface, therefore, depends strongly on symmetry energies.

The differences between the excitation energies of isobaric analog states with isospins T' and T in nuclei with nucleon number A have been introduced and denoted by $\Delta_{T',T}(A)$. In liquid-drop-model or shell-model approaches, these energies can be expressed as differences between symmetry and pairing energies. Numerous such excitation energies are known experimentally. A much more comprehensive global set of these energy differences has been obtained in the present work. Here, the energies $\Delta_{T+1,T}(A)$ are deduced from Coulomb-energy-corrected differences of all available experimental masses of neighboring isobars.

An expression for the symmetry energy has been introduced as

$$E_{\rm sym}(A,T) = \frac{a(A,T)}{A}\, T(T+1)\ . \tag{1}$$

Here, the factor $a(A,T)$ is an operationally defined symmetry energy coefficient. These coefficients as well as the pairing energies $P(A,T)$ have been obtained for the entire experimental mass surface from the above energy differences $\Delta_{T+1,T}(A)$. The results were discussed in detail previously [1,2]. The symmetry-energy coefficients $a(A,T)$ are nearly constant over wide ranges of nuclei where the shell model dominates in the description of symmetry energies. However, systematic deviations from a constant value were also observed particularly in shell regions where neutrons and protons do not occupy the same major shell model orbits. An interesting effect was observed for nuclei with $N \approx Z$ centered near $A \approx 84$ where $\alpha-$particle substructures appear to be present.

Replacing the experimental mass data by available theoretical mass predictions as basis for the above procedures to extract symmetry and pairing energies makes it possible to directly compare theoretical and experimental quantities, particularly the symmetry energy coefficients $a(A,T)$. These are, as noted, related to the curvature of the nuclear mass surface which represents a higher-order characteristics. The comparisons reflect upon the goodness or possible shortcomings of the respective mass equation. A discussion of nine selected mass equations or procedures for reproducing experimental masses and extrapolating into regions of unknown nuclei is presented. Here, the comparisons between the theoretical and experimental coefficients $a(A,T)$ are shown by calculating and displaying the individual differences for each nucleus over the experimental mass surface. Furthermore, a similar comparison is presented for pairs of mass equations. This information reaches into regions of extrapolated mass values beyond the experimentally known masses.

While approximate agreement exists between the theoretical and experimental results, distinct discrepancies are also observed particularly in regions of very neutron-rich and proton-rich nuclei.

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A MISTRAL spectrometer accoutrement for the study of exotic nuclides

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MISTRAL is a radiofrequency, transmission spectrometer devoted to precision mass measurements of exotic nuclides produced at the ISOLDE PS Booster radioactive beam facility at CERN. Due to the fact that the ions are counted after transmission through the spectrometer at the nominal beam transport energy (of 60 keV), MISTRAL is especially suited to the measurement of the shortest-lived nuclides that can be extracted from ISOLDE targets. The technique employed by MISTRAL is based on an excitation of the cyclotron frequency of ions in a homogeneous magnetic field. The mass is determined by comparing the cyclotron frequency to that of a well-known reference mass [1].

Past measurements have included ^{28}Na ($T_{1/2}$ = 30.5 ms), ^{30}Na (48 ms), ^{33}Mg (90 ms), and ^{11}Li (8.6 ms), which have been measured with a relative precision down a few times 10^{-7}. Thus, MISTRAL is capable of providing very good accuracy for nuclides quite far from stability. In order to achieve such accuracy, high resolving power is necessary but this comes, as always, at the expense of transmission: the slits used to define the trajectory through the magnet are only 0.4 mm wide, resulting in an overall transmission of only about 10^{-4}. As the shortest-lived isotopes at ISOLDE are produced at rates of only a few per second, the roughly 30 π mm mrad emittance of the ISOLDE beam must be reduced by a factor of about 100 in order to make mass measurements of the most exotic species possible.

The solution to this problem is found in a gas-filled, Paul-trap beam buncher [2], a device that reduces beam emittance at minimal cost in intensity. The design of such an auxiliary was elaborated in [3] and the first direct demonstration of emittance reduction by such a device reported in [4]. Since then, similar instruments have been built and used successfully in the measurement of exotic nuclides for mass measurements [5,6] and laser spectroscopy [7], while others operate off-line in preparation for weak interaction studies [8], mass measurements of superheavy elements [9] and post-acceleration of exotic nuclides (using negative ions) [10]. A second-generation beam cooler has also now been elaborated [11].

This contribution will present the first results of the beam cooler designed for MISTRAL, called COLETTE (CoOLing for EmiTTance Elimination) which has been developed using beams from the off-line separator SIDONIE (Séparateur Isotopique D'Orsay à source NIEr-Bernas) in Orsay.

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Effects of the pairing energy on nuclear radii

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Given the many facets of nuclear structure reflected by the binding energy, the mass can be considered as one of the most basic nuclear properties. The binding energy will have a decisive impact on the resulting size and shape of a given nuclide and one of the most interesting consequences of this interplay is that of shape coexistence. [1] Given the intimate relationship between masses and radii, it is natural to study correlations between these fundamental properties and at the ISOLDE radioactive beam facility, a strong tradition exists for their determination.

In this contribution we present recent results from mass measurements and laser spectroscopy of heavy nuclides (around Pb) and examine them for correlations. This is a continuation of the work initiated at the last ENAM conference [2] based on the high-accuracy mass measurements of neutron-deficient Hg isotopes [3]. A marked manifestation of shape coexistence was found many years ago from the large odd-even staggering of Hg radii near the $N = 104$ mid-shell region. [4] The explanation for this behavior was thought to be in the neutron pairing energy. As this quantity has an absolute value of only about 1 MeV, mass data available at that time was of insufficient precision for any analysis. Only now, with the advent of high precision mass measurements using the ISOLTRAP spectrometer [5] in some cases requiring *isomeric* resolution [6], is it possible to see structure in the neutron pairing energy. Precision mass measurements with ISOLTRAP have now been performed on neutron-deficient Tl and Bi isotopes [7].

Laser spectroscopy studies have now been extended into the region of very heavy nuclides at ISOLDE. Some years ago, Bi isotopes were investigated using the gas cell technique [8] but more recently, the ISOLDE laser ion source has been exploited to directly perform in-source laser spectroscopy, coupled with nuclear spectroscopy. New results are available now for neutron-deficient Pb isotopes. [9] which can be compared with the Pb masses determined via links to the ISOLTRAP Hg masses [3].

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A High-Current EBIT for Charge-Breeding of Radionuclides for the TITAN Penning Trap Mass Spectrometer

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The TITAN (Triumf's Ion Trap for Atomic and Nuclear science) Penning trap mass spectrometer at ISAC/TRIUMF is designed for making high-precision mass measurements on radionuclides by determining the cyclotron frequency of the ions confined within the Penning trap. The cyclotron frequency, ν depends upon the mass of the ion, the magnetic field of the trap and the charge-state of the ions; $\nu = Bq/m$. For a given accuracy in the frequency determination, $\Delta\nu$, which depends principally upon the duration of the measurement; the relative accuracy of the mass measurement $\Delta\nu/\nu$ can be increased by preparing the ions of interest in a higher charge-state, hence higher absolute frequency ν. Also, as a consequence of the ions being in high charge-states, a desired accuracy can be attained within a shorter measurement interval. This is an important issue for high-accuracy mass measurements on radioactive isotopes with nuclear half-lives significantly shorter than 1 second.

In order to rapidly charge-breed the ions to any charge-state (including fully stripped systems) an EBIT (Electron Beam Ion Trap) is a well-suited device. A high-current electron beam from an electron gun is compressed by means of a strong magnetic field and collected behind the magnet. Ions are radially trapped in the EBIT by the space-charge of the compressed electron beam and longitudinally confined by electrical potentials applied to a set of tubular electrodes. Whilst trapped, the ions are continuously charge-bred due to the impact of the electrons. The Heidelberg EBIT group is part of the TITAN collaboration and is presently constructing an EBIT specifically designed for this purpose. A 5A electron gun has been built and is currently undergoing operation tests along with a 6T cryogenically-cooled magnet. A report on these high-current tests and computer simulations performed, which model the important issues of injection and extraction of ions into and from the trap, will be given.

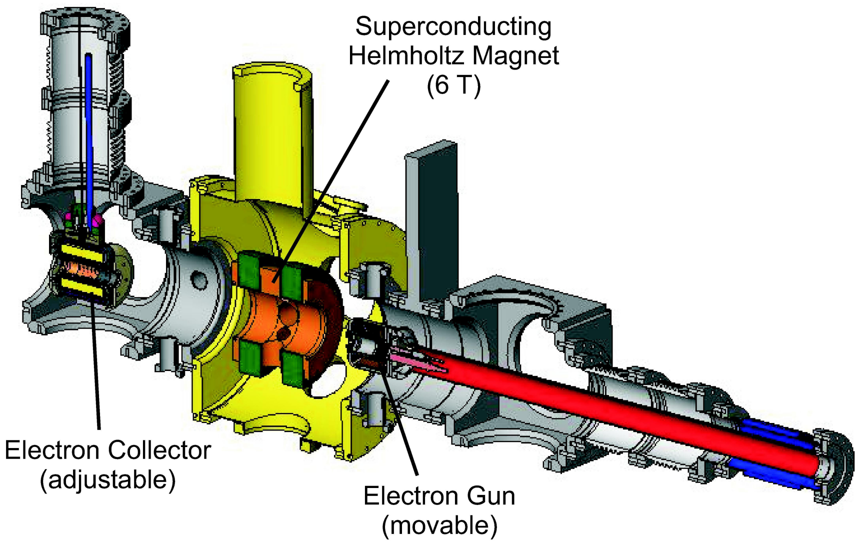

FIG. 1: Schematic overview of the TITAN EBIT.

Solution of large scale nuclear structure problems by wave function factorization *

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Low-lying shell model states may be approximated accurately by a sum over products of proton and neutron states. The optimal factors are determined by a variational principle and result from the solution of rather low-dimensional eigenvalue problems [1]. Application of this method to sd-shell nuclei, pf-shell nuclei, and to no-core shell model problems shows that very accurate approximations to the exact solutions may be obtained. Their energies, quantum numbers and overlaps with exact eigenstates converge exponentially fast as the number of retained factors is increased.

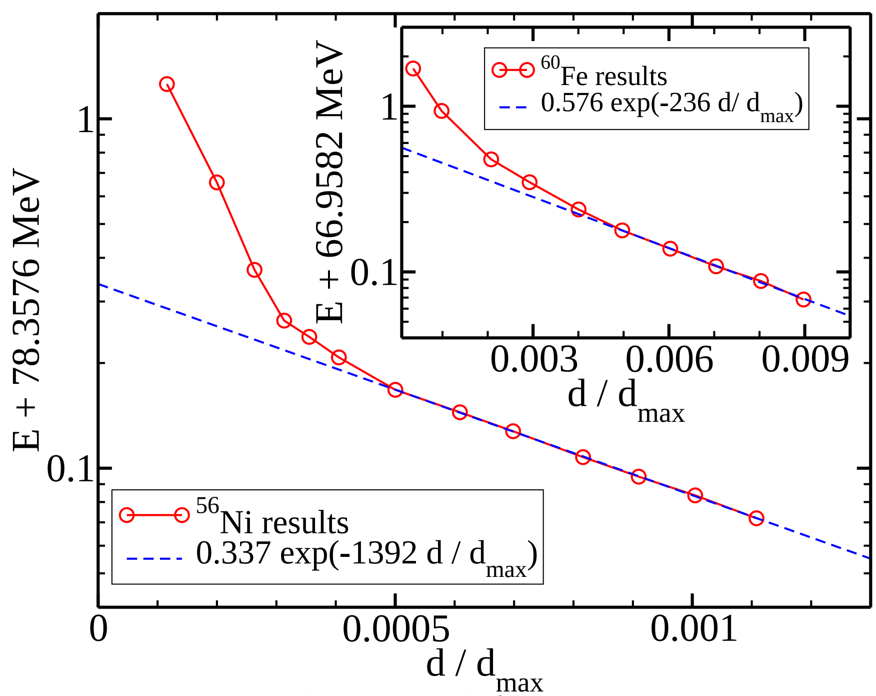

FIG. 1. Ground-state energy E versus the dimension d of the eigenvalue problem relative to the m-scheme dimension $d_{\max} \approx 1.09 \times 10^9$ for ^{56}Ni. The data points are from the m-scheme factorization, and the dashed line is an exponential fit to the data. Inset: Similar plot for ^{60}Fe ($d_{\max} \approx 10^8$). Taken from Ref.[2]

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*This work was supported by the U. S. Department of Energy under contracts DE-AC05-00OR22725 and DE-FG02-96ER40963.

The LEBIT 9.4 Tesla Penning trap system *

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The initial experimental program with the Low-Energy Beam and Ion Trap Facility LEBIT will concentrate on Penning trap mass measurements of rare isotopes, delivered by the Coupled Cyclotron Facility of the NSCL. The LEBIT Penning trap system has been optimized for achieving a high accuracy for very short-lived isotopes. The magnetic field for the cyclotron frequency determination is provided by an actively-shielded persistent superconducting magnet system with a field of 9.4 Tesla. This field is the highest used so far in Penning trap mass spectrometers for rare isotopes. The LEBIT system features an additional coil for compensating external magnetic field changes as they typically occur in an accelerator environment. For the trap electrodes a hyperbolic, highly-compensated electrode configuration has been chosen. This minimizes systematic errors in the mass determination.

Figure 1 shows the assembled electrode system made out of gold-plated copper and aluminum oxide ceramics. The design of the Penning trap system will be presented as well as the results of first test measurements with this system.

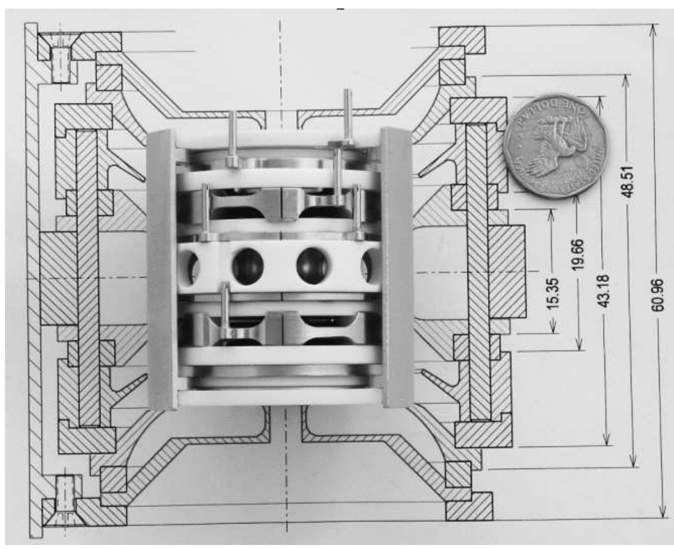

FIG. 1. The electrode system for the LEBIT Penning trap.

*This work was supported by MSU, NSF and DOE.

Mass measurement on the *rp*-process waiting point ^{72}Kr *

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Masses are among the most critical nuclear parameters in nucleosynthesis calculations in astrophysics [1]. Specifically, very precise mass values of elements formed along the rapid proton capture process (*rp*-process), are crucial for reliable calculations of X-ray burst lightcurves. An X-ray burst is a thermonuclear explosion on the surface of a neutron star accreting hydrogen and helium rich matter from a companion star in a binary system. The extreme temperature and density conditions in this scenario can lead the formation of elements up to Te ($Z = 52$). They are formed by continuous rapid proton captures, interrupted at the so-called waiting points by β^+-decays. Waiting point nuclei come on stage when proton capture is hindered by photodisintegration by weakly proton bound or unbound nuclei. This causes a delay in the X-ray burst duration and consecuently, affects the X-ray burst lightcurve and the nucleosynthesis. For any waiting point nucleus, the delay, referred to as effective lifetime, depends exponentially on the mass difference between the waiting point nucleus (Z, A) and the possibly formed nucleus $(Z + 1, A)$. It has been demonstrated that very precise mass values around the three major *rp*-process waiting points ^{64}Ge,^{68}Se, and ^{72}Kr are required to avoid large uncertainties in nucleosynthesis calculations [2].

With the aim to improve nucleosynthesis calculations, we performed for the first time, a direct high-precision mass measurement on the waiting point in the astrophysical *rp*-process ^{72}Kr with the Penning trap mass spectrometer ISOLTRAP, at ISOLDE/CERN. The measurement yielded a relative mass accuracy of $\delta m/m = 1.2 \cdot 10^{-7}$ ($\delta m = 8$ keV). In addition to ^{72}Kr, the masses of other Kr isotopes, also needed for astrophysical calculations, were measured with more than one order of magnitude improved accuracy. The ISOLTRAP mass values of $^{72-74}$Kr are used to reanalyse the role of the ^{72}Kr waiting point in the *rp*-process during X-ray bursts with unprecedented precision. The impact of our new mass values in recent nucleosynthesis calculations will be reported.

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* This work has been supported by the European Commission within the EUROTRAPS network under contract number ERBFM RXCT97-0144, the RTD project EXOTRAPS under contract number HPRI-CT-1998-00018, and the NIPNET network under contract number HPRI-CT-2001-50034.

Commissioning of the ion beam buncher and cooler for LEBIT *

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The Low Energy Beam and Ion Trap (LEBIT) Project converts the DC beam of high-energy fragmentation products at NSCL/MSU into low-energy low-emittance ion pulses. This beam manipulation is done in two steps. First a high-pressure gas stopping cell reduces the beam energy from $\approx 100-150\,\mathrm{MeV/u}$ to several keV. This device will be presented in a separate contribution to this conference. A radiofrequency quadrupole (RFQ) ion buncher then accumulates and cools the beam before it is released as ion pulses. These pulses will be sent to a Penning trap for high-precision mass measurements on short-lived nuclides.

The design of the LEBIT buncher has been changed in several aspects from that of other RFQ ion bunchers used at ISOL facilities to significantly enhance the performance: a) The cooling and bunching of ions is performed in two separate sections. A high-pressure part allows for fast cooling whereas a low-pressure trapping region forms ion bunches with low energy-spread. b) A novel electrode layout allows one to provide the drag force in the cooling section without the need for segmented rods. c) The buncher can be operated at LN_2-temperature. Compared to a room-temperature system the emittance of the ejected ion bunches is expected to be a factor of 4 smaller.

The completed set-up of the LEBIT ion buncher will be presented as well as first experimental results on pulse forming and beam properties. These results will be compared to predictions from Monte-Carlo type ion-trajectory simulations.

FIG. 1. A photograph of the cooler section of the LEBIT buncher.

*This work supported by NSF, DOE, and MSU.

Atomic mass ratios for some stable isotopes of platinum relative to ^{197}Au*

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The Canadian Penning Trap mass spectrometer was designed to precisely determine the masses of stable and unstable isotopes. To date such measurements have been carried out on approximately 60 short-lived species. A laser ablation ion source is also available to produce ions of stable isotopes, intended for use in calibrations, checks for systematic effects and for measurements involving stable isotopes. Here we report the results of our measurements with platinum and gold ions, produced by this source. These measurements were motivated, in part, by the long-standing discrepancy between earlier mass measurements and the Atomic Mass Evaluations in the mercury region. Mass ratios for the isotopes ^{194,195,196,198}Pt relative to ^{197}Au have been determined to a precision of 10^{-8}. No significant deviations from accepted values were found. In addition, the data also demonstrate the stability of the measurement system and set limits on the magnitude of systematic effects.

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*This work was supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. W-31-109-ENG-38, and by grants from the Natural Sciences and Engineering Research Council of Canada.

Simulation, Construction and Testing of TITAN's Gas Filled RFQ Cooler and Buncher

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The TITAN (TRIUMF's Ion Trap for Atomic and Nuclear science) project at TRIUMF will use the unique combination of an Electron Beam Ion Trap (EBIT) charge state breeder and a precision Penning trap to carry out high accuracy mass measurements ($\delta m/m = 1 \times 10^{-8}$) on short-lived ($t_{1/2} \approx 50ms$) radioactive isotopes. This will provide the necessary precision to test fundamental concepts such as the Conserved Vector Current (CVC) hypothesis and, ultimately, the unitarity of the Cabibbo-Kobayashi-Maskawa (CKM) matrix for medium to heavy mass N=Z nuclei.

In order to obtain fast and efficient charge state breeding it is necessary to inject a cooled and bunched beam into the EBIT. As demonstrated at other facilities, e.g. ISOLDE/CERN and Jyväskylä, these beam properties can be achieved by employing a segmented, linear, gas filled RFQ device. At the proposed TITAN facility the continuous beam from the ISAC mass separator facility will be injected into such a device. Within the RFQ the ion beam will be cooled via collisions with an inert buffer gas and bunched via the application of a longitudinal trapping potential. Due to the short half-lives of the isotopes to be studied the device must be capable of quickly cooling the ion beam whilst still producing an ion bunch with a uniform energy spread.

The considerations when designing such a device, the results of computer simulations of the RFQ and preliminary results from offline testing of the system will be presented in this contribution.

Precise Mass Measurements of ^{252}Cf Fission Fragments with The Canadian Penning Trap Mass Spectrometer*

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Mass measurements provide an important tool in understanding astrophysical processes. More than half of the elements in the universe heavier than iron are synthesized by the rapid neutron-capture process (r-process). Mass measurements of neutron-rich isotopes close to the r-process path are critical to network calculations of this astrophysical process that are used to explain the natural abundance of the nuclides.

Mass measurements in this nuclide region have been performed with ^{252}Cf fission fragments using the Canadian Penning Trap (CPT) mass spectrometer at Argonne National Laboratory. We measured 26 neutron-rich Ba, La, Ce and Pr isotopes from the heavy ^{252}Cf fission fragment peak with a precision of a few keV/c^2. An additional 9 neutron-rich Ru, Mo, Tc and Rh isotopes from the lighter fission peak were also measured with a few tens of keV/c^2 accuracy. As compared with the 2003 Atomic Mass Evaluation, most of our measurements have much better precision. More measurements of the light ^{252}Cf fission fragments are in preparation. These new measurements will benefit from a stronger ^{252}Cf fission source in addition to ongoing improvements to the CPT system.

*This work was supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. W-31-109-ENG-38, and by the Natural Sciences and Engineering Research Council of Canada.

Non-Destructive FT-ICR Detection for On-Line Mass Measurements at SHIPTRAP

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The SHIPTRAP facility [1, 2] is designed to deliver very clean and cooled beams of singly charged radioactive ions produced at the SHIP velocity filter [3] at GSI. SHIPTRAP consists of a gas cell for stopping and thermalizing recoil ions from SHIP, a radiofrequency (RF) quadrupole ion guide for extraction of the ions from the gas cell, a linear RF trap for accumulation and bunching of the ions, and a Penning trap for isobaric purification.

The scientific program comprises mass spectrometry, atomic and nuclear spectroscopy and chemistry of elements with Z > 92, which are not available at ISOL- or fragmentation facilities. One of the main limitations to the experimental investigations is the low production rate of most of these exotic nuclei. However, several nuclei in the trans-uranium region exhibit particular long half-lives. Here, a sensitive and non-destructive method, like the Fourier Transform Ion Cyclotron Resonance (FT-ICR) technique, is ideally suited for the identification and characterization of these ions. The signal of charged particles stored in a hyperbolically shaped Penning trap with a segmented ring electrode is picked up with a tuned circuit. It enables the detection of a single ion as well as further successive measurements with the same ion, such as e.g. mass measurement and chemical study.

A narrow-band electronic resonance circuit operated at 4 K has been developed. This will serve for the highly sensitive detection of single trapped ions in a hyperboloidal Penning trap kept at 77 K. This trap along with the preceding purification trap has been designed for SHIPTRAP and is being set up off-line. The principle of FT-ICR, the current status and its future realization at the SHIPTRAP facility will be presented.

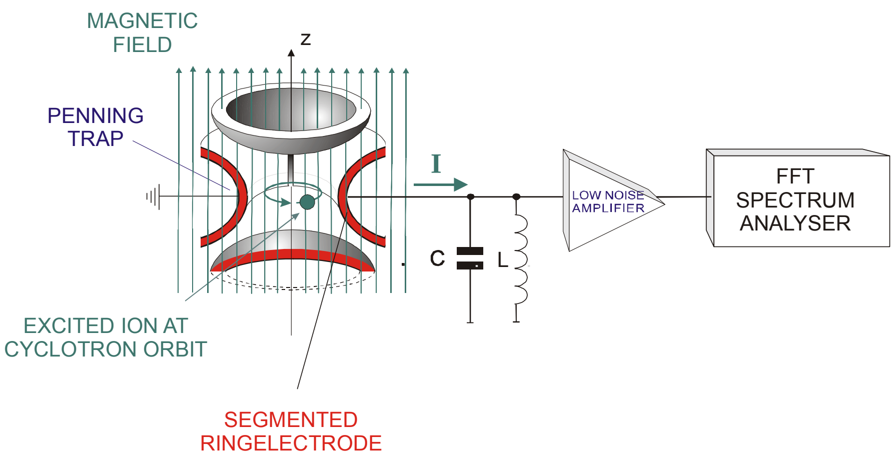

FIG. 1. Schematic for a narrow-band FT-ICR detection of a single ion. An increased sensitivity for a measurement of the ion's motional frequency is obtained by a tuned circuit.

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[2] G. Marx et al., Hyp. Int., **146/147**, 245 (2003).
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*This work is supported by the European Network for Novel Instrumentation for Precision Nuclear Experiments in Traps NIPNET, contract no. HPRI-CT-2001-50034 and the HGF, contract no. VH-NG-037.

The N=Z rp-Process Waiting-Point Nucleus ^{68}Se and its Astrophysical Implication *

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Precise mass measurements of nuclei along the N=Z line are important input parameters for simulations of the rp-process. Of particular interest is the mass of the $^{68}_{34}$Se$_{34}$ rp-process waiting point nucleus for determining the possibility of a two-proton capture branch bypassing its slow β-decay. The mass of ^{68}Se was measured via the β-decay endpoint. ^{68}Se was produced by the ^{12}C(^{58}Ni,2n)^{68}Se reaction and subsequently implanted onto a moving tape system using the Fragment Mass Analyzer at the ATLAS facility of Argonne National Laboratory. A mass excess value of (-54189 $\pm$ 240) keV was determined from the β-endpoint measurement of Q$_{EC}$=4710(200) keV. More recently, a mass measurement of ^{68}Se has been performed using the Canadian Penning trap (CPT) at Argonne National Laboratory. It leads to a mass excess (-54,232 $\pm$ 19) keV [1]. While this accuracy can not be achieved with the β endpoint technique, the present results are still important as the use of two independent methods and techniques for measuring the mass of ^{68}Se removes potential systematic errors in the final analysis. Evaluations of proton separation energies based on the measured mass were used in a one zone type I X-ray burst model. It is concluded that the N=Z=34 isotope ^{68}Se is a waiting point for the rp-process.

[1] J.A. Clark *et al.*, Phys. Rev. Lett. (2004), in print

* Supported by the National Science Foundation grants NSF-PHY01-40324 (Notre Dame) NSF-PHY02-16783 (JINA,) and by the U.S. Department of Energy, Office of Nuclear Physics, under Contract Nos. W-31-109-ENG-38 (Argonne National Laboratory), De-FG02-94ER49834 (University of Maryland), and DE-FG02-88ER40417 (Clark University).

Commissioning and first on-line test of the new ISOLTRAP control system

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ISOLTRAP [1,2] is a Penning trap mass spectrometer tailored for on-line mass measurements of short-lived nuclides produced at ISOLDE/CERN [3]. The main components are three ion traps in which the ions are manipulated by means of radio-frequency (rf) fields and buffer gas collisions. The mass of an ion is determined by measuring its cyclotron frequency in a Penning trap. In the last years the applicability of ISOLTRAP has been extended to cover all nuclides produced at ISOLDE with half-lives ranging from stable nuclides to as low as 68 ms [4]. ISOLTRAP addresses a variety of questions in physics. "Routine" mass measurements ($\delta m/m \approx 1 \cdot 10^{-7}$) investigate trends in nuclear structure, while high precision measurements ($\delta m/m \approx 1 \cdot 10^{-8}$) are performed for fundamental tests like the unitarity of the Cabibbo-Kobayashi-Maskawa mixing matrix [5,6 and 7].

A versatile facility like ISOLTRAP requires a flexible control system with the ability to follow the growth of the experimental set-up in size and complexity. Up to spring 2003, a VME-bus with a Motorola E6 CPU served as the main platform for the control system and a graphical user interface (GUI) was operated from a PC connected to the VME-bus via TCP/IP. This old control system was successfully used for more than ten years. Unfortunately, the VME based hardware had become outdated and unreliable requiring a replacement.

A new control system for the ISOLTRAP facility has been implemented. The GUI is reused as well as practically all existing hardware devices of ISOLTRAP. The VME-bus is replaced by a PC. No attempt was made to port the old control system software to the new platform, instead the all-new Control System (CS) framework has been implemented, which has been developed by DVEE/GSI [8]. The new control system has been implemented in about nine man months. It not only replaces the old system but provides more functionality that enhances the experimental capabilities of ISOLTRAP. The new control system was put into operation by late summer 2003. Meanwhile, this control system is also in operation at SHIPTRAP [9] and is being commissioned at LEBIT [10]. This poster describes the new control system, its commissioning and the experience after first successful off-line and on-line tests.

[1] G. Bollen et al., Nucl. Instr.Meth. A 368 (1996) 675.
[2] F. Herfurth et al., Nucl. Instr. Meth. A 469 (2001) 254.
[3] E. Kugler et al., Nucl. Instr. Meth. B 70 (1992) 41.
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[5] K. Blaum et al., Phys. Rev. Lett. 91 (2003) 260801.
[6] J. Van Roosbroeck et al., Phys. Rev. Lett. 92 (2004) 112501.
[7] A. Kellerbauer et al., submitted for publication.
[8] D. Beck et al., Nucl. Instr. Meth. A, accepted.
[9] J. Dilling et al., Hyp. Int. 127 (2000) 491.
[10] S. Schwarz et al., Nucl. Instr. Meth. B 204 (2003) 507.

Reactions

Posters - Reactions

Number/Session	Name/email	Institution	Title
71/ Tuesday	Basu, Chinmay chinmay@lotus.saha.ernet.in	Saha Institute of Nuclear Physics	Observation of pre-equilibrium alpha particles at extreme backward angles from ^{28}Si+^{nat}Si and ^{28}Si+^{27}Al reactions at E<5 MeV/A
80/ Monday	Bonaccorso, Angela bonac@df.unipi.it	INFN	Italian contributions to the physics of exotic nuclei
74/ Monday	Chaubey, Ashok ashokchaubey@yahoo.com	Aligarh Muslim University	Study of Heavy Ion induced Reactions in some natural elements.
75/ Tuesday	Chuvilskaya, Tatjana V. tatchuv@anna19.npi.msu.su	Moscow State University	Yield of high-spin isomers at Optimal charge-particle reactions
76/ Monday	Davids, Barry davids@triumf.ca	TRIUMF	EMMA: a recoil mass spectrometer for ISAC II at TRIUMF
77/ Tuesday	Johnson, Micah johnsonm@mail.phy.ornl.gov	ORAU	Development of the Oak Ridge Rutgers University Barrel Array (ORRUBA)
78/ Monday	Jones, Kate kate@mail.phy.ornl.gov	Rutgers University	Developing techniques to study A~132 nuclei with (d,p) reactions in inverse kinematics.
72/ Tuesday	Kanungo, Rituparna ritu@postman.riken.jp	RIKEN	A new view to structure of ^{19}C
81/ Tuesday	Liang, Felix liang@mail.phy.ornl.gov	Oak Ridge National Laboratory	Sub-barrier fusion induced by neutron-rich radioactive ^{132}Sn
83/ Monday	Mayet, Pascale pascale.mayet@fys.kuleuven.ac.be	IKS - KU Leuven	Coulomb excitation of neutron-rich Zn isotopes: first results obtained with MINIBALL at REX-ISOLDE (CERN)
84/ Tuesday	Nunes, Filomena nunes@nscl.msu.edu	NSCL Michigan State Univ.	Understanding low energy reactions with exotic nuclei
85/ Monday	Perru, Orianna perru@ipno.in2p3.fr	Institut de Physique Nucleaire d'Orsay	Coulomb excitation of ^{70}Ni and ^{74}Zn at GANIL
Number/Session	**Name/email**	**Institution**	**Title**

Posters - Reactions

Number/Session	Name/email	Institution	Title
86/ Tuesday	Puri, Rajeev rkpuri@pu.ac.in	Panjab University	A comparison of different models for isotopic dependence in fusion dynamics
87/ Monday	Romoli, Mauro mauro.romoli@na.infn.it	Istituto Nazionale di Fisica Nucleare	The EXODET apparatus: features and first experimental results
88/ Monday	Roussel-Chomaz, Patricia patricia.chomaz@ganil.fr	GANIL	MUST2: a new generation array for direct reaction studies
89/ Monday	Samanta, Chhanda chhanda@lotus.saha.ernet.in	Saha Institute of Nuclear Physics	Entrance channel dependence in compound nuclear reactions with loosely bound nuclei
90/ Tuesday	Shapira, Dan shapira@mail.phy.ornl.gov	Physics Division , ORNL	Measurement of Evaporation Residues in Reactions Induced by Neutron Rich Radioactive Beams.
91/ Monday	Takashina, Masaaki takasina@rarfaxp.riken.jp	RIKEN	Effect of halo structure on ^{11}Be+^{12}C elastic scattering
160/ Tuesday	Tengblad, Olof olof.tengblad@cern.ch	Instituto de Estructura de la Materia - CSIC	MAGSiC a modular detector cube for low-energy charged particles
94/ Monday	Terry, Russ terry@nscl.msu.edu	NSCL - Michigan State University	Absolute Spectroscopic Factors from Single-Nucleon Removal Reactions
95/ Tuesday	Umar, Sait umar@compsci.cas.vanderbilt.edu	Vanderbilt University	TDHF Studies of Neutron-Rich Systems
Number/Session	Name/email	Institution	Title

Observation of pre-equilibrium alpha particles at extreme backward angles from $^{28}Si+^{nat}Si$ and $^{28}Si+^{27}Al$ reactions at E<5 MeV/A

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In heavy ion collisions at low incident energies (E ≈ 4 –7 MeV/A) a dominant reaction mechanism is evaporation of light charged particles (LCP). The spectra of evaporation LCPs are generally explained well by the statistical model. However, there are many papers which report that the spectra of α-particles emitted from compound nuclei at high spin and excitation energy are not explained well by the statistical model calculations assuming a spherical compound nucleus [1]. It has been also observed that the entrance channel affects the equilibrium α-spectra to some extent [2]. These conclusions are however based on forward angle measurements only. On the other hand the pre-equilibrium effects are considered to be negligible at these energies. In the light of these controversies we carried out an experiment where α particles were measured at both forward and backward angles to have a more complete understanding of the reaction mechanism.

The experiment was carried out at the Nuclear Science Centre Pelletron facility, New Delhi. $^{28}Si^{9+}$ beam at incident energy of 130 MeV was bombarded on 1mg/cm^2 of natural Si and ^{27}Al self-supporting targets. Standard two detector Si telescopes were used for particle identification. Fig (1)-(4) shows the inclusive alpha spectra measured from this experiment at forward and backward angles. We carried out statistical model calculations using the code ALICE91 [3] (the full Hauser-Feshbach calculations are not very different from ALICE91 results). The forward angle data is not reproduced well unless the excited compound nucleus is considered to be highly deformed. The deformations are calculated by using the rotating liquid drop model. This observation reconfirms the earlier conclusions of [1,2]. However, at extreme backward angles the compound nucleus calculations fail to reproduce the data. This clearly indicates the contribution from non-compound effects, which has not been reported earlier as all the previous data were recorded at forward angles. As for mass symmetric systems the PEQ angular distributions are symmetric about 90^0 c.m. angle [4] there is a possibility that PEQ emissions become more prominent at extreme backward angles, even at such low energies. Detailed study in this direction is in progress for a better understanding of this interesting effect.

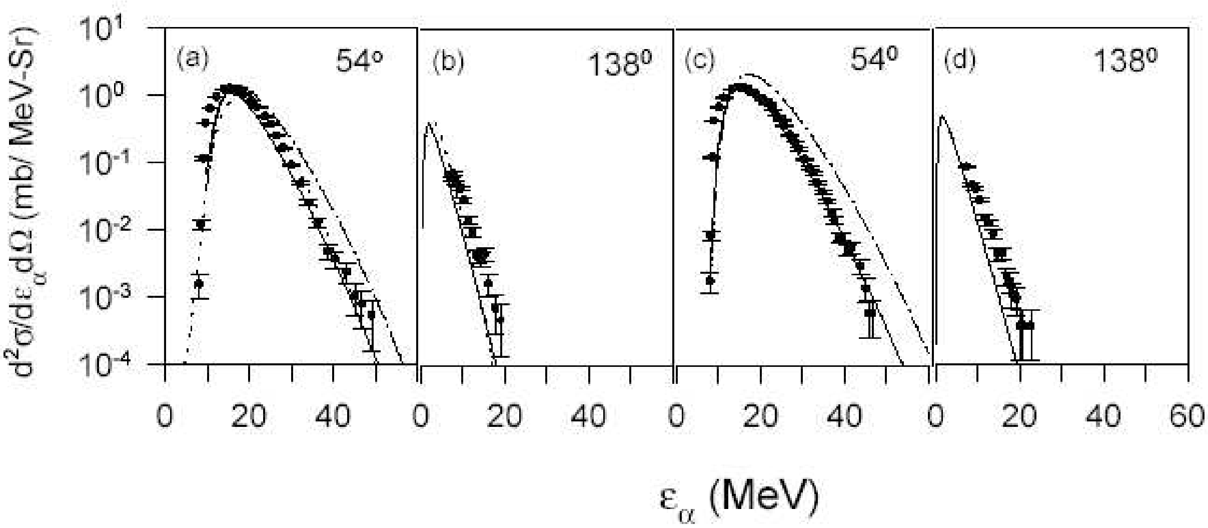

FIG. 1. Inclusive α-spectra for (a), (b) $^{28}Si + ^{nat}Si$ and (c), (d) $^{28}Si + ^{27}Al$ at the specified laboratory angles. The solid lines are ALICE91 calculations including RLDM deformation. In (a) and (c) also shown are ALICE91 calculations without deformation (dash-dotted lines). In (a), (b) the dotted lines are Hauser-Feshbach calculations.

[1] I. M. Govil et al, Phys. Rev. **C 62**, (2000) 064606.
[2] I. M. Govil et al, Phys. Rev. **C 66**, (2002) 034601.
[3] M. Blann, UCRL – JC – 10905, LLNL, California, USA (1991).
[4] C. Basu and S. Ghosh, Phys. Lett. **B 484**, (2000) 218.

Italian contributions to the physics of exotic nuclei

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The talk is intended as a short review of the Italian collaboration project in Theoretical Nuclear Physics and its relations to the national experimental projects, within the scheme of the Italian National Institute for Nuclear Physics (INFN). The project includes reaction aspects such as fusion at the barrier, breakup and transfer to the continuum, optical potentials, high energy collision dynamics and the role of isospin. Structure aspects concern the study of light unbound nuclei such as ^{10}Li and ^{13}Be , properties of nuclear matter at low density, EOS, collective states, pairing and dynamical symmetries.

Study of Heavy Ion induced Reactions in some natural elements.

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Excitation function studies were done for the reactions induced by ^{12}C and ^{16}O in some natural elements at energies around Coulomb barrier. The experiments were performed at Pelletron facility of Nuclear Science Centre, New Delhi, India. Measured excitation functions were compared with theoretical predictions by ALICE-91 and CASCADE computer codes based on Statistical theory. Considerable enhancement of the cross-sections in comparison to theoretical cross-section in some of the reactions has been found. This indicates that these reaction channels are not only populated by the complete fusion (CF) of the projectile but also through In-Complete Fusion (ICF) process. In order to have further confirmation of CF and ICF and to separate their relative contribution, the forward recoil range distribution (FRRD) of evaporation residues produced in reactions has been measured at various energies.

Yield of high-spin isomers at Optimal charge-particle reactions

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The excitation functions and isomeric cross-section ratios for the reactions 84,86,87Sr(6,4He,n,2n)89mgZr were studied. Earlier isomeric cross-section ratios of the reactions 86,87Sr(4He,n,2n)89mgZr were investigated up to E=13-29 MeV [1]. In this work the experimental values of isomeric cross-section ratios of these reactions are more specified. Sigma(g)9/2+/sigma(m)1/2- for 89Zr (T1/2(g)=3.27 d, T1/2(m)=4.18 min) are calculated by code EMPIRE 2.18 [2]. The calculations of the excitation functions and isomeric cross-section ratios of the reaction 84Sr(6He,n)89mgZr are performed for the first time. It is interesting to compare the results of calculated isomeric cross-section ratios in the different nuclear reactions. The results are in a good agreement with the experimental data for the alpha-particles induced reactions.

[1] V.D. Avchuhov et al., Izv. Ak. Nauk,ser. Fiz.44,155(1980).
[2] M. Herman, to be published.

EMMA: a recoil mass spectrometer for ISAC II at TRIUMF*

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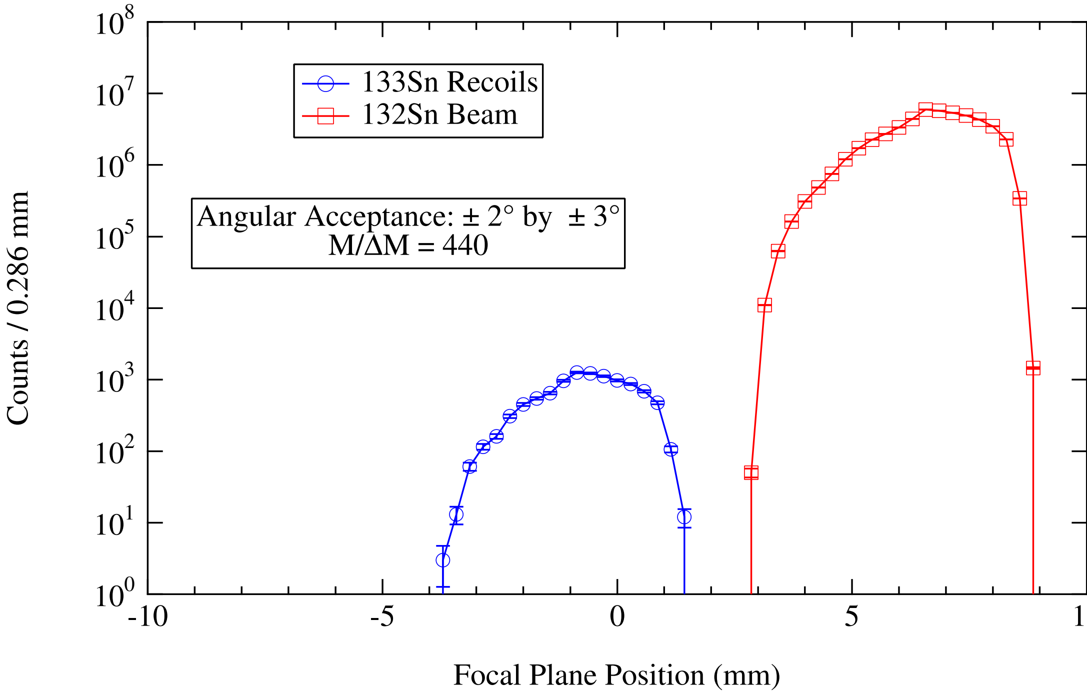
Design work has begun on EMMA, an ElectroMagnetic Mass Analyzer for ISAC II at TRIUMF. EMMA is a recoil mass spectrometer that will be used to separate the recoils of nuclear reactions from the beam, and to disperse them according to mass/charge. ISAC II will provide intense, low-emittance beams of unstable nuclei with masses up to 150 u and maximum energies of at least 6.5 MeV/u. EMMA will be used in many different types of experiments with radioactive beams, including fusion-evaporation and transfer reactions. As such, it must be both efficient and selective, possessing large acceptances in angle, mass, and energy without sacrificing the necessary beam suppression and mass resolution. The physics aims shaping the spectrometer design and the results of detailed ion optical simulations will be presented.



Simulated mass-dispersive focal plane image from d(^{132}Sn,p)^{133}Sn at 6 MeV/u, showing the spatial separation of beam and recoils. Realistic ISAC II beam emittances were assumed, and the ions were propagated through EMMA using the ion optics code GIOS.

*This work was supported by the Natural Sciences and Engineering Research Council of Canada and by the U.S. Department of Energy, Office of Nuclear Physics, under contract No. W-31-109-ENG-38.

Development of the Oak Ridge Rutgers University Barrel Array (ORRUBA) *

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Transfer reactions are an important spectroscopic tool for astrophysics and nuclear structure. Measurements from transfer reactions serve as a probe for spectroscopic quantities such as single-particle excitation energies, angular momentum and spectroscopic factors. These quantities test the nuclear shell model and provide information important to understanding nucleosynthesis. Studying transfer reactions on neutron-rich nuclei is especially important because changes in shell structure are expected and these nuclei lie along the r-process nucleosynthesis path. To study these nuclei it is necessary to use transfer reactions in inverse kinematics with radioactive ion beams (RIBs). However, RIBs su er from low intensity which result in low charged particle production rates used to measure angular distribtions and excitation energies. To counter this e ect a detection array must be able to cover a large solid angle.

Neutron transfer reactions can be measured with 5 MeV-per-nucleon beams at the Holi eld Radioactive Ion Beam Facility (HRIBF). Angular distribution calculations for the ^{132}Sn(d,p) reaction in inverse kinematics show that at 90 degrees in the lab there is a signi cant di erence in di erential cross-section for di erent ℓ values[1]. In addition, the energies of the protons at lab angles around 90 degrees are appropriate for measurements.

Currently, prototype testing for the Oak Ridge Rutgers University Barrel Array (ORRUBA) is underway. ORRUBA will consist of 2 rings of 12 Silicon ΔE-E telescopes bisected at 90 degrees. Each ΔE and E detector will have a position-sensitive 4 cm $\times$ 8 cm area split into four 1 cm wide strips. Charged particle identi cation will be facilitated by ΔE-E measurements.

A detailed outline of ORRUBA's scienti c motivation, technical aspects and timeline for commissioning of ORRUBA will be presented.

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This work was supported in part by the U. S. Department of Energy and the Natioanl Science Foundation

Developing techniques to study A≈132 nuclei with (d,p) reactions in inverse kinematics. *

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Neutron-transfer reactions on stable targets have been used extensively to study the spectroscopy of both ground and excited states in the nal nucleus. By utilizing this technique in inverse kinematics with rare isotope beams (RIBs), it is possible to study the evolution of single-particle structure away from the valley of stability. This is of importance to the understanding of both e ective interactions and the synthesis of heavy elements in the r-process.

To date there have been only a few measurements performed using (d,p) reactions in inverse kinematics, with either stable beams [1] or A≈80 RIBs [2]. There are signi cant experimental challenges in obtaining adequate energy resolution in the center-of-mass system and in measuring angular distributions close to the Coulomb barrier. These become more pronounced with increasing mass and greater asymmetry of the reaction. Transfer reactions will represent a key tool at RIA to study nuclei close to the drip lines and important for astrophysics. Therefore, it is of vital interest to develop the techniques required to expand the method into higher mass regions.

Results from a recent test experiment using a stable beam of ^{124}Sn to develop these techniques will be presented. Comparisons to data from the same reaction performed in normal kinematics on a stable ^{124}Sn target in the 1970's [3,4] will be shown. A resolution in Q-value of about 200 keV was achieved. The sensitivity of the technique to the properties of the nal nucleus will be demonstrated. Measurements of ^{130}Sn, ^{132}Sn and other heavy ssion fragments are planned at the HRIBF.

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This work was funded in part by the National Science Foundation under contract number NSF-PHY-00-98800; the U.S. Department of Energy under contract numbers DE-FC03-03NA00143 (Rutgers), DE-AC05-00OR22725 (ORNL), DE-FG02-96-ER40955 (TTU), and DE-FG03-93ER40789 (Mines); and the LDRD program of ORNL. KLJ would like to thank the English-Speaking Union and the Lindemann Trust Committee.

A new view to structure of ^{19}C

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The ^{19}C nucleus was subject to much attention due to its possibility of having a one-neutron halo structure. Such suggestion came from observation of large interaction cross section [1], and Coulomb dissociation cross-section [2] . The longitudinal momentum distribution from one-neutron removal, however had some disagreements between experiments at high [3] and low energies [4], which raised questions about reaction effects influencing the observations at different energies. We will report new measurements of one-neutron removal which brings in a first confirmation that the shape of momentum distribution is independent of energy and thus reflects the internal structure of the nucleus.

Two important information on this nucleus still remains ambiguous, namely its ground state spin and the one-neutron separation energy. The large cross-sections have so far led to the understanding that ^{19}C has a spin of $1/2^+$ and the configuration is dominated by ^{18}Cgs + n($2s_{1/2}$). A new measurement of the momentum distribution from two-neutron removal, as will be discussed, brings in interesting question whether the ground state of ^{19}C can have a $1/2^+$ ground state. The observed width suggests that the ^{18}C core undergoes modification. The reason for such modification will be discussed and it will be shown that the large cross-section can also be understood with this new view of the nucleus. Renewed consideration on ground state spin thus emerges from such study and is also associated to some recent observations on excited states for this nucleus. This, in general puts forward a different understanding on structure of very neutron rich nuclei.

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Sub-barrier fusion induced by neutron-rich radioactive ^{132}Sn *

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The cross section for heavy ion fusion at sub-barrier energies is often found to be enhanced over the one-dimensional barrier penetration model prediction. It has been suggested that the fusion yield may be further enhanced when the reaction is induced by unstable neutron-rich nuclei[1,2,3,4]. If this is correct such reactions may be applied to synthesize heavy elements.

We have measured evaporation residue cross sections using neutron-rich radioactive ^{132}Sn beams incident on a ^{64}Ni target in the vicinity of the Coulomb barrier. This is the first experiment using accelerated ^{132}Sn beams to study nuclear reaction mechanisms. The average beam intensity was 2×10^4 particles per second and the smallest cross section measured was less than 5 mb. A large sub-barrier fusion enhancement was observed compared to evaporation residue cross sections for ^{64}Ni on stable even Sn isotopes. The enhancement cannot be accounted for by a simple barrier shift due to the difference in nuclear sizes. Coupled-channels calculations including inelastic excitation and neutron transfer underpredict the measured cross sections below the barrier. The presence of several neutron transfer channels with large positive Q-values suggests that multinucleon transfer may play an important role in enhancing the fusion of ^{132}Sn and ^{64}Ni.

The calculations used parameters obtained from stable projectile and target reactions. Further measurements to obtain the input parameters directly would help in improving the calculations. Experiments using even more neutron-rich radioactive beams can shed some light on the reaction mechanisms responsible for the observed sub-barrier enhancement. Our near term experimental plans will be presented.

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*This work was supported by the U. S. Department of Energy under contracts DE-AC05-00OR22725 with UT-Battelle, LLC.

Coulomb excitation of neutron-rich Zn isotopes: first results obtained with MINIBALL at REX-ISOLDE (CERN)

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The region around ^{68}Ni (subshell closure at N = 40) and the doubly magic ^{78}Ni nuclei is of interest because of its delicate interplay between single-particle properties and their interaction with the underlying core. These nuclei have already been intensively investigated but mainly decay and ground-state (as well as long lived isomeric state) properties have been deduced yet. These properties contain of course very valuable information but the picture is not complete. Coulomb excitation experiments can provide important and complementary information. Recent B(E2) measurements suggested that ^{68}Ni apparently behaves like a doubly magic nucleus. However recent theoretical calculations [1] state that the small experimental B(E2) value to the first 2^+ state is not a strong evidence for the doubly magic character of ^{68}Ni. On the contrary, neutron-rich Zn isotopes with N>38 exhibit a sudden increase of B(E2) values which may be the signature of deformation. These B(E2) values were measured at intermediate energies at GANIL [2,3] and a second measurement at low energy can provide a reliable confirmation since sub barrier Coulomb excitation is a very well known process.

Therefore we measured Coulomb excitation of neutron-rich ^{74,76}Zn beams ($T_{1/2}$ = 96 s and 5.6 s respectively) accelerated at an energy of 2.2 MeV/u through the REX-ISOLDE accelerator. The radioactive Zn nuclei were produced at ISOLDE after the proton bombardment of a U Carbide target and ionised using a resonance ionisation laser ion source. The γ-rays from the Coulomb excitation were detected by the MINIBALL array, consisting of 24 six-fold segmented Ge-detectors. The coincident scattered charged particles were detected by the CD-detector, a highly segmented double-sided silicon strip detector.

After a short description of the experimental set-up, the first results obtained from Coulomb excitation of ^{74,76}Zn below the Coulomb barrier will be presented.

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Understanding low energy reactions with exotic nuclei

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Light nuclei on the driplines can be studied through a variety of reactions. Models for nuclear reactions have been developed in recent years in order to incorporate the exotic features of these dripline nuclei. The real challenge for reaction theory lies in the low energy regime where most approximations are not valid [1].

Three body effects need to be carefully considered in the lower energy regime. At energies close to the breakup threshold, Integral Faddeev Equations would be the appropriate choice. However, due to technical problems the Continuum Discretized Coupled Channel Method (CDCC) [2] is the best working alternative.

The proximity to the breakup threshold has been shown to have important effects in the reaction mechanism [3]. Continuum couplings are a way of looking into the effect of the final state interaction, integral part of CDCC. We will discuss the properties of these couplings and the influence they can have on breakup observables [4].

Historically, there has always been the underlying assumption that, by appropriately choosing the experimental conditions, Coulomb effects can be isolated from nuclear effects. Especially when breakup reactions are used to extract Astrophysical information, such as radiative capture rates, this separation is crucial [5]. We discuss the influence of nuclear breakup in some cases of relevance to Astrophysics [6].

A variety of breakup models are presently in use and, when two different models are applied to the same problem, there is often a disparity in the predictions. In this sense, a generalized effort to bridge the various approaches is very much needed. One of the important issues lies in the choice of the coordinate representation of the continuum wavefunctions. We present results of a comparative study between the standard CDCC breakup approach and the so called transfer to the continuum [7].

* This work has been partially supported by National Superconducting Cyclotron Laboratory at Michigan State University, the Portuguese Foundation for Science (F.C.T.), under the grant POCTIC/36282/99, the Department of Energy under Grant No. DE-FG03-93ER40773 and the U.S. National Science Foundation under Grant No. PHY-0140343.

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Coulomb excitation of ^{70}Ni and ^{74}Zn

Within the research program related to the study of shell structure evolution in neutron rich nuclei, we have recently performed at GANIL an experiment aiming for the B(E2: 0+ to first 2+ measurements in Ni and Zn isotopes beyond N=40 using Coulomb excitation method. Secondary beams of 70Ni and 74Zn have been produced using fragmentation reactions of a primary 76Ge beam at 60MeV/u. They were selected and transmitted using the lise spectrometer, to a Pb target where Coulomb excitation is induced. Gamma-rays corresponding to the de-excitation of the projectile excited states are detected using an array of four EXOGAM four- fold-segmented-Clover detectors, closely packed in a cubic geometry around the Pb target. B(E2) values have been successfully extracted for both 74Zn and 70Ni which extends the systematics of the B(E2)à values beyond the N=40 shell-closure. This sytematics will be discussed in the light of model calculations.

A Comparison of Different Models for Isotopic Dependence in Fusion Dynamics

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During last couple of decades, several theoretical models have been developed to study the low energy phenomena such as fusion of colliding nuclei [1,2]. These models are able to reproduce experimental data quite nicely. At the same time, availability of large number of neutron-rich and deficient nuclear beams pose a new test to all these models at the extremes. We here report a comparative study of the isotopic dependence in fusion using variety of models such as Skyrme Energy Density Model, Proximity potential, Potential due to Bass, Christian and Winther, as well as potential due to Denisov. For the details of the models, we refer the reader to refs. [1,2] .

The present comparison of fusion variation with neutron content is carried out for three series: Ca+Ca, Ca+Ni and Ni+Ni. Starting from the symmetric (N=Z) nuclei, neutrons are added/removed gradually from the projectile and/or target [2]. We calculated the fusion barrier heights and positions for a large number of isotopes with $0.6 \le N/Z \le 2.0$ and analyzed the normalized variation in the barrier heights and positions over N=Z pair as:

$$\Delta R_B\,(\%) = \frac{R_B - R_B^0}{R_B^0} \times 100\;; \qquad (1)$$

$$\Delta V_B\,(\%) = \frac{V_B - V_B^0}{V_B^0} \times 100\,, \qquad (2)$$

where R^0_B and V^0_B are, respectively, the positions and heights of the barriers for N=Z colliding pair. In figure 1, we display $\Delta V_B(\%)$ and $\Delta R_B(\%)$ as a function of [N/Z-1] using Skyrme Energy Density model with SIII force. The addition of neutrons pushes R_B toward larger distances whereas V_B decreases linearly. One sees a reverse trend in the case of neutron-deficient colliding nuclei. These variations can be parameterized in terms of non-linear term [N/Z-1]. The variation for fusion cross-sections , however, follow a linear dependence in terms of [N/Z-1]. Similar dependences also occur for all types of other potentials. The slopes within different models are very close to each other, therefore, justifying the universal isotopic dependence of fusion on neutron content [2].

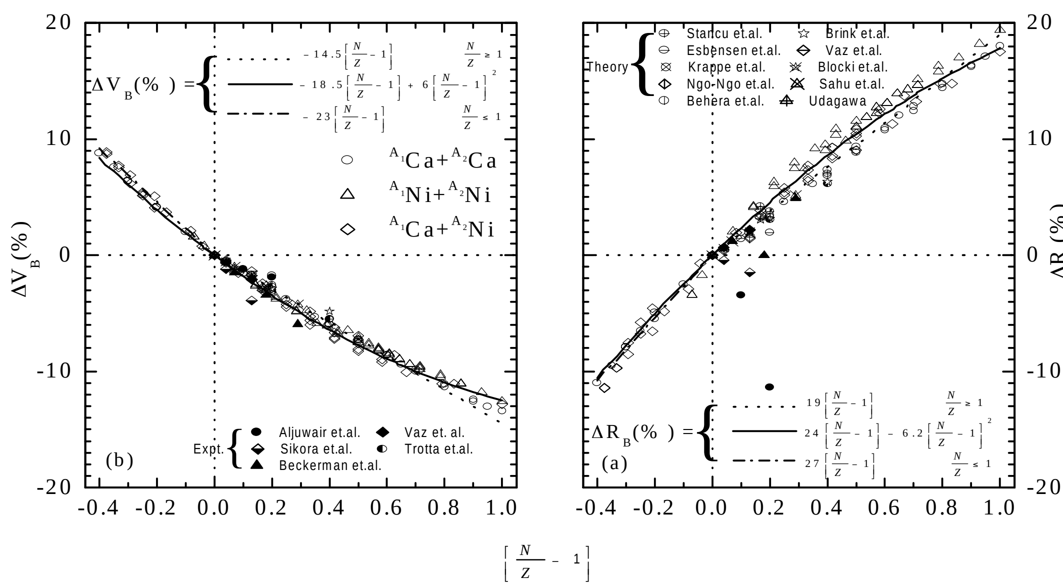

FIG. 1: The $\Delta V_B(\%)$ and $\Delta R_B(\%)$ as a function of [N/Z-1] using Skyrme Energy Density Model.

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4th int conf. on Exotic Nuclei and Atomic masses, Sept 12-16, 2004, Callway, Georgia, USA

The EXODET apparatus: features and first experimental results

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The low intensity of the RIBs presently available at the first generation production facilities (10^5 – 10^6 pps) and the necessity to reconstruct the event kinematics in RIB measurements require detection systems having both a large solid angle coverage and a high granularity. The EXODET (EXOtic DETector) apparatus has been designed to respond to these requirements. It consists of 16 large area silicon detectors (50x50 mm^2), each of them having the front side segmented in 100 strips with a 0.5 mm pitch size and a 50 μm inter-strip distance. The detectors are arranged in 8 telescopes placed near the target both in the forward and backward hemispheres, subtending a total solid angle of about 70% of 4π sr. The strips of the first layer detectors (60 μm thick) are orthogonal to the beam direction and perpendicular to the strips of the second layer (500 μm thick), defining a position pixel of 0.5x0.5 mm^2 for the particles passing through the first layer. For such particles, a Z identification is also possible by using the usual ΔE-E technique. The overall energy resolution obtained with a standard readout electronic chain for the signals outcoming from the unsegmented rear side of the detectors is about 1-3% (depending on the thickness of the silicon die). Due to the large number of channels (1600 for the whole apparatus) to be analyzed in order to get the position information, an innovative readout system based on highly integrated electronic circuitry (ASIC microchips) has been used. Front-end modules to process the already digitalized position information, outcoming from the microchips, and an appropriate acquisition system for the contemporary treatment of energy, timing and position information have been also developed.

The first successful experiment has been performed, using a part of the EXODET apparatus, at the Argonne National Laboratory (USA). The scattering of a ^{17}F exotic beam by a ^{208}Pb target has been measured in the angular range θ_{lab}=98° to 154° at an incident energy of 90.4 MeV. The data collected have been analyzed in terms of the optical model to find the best fit parameter set of the nuclear potential and a comparison with the behavior for other stable nuclei in the same mass region has been discussed. The ^{17}F seems to behave more similarly to the Oxygen stable isotopes (^{16}O and ^{17}O) than to the stable ^{19}F nucleus. Despite the short data collection time (around 17 hours), also the cross section for the $^{17}F \rightarrow {}^{16}O + p$ break-up process has been evaluated and found in good agreement with literature estimations.

Recently, at the end of March 2004, an experiment devoted to the study of the elastic scattering of the ^{11}Be from ^{209}Bi around the Coulomb barrier has been successfully performed at the RIKEN Laboratory (Japan). In this case, the whole EXODET apparatus has been utilized together with two position sensitive PPAC and a plastic scintillator (^{11}Be beam tagging system of the RIKEN Laboratory). The analysis of the data is presently in progress and the preliminary results will be presented to show the capabilities of the detection apparatus and of the associated electronics for this kind of measurements involving RIBs.

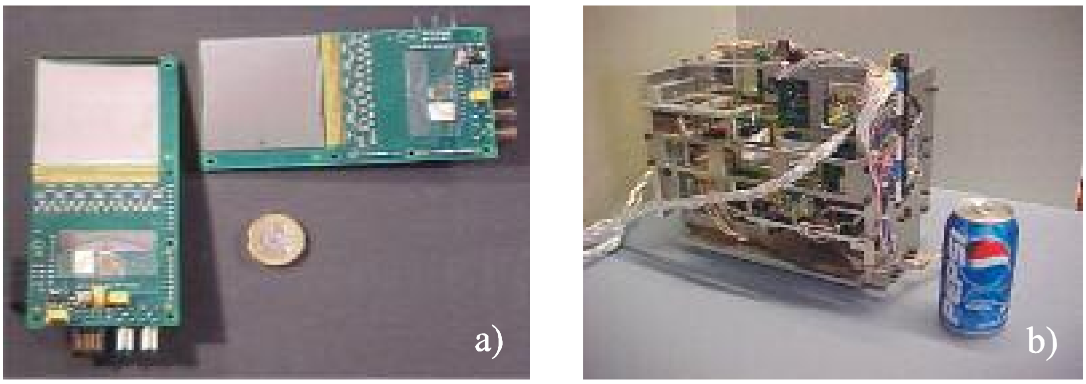

FIG. 1. a) The two detectors of one EXODET telescope before their assembling. b) The whole EXODET apparatus mounted on its own mechanical support.

MUST2 : a new generation array for direct reaction studies

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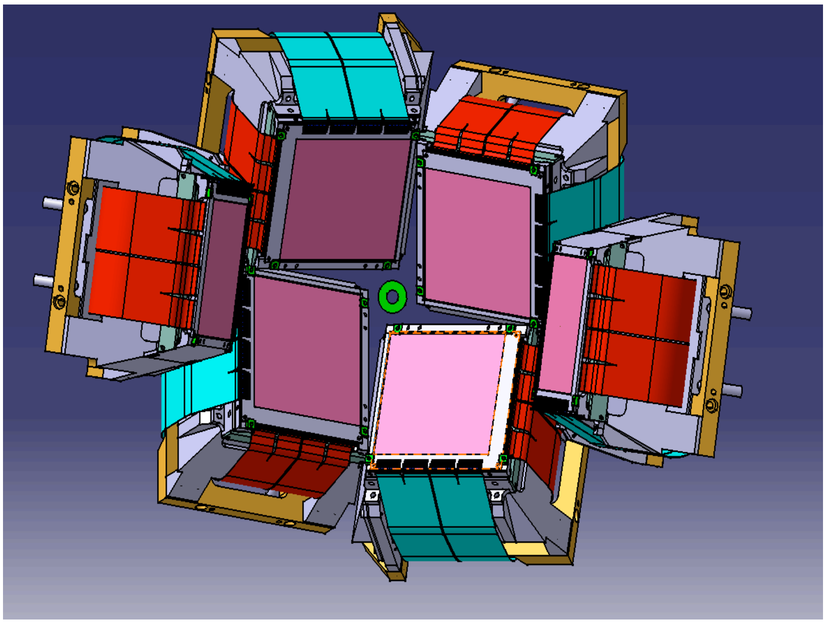
A new and innovative array, MUST2, based on silicon strip technology and dedicated to the study of reactions induced by radioactive beams on light particles, is presently under construction. The detector will consist of 6 silicon strips-Si(Li)-CsI telescopes (see figure). Compared to the existing MUST array [1], the innovation comes from the new Si strip detectors (10x10 cm^2 instead of 6x6), the number of strips on each of them (128 instead of 60), the compactness of the array (volume divided by 6) and above all, the electronics which is based on ASIC chips. Each BCMOS 36 mm^2 chip has 16 bipolar channels, with energy and time measurement. The data are multiplexed and coded with VXI ADC's. The characteristics of the new array will be detailed and the results of the first tests performed with one complete telescope will be presented. They show that both the energy and time resolution are excellent (30keV and 250 ps FWHM respectively). When complete, the array will correspond to more than 3000 channels of electronics.



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Entrance channel dependence in compound nuclear reactions with loosely bound nuclei

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Reactions with loosely bound stable nuclei like ^{6,7}Li, ^{9}Be etc. provide a good analogue to study reactions with Radioactive Ion Beams (RIB). Reaction mechanisms with these loosely bound nuclei are still not well understood. For example, an open question in this field is whether fusion is suppressed or not for such fragile systems due to low breakup threshold. Generally for loosely bound nuclei at energies above Coulomb barrier the fusion cross-section is suppressed in comparison to one dimensional barrier penetration model calculation [1, 2]. At below barrier energies, the measured cross-sections are enhanced. This aspect of fusion may be studied either by direct measurement of fusion cross-section [2] or, by indirectly measuring the evaporated light particles [3]. In this work we report the measurement of light charged particles from reactions between ^{6,7}Li nuclei. The experiment was carried out using the 14UD BARC-TIFR Pelletron facility, Mumbai, India. Incident energies were chosen between 14 to 20 MeV for ^{7}Li and 20 MeV for ^{6}Li incident beams. A 4mg/cm^2 thick ^{6}Li target was used for the experiment and ΔE-E Si-detectors were used as particle identifier telescopes. The α-particles were detected at extreme backward angle (175^o). Fig. 1(c) and (d) show the inclusive α-spectra measured at incident energies of 14 and 16 MeV respectively. The data are analyzed in terms of the statistical model code ALICE91 [4] because at backward angles the dominant reaction mechanism is expected to be fusion evaporation. To check the reliability of the ALICE91 code for lighter systems we reanalyze the published experimental data for ^{28}Si(^{6}Li,α) and ^{12}C(n,α) reactions [3,5]. Calculation (dotted line) using Fermi gas level density (a=A/9) in the Weisskopf-Ewing approximation reproduces experimental data satisfactorily (Fig.1a, b). However, same calculations grossly over predict ^{7}Li(^{6}Li,α) reaction data. The over prediction is removed (solid line) when the rotational energy of the compound nucleus is considered in calculating the excitation energy of the residual nucleus and the moment of inertia is calculated from the rotating liquid drop model. Thus fusion is not suppressed in loosely bound ^{6,7}Li+^{6}Li systems at above barrier energies. Interestingly, the excited compound nucleus is found to be deformed for ^{6,7}Li+^{6}Li systems, but spherical for asymmetric n+^{12}C system. This indicates entrance channel dependence for the light particle evaporation cross-section, a phenomenon though known for heavier systems has not been reported earlier for such light loosely bound nuclei.

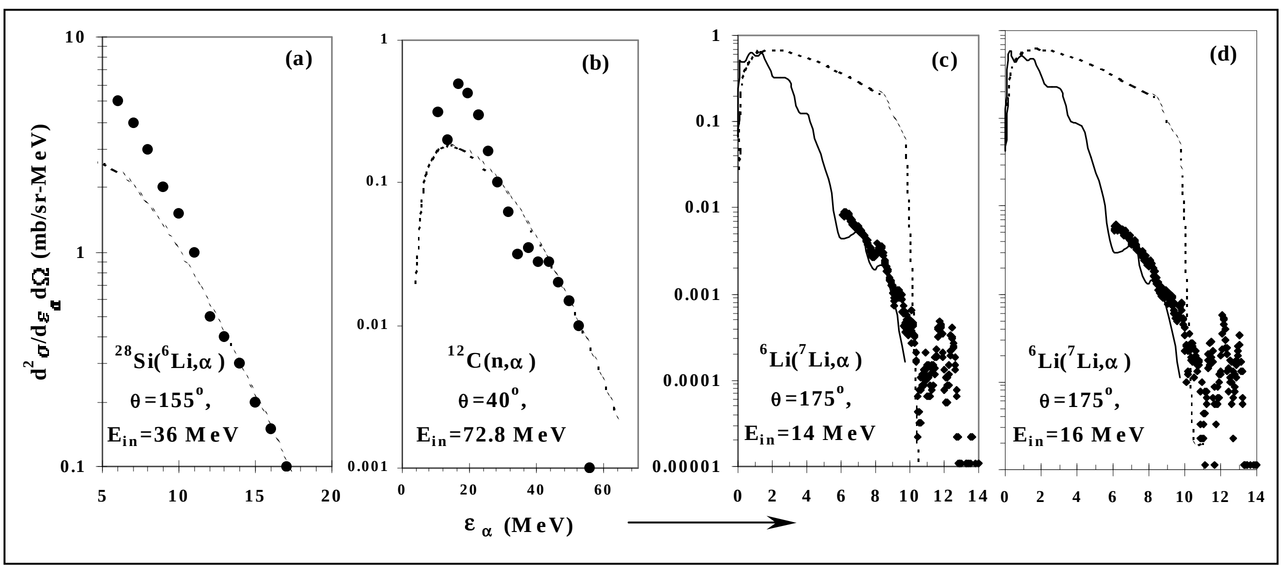

FIG. 1 Inclusive α-particle cross-section versus α-energy and fusion-evaporation calculations by ALICE91 [4]

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Measurement of Evaporation Residues in Reactions Induced by Neutron Rich Radioactive Beams. *

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The compound formed in fusion between very neutron-rich nuclei is less likely to fission than similar systems formed with less neutrons. It has also been suggested that the fusion probability would be further enhanced [1,2,3]. in such reactions in part due to the large N/Z ratio leading to reduced barrier heights and in part due to the presence of loosely bound neutrons. We have built a compact portable system with which we could measure small (1mb) cross sections for evaporation residue formation in collisions between very neutron rich radioactive beams and stable targets.

The incorporation of beam detection in a fast, first level trigger allows for the efficient measurement of evaporation residue cross sections in reactions induced by heavy ion at angles around the beam direction. The pre-triggering scheme is used to suppress background counts and reduce the load on the data acquisition computer system. The method is most efficient in studies involving low intensity ion beams of rare heavy nuclei on lighter targets (inverse kinematics). The technique was tested with 58Ni+64Ni and was used to measure 132Sn+64Ni evaporation residue production cross sections down to a few mb. As presented, the method works well with beam intensities below 50,000/sec but may be extended to handle higher beam intensities.

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*This work was supported by the U. S. Department of Energy under contracts DE-AC05-76OR00033 and DE-AC05-96OR22464.

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Effect of halo structure on ^{11}Be+^{12}C elastic scattering

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Nuclear reactions involving neutron-rich nuclei have been current important subjects in nuclear physics. Particularly, in light neutron-halo nucleus induced reactions, it is very interesting to study how the halo structure affects the reaction mechanisms. Because of the weakly bound feature, the breakup process of halo nucleus would be the most important. In order to describe its dynamical effect exactly, one needs to treat it as at least three-body problem.

One of the practical and reliable methods to study the tree-body reaction process is the continuum-discretized coupled-channels (CDCC) method [1], in which the continuum two-body breakup states of the projectile nucleus are approximately represented in terms of a finite number of discretized states, and they are treated in the same manner as usual discrete excited states. In the present study, we apply the CDCC method to investigate the ^{11}Be $\rightarrow$ ^{10}Be+n breakup effect on the elastic scattering of ^{11}Be by ^{12}C at E/A=49.3 MeV.

Figure 1 shows differential cross section angular distributions (ratio to Rutherford) of the ^{11}Be+^{12}C elastic scattering calculated by the CDCC method (solid line) with the result of a single-channel calculation using folding-potential (dotted line) and experimental data (dots) [2]. The CDCC calculation well reproduces the experimental data, and shows a great difference from the single-channel calculation, which indicates that the breakup effect is significant. From further analysis, it is found that the coupling to the p-wave continuum states has a dominant contribution to the breakup effect. As shown in Fig.2, a dynamical polarization potential which simulates the breakup effect is evaluated as ratio to the folding potential, and found to have a weakly repulsive real part (solid line) and a long-range imaginary part of absorptive nature (dashed line). These results show a characteristic of the weakly-bound halo nucleus.

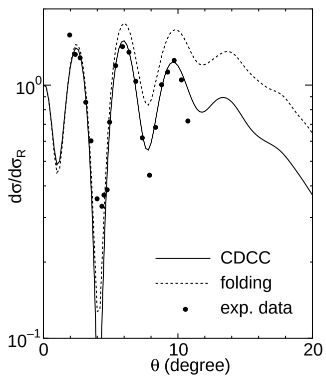

FIG. 1: Angular distribution of ^{11}Be+^{12}C elastic scattering at E/A=49.3 MeV.

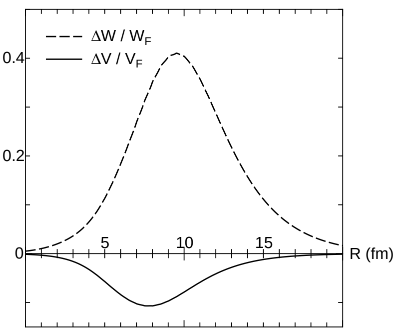

FIG. 2: Ratio of a dynamical polarization potential to the folding potential.

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MAGSiC a modular detector cube for low-energy charged particles *

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The research on reaction mechanisms and decay modes of very exotic nuclei in the vicinity of the drip-lines has now reached a level of sophistication where new dedicated detector arrays and corresponding electronics are needed. In beta decay of exotic nuclei many different multi-particle channels are open giving a final state consisting of up to five different particles. The energy regime of the new RIB facilities brings us to experiments where we may utilize resonance scattering and transfer reactions to study both bound and unbound nuclear species.
The complexity is manifested both in the number of emitted particles and in their angular correlation. This is true for both decay experiments and reaction studies. Especially for decay studies of exotic nuclei, where many weak disintegration channels may be open, the low kinetic energies of the emitted charged particles require extremely low detection thresholds[1]. This requirement implies a high granularity of the detector set-up[2]. Our chosen solution is a modular detector system composed of different detector elements. To allow identification of the different charged particles (e, p, d, t, α) emitted in the decay process part of the detector elements has to be of telescope type.
We report here on the development of a versatile compact Si-cube for low energy multi particle detection. The key issue is a) tight geometry giving high efficiency and b) high granularity giving high angular definition and multi-hit possibility. The six faces of the $10x10x10\ cm^3$ cube is fitted with either 60 μm Double Sided Si Strip Detectors (DSSSD) stacked with a 1500 μm Si-pad detector or (for the specific identification of low energy charge particles) an array of 56 monolithic detector telescopes. The characteristic design parameters of the monolithic detector telescope are; Device area: $5x5\ mm^2$ of which the active area is $3x3\ mm^2$, Thickness: ΔE stage 1 μm and E stage 400 $\pm$ 15 μm, The small active area of the detector was chosen in order to achieve an acceptable capacitance of the energy loss detector. In the case of the DSSSDs, we present here a new design to achieve ultra thin dead layers. The first generation of strip detectors has in comparison to standard Si-detectors the disadvantage of having a significantly thicker entrance window, in the order of 600 nm. The dead layer from this contact and implantation layers induces a non-linear energy loss of charged particles impinging on the detector, and results in effective trigger thresholds that depend on the incident particle type, energy and angle [3]. Further, it introduces a very high energy cut-off when studying emission of heavy charged particles e.g. in the case of α-particles as high as 800 keV, and thus hiding specific decay channels [4]. In the new design the traditional contact layer making up the strip is replaced by a grid covering only 2% of the strip area. The dead layer is thus (over 98% of the active surface) reduced to become the implantation depth only. Furthermore, the implantation depth has been reduced from 400 nm to 100 nm [5].
The performance of the different detectors and their associated electronics will be demonstrated. Finally, we illustrate, using data from an on-line experiment, the remarkable improvements of the experimental results obtained with the new thin-window design.

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*This work was supported by the Knut & Alice Wallenberg Foundation Sweden and the Spanish CICYT (FPA2002-04181-C04-02).

Absolute Spectroscopic Factors from Single-Nucleon Removal Reactions *

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Many-body theory based on the independent-particle shell model has enjoyed great success in interpretting nuclear structure. This model employs a truncated model space to reduce the degrees of freedom in a many-body system. Such models implicitly deny occupancy in the many states beyond the model space, thereby inflating the calculated occupancy within the model space. This effect has been observed for proton states in stable nuclei via electron scattering. These experiments, employing the (e,e'p) reaction, have yielded a general mass-independent quenching of 0.6-0.7 of the shell model spectroscopic strength.

Given the well-understood nature of the Coulomb force, spectroscopic factors measured via the (e,e'p) reaction constitute a benchmark value. However, this technique is limited to proton states in stable nuclei. Recent work at MSU has shown that single-nucleon removal reactions at intermediate energies reproduce absolute spectroscopic factors observed in electron scattering. Therefore, this technique extends measurements of absolute spectroscopic factors to neutron states and exotic nuclei. The aforementioned work includes the first such analysis of neutron states in stable nuclei and, of greater interest, states in an exotic nucleus, ^{8}B. The result is an observation of a quenching factor closer to unity for the more loosely bound state in this exotic nucleus as compared to the more well-bound states in stable nuclei.

Since the observation of this effect a number spectroscopic factors have been extracted from both previous and new measurements. Such observations include results for rather loosely bound systems such as the precision measurement of the $\nu 1s_{1/2}$ spectroscopic factor in ^{15}C [1], as well as well-bound states such as the $\nu 0d_{5/2}$ spectroscopic factor in the proton-rich nucleus ^{32}Ar [2]. Systematics from these studies reveal a possible correlation between quenching and nucleon separation energy as shown in the figure below.

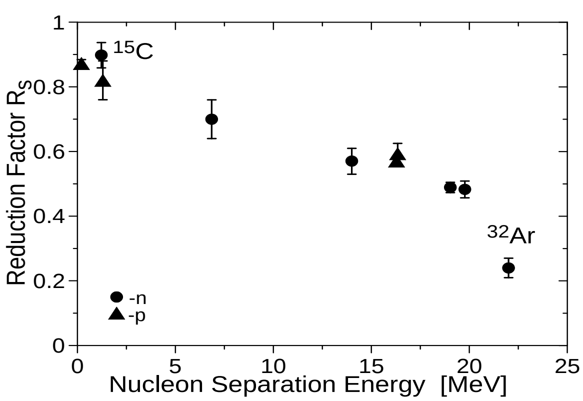

FIG. 1. Systematics for observed quenching of spectroscopic strength with respect to nucleon separation energy.

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*This work is supported by the NSF under grant Nos. PHY-01 10253 and PHY-00 70911 and by the United Kingdom EPSRC Grant No. GR/M82141.
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TDHF Studies of Neutron-Rich Systems

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Recently, experiments have been performed at the HRIBF accelerator at ORNL to study fusion-evaporation residue cross sections with neutron-rich ^{132}Sn beams on ^{64}Ni. Using this inverse-kinematics fusion technique, surprisingly large sub-barrier fusion enhancement was observed {1}. Similar experiments are planned in the future, not only at ORNL but also at other RIB facilities. In general, the heavy-ion reactions of nuclei far from stability have not been theoretically explored and pose great challenges to our microscopic approaches.

In 1991, we have developed the world's most accurate unrestricted 3-D TDHF code with spin-orbit coupling, using B-Spline techniques {2}, and applied it to fusion and deep-inelastic heavy-ion reactions. Given the experimental interest in fusion of neutron-rich nuclei we have updated this TDHF code. The code has been completely rewritten taking advantage of the array processing capabilities of Fortran 95, and using the modern versions of effective interactions.

We will show results of TDHF calculations performed for neutron rich systems, including the energy and impact parameter dependence, mass and charge transfer, energy loss, and other reaction properties that are radically different for neutron rich system as compared to the reactions of stable nuclei.

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* This work is supported by the U.S. Department of Energy under grant No. DE-FG02-96ER40963 with Vanderbilt University. Some of the numerical calculations were carried out on IBM-SP supercomputer at the National Energy Research Scientific Computing Center (NERSC).

Nuclear Astrophysics

Posters - Nuclear Astrophysics

Number/Session	Name/email	Institution	Title
101/ Tuesday	Barron Palos, Libertad libertad@fisica.unam.mx	Universidad Nacional Autonoma de Mexico	$^{12}C+^{12}C$ Cross Section Measurements at Low Energies
102/ Tuesday	Fisker, Jacob jfisker@nd.edu	University of Notre Dame	Obtaining a lower limit on the $^{15}O(a,p)^{19}Ne$-rate from type I X-ray bursts
103/ Tuesday	Hennrich, Stefan hennrich@uni-mainz.de	Institut für Kernchemie	Beta-delayed neutron measurements of very neutron-rich isotopes in the ^{132}Sn region at the limits
104/ Tuesday	Smith, Michael msmith@mail.phy.ornl.gov	ORNL Physics Division	Nuclear Data Evaluations of Structure and Reactions of Exotic Nuclei for Astrophysics
105/ Tuesday	Summers, Neil summers@nscl.msu.edu	NSCL, Michigan State University	^{7}Be breakup on heavy and light targets
106/ Tuesday	Teran, Edgar terane@sciences.sdsu.edu	San Diego State University	A statistical spectroscopy approach for calculating nuclear level densities
107/ Tuesday	Tumino, Aurora tumino@lns.infn.it	Universita' di Catania e INFN LNS	Quasi-free $^{6}Li(n,alpha)^{3}H$ reaction at low energy from ^{2}H break-up
Number/Session	Name/email	Institution	Title

$^{12}C+^{12}C$ Cross Section Measurements at Low Energies

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Abstract

Nuclear reaction cross sections at the lowest attainable energies are needed to feed accurate data to the various calculations made around the world to understand the evolution of a stellar systems, the production of energy, the genesis of a nova or supernovae, the chemistry of a galaxy and of the universe. In this work we focus our attention in a reaction that is necessary to various such calculations: the $^{12}C +^{12} C$. There are two important stellar scenarios where this cross section is relevant: For massive white dwarfs, consisting of carbon and oxygen, when the Chandrasekhar mass limit ($1.4M_{\odot}$) is reached by the accretion of carbon and oxygen rich matter from a companion star, the density and temperature in the centre of the star become high enough to ignite the explosive carbon burning, so that a Type Ia supernovae event is produced [1, 2, 3]. For normal intermediate mass stars (main sequence mass $> 9M_{\odot}$), after the helium burning, the increase in the mass of the carbon core by the helium burning in a shell also can ignite the carbon burning in the degenerate core, leading a disrupt of the star in a process known as a Type II supernovae explosion [4, 5, 6].

The lowest center of mass energy where this cross section has been measured to date is only 2.45 MeV [7]. It is needed at the energy range from 1 to 3 MeV for these stellar scenarios. In order to attain the lowest energy possible, the detection of secondary gamma rays in a tightly shielded Germanium detector, together with a high intensity heavy ion beam on a tick target has been used to successfully measure the fusion cross section for the $^{12}C +^{12} C$ system. Our results are compared with previous measurements [7, 8]. The experimental apparatus is described as well as the improvements needed to continue our measurement down below the 2.45 MeV limit.

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Obtaining a lower limit on the ^{15}O(α,)^{19}Ne-rate from type I X-ray bursts*

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A type I X-ray burst obtains, when a thermonuclear instability in the degenerate atmosphere of an accreting neutron star in a binary system causes a nuclear runaway of the accreted material. This produces proton-rich nuclei with masses up to $A \sim 100$ and releases 2-7 MeV/nucleon in a network of competing β^+-decays and proton-captures known as the *rp*-process.
Most observed X-ray bursters rely on the β-limited hot-CNO cycle to convert accreted hydrogen into helium until the helium burning triple-alpha reaction eventually heats the material su ciently to ignite the breakout-reactions of the hot-CNO cycle which allow the synthesis of heavier isotopes. One of the two breakout reactions of the hot-CNO cycle is the astrophysical ^{15}O(,γ)^{19}Ne-reaction rate which for low energies mostly depends on the elusive 4033keV resonance in ^{19}Ne. Only the upper limit of this rate has been measured experimentally, whereas the lower limit is experimentally unknown. However, it turns out that this particular breakout reaction is crucial to the thermonuclear runaway which causes type I X-ray bursts. Our calculations show that if the rate was zero then accreting material would burn stably with no bursts appearing. The observation and existence of type I X-ray bursts and so-called superbursts consequently indicate a lower limit on ^{15}O(,γ)^{19}Ne-reaction rate. This allows us to infer conclusions about nuclear physics based on astronomical observations.

This work was supported by the Swiss NSF grant 20-068031.02 and through the Joint Institute of Nuclear Astrophysics (www@JINAweb.org) NSF-PFC grant PHY02-16783.

Beta-delayed neutron measurements of very neutron-rich isotopes in the ^{132}Sn region at the limits

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and IS 333, IS 378 and IS 393 ISOLDE – Collaborations[4]
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Using highest possible selectivity in production and detection at the CERN-ISOLDE facility, we have measured beta-decay properties of a number of new r-process isotopes in the region below and beyond doubly-magic ^{132}Sn. Delayed neutron data on ^{129,130}Ag, $^{129-133}$Cd, ^{135}In and ^{137,138}Sn will be compared to QRPA predictions used so far in r-process calculations.

Nuclear Data Evaluations of Structure and Reactions of Exotic Nuclei for Astrophysics

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Thousands of species of exotic neutron-rich nuclei are believed to be synthesized in supernova explosions. To simulate these cataclysmic events, a knowledge of the structure of unstable neutron-rich nuclei and the reactions involving them is essential. Similarly, information on proton-rich radioactive nuclei is needed to understand nova explosions occurring on the surface of white dwarf stars and X-ray bursts occurring on the surface of neutron stars. Recent measurements with radioactive beams at ORNL's Holifield Radioactive Ion Beam Facility (HRIBF) have prompted the evaluation of a number of reactions involving unstable nuclei needed for stellar explosion studies. This effort is necessary to ensure that information from the latest experimental measurements are incorporated into nuclear astrophysics datasets [1] used in simulations of stellar explosions. Some reactions slated for future experiments are also being assessed in order to better plan those measurements. The ^{14}O(α,p)^{17}F, ^{17}F(p,γ)^{18}Ne, ^{18}F(p,γ)^{19}Ne, ^{18}F(p,α)^{15}O, ^{30}P(p,γ)^{31}S, ^{33}Cl(p,γ)^{34}Ar, and (direct capture) ^{82}Ge(n,γ)^{83}Ge reactions are among those being studied. Highlights of evaluation results will be presented, as well as plans for additional work in this area. Unique tools to swiftly process these evaluations into thermonuclear reaction rates and share them with the research community have also been developed.

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

1. **http://www.nucastrodata.org**.

^{7}Be breakup on heavy and light targets *

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At present, the capture rate ^{3}He(α,γ)^{7}Be is one of the most uncertain in the *pp* chain, with implication to the solar neutrinos. At the low energies of astrophysical relevance, these rates are exceptionally hard to measure directly. Consequently, indirect methods using the inverse breakup reaction have been considered. These are: i) The Coulomb dissociation method proposes the measurement of radiative capture rates from breakup data on heavy targets [1], ii) The Asymptotic Normalization Coefficient (ANC) method proposes the measurement of the capture rate from transfer reactions [2] or breakup reactions [3].

The uncertainties on the direct capture measurements for the ^{3}He(α,γ)^{7}Be reaction has motivated two breakup experiments: one performed recently at the NSCL, measured the ^{7}Be breakup on ^{208}Pb at 100 MeV/nucleon, and the other planed for the Cyclotron Lab at Texas A & M, will use a ^{7}Be 25 MeV/nucleon beam on a ^{12}C target.

We present all-order quantum mechanical calculations [4] for these two experiments using the method of Continuum Discretized Coupled Channels (CDCC) [5]. We discuss the issues concerning the extraction of the astrophysical $S_{34}(0)$ from the breakup data using the methods of Coulomb dissociation and the Asymptotic Normalization Coefficients.

It is often assumed that by measuring the breakup on heavy targets at forward angles, the cross section can be measured free from nuclear effects. We show that ^{7}Be breakup at forward angles is actually dominated by nuclear breakup (diffraction dissociation). We discuss how by careful kinematic selection, regions where Coulomb breakup is the dominant mechanism can be chosen. The extraction of the S_{34} using the ANC method requires a peripheral reaction. We show that contributions from the nuclear interior must be taken into consideration.

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*This work has been supported by the National Superconducting Cyclotron Laboratory at Michigan State University

An Statistical Spectroscopy approach for calculating Nuclear Level Densities

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We compute level densities with a nuclear statistical spectroscopy approach. This model is based in the microscopic physics of the interactive shell model. The level density is constructed by means of a binomial distribution. Each partition of the valence space contributes to the total level density, and the binomial fit of individual partitions is based on the nuclear moments. We calculate nuclear moments up to 4th order.

This method of calculating level densities becomes highly convenient, since the computational load is not as limiting as conventional shell-model calculations. Locally averaged expectation values and spin-cutoff factors computations are also possible within this approach. To demonstrate the reliability of the method, we show calculations of level densities for several nuclides and compare them to exact calculations with full-diagonalization shell-model.

Quasi-free ^{6}Li(n,α)^{3}H reaction at low energy from ^{2}H break-up

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The ^{6}Li+d interaction was studied in order to investigate the quasi-free ^{6}Li(n,α)^{3}H reaction, off the proton in ^{2}H. A kinematically complete experiment was performed at a beam energy of 14 MeV. Coincidence spectra show the contribution of the quasi-free n+^{6}Li reaction in the relative energy range from 1.5 MeV down to zero. The shape of the experimental momentum distribution for the spectator proton reflects the expected theoretical behaviour, that for a proton/neutron in ^{2}H is described by a Hulthén function in momentum space. The extracted ^{6}Li(n,α)^{3}H quasi-free cross-section was compared with the behaviour of direct data throughout the investigated energy range. No penetrability corrections were introduced on the quasi-free data, being the ^{6}Li(n,α)^{3}H direct reaction free of Coulomb suppression. This represents an important test for the known and successful application of the quasi-free mechanism to the study of reactions between charged particles at astrophysical energies by means of the Trojan Horse Method [1-4]. Indeed the present study allows to investigate possible off-energy-shell effects in a situation where the Coulomb barrier is absent. The results of this experimental work will be presented and possible future applications of the method to some key astrophysical reactions using ^{2}H ions as source of a neutron beam will be discussed.

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Radioactivity

Posters - Radioactivity

Number/Session	Name/email	Institution	Title
111/ Tuesday	Arumugam, P. aru@iopb.res.in	Institue of Physics	Study of proton radioactivity from exotic nuclei with a cluster decay model
112/ Monday	Basu, Chinmay chinmay@lotus.saha.ernet.in	Saha Institute of Nuclear Physics	Single particle states and spectroscopic factors for two proton emitters
113/ Tuesday	Batchelder, Jon batcheld@mail.phy.ornl.gov	UNIRIB/ORAU	Study of Fine Structure in the Proton Radioactivity of ^{146}Tm
114/ Monday	Davids, Cary davids@anl.gov	Argonne National Laboratory	Decay Rate of Triaxially Deformed Proton Emitters
115/ Tuesday	Gross, Carl cgross@phy.ornl.gov	Oak Ridge National Laboratory	A novel way of doing decay spectroscopy at an ISOL-RIB facility
116/ Monday	Grzywacz, Robert grzywacz@mail.phy.ornl.gov	University of Tennessee	Discovery of the new proton emitter ^{144}Tm
117/ Monday	Kadmensky, Stanislav kadmensky@phys.vsu.ru	VSU	Theory of Two-Proton Radioactivity
118/ Monday	Leppänen, Ari leppanen@phys.jyu.fi	University of Jyväskylä	Alpha decay study of ^{218}U; a search for the predicted sub-shell closure at Z=92
125/ Tuesday	Woehr, Andreas awoehr@nd.edu	Notre Dame	Decay spectroscopy of very neutron-rich silver isotopes
Number/Session	**Name/email**	**Institution**	**Title**

Study of proton radioactivity from exotic nuclei with a cluster decay model

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A new simple approach based on cluster decay model [1] has been put forth to study proton radioactivity. This model comprise Yukawa-plus-exponential potential for the post scission region and the inner part is connected smoothly by a third order polynomial. To study sensitiveness of the decay rates to the orbital angular momentum, a centrifugal barrier is added to the region after the touching configuration. The deformation effects of parent as well as the daughter nuclei are taken care. The finite range effects around the touching configuration has been treated properly. Only some minor modifications were made to the cluster decay model to take into account the proton radius and its surface-asymmetry constant. Calculations are performed for several experimentally seen, spherical and deformed nuclei around the proton drip line and some of the results are shown in Fig. 1. Without any adjustable parameters in the formalism, the half-life values calculated by our approach are shown to be well in conformity with experimental and other theoretical results [2]. The centrifugal barrier plays vital role in proton radioactivity. Our results are found to be very sensitive to the angular momentum of the proton emitter. Deformation effects in the parent as well as the daughter nuclei are also found to alter the half-life values considerably. Hence, with commendable satisfaction, proton radioactivity can be explained in a way very similar to cluster decay and alpha decay.

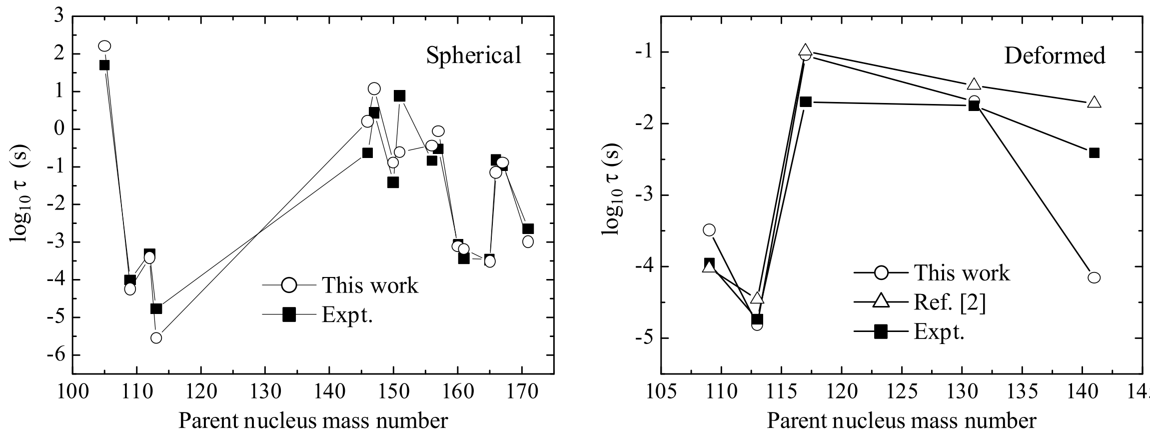

FIG. 1. Theoretical and experimental half-lives of spherical and deformed proton emitters.

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Single particle states and spectroscopic factors for two proton emitters

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Nuclei at the proton drip line spontaneously decay by the emission of one and two protons from their ground states. True two-proton decay occurs from a nucleus when one proton emission is forbidden energetically due to pairing interaction. Though the phenomenon of two-proton radioactivity was predicted by Goldansky in the early sixties, the experimental observation of this decay mode in ^{45}Fe has been reported only very recently [1]. A theoretical challenge in this field is to calculate the decay width (lifetime) of these exotic nuclei. The calculation of decay width primarily involves the solution of the barrier penetration problem and this has been done by a number of workers either in the framework of the di-proton theory [2] or the three-body model [3]. The branching ratio for decay also depends on the spectroscopic factor, which is dependent on the structure of the two proton emitting nucleus. Calculations of spectroscopic factors for two proton radioactive nuclei are sparse in literature. The only calculation in the recent past is by Brown in the cluster overlap approximation [2]. This method is complex and requires knowledge of the initial, final and di-proton wave functions. In this work we present a more simple calculation of spectroscopic factors for two proton-emitting nuclei in the BCS approximation using the di-proton model. For the spectroscopic factor we use the formalism of [4] applied to two particle transfer reactions. The spectroscopic factor involves the calculation of occupation probabilities, which are evaluated from BCS theory. In this calculation the pairing gap and Fermi level are obtained by a numerical solution of the BCS gap equations. The solution requires the single particle (proton) energies of the proton drip line nuclei that are not known experimentally. We have evaluated the single particle basis from the experimental states of their corresponding mirror nuclei (stable), by using the empirical expression of Goldansky , Nazarewicz[5]. The jj-coupling spectroscopic factors are converted to the LS coupling scheme (with L=0, S=0) and are compared with the results of Ref.[2]. In Table 1 we show our calculations in A and those from Brown [2] in B. The calculations of Brown are shown without the correction factor introduced in his calculations due to the use of shell model wave functions instead of the actual internal wave function. So far in our calculations we have considered only the bound states. However, for nuclei close to drip line the effect of the continuum on the pairing properties cannot be neglected [6]. A possible way to include the effects of continuum is to calculate the single particle spectrum from Wood-Saxon (WS) type potential and solve the BCS equations in a basis that includes both bound and resonant states [6,7]. We use the code GAMOW [8] to calculate the single particle states with an average WS potential having real and spin-orbit term. The real part is adjusted to fit the single proton separation energy. The bound and resonant (non zero width Γ_0) single particle states for ^{48}Ni calculated from GAMOW are compared to the calculations of [5] and [7] in Table 2. It will be interesting to see how the inclusion of resonance states in the BCS calculations affects the spectroscopic factors.

2p Emitter	A	B
^{48}Ni	0.324	0.341
^{45}Fe	0.410	0.475
^{54}Zn	0.820	-

Table 1

Orbital	GAMOW		From ref [5] & [7]	
	E_o	Γ_o	E_o	Γ_o
$1f_{7/2}$	-.46	0	-.90	0
$2p_{3/2}$	4.53	-.29	2.856	-.0132
$2p_{1/2}$	5.23	-.56	4.288	-0.168
$1f_{5/2}$	6.67	-.12	6.811	-0.113
$1g_{9/2}$	11.7	-.74	10.266	-0.255
$2s_{1/2}$	-2.6	0	-3.38	0
$1d_{3/2}$	-2.9	0	-3.41	0

Table 2

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Study of Fine Structure in the Proton Radioactivity of ^{146}Tm

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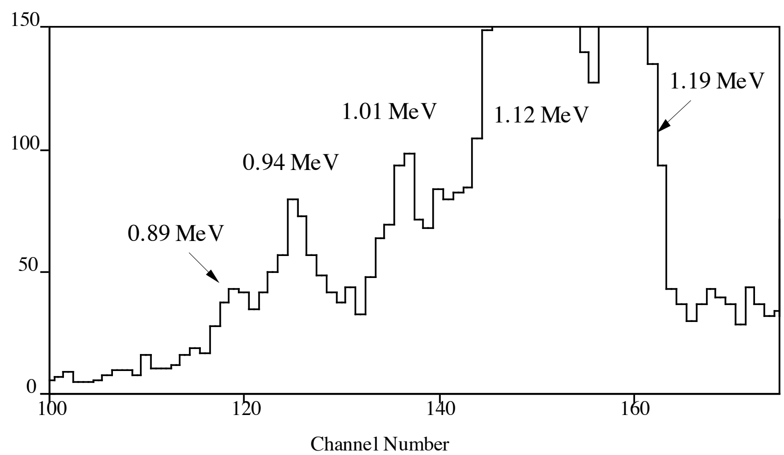
The observation of fine structure in proton emission allows one to deduce the composition of the parent state's wavefunction. The proton emitting state of an odd-odd nucleus consists of coupled proton and neutron states, with the final state being a low-energy neutron configuration in the daughter nucleus. By studying the fine structure in the decay of these odd-odd nuclei one can identify and determine relative energies of these low-energy neutron levels in the (even Z, odd N) daughter nucleus in nuclei that are inaccessible during in-beam experiments. In the case of ^{146}Tm, three neutron orbitals $\nu s_{1/2}$, $\nu d_{3/2}$ and $\nu h_{11/2}$, and three proton orbitals $\pi s_{1/2}$, $\pi d_{3/2}$, and $\pi h_{11/2}$ are expected to be close to the Fermi surface.

Thulium-146 was first observed by Livingston *et al*. [1], using the Daresbury Recoil Separator/DSSD system in 1993. In this work, two transitions were reported with E_p = 1119(5) keV ($T_{1/2}$= 235(27) ms), and E_p = 1189(5) keV ($T_{1/2}$= 72(23) ms). These were assigned to high and low spin isomers of ^{146}Tm respectively. A reinvestigation of this isotope by our group [2] with much higher statistics reported three new proton peaks in the decay of ^{146}Tm with energies of 889(10), 936(10), and 1014(15) keV, which were attributed to fine structure decay from these isomers. Based on the half-lives of the individual peaks, the 889 keV transition was assigned to the 200(10) ms high spin (8+) isomer and the 936 keV transition was assigned to the 80(10) ms low spin (5-) isomer. Lack of statistics and contamination from ^{147}Tm, however, prevented us from assigning the 1014 keV transition.

We have reinvestigated ^{146}Tm at the Holifield Radioactive Ion Beam Facility (HRIBF) at Oak Ridge National Laboratory. In this study, recoil nuclei of interest were separated spatially according to their mass/charge (A/Q) values by the HRIBF Recoil Mass Spectrometer (RMS), and then implanted into a ~ 60-μm thick DSSD with 40 horizontal and 40 vertical strips. Surrounding the DSSD on four sides was a Si-box, with a thick SiLi detector located behind the DSSD. Both of these auxiliary detectors were used to veto escape particles, betas and β-delayed protons. Signals from all the detectors were then processed with a digital spectroscopy system using 40 MHz flash ADCs and digital signal processors. Statistics collected in this recent work were a factor of 4 - 5 greater than the previous experiment. A spectrum containing the proton peaks is shown below. The previously unassigned 1014 keV transition has been shown to have a half-life of ~75 ms. On this basis, we assign it to the fine structure decay of the (5$^-$) state in ^{146}Tm. This transition is interpreted as a ℓ=3 proton arising from the $\nu s_{1/2}$-$\pi f_{7/2}$ 2$^+$ portion (a few percent of the total configuration) of the parent ground state to a 0.18 MeV $\nu s_{1/2}$ 2$^+$ state in the daughter.



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Decay Rate of Triaxially Deformed Proton Emitters*

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The decay rate of a triaxially-deformed proton emitter is calculated in a particle-rotor model, which is based on a deformed Woods-Saxon potential and includes a deformed spin-orbit interaction [1]. As an application, the wave function of the I=7/2$^-$ ground state of the deformed proton emitter ^{141}Ho is obtained in the adiabatic limit, and a Green's function technique is used to calculate the decay rate and branching ratio to the first excited 2$^+$ state of the daughter nucleus. Only for values of the triaxial angle $\gamma < 5°$ is good agreement obtained for both the total decay rate and the 2$^+$ branching ratio. The figure shows the calculated value of the branching ratio *vs*. triaxial angle γ (solid line) and the experimental value (shaded area) [2]. The generic error bar on the calculated value represents the uncertainty due to the uncertainty in the measured proton energy [3].

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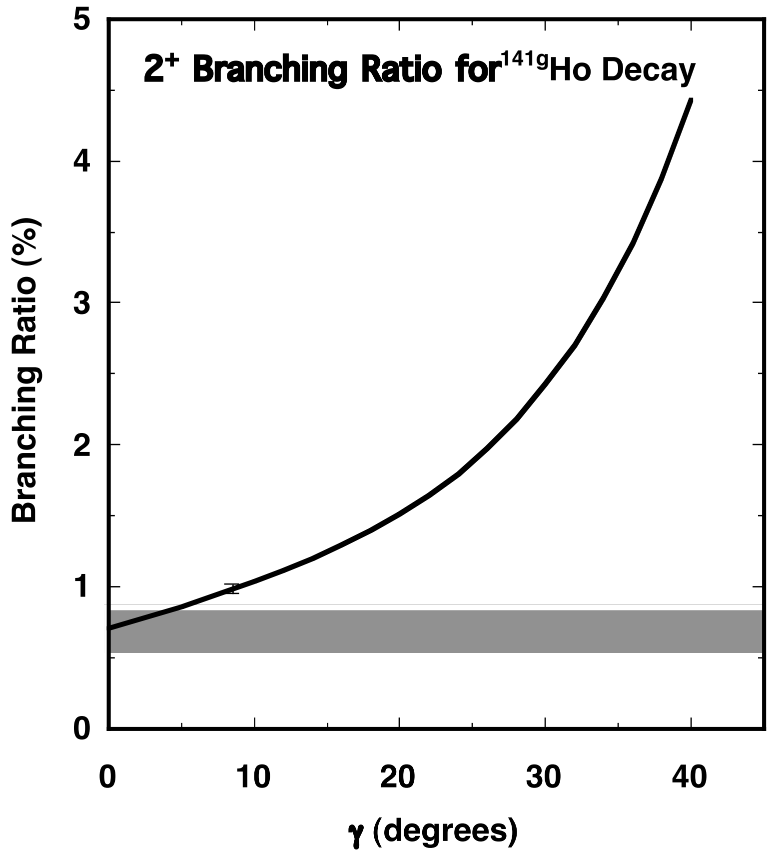

* Work supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. W-31-109-ENG-38

A Novel Way of Doing Decay Spectroscopy at an ISOL-RIB Facility *

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A novel technique has been developed at HRIBF to perform traditional beta spectroscopy. In this technique, we take advantage of several factors available to our facility:

- Accelerated ISOL-produced radioactive ion beams (RIBs) in excess of 3 MeV/u
- Neutron-rich RIBs produced by proton-induced fission on uranium carbide targets
- Good emittance of tandem beams
- Enhanced purity of some RIBs due to chemical selectivity
- Experience with experimental techniques employed in nuclear structure and nuclear reactions

In this technique, we accelerate a neutron-rich RIB of a given mass to 3 MeV/u and send this beam directly into a double-window ionization chamber operating at high gas pressure. Isobars with a given Z lose less energy in the gas than those isobars with higher Z. Thus, by careful adjustment of the gas pressure, high Z beam contaminants can be stopped inside the gas volume while lower Z ions exit the ionization chamber and are deposited at the measuring station. For neutron-rich beams, the most exotic isobars have the lowest Z. This "ranging out" of the more prolific beam contaminants results in:

- Absolute identification and counting of the sample atoms
- Factor $\approx$5 reduction in contaminants with ΔZ=2 at Z$\approx$50
- Large implantation areas
- The optional use of thick double-sided silicon strip detectors for half-life measurements

In our test case, we accelerated Ag RIBs with masses 120, 122, 124, 125, and 126. Each beam had varying amounts of contamination from In and Sn isotopes. Cd isotopes do not make a negative ion and therefore are not accelerated through the tandem. This poster will discuss the results of our initial tests.

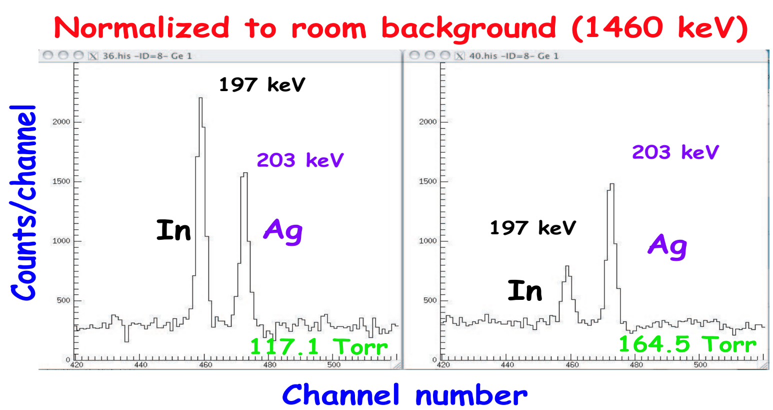

FIG. 1. Ungated gamma-ray spectra for A=120 ions at 117 Torr and 164 Torr gas pressure in the ionization chamber. (b) Note the enhancement of the 203 keV isomeric transition in ^{120}Ag. A factor of approximately 6 enhancement is observed.

*Oak Ridge National Laboratory is managed by UT-Battelle, LLC, under Contract DE-AC05-00OR22725 with the U. S. Department of Energy.

Discovery of the new proton emitter ^{144}Tm

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Proton emitter studies enable precise probing of the composition of the wave function of nuclei beyond the proton dripline. In a decay of proton radioactive odd-odd nuclei excited levels in the (even-Z,odd-N) daughters can be populated allowing us to deduce the properties of single particle neutron states. So far, fine structure in proton emission was observed for only one odd-odd emitter, ^{146}Tm [1]. The neighbouring odd-odd isotope ^{144}Tm is an obvious candidate to exhibit similar decay pattern . Its decay should be dominated by a large $\pi h_{11/2}$ component present in the ground and isomeric state wavefunction, as it was observed for ^{146}Tm[1] and ^{145}Tm[2]. The admixture of the $2^+ \otimes \pi f_{7/2}$ component or of the mirror $[\nu h_{11/2}\ \pi s_{1/2}]$ proton-neutron configuration can cause the fine structure in proton emission.

Evidence for the proton decay of ^{144}Tm was found in an experiment at the Recoil Mass Spectrometer [3] at Oak Ridge National Laboratory. The ^{144}Tm events were found in a weak ($\sigma \approx 10$ nb) p5n channel of the fusion reaction of ^{58}Ni beam at 340 MeV on a ^{92}Mo target.

The observed decay energy of about 1.8 MeV and the half-life of the order of ≈ 1 μs suggest proton emission from the dominant $\pi h_{11/2}$ part of the wave function. The detection of this very short proton emitter was made possible by use of a double-sided silicon strip detector connected to a fast Digital-Signal-Processing-based acquisition system [4].

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Theory of Two-Proton Radioactivity*

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Only recently the experimental case of one step two-proton decay of nucleus 45Fe was found. The three-body theory [1] used for description of two-proton radioactivity is close to R-matrix theory of nuclear reactions because of the application of the very difficult procedure of sewing together of internal and external components of decaying nucleus wave function.

By use of the methods of the quantum theory of ternary fission [2] for one-step two-proton decay the amplitude of partial width and potential phase of two-proton decay can be found through the integral of overlapping of the many-particle shell model wave function of parent nucleus taking into account the superfluid nucleon-nucleon correlations, total Hamiltonian of parent nucleus and complex cluster wave function, describing the potential scattering of two-proton decay products for the strong coupling of decay channels. It allows avoid the sewing procedure [1] and to reduce the description of two-proton radioactivity to calculations of shell model and cluster wave functions of decaying system.

The account of the superfluid correlations for parent and daughter nuclei gives the possibility to reduce the many-particle task of two-proton radioactivity to three-body task and to classify the two-proton transitions as favorable, semifavorable e.t.c. For favorable two-proton transition the wave function of two protons bound in the parent nucleus is calculated as Cooper pair wave function for the superfluid model. The cluster wave function is calculated with use of hyperspherical function basis [1,2] by resolving of the system of strongly coupling radial equations with boundary conditions connected with potential three-body S-matrix. The asymptotic states of two protons for favorable transitions are characterized by zero values of total and proper spins of two protons and by equal values of relative orbital moments of two protons and daughter nucleus.

For case of deeply subbarrier two-proton decay by analogy with successful results of the theory of deeply subbarrier one-proton decays [3] the influence of nuclear interactions of daughter nucleus with protons to the cluster wave function can be neglected. But for this case the account of nuclear interaction between two protons in asymptotic region leads to description of influence of diproton potential resonance state to two-proton decay widths and angular and energy distributions of two emitting protons.

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*This work was supported by INTAS (grant N03-51-6417) and Fond of Russian Universities (grant УР-02.01.003).

Alpha decay study of ^{218}U; a search for the predicted sub-shell closure at Z=92

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The Uranium isotope ^{218}U is predicted to be a doubly magic nucleus in many recent theoretical calculations for super heavy elements [1,2]. In addition to the magic neutron number N=126, there are predictions for a shell gap at Z=92 between the $h_{9/2}$ and $f_{7/2}$ proton orbitals. The Nilsson diagram for the deformed nuclei has been quite successful in explaining the single-particle levels and the semi-magic numbers when the super-heavy elements (Z≥98) have been studied. Since the Nilsson diagrams partly rely on the input of single-particle shell model energies also the magicity of Z=92 has an important role.

The existence of the two nearly-degenerate 8^+ states in the even N=126 nuclei disagrees with the idea of a substantial shell gap at Z=92. The two 8^+ states are based on configurations $\pi h_{9/2}^2$ and $\pi h_{9/2}f_{7/2}$. In ^{216}Th the 8^+ state with the configuration $\pi h_{9/2}f_{7/2}$ becomes an yrast state with a relatively long half-life $T_{½}$=180μs [3,4]. This state decays with a 3% α-branch to the ground state of ^{212}Ra. This is considered to prove the near degeneracy of the $h_{9/2}$ and $f_{7/2}$ quasi-particle states which then disproves the existence of the Z=92 sub-shell closure [5].

The experiment to study ^{218}U was performed with the gas-filled recoil separator RITU and the K-130 cyclotron at JYFL. The ^{40}Ar + ^{182}W fusion evaporation reaction was used to produce ^{217}U, ^{218}U and ^{219}U. Also the recently installed focal plane detector system (GREAT) and the triggerless Total Data Readout (TDR) system were utilized in this experiment. The recoils were implanted into a double-sided silicon strip detector (DSSSD) at RITU focal plane after separation from beam particles. The α-particle decay properties of the implanted recoils and their decay products were measured. The decays of ^{217}U, ^{218}U ja ^{219}U were seen. In the case of ^{218}U not only the ground state to ground state decay was observed but also the decay from an isomeric state to the ground state of ^{214}Th. The observed alpha decay properties from this isomeric state point to a situation where the 8^+ state (from the configuration $\pi h_{9/2}f_{7/2}$) falls below the 6^+ (from the configuration $\pi h_{9/2}^2$) forming an yrast trap in ^{218}U.

The results of this study and interpretations will be discussed in more detail.

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[5] H. Grawe et al., Annual Report, JYFL, **41** (1999)

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Decay Spectroscopy of very Neutron-Rich Silver Isotopes*

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Gamma spectroscopic data on the beta decay of very neutron-rich Ag isotopes have been taken at the GPS separator of CERN/ISOLDE using a chemically selective laser ion source (RILIS). Extended level schemes of ^{124}Cd, ^{126}Cd and ^{128}Cd will be presented and discussed in terms of level systematics in the ^{132}Sn region and recent OXBASH shell-model predictions. An attempt to measure the beta decay of ^{130}Ag to the neutron-magic r-process waiting-point nucleus ^{130}Cd has been scheduled using the HRS separator using a combination of RILIS and a neutron converter target.

‡ This work comprises the PhD theses of Thomas Kautzsch and Oliver Arndt.

* Supported by the German BMBF, the National Science Foundation grants NSF-PHY01-40324 (Notre Dame) and DE-FG02-94ER49834 (University of Maryland)

Nuclei at the Drip Lines and Cluster Phenomena

Posters - Clusters and Dripline

Number/Session	Name/email	Institution	Title
58/ Monday	Aksouh, Farouk Farouk.Aksouh@fys.kuleuven.ac.be	K.U. Leuven	New measurement of alpha+d emission following beta-decay of ^{6}He
59/ Tuesday	Antonenko, Nikolay antonenk@thsun1.jinr.ru	Bogoliubov Laboratory of Theoretical Physics	Cluster phenomena in nuclei structure
43/ Monday	Arumugam, P. aru@iopb.res.in	Institute of Physics	Finite nuclei to infinite matter in an effective lagrangian approach
44/ Tuesday	Blazkiewicz, Artur a.blazkiar@vanderbilt.edu	Vanderbilt University	2-D Lattice HFB calculations for neutron-rich Sulfur and Zirconium isotopes.
45/ Monday	Dlouhy, Zdenek dlouhy@ujf.cas.cz	Nuclear Physics Institute ASCR	Structure of Light Neutron-Rich Odd-Z Nuclei
46/ Tuesday	Faes, JB faes@ganil.fr	GANIL	Shell-model embedded in the continuum for the description of alpha particle emission and radiative capture processes
47/ Monday	Kankainen, Anu anu.kankainen@phys.jyu.fi	University of Jyväskylä	Beta-delayed gamma and proton spectroscopy near the Z = N line
48/ Tuesday	Kimura, Masaaki masaaki@postman.riken.go.jp	RIKEN	Many-Particle Many-Hole States in Neutron-Rich Ne isotopes Related to Broken N=20 Shell Closure
49/ Monday	Masui, Hiroshi hgmasui@riken.jp	RIKEN	Study of drip-line nuclei with a core plus multi valence nucleon model
50/ Tuesday	Ong, H. Jin onghjin@nucl.phys.s.u-tokyo.ac.jp	University of Tokyo	Inelastic Proton Scattering on ^{16}C
51/ Monday	Pain, Steve pain@mail.phy.ornl.gov	Rutgers University	Evidence of a $(1d_{5/2})^2$ component to the ^{12}Be ground state
Number/Session	**Name/email**	**Institution**	**Title**

Posters - Clusters and Dripline

Number/Session	Name/email	Institution	Title
52/ Tuesday	Raabe, Riccardo riccardo.raabe@fys.kuleuven.ac.be	KU Leuven	New measurement of alpha+d emission following beta-decay of ^{6}He
53/ Tuesday	Samanta, Chhanda chhanda@lotus.saha.ernet.in	Saha Institute of Nuclear Physics	Shell Effects of Magic Nuclei near Drip Lines
54/ Tuesday	Shrivastava, Aradhana aradhana@apsara.barc.ernet.in	Bhabha Atomic Research Centre	Exclusive break-up of $^{6,7}Li$ on ^{65}Cu at near barrier energies
55/ Monday	Stoitcheva, Gergana stoitchevags@ornl.gov	ORNL	The sign problem in shell model monte carlo calculations
56/ Tuesday	Sugimoto, Sugimoto satoru@riken.jp	The Institute of Physical and Chemical Research	Charge- and parity-projected Hartree-Fock method for the strong tensor correlation and its application to the alpha particle
57/ Monday	Tengblad, Olof imtot4a@iem.cfmac.csic.es	Instituto de Estructura de la Materia - CSIC	Beta-transition asymmetry in the A=9 isobars.
Number/Session	**Name/email**	**Institution**	**Title**

New measurement of α + *d* emission following *β*-decay of ^{6}He

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A sensitive test of the ^{6}He halo structure is provided by the measurements of the branching ratio of the *β*-decay into the ^{6}Li two-body continuum, $^6\mathrm{He} \rightarrow \alpha + d + e^- + \bar{\nu}$ (*Q* = 2.033 MeV), and the corresponding energy spectrum of deuterons. The precise determination of this branching ratio can provide information about the $\alpha + d$ wave-functions. The calculations of the $\alpha + d$ transition probability in the framework of different models give the branching ratio values varying within 2 orders of magnitude and show that the energy range below 500 keV is the the best for the choice of the model parameters. The present experimental results on this branching ratio are in disagreement: $7.6(6) \times 10^{-6}$ [1], and $1.8(9) \times 10^{-6}$ [2] (both $E_{\alpha+d} > 525$ keV). The crucial point to register minimum energies of alphas and deuterons is the experimental low energy cutoff limit due to the presence of a high intensity *β*-background from the main branch of the ^{6}He decay.

To reduce the *β*-background and to obtain an absolute normalization, we used an experimental technique in which the ^{6}He ions have been implanted into a double-sided strip detector with thickness 78 µm and strip pitch 335 µm, each side of the detector having 48 strips. As α-particles and deuterons deposit all their energy only into 1-2 strips while the *β*'s into many more strips, the total $\alpha + d$ signal could be separated from the low energy *β*-background.

The experiment was performed at the CRC in Louvain-la-Neuve, Belgium [3]. The ^{6}He beam, average 10^4 pps, with an energy of 8 MeV was implanted into the detector for 1 sec followed by a decay period of 2 sec. To check the sensitivity of the detector to *β*-particles, we used a 10 MeV ^{18}Ne beam whose β^+ spectrum has an end-point energy 3.424 MeV close to the end-point energy of the ^{6}He β^- spectrum 3.508 MeV. The $\alpha + d$ contribution of ^{6}He *β*-delayed decay was extracted through an accurate comparison between the decay spectra of the two nuclei.

In the first measurement, the branching ratio for an energy above 525 keV was determined to be $1.7(4) \times 10^{-6}$, and a preliminary $\alpha + d$ spectrum was obtained (see Fig. 1) which confirms the results reported in [2]. Results from a second measurement will also be presented, where technical improvements allowed to significantly lower the cutoff energy.

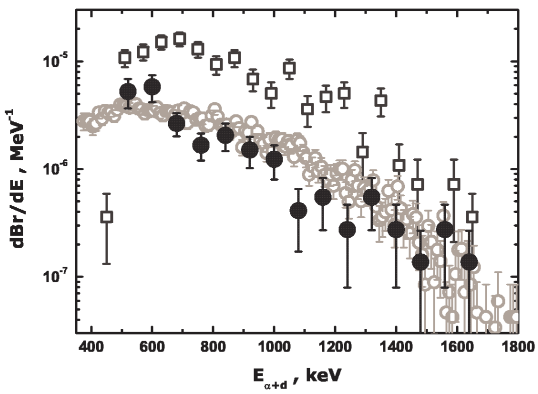

Fig. 1. Preliminary α-*d* spectrum from *β*-decay of ^{6}He (●) compared with the results from [1] (□) and [2] (○).

[1] M.J.G. Borge et al., Nucl. Phys. A **560**, 664 (1993).
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CLUSTER PHENOMENA IN NUCLEI STRUCTURE

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A cluster model is applied to the description of the low-lying alternative parity normal deformed (ND) states and superdeformed (SD) states [1,2,3]. The model is based on the assumption that cluster-type shapes are produced by a collective motion of the nuclear system in the charge (mass) asymmetry coordinate. The yrast SD band and ND band are related to ^{8}Be-cluster configuration (or two alphas on opposite sides of the heavy cluster) and to the α-particle clusterization, respectively.

All observable characteristics (parity splittings and electric dipole, quadrupole, octupole moments) of nuclei $^{220-226}$Ra, $^{220-232}$Th, $^{230-238}$U, $^{236-244}$Pu, $^{142-146}$Ba, $^{144-148}$Ce and $^{146-150}$Nd are described [1]. The results of calculations agree well with the experimental data, especially of the variation of the parity splitting with mass number of nucleus at low spin of system and of the value of the critical spin at which the parity splitting disappears.

The cluster approach provides a good description of the spectra and decay out of the lowest SD bands in nuclei ^{60}Zn, ^{190,192,194}Hg and ^{192,194,196}Pb [2,3]. As follows from our analysis of the yrast SD bands in the mass-190 region, the sudden transition from the SD minimum to the ND minimum occurs because of the crossing of SD band with the nearest neighboring excited ND band and spreading of collective states among the compound states.

A new method for the spectroscopic studies of the SD nuclei is suggested within the cluster approach.

[1] T. M. Shneidman *et al.*, Phys. Rev. B **526** 322 (2002).
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Finite nuclei to infinite matter in an effective lagrangian approach

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The relativistic mean field treatment of quantum hadrodynamics (QHD), has been proven to be very successful in dealing with the nuclear many-body problem. Since the model was proposed to be renormalizable, only cubic and quartic scalar self-interactions were included. More recently, inspired by the modern concepts of effective field theory (EFT) and density functional theory (DFT) for hadrons, Furnstahl, Serot and Tang [1] abandoned the idea of renormalizability and extended the relativistic mean field model (RMF) by allowing other non-linear scalar-vector, vector-vector and tensor couplings. This new formulation is termed as E-RMF. In the case of nuclear matter the RMF (with NL1 and NL3 parameters) gives too stiff equation of state (EOS) whereas the E-RMF (with G1 and G2 parameters) gives softer EOS. The recent experimental determination [2] of the EOS of dense matter favor the predictions of E-RMF (See Fig. 1). From our past [3] and present extensive E-RMF calculations, we find that the G2 set explain finite nuclei, infinite nuclear matter and neutron star in a unified way with commendable level of accuracy in all the cases. The quality of our results and the analysis of shortcomings of other relativistic models indicate that at present the E-RMF approach can be considered as a salient step towards a unified theory for finite nuclei as well as for infinite nuclear matter.

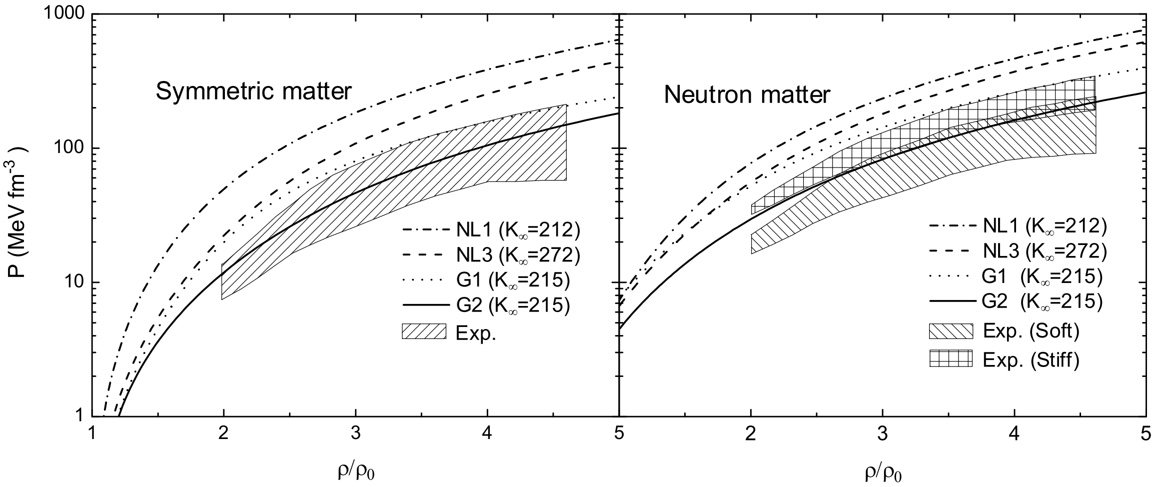

FIG. 1. Zero temperature EOS for symmetric nuclear matter and neutron matter.

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2-D Lattice HFB calculations for neutron-rich Sulfur and Zirconium isotopes *

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We have solved, for the first time, the Hartree-Fock-Bogoliubov (HFB) continuum problem in coordinate space on a 2-D lattice, without any further approximations. Our computer code has been specifically designed for deformed axially symmetric nuclei near the drip lines [1]. The unique feature of the Vanderbilt HFB code is that it treats the continuum wavefunctions consistently on the lattice and takes into account the strong coupling to high-energy continuum states, up to an equivalent single-particle energy of 60 MeV or higher.

We solve the HFB equations for deformed, axially symmetric even-even nuclei in coordinate space on a 2-D lattice with Basis-Spline methods. For the p-h channel, the Skyrme (SLy4) effective N-N interaction is utilized, and for the p-p and h-h channel we use a delta interaction.We do not assume left-right symmetry thus allowing for octupole shapes.

For axially symmetric nuclei, we diagonalize the HFB Hamiltonian separately for fixed isospin projection q and angular momentum quantum number Ω (typically up to 21/2). For fixed values of q and Ω, we obtain $4 \cdot N_r \cdot N_z$ eigenstates, typically up to 1,000 MeV. The following structure of the code enabled us to parallelize it in isospin projection q and angular momentum quantum number Ω. The most common number of processors we use is equal to 22.

Production runs are carried out on parallel computers using OPENMP/MPI message passing. We make use of IBM-RS/6000 SP supercomputer at NERSC in Berkeley as well as our local "Vampire" cluster of Linux workstations.

In particular, we recently calculated the properties of the light sulfur ($^{40-52}S$) isotope chain up to the two-neutron dripline. Furthermore, we study the strongly deformed heavy system of zirconium (starting from ^{102}Zr up to the $2n$-dripline). Comparison with relativistic mean field theory and with experimental data is given whenever available. We show some representative color plots [2] of calculated observables including: normal densities and pairing densities.

[1] E. Teran, V.E. Oberacker and A.S. Umar, Phys. Rev. C 67, 064314 (2003)

[2] Hartree-Fock-Bogoliubov Calculations for Neutron-rich Oxygen, Sulfur, Zirconium, Cerium, and Samarium Isotopes, V.E. Oberacker, A.S. Umar, E. Terán, and A. Blazkiewicz,Phys. Rev. C 68,064302 (2003)

*This work has been supported by the U.S. Department of Energy under grant No. DE-FG02-96ER40963 with Vanderbilt University. The numerical calculations were carried out on the IBM-RS/6000 SP supercomputer at NERSC in Berkeley.

Structure of Light Neutron-Rich Odd-Z Nuclei*

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In the past twenty years our understanding of the structure of light neutron-rich nuclei has developed very dramatically. The nuclear shell model has been successful in the description of various aspects of nuclear structure for nuclei near the valley of stability, and has enabled to involve the magic numbers that have become very important quantities reflecting the nuclear structure. Basic nuclear properties such as binding energies and shapes depend strongly on the underlying shell structure. However, the situation for neutron-rich nuclei far from stability has changed drastically and the standard magic numbers of the shell structure have disappeared. In the case of light nuclei, the rapid change in the location of the neutron drip line between the O and F isotopes is still not understood. The neutron drip line seems to be reached at N=16 in O isotopes whereas in the neighbouring F isotopes, it has been found to extend up to N=22 [1,2]. Obviously, the understanding of how shell structure evolves when going from oxygen to fluorine nuclei would shed light on how the nuclear force can facilitate the binding of six neutrons by the addition of a single proton as in ^{31}F. However, near the neutron drip line, a breaking of magicity has been observed at the N=20 shell closure where an "island of inversion" in shell ordering has been established, as well at N=8 where the doubly magic ^{10}He nucleus has been confirmed to be unbound. Though some theoretical calculations predict the existence of new neutron magic numbers N=6, 16 and 34 [3,4] until lately, no experimental evidence about new magic numbers has been available.

Two experimental surveys resulting in an appearance of neutron magic number N=16 have been published. A survey [5] of experiments performed at GANIL from the point of view of two-neutron separation energies has firmly established the determination of neutron shells closure at N=16 in this region. On the other hand, Ozawa et al. [6] have inspected the information from one neutron separation energies and interaction cross section $_I$. Kanungo et al. [7] have published systematic of the beta decay Q-values indicating new regions of shell closures at N=6, 16 and also near 32. The magicity of the N=16 was established using analysis of a derivate of the two neutron separation energy [8] and the magicity of both N=14 and 16 from the analysis of energies of first excited states in heavy oxygen nuclides [9].

The mass measurement of neutron-rich nuclei at GANIL [10] has enabled us to perform the analysis of triton separation energies of light neutron-rich odd-Z and even-Z nuclei. The deduced S_t separation energies show the tendency to form the nuclear halo by adding a virtual triton to new doubly magic even-Z ^{8}He and ^{24}O nuclei forming ^{11}Li and ^{27}F, respectively.

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[10] F. Sarazin et al., Phys. Rev. Lett. **84**, 5062 (2000).

*This work was supported by the Grant Agency of the Czech Rep. under contract 202/04/0791

Shell-Model Embedded in the Continuum for the Description of α-Particle Emission and Radiative Capture Processes

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Most states of a nucleus are embedded in the continuum of decay channels due to which they get a final lifetime. Unified description of both nuclear spectra, including particle decay width, and nuclear reactions is a long standing goal of the nuclear theory. This ambitious quest for a unified description is necessary because the spectroscopic information of nuclei that are close to the drip lines is dramatically affected by open channels. The rigorous treatment of continuum in multi-configuration mixing calculations of spectra and reactions has been demonstrated for one-nucleon continuum (Shell Model Embedded in the Continuum (SMEC)) [1,2]. Recently, we have developed a theory of 2p radioactivity based on the extension of SMEC [3,4] for the two-particle continuum. In this contribution, we formulate the SMEC for any number of nucleons in the particle continuum and develop further this theory for the description of α-particle decay and low-energy α-particle radiative capture reactions.

The total A-body Hilbert space is splitted into subspaces $\mathcal{P}_i$ $(i = 0, \ldots, i_{\max})$, where i denotes the number of particles in the continuum states. To each of these subspaces, one associates the corresponding projector P_i and the partial Hamiltonian $H_{ii} = P_i H P_i$. The couplings between subspaces with different number of particles in the continuum are given by $H_{ij} = P_i H P_j, (i \neq j)$. In the same way, one separates the total wave function $|\Psi>$ into its projections $|\Psi_i >= P_i|\Psi>$. The first step is to find an effective Hamiltonian H_{00}^{eff} in $\mathcal{P}_0$ which takes into account virtual couplings to the embedding subspaces $\mathcal{P}_i$. In general, H_{00}^{eff} is non-hermitean. In the following, we shall include only 'nearest neighbour' couplings in the super-operator $[H_{ij}]$, i.e. $H_{ij} = 0$ for $|i-j| > 1$. In this approximation, H_{00}^{eff} takes a ladder form :

$$H_{00}^{eff} = H_{00} + H_{01} \frac{1}{E - H_{11} - H_{12} \frac{1}{E - H_{22} - H_{23} \frac{1}{E - H_{33} - H_{34} \frac{1}{E - H_{44}} H_{43}} H_{32}} H_{21}} H_{10} \tag{1}$$

where H_{00} is given by the Shell-Model (SM) Hamilonian, and can be decomposed into a sum of separate terms representing modifications of H_{00} due to the couplings with 0,1,..., $i_{\max}$ particles in the continuum ($i_{\max} = 4$ in the above expression), respectively. For processes involving α-particle, a relevant coupling is : $H_{00}^4 = H_{01}G_1H_{12}G_2^1H_{23}G_3^{21}H_{34}G_4^{321}H_{43}G_3^{21}H_{32}G_2^1H_{21}G_1H_{10}$, where $G_i^{jkl\ldots}$ are the effective Green's operators acting in $\mathcal{P}_i$, and taking into account the transition through the subspaces $\mathcal{P}_j, \mathcal{P}_k, \mathcal{P}_l, \ldots$, respectively.

In solving SMEC problem for α-decay, one has to calculate the continuation in $\mathcal{P}_4$ of the $\mathcal{P}_0$ solution $|\phi_0^i>$ of standard SM : $|\omega^i >= G_4H_{43}G_3^4H_{32}G_2^{34}H_{21}G_1^{234}H_{10}|\phi_0^i>$. $|\omega^i>$ is a solution of an inhomogeneous coupled-channel equation : $(E - H_{44})|\omega >= |\tilde{w}>$, where $|\tilde{w} >= H_{43}G_3^4H_{32}G_2^{34}H_{21}G_1^{234}H_{10}|\phi_0^j>$. These general $\mathcal{P}_4$ wave functions have then to be projected into physical channels of $[A-4] \oplus [\alpha]$ system.

In this contribution, we shall present details of the SMEC formalism for the description of nuclear α-decay and low-energy radiative α-capture processes.

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[3] J. Rotureau, J. Okołowicz, M. Płoszajczak, in Proc. *XXVIII Mazurian Lakes Conference on Physics*, September 2003, Krzyże, Poland, Acta Phys. Pol. (2004).
[4] J. Rotureau, R. Chatterjee, J. Okołowicz, M. Płoszajczak, to be published.

Beta-delayed gamma and proton spectroscopy near the Z = N line*

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A series of beta decay experiments on nuclei near the Z = N line has been performed using the ISOL technique at IGISOL facility in Jyväskylä and at ISOLDE, CERN. The decay properties of these neutron-deficient nuclei are important in astrophysics and also in the studies of isospin symmetry and quenching of the Gamow-Teller (GT) strength.

In massive ONe novae, where nucleosynthesis of elements heavier than phosphorous is concerned, two paths for the synthesis of ^{32}S both proceeding via ^{30}P(p,γ) have been suggested [1]. The reaction rate of ^{30}P(p,γ)^{31}S, which is crucial for determining the end-point of that nucleosynthesis cycle, can be inversely studied via beta-delayed proton and gamma decay of ^{31}Cl. This has been recently done at IGISOL where ^{31}Cl ions were produced by a 40 MeV proton beam on a ZnS target and implanted in a thin carbon foil. The set-up consisted of three double-sided silicon strip detectors backed with thick silicon detectors, the ISOLDE Silicon Ball [2] and a 70 % HPGe detector. The analysis of the data is in progress.

The beta decay of ^{58}Zn can be used to probe the isospin symmetry of transitions. The GT strength of the transitions from ^{58}Zn (T_Z = -1) to the states in ^{58}Cu (T_Z = 0) can be compared to the GT strength of analogous transitions from ^{58}Ni (T_Z = +1) to ^{58}Cu studied via charge-exchange reactions at RCNP in Osaka [3]. The Zn isotopes were produced via spallation reactions induced by a 1.4 GeV proton beam on a Nb foil target at ISOLDE, CERN. From the measurements at ISOLDE we could confirm the earlier results concerning the gamma rays and half-life but no beta-delayed protons were observed. The proton spectroscopy part will be done using ^{58}Ni + ^{3}He fusion-evaporation reaction and the ISOLDE Silicon Ball set-up at IGISOL in spring 2004.

The nuclei near A = 80 play a particular role in the rapid proton capture process in hot stellar conditions. The rp-process flow beyond the Zr-Nb cycle depends on the spectroscopic properties of these nuclei. The beta decays of ^{81}Y, ^{81}Sr, ^{85}Nb, ^{85}Zr, ^{86}Mo and ^{86}Nb have been investigated at IGISOL. A beam of ^{32}S on ^{54}Fe and ^{nat}Ni targets was used to produce the isotopes of interest and the Ion Guide Isotope Separator On-Line (IGISOL) delivered the reaction products to the experimental set-up consisting of two HPGe detectors, the ELLI electron spectrometer and a low energy Ge detector. A new isomeric state with a half-life of 3.3 s has been observed in ^{85}Nb. The measured half-lives for the ground and isomeric states of nuclides at the rp-process path are in agreement with the known values.

In the future, a chemically selective laser ion source at IGISOL will substantially reduce background contaminants particularly in the region near A = 80. In addition, the binding energies and Q-values important both in astrophysical modeling and studies of GT strength can be measured for nuclei in this region at the JYFLTRAP.

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*This work was supported by the Academy of Finland under the Finnish Center of Excellence Program 2000-2005 (project No. 44875, Nuclear and Condensed Matter Physics Program at JYFL).
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Many-Particle and Many-Hole States in Neutron-Rich Ne Isotopes Related to Broken N=20 Shell Closure

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The low-lying level structures of ^{26}Ne, ^{28}Ne and ^{30}Ne which are related to the breaking of the N=20 shell closure have been investigated to study the change of the shell structure around the neutron-drip line. The theoretical framework of the the deformed-basis antisymmetrized molecular dynamics plus generator coordinate method [1] is employed. The properties of the positive- and negative-parity bands which have many-particle and many-hole structures are discussed as well as those of the ground band [2]. The obtained level structures indicate the 'softness' of neutrons in the $0d_{3/2}$ orbit against the promotion into the pf shells, while the neutrons below N=16 show the 'hardness' against the promotion. We predict that the negative-parity states in which one or three neutrons are promoted into pf-orbit from sd orbit have the small excitation energies in the cases of ^{28}Ne and ^{30}Ne which, we regard, is a typical phenomena accompanying the breaking of N=20 shell closure. It is also found that the neutron $4p4h$ structure of ^{30}Ne appears in low excitation energy which contains α+^{16}O correlations. The observed parity-inversion of the ground state of ^{33}Mg [3] will be also discussed based on our recent study.

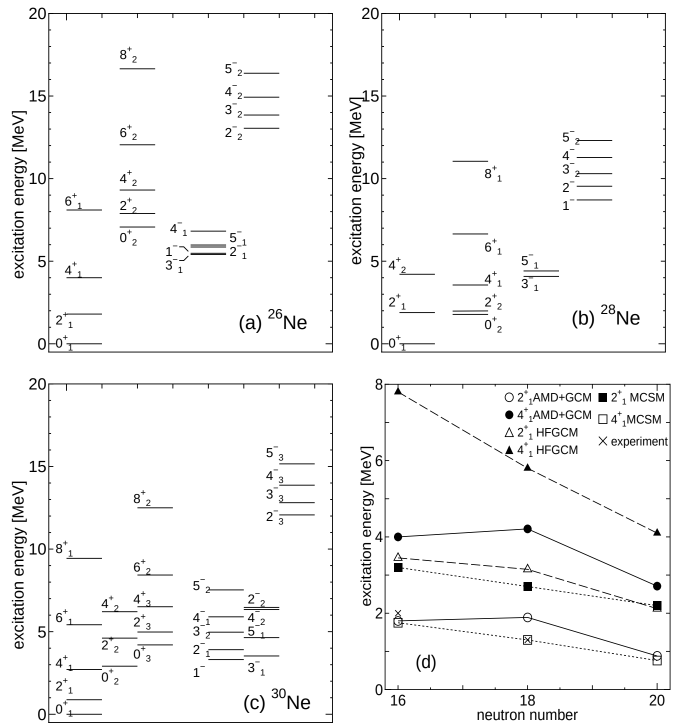

FIG. 1. Calculated low-lying level schemes of (a) ^{26}Ne, (b) ^{28}Ne and (c) ^{30}Ne. (d) shows the comparison of the excitation energies of 2^+_1 and 4^+_1 states obtained by the present work, the monte carlo shell model[4] (MCSM), HFB+AMPGCM[5] and the experiment.

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Study of Drip-Line Nuclei with a Core Plus Multi Valence Nucleon Model

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In recent years, with the much development of the experimental technique, the halo structure and a change of the magic number for nuclei near the drip line have been observed. Such phenomena have brought us much interest as new aspects of the nuclear physics. Among these nuclei, ^{23}O and ^{24}O are suggested to be candidates of halo nuclei with a particular nature[1,2]. It is suggested from the experiment and the analysis using the Glauber theory that the modification of the ^{22}O core is sizable[2].

For the theoretical study of the ground state properties of the oxygen isotopes, it becomes plausible that ^{16}O is the inert "core", since the excitation energy of ^{16}O is large enough compared to the excitation energy of valence neutrons. Moreover, due to the heavy core and light valence neutrons, the coordinate system in the cluster orbital shell-model (COSM) becomes a good choice for representing the total system.

Hence, we develop a core plus multi valence nucleon model, where we use a model space of a heavy core and many valence nucleons. In our model, we use the Gaussian basis functions for describing the radial part of each core-n wave function in the COSM basis, and solve the radial part exactly with the help of the stochastic variational approach[3]. The important point of our model is that the total eigen function is expressed a linear combination of Gaussian functions with different width parameters. Therefore this model has an ability of describing the halo structure.

In this study, we treat the ^{16}O core as inert as a first step and construct the core-n potential using the folding technique taking into account the exchange property of coming from the anti-symmetrization. So far, we have performed the calculation up to ^{20}O with a ^{16}O+4n model. The calculated R_{rms} and S_n agree with the experimental values.

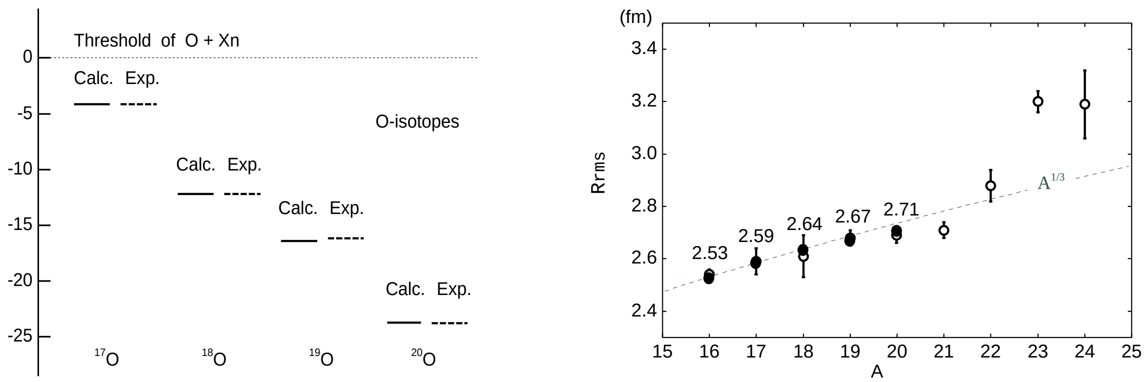

FIG. 1. Calculated Energies and R_{rms} of the oxygen isotopes using our model.

Further, we perform an analysis using the completeness relation of the subsystem; core-n eigen functions and see the correspondence to the Gamow shell model calculation[4], which is developed so as to calculate the resonant states in the shell model calculation. We also study other nuclei using our model, the helium isotopes and proton rich nuclei. The results and discussions will be given.

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Inelastic Proton Scattering on ^{16}C

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A recent lifetime measurement of the first 2^+ state in neutron-rich ^{16}C has produced fascinating result. The $B(E2)$ was found to be anomalously small [1], indicating a possible existence of significant isovector contributions to the 2^+ state in ^{16}C. This presumption has been revealed recently by another experiment in which the Coulomb-nuclear interference method was applied to the ^{208}Pb+^{16}C inelastic scattering [2]. In this latter experiment, the $(M_n/M_p)/(N/Z)$ was determined to be 4.6 ± 1.0, which turned out to be more than two times greater than that of any other nuclei observed (see for example Ref.[3,4]). A study of the 2^+ state in ^{16}C using a simpler and less model-dependant probe is then of paramount importance in order to confirm this exotic feature.

Here, we report on the results of an inelastic proton scattering on ^{16}C in inverse kinematics. At intermediate energies, the proton probe is more sensitive to the neutron matter than to that of the proton. On the other hand, the proton collectivity can be studied by the electromagnetic probe such as Coulomb excitation or lifetime measurement. Comparison of these two different probes allows ones to determine the neutron and proton contributions to the transitions between two nuclear states [3]. This method has been successfully used to reveal the large isovector contributions, with $(M_n/M_p)/(N/Z) \sim 2$, to the low-lying 2^+ states in ^{20}O [5]. In our present work, we have obtained $(M_n/M_p)/(N/Z) \sim 5$, thus comfirming the result reported in Ref.[2].

The experiment was performed at the RIKEN Accelerator Research Facility using the RIKEN Projectile-fragment Separator (RIPS) [6]. The secondary ^{16}C beam bombarded a liquid hydrogen target with an average thickness of 225 mg/cm^2. To determine the angle-integrated cross section for the $0^+_{\rm gs} \rightarrow 2^+_1$ transition, we have measured the de-excitation γ-rays, instead of the recoil protons. The implementation of γ-ray spectroscopic method which enables the use of thick target and the choice of the liquid hydrogen target have greatly enhanced the efficiency of the experiment. In this talk, the data analysis and determination of $(M_n/M_p)/(N/Z)$ will be presented.

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Evidence of a $(1d_{5/2})^2$ component to the ^{12}Be ground state

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Data have been obtained on exclusive single neutron knockout cross sections from ^{12}Be to study its ground state structure. The cross sections for the production of ^{11}Be in its ground state ($1/2^+$) and first excited state (0.32 MeV, $1/2^-$) have previously been measured [1], indicating a strong $(2s_{1/2})^2$ component to the ^{12}Be ground state. In the present experiment, performed at the GANIL laboratory, cross sections for the first (0.32 MeV, $1/2^-$) and second (1.78 MeV, $5/2^+$, *unbound*) excited states in ^{11}Be were measured, which gives information on the admixture of $(1p_{1/2})^2$ and $(1d_{5/2})^2$ components in the ground state of ^{12}Be.

A fragmentation beam of ^{12}Be of ~10000 pps (95% pure) was incident on a carbon target at 41 MeV/u. The beam particles were tracked onto the target, and their energies were measured event-by-event. The beam-like residues were measured in a position sensitive telescope mounted at zero degrees, and neutrons were measured in the DéMoN array [1]. The $1/2^-$ state of ^{11}Be was identified by measuring coincident 320 keV γ-rays, using four NaI detectors. Full kinematic reconstruction of unbound states in ^{11}Be was performed using coincident neutrons and ^{10}Be ions. Neutron angular distributions in the laboratory frame were measured in coincidence with ^{10,11}Be, and momentum distributions of neutrons and beam-like particles were measured for exclusive reaction channels. Data were also acquired for the Coulomb excitation and breakup of ^{11}Be on Pb and C targets.

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New measurement of $\alpha + d$ emission following β-decay of ^{6}He

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A sensitive test of the ^{6}He halo structure is provided by the measurements of the branching ratio of the β-decay into the ^{6}Li two-body continuum, $^6\mathrm{He} \rightarrow \alpha + d + e^- + \overline{\nu}$ (Q = 2.033 MeV), and the corresponding energy spectrum of deuterons. The precise determination of this branching ratio can provide information about the $\alpha + d$ wave-functions. The calculations of the $\alpha + d$ transition probability in the framework of different models give the branching ratio values varying within 2 orders of magnitude and show that the energy range below 500 keV is the the best for the choice of the model parameters. The present experimental results on this branching ratio are in disagreement: $7.6(6) \times 10^{-6}$ [1], and $1.8(9) \times 10^{-6}$ [2] (both $E_{\alpha+d}$ > 525 keV). The crucial point to register minimum energies of alphas and deuterons is the experimental low energy cutoff limit due to the presence of a high intensity β-background from the main branch of the ^{6}He decay.

To reduce the β-background and to obtain an absolute normalization, we used an experimental technique in which the ^{6}He ions have been implanted into a double-sided strip detector with thickness 78 μm and strip pitch 335 μm, each side of the detector having 48 strips. As α-particles and deuterons deposit all their energy only into 1-2 strips while the β's into many more strips, the total $\alpha + d$ signal could be separated from the low energy β-background.

The experiment was performed at the CRC in Louvain-la-Neuve, Belgium [3]. The ^{6}He beam, average 10^4 pps, with an energy of 8 MeV was implanted into the detector for 1 sec followed by a decay period of 2 sec. To check the sensitivity of the detector to β-particles, we used a 10 MeV ^{18}Ne beam whose β^+ spectrum has an end-point energy 3.424 MeV close to the end-point energy of the ^{6}He β^- spectrum 3.508 MeV. The $\alpha + d$ contribution of ^{6}He β-delayed decay was extracted through an accurate comparison between the decay spectra of the two nuclei.

In the first measurement, the branching ratio for an energy above 525 keV was determined to be $1.7(4) \times 10^{-6}$, and a preliminary $\alpha + d$ spectrum was obtained (see Fig. 1) which confirms the results reported in [2]. Results from a second measurement will also be presented, where technical improvements allowed to significantly lower the cutoff energy.

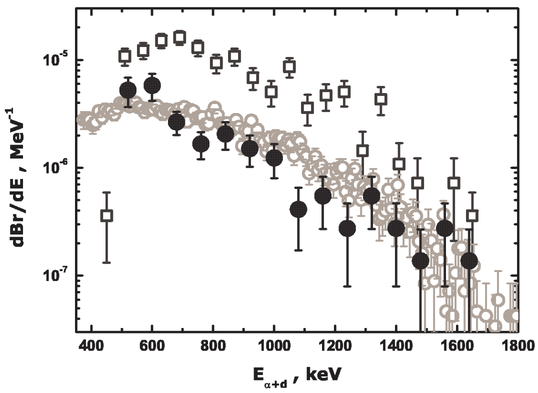

Fig. 1. Preliminary α-*d* spectrum from β-decay of ^{6}He (●) compared with the results from [1] (□) and [2] (○).

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Shell Effects of Magic Nuclei near Drip Lines

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Since the N=82 shell quenching was found to have important consequences in astrophysical r-processes [1], the shell effect of all magic nuclei near the drip lines has become a topic of current interest. Recent high quality atomic mass data [2] for nuclei away from the line of stability provide an opportunity to evaluate their shell effects. Shell effects can be evaluated using the experimental mass and the Bethe-Weizsäcker mass formula (BW) which was designed to fit medium to heavy mass nuclei without shell effects. With the discovery of many light nuclei near the drip lines, it has now been possible to extend the BW for light nuclei [3]. Inadequacy of BW near drip lines stem mainly from the lack of nucleon number dependence of the symmetry coefficient which reflects the density dependence of the asymmetry term of the nuclear equation of state. Also, the observed quenching of the pairing effect near the neutron drip line is missing in both BW and its improved version ILDM [4]. To alleviate these problems, the asymmetry and the pairing terms of BW were modified [3]. The modified Bethe-Weizsäcker mass formula (BWM) fits the general trend of the binding energy versus neutron number curves of all the nuclei from Li to Bi and gives a better chi-square value compared to ILDM [5]. In BWM, the expression for the binding energy is,

$$BE(A,Z) = 15.777A - 18.34A^{2/3} - 0.71\frac{Z(Z-1)}{A^{1/3}} - \frac{23.21}{(1+e^{-A/17})}\frac{(A-2Z)^2}{A} + (1-e^{-A/30})\delta$$

where, $\delta = +12\ A^{-1/2}$ for even Z-even N nuclei, $-12\ A^{-1/2}$ for odd Z-odd N nuclei and, 0 for odd A nuclei. Both BWM and ILDM are applicable only for the nuclei without any significant shell effect as none of these formulas has shell correction or, Wigner term incorporated. When the shell effect quenches, the experimental mass comes close to the BWM prediction whereas, extrastability at N=Z and magic numbers stand out in comparison [3, 5]. The shell effects (ΔB =the difference between the experimental and BWM-predicted binding energies) of nuclei with magic numbers 8, 20, 28, 50, 82 and 126 are found to vary with nucleon number but, not always negligible near the drip lines. For example, the ΔB values of Z= 48, 50 and 52 peak at N=82 and reduce approaching the neutron drip line (Fig.1). The N=82 magicity was predicted to quench significantly in ^{130}Cd [1]. But the S_n versus N plot (Fig.2) indicates a break at N=82 in contrast to the BWM results. As the data points in Fig.2 at N=81-84 are from systematics (×) only [2], accurate measurement of mass data for Cd at N=81, 83, 84 are needed to ascertain the N=82 shell quenching.

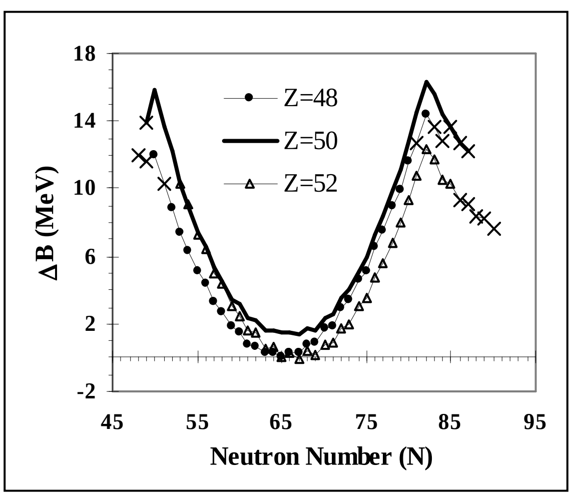

FIG. 1. Shell effect (ΔB) in Cd, Sn and Te isotopes.

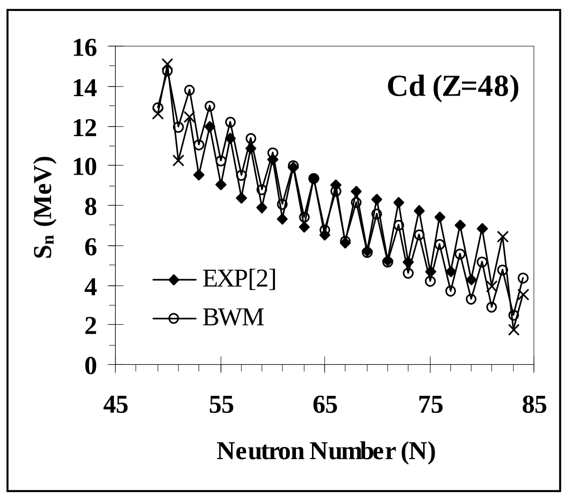

FIG. 2. One-neutron separation energy (S_n) in Cd isotopes.

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Exclusive breakup of ^{6,7}Li on ^{65}Cu near the Coulomb barrier

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Study of the breakup reactions with light weakly bound nuclei is important both for understanding the mechanism and its implication on fusion. There are contradictory results/predictions on its role in enhancing or suppressing the fusion cross-sections around the Coulomb barrier [1]. As it is difficult to identify the breakup contribution from an inclusive measurement of the fragments, a coincidence measurement is essential to get reliable information on the coupling strength of the breakup channel. In a recent exclusive measurement with ^{6}Li+^{208}Pb system [2], breakup arising from the resonant states and non-resonant states were not separated. The resonant states have larger transition strengths and hence are expected to have a greater influence than the non-resonant states. We report here the first comparative study of exclusive breakup with ^{6}Li and ^{7}Li on a medium-mass target, to understand the role of the resonant and non-resonant breakup on fusion.

The measurement of inclusive and exclusive breakup reactions, and elastic scattering were performed at the BARC-TIFR Pelletron, Mumbai with ^{6,7}Li beam on ^{65}Cu target at energies around the Coulomb barrier. The breakup fragments were detected in surface barrier telescopes and a CsI(Tl) detector covering an angular range around the grazing angle. The angular separation of 20° between the detectors was within the maximum cone angle for the breakup fragments corresponding to the first resonant state (2.18 MeV in ^{6}Li and 4.63 MeV in ^{7}Li). Two strip detector telescopes were used with smaller angular separation of 8° to measure the cross-sections near the breakup threshold. Figure 1 shows preliminary results of the measured and calculated angular distributions at 25 MeV, for the first resonant state in ^{6}Li and ^{7}Li. The difference in the cross-section between the two isotopes is due to smaller threshold for α breakup and larger B(E2) value for the first resonant state in ^{6}Li. The calculations were performed using the continuum discretized coupled channels (CDCC) formalism with the code FRESCO [3] assuming an $\alpha - d$ (t) cluster structure for the ground and continuum states of ^{6}Li (^{7}Li). The present work with stable weakly bound projectile complements a recent measurement with ^{6}He beam on ^{65}Cu target [4]. The results at 19.3 and 18.2 MeV along with the CDCC calculations for ^{6,7}Li on ^{65}Cu will be presented.

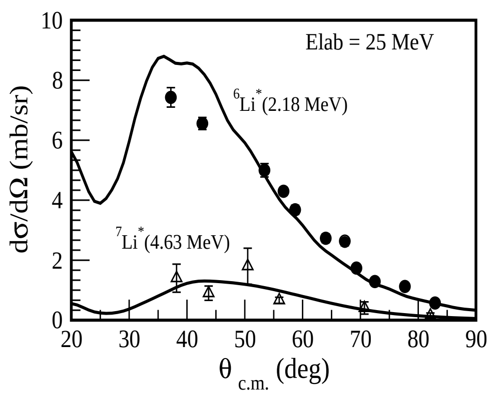

FIG. 1. Angular distribution of break up cross-section for the first resonant state in ^{6,7}Li.

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The Sign Problem in Shell Model Monte Carlo Calculations

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The shell model is one of the most powerful methods for describing various properties of atomic nuclei. In particular, the formalism of the auxiliary-field Monte Carlo method is well suited to studying the finite-temperature properties of nuclear structure. Since this approach avoids an explicit enumeration of the many-body states, spaces larger than in the conventional methods can be reached.

However, the applicability of the shell model Monte Carlo method is limited by the 'sign' problem associated with the Monte Carlo weight function when using realistic two-body interactions. A new approach for alleviating the 'sign' problem will be presented. This method, as applied to the nuclear many-body is based on using mean-field.

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Charge- and parity-projected Hartree-Fock method for the strong tensor correlation and its application to the alpha particle

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We propose a mean-field-type framework in which we can treat the tensor correlation directly. Many studies including the recent exact-type calculations show that the tensor force (one-pion-exchange force) plays important rolls in nuclear structure. However, the tensor force does not appear in usual mean field models because the tensor force is hard to treat in a simple mean-field framework.

To treat the tensor correlation in a mean field framework, we take mixed states of the positive and negative parities as single-particle states. This mixing is inspired by the pseudoscalar character of the pion, which mediates the tensor force. Because of the pseudoscalar character of the pion, a single-particle state in a nuclear mean field must change its parity when it emits or absorbs a pion. Therefore, if single-particle states are mixied states of parities, they can exchange a pion. We applied this idea in the relativistic mean field (RMF) theory and showed that by introducing the parity-mixed single-particle state, the correlation induced by the pion can be incorporated in the RMF theory [1]. Further, we mix the proton and neutron components in a single-particle state to take the isovector character of the pion into account. We take a Slater determinant consisting of single-particle states with the parity and charge mixings as an intrinsic wave function. Because this intrinsic wave function does not have a good parity and a definite charge number, we need to perform the parity and charge projections on the wave function. By taking the variation of the energy expectation value evaluated with the projected wave function with respect to each single-particle state, we obtain a Hartree-Fock-like equation, the charge- and parity-projected Hartree-Fock (CPPHF) equation. We solve the CPPHF equation self-consistently [2].

By applying the CPPHF equation to the alpha particle [2], we found that the tensor correlation can be treated in a mean field framework with the projection method by introducing parity-mixed single-particle states. The charge mixing makes the tensor correlation much larger than the case with only the parity mixing. We note that taking the parity and charge projections before variation is very important to treat the tensor force in a mean-field-type framework, because if we do not perform the projections the tensor correlation energy becomes zero in the alpha particle case. We also found that the width of the p-state component mixing into the s-state component is much narrower than that of the s-state. It suggests that the tensor correlation necessitates higher-momentum components. We calculate the negative-parity (0^-) state in the same framework and found that the excitation energy of the 0^- state close to the experimental value. We are working on heavy nuclei as C and O isotopes in the CPPHF framework.

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β-transition asymmetry in the $A = 9$ isobars *

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Beta decays that are followed by multi-particle emissions present a special experimental challenge that has only been met recently with the introduction of detectors with high granularity and large solid angle [1]. A unique case is presented by the $A = 9$ nuclei where all decays of ^{9}Li / ^{9}C (except for the ground state transition from ^{9}Li) reach states that break up into two α-particles and a neutron / proton [2].
In this presentation we will focus on the transitions to states around 12 MeV excitation energy in ^{9}Be / ^{9}B respectively that have an unusually large B$_{GT}$-value. Two recent experiments on ^{9}C [3,4] gave values of 1.58(16) and 1.20(15) (we adhere to the convention where quoted B$_{GT}$ values do not include the ratio $(g_A/g_V)^2$ of weak coupling constants), whereas the only earlier determination for ^{9}Li [5] gave 5.6(1.2). The experiments on ^{9}C employed coincidence detection of charged particles thereby allowing for a detailed analysis, whereas the older ^{9}Li experiment only included singles spectra. The only previous ^{9}Li experiment where α-particle coincidences were measured [6] did not have sufficient angular resolution and no detailed analysis of the break up mechanism was performed. The mirror asymmetry between the two decays is quite striking and in view of the discrepancies [3,4] on the interpretation of the earlier ^{9}Li result [5] we have undertaken a remeasurement with modern detectors that allow a direct comparison to be made with our ^{9}C data [4]. As will be explained, we confirm the observed asymmetry, we will also demonstrate that the main β-branch at high excitation energy goes to the 11.8 MeV state and show that it has $I^\pi = 5/2^-$ [7].
The extracted B$_{GT}$ value is a factor 4.4 ± 1.0 larger than the one for the mirror transition from ^{9}C, as measured [4] with an almost identical set-up and analysis procedure. This is the largest asymmetry reported for a strong β-transition (for very weak transitions larger asymmetries can occur, an example being the decays of ^{14}C and ^{14}O).
We believe that this surprisingly large difference is due to differences in the structure of the resonances in ^{9}Be and ^{9}B, probably arising from the different coupling to the α-α-nucleon continua. To explain this asymmetry will be a challenge for theoretical models of light nuclei.
Further, in the light of the data taken with a novel DSSSD-detector design [8] with ultra-thin entrance window, new analysis of the low energy region of ^{9}Be fed in the beta decay of ^{9}Li, will be discussed.

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[5] G. Nyman *et al.*, Nucl. Phys. **A510** (1990) 189.
[6] M. Langevin *et al.*, Nucl. Phys. **A366** (1981) 449.
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*This work was supported the Spanish CICYT under project: FPA2002-04181-C04-02.

Nuclear Structure

Posters - Nuclear Structure

Number/Session	Name/email	Institution	Title
161/ Monday	Aggarwal, Mamta drmamta@nsc.ernet.in	Nuclear Science Centre	Stability in unstable nuclei at proton drip line
163/ Monday	Andreoiu, Corina corina@physics.uoguelph.ca	University of Guelph	Gamma decay-out versus prompt proton decays in ^{59}Cu
164/ Monday	Arumugam, P. aru@iopb.res.in	Institue of Physics	Giant dipole resonance and hyperdeformation in hot rotating nuclei
166/ Monday	Blackmon, Jeff blackmon@ornl.gov	Oak Ridge National Laboratory	The structure of ^{18}Ne
169/ Monday	Fedorov, Dmitri fedorov@phys.au.dk	Aarhus University	Borromean nuclei and three-body resonances
170/ Monday	Fetea, Mirela mfetea@richmond.edu	University of Richmond	Chiral symmetry and signature splitting in odd-odd neutron deficient Pr nuclei
171/ Tuesday	Fong, Dennis d.fong@vanderbilt.edu	Vanderbilt University	Investigations of Short Half-Life States from SF of ^{252}Cf
173/ Tuesday	Gore, Philip philip.m.gore@vanderbilt.edu	Vanderbilt University	Unexpected Rapid Variations in Odd-Even Level Staggering in Gamma-Vibrational Bands
174/ Monday	Grahn, Tuomas tuomas.grahn@phys.jyu.fi	University of Jyväskylä	RDDS lifetime measurements with JUROGAM + RITU
175/ Monday	Higashiyama, Koji higashi@nt.phys.s.u-tokyo.ac.jp	University of Tokyo	Beta decay in medium-heavy nuclei and its application to nuclear astrophysics
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179/ Monday	Inakura, Tsunenori inakura@nt.sc.niigata-u.ac.jp	Niigata University	Soft Octupole Vibrations on Superdeformed States in Nuclei around ^{40}Ca suggested by Skyrme-HF and Selfconsistent RPA Calculations
181/ Tuesday	Jones, Elizabeth elizabethfj@earthlink.net	Vanderbilt University	Identification of Levels in Levels in ^{162,164}Gd and Decrease in Moment of Inertia between N = 98 - 100
182/ Monday	Kavatsyuk, Myroslav m.kavatsyuk@gsi.de	Gesellschaft fuer Schwerionenforschung	Beta Decay spectroscopy of ^{103,105}Sn

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183/ Monday	Kettunen, Heikki heikki.kettunen@phys.jyu.fi	University of Jyväskylä	Decay studies of neutron deficient odd-mass At and Bi isotopes
185/ Monday	Kobayashi, Masato kobayasi@ruby.scphys.kyoto-u.ac.jp	Kyoto University	Collective Path connecting the Oblate and Prolate Local Minima in Proton-Rich N=Z Nuclei around ^{68}Se
186/ Monday	Kondev, Filip G. kondev@anl.gov	Argonne National Laboratory	Study of multi-quasiparticle isomers in deformed A~180 nuclei near and beyond the valley of stability
187/ Tuesday	Kondev, Filip kondev@anl.gov	Argonne National Lab	Nuclear Structure and Decay Data Evaluation
188/ Monday	Korgul, Agnieszka korgul@fuw.edu.pl	Warsaw University	^{135}Sb and the "new world" of exotic nuclei
189/ Tuesday	Kumar, Ashok ashok@pa.uky.edu	University of Kentucky	Lifetime measurements by RDM in ^{118}Xe
190/ Monday	Lisetskiy, Alexander lisetski@nscl.msu.edu	NSCL, Michigan State University	Exotic nuclei near ^{78}Ni in a shell model approach
191/ Tuesday	Matsuo, Masayuki matsuo@nt.sc.niigata-u.ac.jp	Niigata University	Di-neutron correlation in medium mass neutron-rich nuclei near drip-line
192/ Monday	Michel, Nicolas michel@mail.phy.ornl.gov	Oak Ridge National Laboratory	Gamow Shell-Model Description of Weakly Bound and Unbound Nuclear States
193/ Monday	Mukha, Ivan Ivan.Mukha@fys.kuleuven.ac.be	Catholic University of Leuven	Study of the (21^+) high-spin trap in ^{94}Ag
195/ Monday	Odahara, Atsuko odahara@nishitech.ac.jp	Nishinippon Institute of Technology	High Spin Shape Isomers and Nuclear Jahn-Teller Effect
196/ Monday	Ogloblin, Alexey aoglob@dni.polyn.kiae.su	Kurchatov Institute	The problem of superheavy hydrogen isotope ^{6}H
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Posters - Nuclear Structure

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197/ Monday	Ohta, Hirofumi ohta@nucl.ph.tsukuba.ac.jp	University of Tsukuba	Light exotic nuclei studied with the parity-projected Hartree-Fock method
198/ Monday	Orce, Nico jnorce@pa.uky.edu	University of Kentucky	Mixed-symmetry states in $^{93}{}_{41}Nb_{52}$
199/ Tuesday	Orce, Nico jnorce@pa.uky.edu	University of Kentucky	Triaxiality vs K-quantum number in ^{128}Xe
201/ Monday	Pavan, John pavan@mail.phy.ornl.gov	Oak Ridge National Laboratory	Gamma-Ray Spectroscopy of the T=2 Nucleus ^{22}F
206/ Monday	Popa, Gabriela gxpsps@rit.edu	Rochester Institute of Technology	Systematics in the structure of low-lying, non-yrast bandhead configurations of strongly deformed nuclei
202/ Tuesday	Rasmussen, John oxras@comcast.net	LBNL	Shape transitions and triaxiality in neutron-rich Y and Nb isotopes
203/ Tuesday	Rasmussen, John oxras@comcast.net	LBNL	Triaxiality in neutron-rich Tc and Rh isotopes
204/ Monday	Ravuri, Chakrawarthy rsc1@triumf.ca	TRIUMF	Discovery of a new 2.5 s isomer in ^{174}Tm
205/ Tuesday	Rinta-Antila, Sami sami.rinta-antila@phys.jyu.fi	University of Jyväskylä	Structure of doubly-even Cd nuclei studied by b- decay
207/ Monday	Satula, Wojtek satula@fuw.edu.pl	University of Warsaw	Using high-spin data to constrain spin-orbit term and spin-fields of Skyrme forces: The need to unify the time-odd part of the local energy density functional
208/ Tuesday	Seweryniak, Darek seweryniak@anl.gov	Argonne National Laboratory	Particle-Core Coupling in the Transitional Proton Emitters $^{145,146,147}Tm$
209/ Monday	Shimizu, Noritaka shimizu@nt.phys.s.u-tokyo.ac.jp	University of Tokyo	Symmetry for randomly interacting fermions and bosons
210/ Monday	Stetcu, Ionel stetcu@physics.arizona.edu	University of Arizona	Effective Operators in the NCSM Formalism
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213/ Tuesday	Tonev, Dimitar mitko@lnl.infn.it	INFN - Laboratory Nazionali di Legnaro	Chirality in real nuclei
214/ Monday	Werner, Volker vw@ikp.uni-koeln.de	University of Cologne	First observation of a scissors mode to gamma-band decay in ^{164}Dy
215/ Monday	Yamagami, Masayuki yamagami@riken.jp	RIKEN	Pairing effects on the collectivity of quadrupole states around ^{32}Mg
217/ Monday	Yoshida, Kenichi kyoshida@ruby.scphys.kyoto-u.ac.jp	Kyoto University	Microscopic Structure of Negative-Parity Vibrations built on Superdeformed States in Sulfur Isotopes close to the Neutron Drip Line
218/ Monday	Yoshinaga, Naotaka yoshinaga@phy.saitama-u.ac.jp	Saitama University	Shell model study of nuclei around mass 130 in the pair-truncated model
219/ Monday	Yu, Chang-Hong chy@mail.phy.ornl.gov	Oak Ridge National Laboratory	First Coulomb Excitation Experiment Using Odd-A Neutron-Rich Radioactive Beams
221/ Monday	Zamick, Larry Z. zamick@physics.rutgers.edu	Rutgers University	Simplified expressions for pair transfer, especially N=Z nuclei
Number/Session	**Name/email**	**Institution**	**Title**

Stability in unstable nuclei at proton drip line

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We investigate extremely proton rich fp shell nuclei in highly excited state. In view of the very high excitations possible in the nuclei formed in collisions, the effects of thermal and rotational excitations on the particle stability are studied through the variations in the proton separation energy. Knowledge of the separation energies and precise location of proton drip line near fp shell region is an important input for understanding rp processes and the intereseting nuclear structure found in fp shell region.

We explore the hot rotating fp shell proton rich isotopes of Ni, Fe and Cr, in a theoretical framework and calculate their proton separation energy as a function of temperature and spin using statistical theory of hot rotating nuclei [1,2] combined with the macroscopic-microscopic approach for the ground state. We find that the shell effects and shape transition due to rotation alter the boundary of the drip line at low temperatures and with increasing temperature the drip line is pushed to higher neutron number.

The unstable drip line nuclei ^{42}Cr, ^{46}Fe, ^{50}Ni have ground state proton separation energy $S_{2P} \leq 0$, but surprisingly, these nuclei are stable with positive separation energy at high spins (see Fig.1). Thus nuclear rotation makes it possible to get these unstable drip line nuclei stable with positive separation energy at certain excitations. As thermal excitation increases, proton separation energy decreases and eventually reduces to zero and the nuclei which were stable in ground state become unstable against proton decay e.g. ^{47}Fe [1] is a stable nucleus in ground state but decays by proton emission at thermal excitation corresponding to T=2.8 MeV.Thus by this method, we also come to know the exact excitation energy at which a particular stable nucleus will become unstable against proton emission. The shell effects at proton drip line are seen through the level density parameter. Entropy of these nuclear systems is computed.

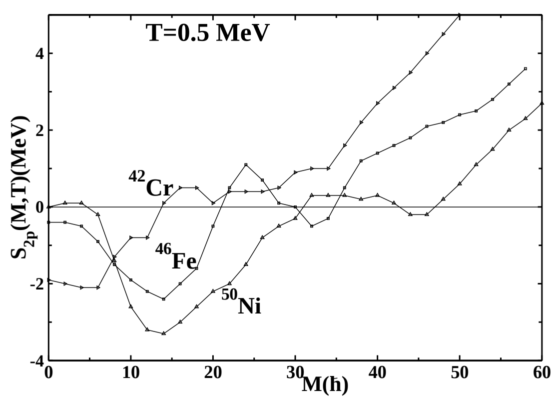

FIG. 1: Two proton separation energy vs. spin

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Gamma Decay-Out Versus Prompt Proton Decays in ^{59}Cu*

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Nuclei in the mass A~60 region have been observed to some of the highest rotational frequencies, $h\omega_x$ ~ 1.5-2.0 MeV, in Nature. At these rotational frequencies, the nucleus takes on a highly- or super-deformed shape. For the superdeformed states to be pure they need to be shielded from the normally deformed states by an energy barrier in the deformation coordinates. These states prefer to decay by a cascade of gamma-ray transitions to the normally deformed, spherical states in the same nucleus, or by fast (prompt) particle decays in spherical states of the corresponding daughter nucleus. The shape change occurring in the decay-out implies a substantial rearrangement of nucleonic states. Especially the nucleonic states from higher shells, which are occupied in the superdeformed bands, need to be vacated. The gamma decay-out process is facilitated by vibrational coupling through the barrier between the superdeformed state and the doorway states, which in turn typically are coupled to a very large number of normally deformed states.

The decay-out process of the yrast superdeformed band in ^{59}Cu has been recently investigated and a multitude of linking transitions connecting this band to the low-spin states in ^{59}Cu were experimentally observed. The firm determination of spin, parity, excitation energy, and configuration of the states involved in this process constitutes a unique situation for a detailed understanding of the decay-out mechanism. Doorway states involved in this mechanism have been observed and are classified for the first time [1] using a theoretical model that includes a residual interaction and tunneling matrix element between bands, calculated in the configuration-dependent cranked Nilsson-Strutinsky model. This provides another perspective of the decay-out process as compared to the heavier A~150 and A~190 regions, where the coupling to the doorway states is masked by a chaotic environment of the normally deformed states, which leads to a very large number of linking transitions.

In competition with the gamma decay-out mechanism, two superdeformed states in ^{59}Cu decay by two prompt protons into the same spherical state in ^{58}Ni. This observation represents the first evidence of "fine structure" of the prompt proton decay mode [2].

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[2] D. Rudolph *et al.,* Phys. Rev. Lett. 8**9**, 022501 (2002), and the references therein.

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* This work was supported by the Swedish Research Council, and the Swedish Foundation for International Cooperation in Research and Higher Education, and by the Natural Sciences and Engineering Research Council of Canada.

Giant dipole resonance and hyperdeformation in hot rotating nuclei

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The Giant Dipole Resonance (GDR) studies have been proved to be a powerful tool to study hot and rotating nuclei and recently the domain of GDR spreads rapidly over different areas of theoretical and experimental interest. In a macroscopic approach to GDR, the observables are related to the nuclear free energy surface with consideration of thermal shape fluctuations. We have revisited this formalism with more exact methods. The Nilsson-Strutinsky (NS) method extended to high spin and temperature is used for free energy calculations. Shell effects causing the quantal fluctuations are treated with exact temperature and spin dependence. The GDR built on the states determined by NS method are studied with a macroscopic model comprising anisotropic harmonic oscillator potential with separable dipole-dipole interaction [1]. Thermal fluctuations are dealt without any parameter fitting, in an exact way by calculating the free energies at the mesh points using the NS method. We have carried out a systematic study of the GDR properties in several nuclei and our results are well in conformity with experimental results. The Landau theory [2] results are found to deviate from exact calculations in the presence of strong shell effects (See Fig.1). Shell effects which appear at higher spins could be taken care only in the exact fluctuation calculations (See Fig.1(b)). With our present calculations, we have identified the zirconium region as a very fertile region to detect Jacobi transition which at lower temperatures leads to hyperdeformation. Even though the Jacobi transition survives higher temperatures we found that it may not lead to hyperdeformation.

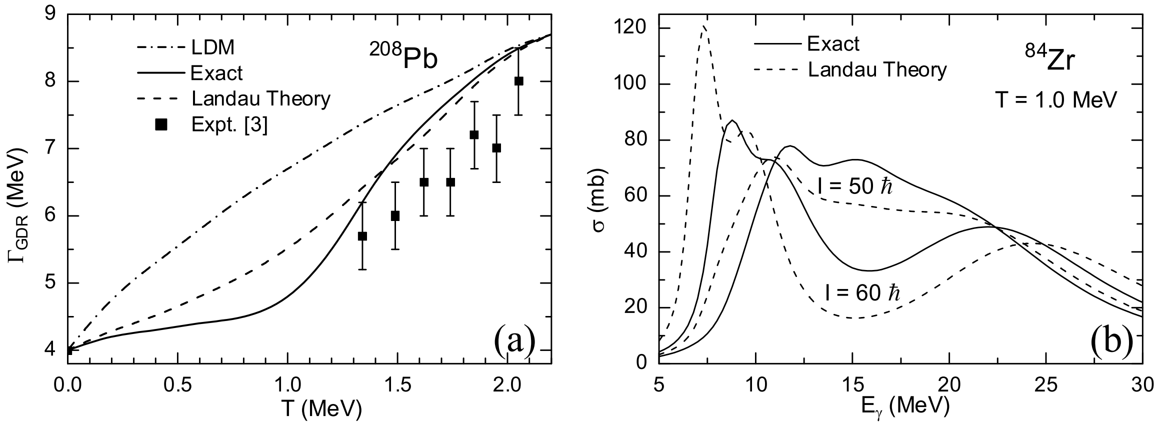

FIG. 1. Comparison of GDR observables obtained using the Landau theory and exact method.

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The structure of ^{18}Ne*

J. C. Blackmon[1], D. W. Bardayan[1], C. R. Brune[2], A. E. Champagne[3], T. Davinson[4], C. A. Gagliardi[5], U. Greife[6], C. J. Gross[1], P. A. Hausladen[1], K. I. Hahn[7], G. M. Hale[8], R. L. Kozub[9], F. Liang[1], Z. Ma[10], A. M. Mukhamedzhanov[5], C. D. Nesaraja[9], F. M. Nunes[11], P. D. Parker[12], D. C. Radford[1], L. Sahin[3], D. Shapira[1], M. S. Smith[1], J. S. Thomas[13], L. Trache[5], R. E. Tribble[5], L. A. Van Wormer[14], D. W. Visser[3], P. J. Woods[4], and C.-H. Yu[1]

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[10] *Department of Physics and Astronomy, University of Tennessee, Knoxville, TN 37996, USA*
[11] *Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824 USA*
[12] *A. W. Wright Nuclear Structure Laboratory, Yale University New Haven, CT 06511, USA*
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The structure of ^{18}Ne is interesting since its states exhibit a mixture of two-particle and deformed con gurations [1]. The properties of levels in ^{18}Ne also determine rates for the ^{14}O($,p)^{17}$F and ^{17}F$(p,\gamma)^{18}$Ne reactions that are important for explosive hydrogen burning which drives novae and X-ray bursts. States in ^{18}Ne could only previously be studied through transfer of correlated pairs of nucleons, for example by the ^{20}Ne$(p,t)^{18}$Ne reaction [2]. Despite numerous studies, many imporant uncertainties remained regarding the structure of states in ^{18}Ne. The development of beams of radioactive ^{17}F ions has provided a powerful new probe of valence proton con gurations in ^{18}Ne, including those most important for nuclear astrophysics.

We have used beams of ^{17}F from the Holi eld Radioactive Ion Beam Facility at Oak Ridge National Laboratory to study the the structure of states in ^{18}Ne. The structure of bound levels was studied using the ^{14}N(^{17}F,^{18}Ne*)^{13}C proton transfer reaction with a ^{17}F beam of 170 MeV. The structure of unbound levels was studied by the ^{17}F$(p,p)^{17}$F, ^{17}F$(p,p_1)^{17}$F*, and ^{17}F$(p,$ $)^{14}$O reactions using ^{17}F beams with energies ranging from 37 to 70 MeV. Outgoing charged particles were detected in arrays of silicon-strip detectors, allowing the angular distribution of reaction products to be determined. In some measurements, heavy ion recoils or gamma rays were detected in coincidence in order to allow the weak channels to be cleanly detected and resolved. An analysis of the combined results from these measurements has yielded important new information on the structure of states in ^{18}Ne and has allowed much improved determinations of the ^{17}F$(p,\gamma)^{18}$Ne and ^{14}O($,p)^{17}$F reaction rates.

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Oak Ridge National Laboratory is managed by UT-Battelle, LLC, for the U. S. Department of Energy under contract DE-AC05-00OR22725.

Borromean nuclei and three-body resonances

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The properties of three-body systems are directly determined by the internal two-body structures. This statement is actually obvious as soon as only two-body interactions are involved in the three-body system. However, a direct and clean connection between the two-body and three-body properties has not been provided yet.
In this work we compute the three-body states by the complex scaled hyperspheric adiabatic expansion method [1,2], which gives bound states and resonances as *bound* solutions of the Faddeev equations (the position in the energy plane is independent of the scaling angle).
Starting from a trivial system in which the core has infinite mass and the two light particles do not interact with each other, we can first test the method, since the numerical calculations reproduce accurately the expected trivial result. Secondly, this simple system is used as starting point in the calculations, being then possible to trace the different three-body states when more and more realistic features are introduced in the numerical calculations (finite core mass, interaction between the two light particles, finite particle and core spins, Pauli principle, ...).

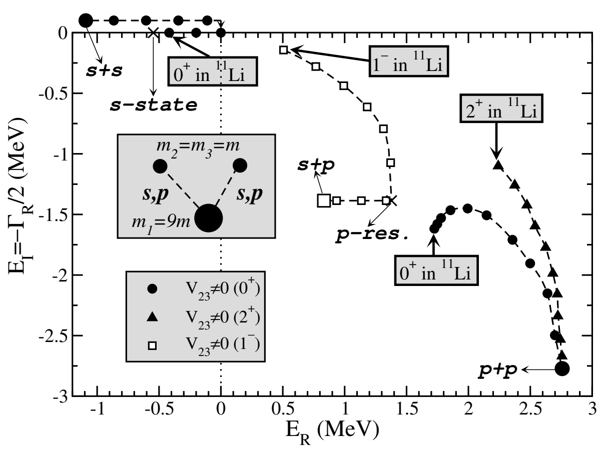

FIG. 1. Evolution of the ^{11}Li states when the neutron-neutron interaction V_{23} is progressively introduced. The core is assumed to have zero spin.

In the figure we show the three-body states for a system made by a zero spin core with mass equal to $9M$ (M=nucleon mass) and two neutrons. When the interaction between the neutrons is introduced the different states (two 0^+, one 1^- and one 2^+) evolve as shown in the figure, such that the final points on each curve correspond to the states when the full neutron-neutron interaction is included. In particular, one of the 0^+ states is a bound Borromean state. The effects arising from the 3/2-spin of the ^{9}Li core and other systems like ^{6}He are also investigated.
Tracing the evolution of the three-body states permits to visualize the features responsible for the existence of the different states, in particular the Borromean states. For a system like ^{6}He the Borromean ground state is due to the neutron-neutron interaction, while other systems like two heavy particles and a light one can have a Borromean state produced only by center of mass effects, even if the two heavy particles do not interact with each other. Furthermore, an understanding of the contribution from the different "realistic" features permits to use the very schematic case as starting point and make crude estimates of the spectrum of realistic three-body systems.

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Chiral Symmetry and Signature Splitting in Odd-Odd Neutron deficient *Pr* Nuclei*

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The recent progress in studying nuclei far from stability is mainly due to experimental development offered by the use of radioactive ion beams and inducing reactions in neutron-rich targets. New experiments are studying nuclei at extreme temperatures, angular momenta, and/or neutron/proton balance. Over the past few years, sufficient data have been accumulated to enable a meaningful study of the systematic trends. While general characteristics seen in experiments are understood by various mean-field nuclear models, there are key features that are not fully explained. Of particular interest are the chiral symmetry (chiral bands) [1] and signature splitting/inversion phenomena.
We report on our investigation on the association of signature inversion in an odd-odd band of two quasiparticles pointed along different axes with the formation of chiral twin bands [2], and understanding systematic chiral symmetry and signature splitting/inversion features within the framework of particle rotor model for neutron deficient *Pr* nuclei.

[1] S. Frauendorf, *Spontaneous symmetry breaking in rotating nuclei*, Rev. Mod. Phys. 73(2), 463, (2001)
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*This work was supported by the U.S. NSF Grant No. PHY 0204811 and U.S. Research Corporation Grant No. CC5494.

Investigations of Short Half-Life States from SF of ^{252}Cf

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Using the time-gated triple γ coincidence method[1], the half-lives of several short lived states have been studied. The first excited states in the ground state band decay by delayed γ emission, allowing us to apply our triple coincidence technique to determine their half-lives. In particular, the short half-life states can be challenging to investigate, due to the large magnitude of timing corrections. By creating short triple γ coincidence time windows, 8, 16, 20, 28, and 48 nsec, we can measure states with half-lives below 10 nsec.
Measured half-lives of ^{98}Sr, ^{143}Ba, and ^{152}Nd are in reasonable agreement with previously reported values. We report, for the first time, the half lives of ^{104}Zr and ^{152}Ce. These states with short half-lives present many challenges, and there is considerable uncertainty in these results. Previously reported values in the literature also vary widely. Analysis continues for several other isotopes with short-lived states, and progress will be discussed, along with problems and future studies.

[1] J.K. Hwang *et al*, Phys. Rev. **C**, Accepted for publication, April (2004)

Unexpected Rapid Variations in Odd-Even Level Staggering in Gamma-Vibrational Bands

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We have used our γ - γ - γ data (5.7×10^{11} triples and higher folds) from the spontaneous fission of ^{252}Cf taken at Gammasphere to study the gamma-type vibrational bands in $^{104-106}$Mo, $^{108-112}$Ru, and $^{112-116}$Pd. The γ bands are seen to 14^+ in $^{104-106}$Mo, to 13^+ in ^{108,110}Ru, to 17^+ in ^{112}Ru, to 11^+ in ^{112}Pd, and to 15^+ in ^{114,116}Pd. The even-odd spin energy level splittings, e.g. $\Delta E = E_3^+ - E_2^+, E_4^+ - E_3^+, ...$, show striking and rapid variations with spin, e.g. in ^{104}Mo to 12^+ the odd spin is pushed up closer to the even spin with little variation in ^{106}Mo. The pattern in ^{108}Ru is the same as in ^{104}Mo, but ^{112}Ru has exactly the opposite staggering, even spin pushed up close to the odd spin level, as seen in Figure 1. The pattern in ^{112}Pd is like in ^{104}Mo, with a reversal in pattern in ^{114}Pd, which looks like ^{112}Ru.

To better understand the behavior of γ-vibrational bands, the ΔE values for known γ-vibrational bands in even-even ^{152,154}Sm, $^{152-160}$Gd, $^{154-166}$Dy, $^{156-170}$Er, $^{162-174}$Yb, $^{168-180}$Hf, $^{170-186}$W, $^{172-192}$Os, and $^{180-196}$Pt were calculated. In general, Sm, Gd, Dy, and Er exhibited little staggering in ΔE, with differences in $\Delta E \lesssim 40$ keV, up to spin 10^+ except for differences up to 200 keV in ^{152}Gd, ^{154}Dy, ^{156}Er with N = 88 (which is outside the onset of large deformation at N = 90). At higher spins, differences up to 100 keV are seen. Only in ^{162,166}Yb and ^{176}Hf are γ bands known above 6^+ and in ^{162,166}Yb the differences in adjacent ΔE values reach 200 and 640 keV, respectively. In ^{192}Os between 5^+ and 8^+, significant differences are seen. For $^{180-186}$Pt, there is a strong oscillation to the maximum known spin 7^+, but with a reverse pattern to the above cases, e.g., the ΔE adjacent differences start out large, 200 and in one case 300 keV, and get smaller, 100 – 200 keV. In $^{188-196}$Pt, only in ^{192}Pt are the γ-band levels known above 6^+ and staggering sets in at 5^+ with an increasing difference to 220 keV. The three largest energy differences are at the highest spins in ^{112}Ru, 570 keV, ^{114}Pd, 480 keV, and ^{166}Yb, 640 keV.

Stable triaxial deformation is likely playing an important role in the rapidly varying and large odd-even spin staggering. It is not clear what causes the sudden complete reversal as found for ^{108,112}Ru and ^{112,114}Pd. This is a new phenomenon not seen for Sm to Pt in γ bands. Clearly, the data call for a more microscopic description of γ-vibrational bands, including γ-soft and stable triaxial deformations.

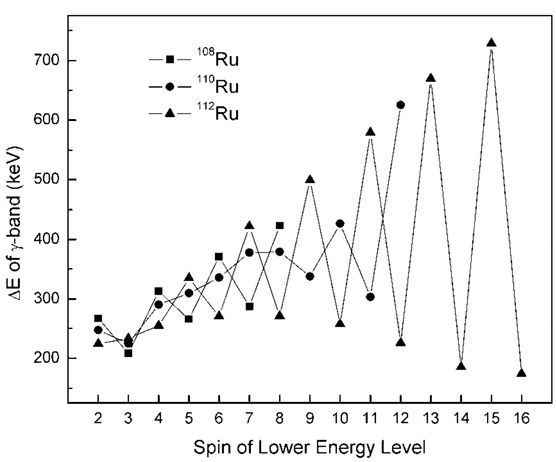

FIG. 1. Level energy differences in ^{108,110,112}Ru.

RDDS lifetime measurements with JUROGAM + RITU *

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Lifetime measurements play a crucial role in nuclear structure physics. Transition probabilities for electromagnetic transitions can be directly extracted from the lifetime data. The recoil distance Doppler shift method (RDDS) [1] is a well known method for lifetime measurements of nuclear excited states. It is based on the Doppler shift of γ-rays emitted from a nucleus in ight. In the present work a special plunger device was designed for RDDS measurements at the RITU gas- lled separator [2]. The plunger consists of a target and a moveable degrader foil which replaces the conventional stopper foil after the target. Gamma-rays emitted from a nucleus moving with di erent velocities are separated in energy according to their Doppler-shift. From the ratio of the peak areas of the fully shifted and retarded components the lifetime of the excited state can be deduced. Gamma-ray spectra from exotic nuclei produced via weak fusion evaporation channels can be extracted by tagging with the fusion residues detected at the RITU focal plane with GREAT spectrometer [3].

So far the lifetime measurements for the low-lying yrast states of ^{188}Pb have been performed employing the RDDS method, the JUROGAM germanium detector array and RITU at the Accelerator Laboratory of the University of Jyväskylä. Results of these measurements along with plans for the future experiments will be discussed.

FIG. 1. Plunger device at JUROGAM target position.

[1] A. Z. Schwarzschildt, E. K. Warburton, Ann. Rev. Nucl. Sci. **18**, 265 (1968).
[2] M. Leino *et al.*, Nucl. Instr. Meth. B **99**, 653 (1995).
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This work is supported in part by the U.S. D.O.E. under grant number DE-FG02-91ER-40609, the Academy of Finland (the Finnish Centre of Excellence Programme, project 44875) and the EU-FP6 projects EXOTAG (HPRI-1999-CT-50017) and Access to Research Infrastructure (HPRI-CT-1999-00044).

Beta decay in medium-heavy nuclei and its application to nuclear astrophysics

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The accurate prediction of beta-decay rates requires a detailed knowledge of nuclear structure properties of both the initial and final nuclear states. Moreover, the beta-decay rates provide us important information for predicting the abundance of nuclei in neutron capture reactions by the rapid neutron capture r-process in super-nova explosions. Therefore, it is of great interest to study the beta-decay rates in terms of a microscopic framework, where the neutron and proton degrees of freedom are explicitly taken into account.

The nuclear shell model remains one of the most fundamental approaches for a microscopic description of nuclear structure. Although its applications to light nuclei were very successful, the model cannot be applied to medium and heavy nuclei except a few nuclei lying near a shell closure. The main difficulty is the uncontrollable problem of dimension explosion. In order to avoid this problem, some kinds of truncation schemes are necessary. As such an approach, we propose the pair-truncated shell model (PTSM). In the simplest version of the model, low-lying states of even-even nuclei are represented by collective nucleon pairs with angular momenta zero (S) and two (D). For the description of odd-mass and odd-odd nuclei, the PTSM is extended by including an unpaired neutron and/or proton in addition to SD pair states. Studies of the nuclei in the $A \sim 130$ region were carried out in the context of the PTSM [1,2], and energy spectra as well as electromagnetic transitions were successfully described.

Recently, we applied the PTSM to the even-even and odd-mass nuclei in the $A \sim 100$ region, and our calculation reproduced energy levels and E2 transition rates very well. Using this result, we calculate beta-decay rates, and discuss the internal structure of both the initial and final nuclear states. The results of this calculation will be presented and discussed in detail in this conference.

[1] K. Higashiyama, N. Yoshinaga, and K.Tanabe, Phys. Rev. C **67**, 044305 (2003).
[2] N. Yoshinaga and K. Higashiyama, Phys. Rev. C, in press.

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Half-lives of several states in neutron rich nuclei from SF of ^{252}Cf

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Half-lives ($T_{1/2}$) of several states which decay by delayed γ transitions were determined from time-gated triple γ coincidence method[1,2]. We determined, for the first time, the half-life of 330.6+x state in ^{108}Tc and the half-life of $19/2^-$ state in ^{133}Te based on the new level schemes[1]. Four half-lives of ^{95}Sr, ^{99}Zr, ^{134}Te and ^{137}Xe are consistent with the previously reported ones. These results indicate that this new method is useful for measuring the half-lives.
Also, the half-life of the 829.8 keV state in ^{97}Sr was determined[2]. Coincidence spectra with double gates on 239.6 and 272.5 keV transitions of ^{97}Sr[2] with time windows of 100, 300, 500 nsec are shown in Fig. 1. This new band, built on this isomeric state, is interpreted as the $\nu 9/2[404]$ rotational band with a very deformed shape. The new band indicates that the emptying of the upslopping $g_{9/2}$ orbital with K=9/2 is closely related to the strong prolate shapes of some bands in the Sr and Zr regions with A≈100.
In order to determine the short half-lives $\leq$ 5 nsec we need to use the short triple γ coincidence time windows $\leq$ 10 nsec Therefore, the problems associated with the short time windows are addressed and future direction of this work is discussed to solve this problem.

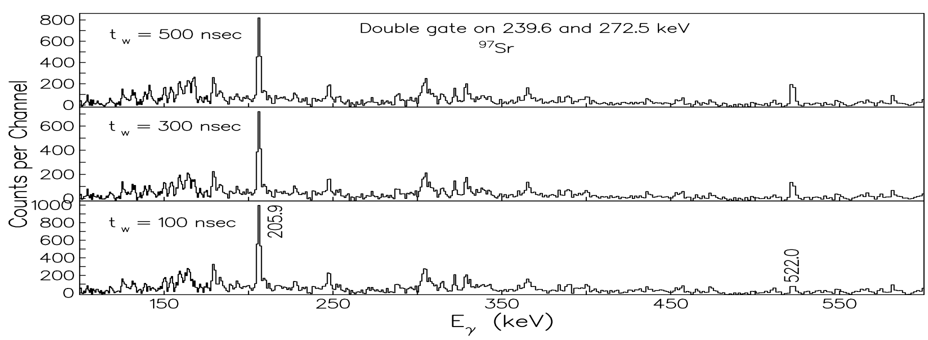

FIG. 1. Coincidence spectra with double gates on 239.6 and 272.5 keV transitions of ^{97}Sr[2] with time windows of 100, 300, 500 nsec.

[1] J.K. Hwang *et al.*, Phys. Rev. **C**, Accepted for the publication, April (2004).
[2] J.K. Hwang *et al.*, Phys. Rev. **C67**, 054304 (2003).

Soft Octupole Vibrations built on Superdeformed States in Nuclei around ^{40}Ca suggested by Skyrme-HF and Selfconsistent RPA Calculations

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Recently, Superdeformed (SD) bands were discovered in the ^{40}Ca region[1]. One of the important new features of them is that they are built on excited 0^+ states and observed up to high spin, in contrast to the SD bands in heavier mass regions where low-spin portions of them are unknown in almost all cases. In [2] we reported results of the symmetry-unrestricted, Skyrme-Hartree-Fock (SHF) calculations for these SD bands and suggested that they are very soft against both axially symmetric and asymmetric octupole deformations. The calculation were carried out with the use of the fully three-dimensional (3D) coordinate-mesh representation without imposing any symmetry restriction. Quite recently, Imagawa *et al.*[2] constructed a new computer code that carries out a selfconsistent RPA in the mixed representation where *particles* are represented by Cartesian coordinate mesh with box boundary condition while *holes* are defined as single-particle eigen-states for the the SHF mean field. All terms of the residual interaction are taken into account including time-odd terms and the residual Coulomb interaction. Solving these RPA eigenvalue equations on the 3D Cartesian mesh in a box, a strongly collective octupole vibrational mode with $K^\pi = 1^-$ was obtained at about 1.1 (0.6) MeV above the SD band head of ^{40}Ca, for the SIII (SkM*) interaction. With the use of this RPA code, we have carried out a systematic investigation on soft octupole vibrations built on SD states in N=Z nuclei around ^{40}Ca. A number of strongly collective octupole excitations has been predicted by the theoretical calculation. A typical example is presented in Fig.1.

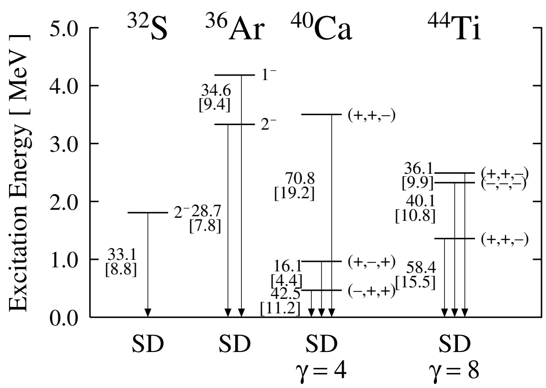

Figure 1: Soft octupole vibrations built on the SD states in N=Z nuclei around ^{40}Ca calculated by the mixed representation RPA with SkM*. Numbers beside the arrows (in parentheses) indicate the squared transition matrix elements for the mass (electric) octupole operators in the Weisskopf unit. The RPA matrix is constructed using 30 mesh points in each direction with mesh size h=0.6 fm. The calculated SD band head in ^{40}Ca (^{44}Ti) is slightly triaxial with $\gamma = 4°(\gamma = 8°)$ so that the $K^\pi = 1^-(K^\pi = 2^-)$ mode splits into a doublet.

[1] E. Ideguchi *et al.*, Phys. Rev. Lett. 87 (2001), 222501.
[2] T. Inakura, S. Mizutori, M. Yamagami, and K. Matsuyanagi, Nucl. Phys. A 710 (2002), 261.
[3] H. Imagawa, Docter Thesis, University of Tsukuba, April 2003; H. Imagawa and Y. Hashimoto, Phys. Rev. C 67 (2003), 037302, and to be published.

Identification of Levels in ^{162,164}Gd and Decrease in Moment of Inertia between N = 98 - 100

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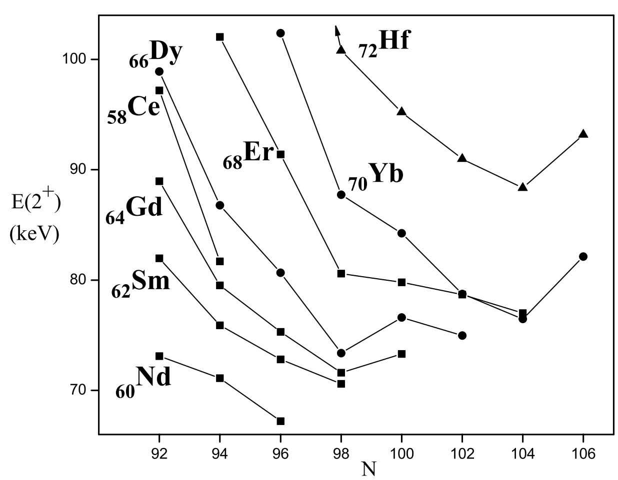
A γ - γ - γ coincidence study of prompt γ rays emitted in the spontaneous fission of ^{252}Cf was carried out using Gammasphere with 5.7x10^{11} triples and higher coincidences recorded. The yrast levels in neutron-rich ^{162,164}Gd were identified for the first time from 2^+ to 16^+ in ^{162}Gd and from 2^+ to 14^+ in ^{164}Gd. The 2^+ energy in known ^{160}Gd is at 75.3 keV and, from our data, in ^{162,164}Gd at 71.6 and 73.3 keV, respectively. The transition energies from every level in ^{164}Gd are higher than those from the same levels in ^{162}Gd. These data show that there is the same decrease at every level of the moment of inertia in N = 100 ^{164}Gd compared to N = 98 ^{162}Gd. As seen in the figure, there is at least a local minimum in the 2^+ energies and maximum in the moments of inertia in Gd nuclei at N = 98. The N = 98, 100 ^{164,166}Dy [1] transition energies likewise increase from N = 98 to 100, and the J_1 and J_2 values of ^{166}Dy similarly fall between those of ^{162,164}Dy from $2^+ \rightarrow 0^+$ up to $12^+ \rightarrow 10^+$, then become less than those of ^{162}Dy at 12^+. However, Asai et al. [2] found that the 2^+ and 4^+ energies in ^{168}Dy are lower than those of ^{166}Dy, so the J_1 values of ^{168}Dy for N = 102 fall above the N = 100 values but still below the N = 98 values.

This behavior is unexpected both because the minimum in 2^+ energies and maximum in β_2 and MOI are expected at midshell N = 104 and because such minima and maxima are found there in Er, Yb, and Hf nuclei. While isotopes of Gd and Dy have an E(2^+) minimum and presumably a β_2 maximum at N = 98, Yb and Hf nuclei have an E(2^+) minimum at N = 104 with the E(2^+) values for Er isotopes following this trend. However, Er and Yb have a kink and change of slope above N = 98. With the new Gd and Dy data, the lowest known E(2^+)s in this region for N = 92 - 110 are for Z = 60 Nd, followed by Z = 62 Sm and then Z = 64 Gd, with Z = 58 Ce E(2^+)s curiously falling between the Gd and Dy values at N = 92 and 94. These results in the most neutron-rich known nuclei in this region provide new challenges for microscopic nuclear models.



[1] C. Y. Wu *et al.*, Phys. Rev. **C57**, 3466 (1998).
[2] M. Asai *et al.*, Phys. Rev. **C59**, 3060 (1999).

Beta Decay spectroscopy of ^{103,105}Sn

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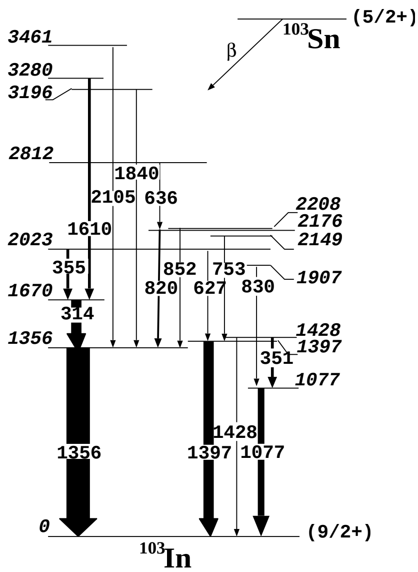
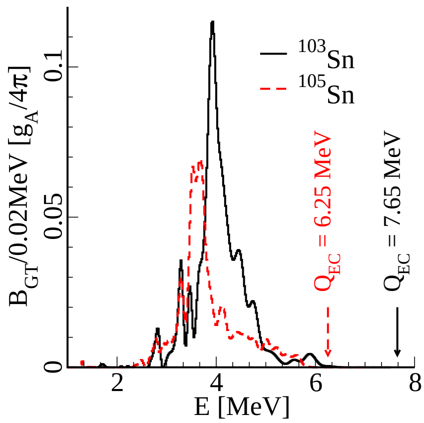
^{100}Sn is the heaviest self-conjugated doubly-magic nucleus where protons and neutrons occupy identical orbitals. Therefore, experimental data on the structure of nuclei in the ^{100}Sn region allow one to stringently test predictions of the nuclear shell model. The β decay in this region is dominated by an allowed Gamow-Teller (GT) $\pi g_{9/2} \rightarrow \nu g_{7/2}$ transition. Two complementary setups were used to investigate the decay of ^{103,105}Sn at the GSI-ISOL facility (for the results on even-tin beta decay studies see *M. Karny et al.*, contribution to this conference), namely a high-resolution array of germanium (17 crystals) detectors and a total-absorption spectrometer (TAS). The β-delayed γ rays of ^{103}Sn were measured for the first time in high-resolution. In addition to the transition from the 1077 keV (11/2+) state known from in-beam spectroscopy [1] fifteen new γ transitions in ^{103}In were identified. The half-life of ^{103}Sn was determined to be 6.9±0.4 s, and the level scheme (see upper figure) of the daughter nucleus ^{103}In was constructed by using β-γ-γ coincidence data.





The GT strength distributions of ^{103,105}Sn, measured by using the TAS, are shown in the lower figure. Dominant GT resonances were identified at 3.9 and 3.6 MeV in ^{103}Sn and ^{105}Sn, respectively. The corresponding preliminary values for the summed GT strength are 3.6 and 2.6 $g_A/4\pi$ assuming the Q_{EC} values shown in the lower figure.

In addition a measurement of β-delayed protons of ^{103}Sn decay was performed, yielding a half-life of 7.0 ± 0.6 s for this nucleus. The β^+/EC ratio for the proton emission to the ground state of ^{102}Cd was evaluated to be 0.6. This result, together with the average energy of β-delayed protons taken from [2], yielded a Q_{EC} value of 7.5 ± 0.5 MeV for ^{103}Sn.

The experimental data will be discussed in comparison with shell-model predictions, and the results of a search for β-delayed γ rays of ^{101}Sn will be reported.

[1] J. Kownacki *et al.,* Nucl. Phys. A 627 (1997) 239
[2] P. Tidemand-Petersson *et al.*, Z. Phys. A 302 (1981) 343

Decay studies of neutron deficient odd-mass At and Bi isotopes

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The region of neutron-deficient nuclei far from stability around the closed Z=82 proton shell and the N=104 neutron mid-shell offers an interesting challenge for various theoretical models as well as experimental instruments. A variety of nuclear phenomena can be observed in this limited region of the nuclear chart and understood by the coupling of the particles and particle holes to the proton-magic Pb core. In addition, the vicinity of the proton drip line in odd-Z nuclei offers an opportunity to observe proton emission in this region.

During the past few years the decay spectroscopy of neutron deficient odd-mass At- and Bi-isotopes beyond the proton drip line has been one of the main goals of the studies performed at the gas-filled recoil separator RITU [1]. So far unclear decay properties of ^{193,195}At isotopes are now clarified using the sensitive alpha-gamma coincidence method [2,3]. In addition, the alpha decay of the next odd-mass astatine isotope ^{191}At was also studied [3]. The level scheme of these nuclei are suggested to differ from those observed in heavier odd-mass astatine isotopes. For each of these isotopes the oblate 1/2+ intruder state was observed to be the ground state instead of the nearly spherical 9/2- state which is the ground state in the heavier odd-mass astatine isotopes. In addition, a 7/2- state rather than the 9/2- state is suggested to represent the first excited state in these light odd-mass astatine isotopes. Correspondingly, a new low-lying 7/2- state, fed by the alpha decay of the astatine isotopes, was observed via gamma-ray de-excitation in ^{189,191}Bi isotopes. The existence and the excitation energy of this state in ^{187}Bi was deduced based on the shape of the alpha-decay spectrum of ^{191}At and the systematics in the heavier odd-mass bismuth isotopes. The emergence of a low-lying 7/2- state in light odd-mass At and Bi isotopes was understood via the 7/2-[514] Nilsson proton orbital associated with an oblate deformed structure. Based on the experimental results, the 7/2- state is observed to come down in excitation energy even in ^{187}Bi. Thus, the state may play a vital role in the decay scheme of the proton emitting nucleus ^{185}Bi.

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*This work was supported by Academy of Finland under the Finnish Center of Excellence Programme 2002-2005 (Project No. 44875, Nuclear and Condensed Matter Physics Programme at JYFL).
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Collective Path connecting the Oblate and Prolate Local Minima in Proton-Rich N=Z Nuclei around ^{68}Se

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Shape coexistence phenomena are typical examples of large amplitude collective motion in nuclei. These phenomena implies that different solutions of the Hartree-Fock-Bogoliubov (HFB) equations (local minima in the deformation energy surface) appear in the same energy region and that the nucleus exhibits large amplitude collective motion connecting these different equilibrium points. Recently, we have proposed a new method of describing such large-amplitude collective motion, which is called Adiabatic Self-consistent Collective Coordinate (ASCC) method[1]. It does not assume a single local minimum, so that it is expected to be suitable for the description of the shape coexistence phenomena. The ASCC method also enables us to include the pairing correlations self-consistently, removing the spurious number fluctuation modes.

Quite recently, with use of the Pairing-plus-Quadrupole (P+Q) interaction, we have applied the ASCC method to the shape coexistence phenomena in ^{68}Se discovered by Fischer *et al.*[2], where the oblate ground band and the prolate excited bands compete in energy, and investigated the collective path connecting the oblate and prolate local minima in the collective potential energy landscape. It is found that the collective path goes through the change of the axially asymmetric quadrupole moment Q_{22}; in the terminology of the Bohr-Mottelson collective Hamiltonian, it roughly corresponds to the path along which the triaxial deformation parameter γ changes between 0° and 60° keeping the axially symmetric deformation parameter β approximately constant. This is the first time that a self-consistent collective path between the oblate and prolate minima is obtained for the realistic P+Q model. We shall present results of the systematic calculation including neighboring nuclei at the time of the ENAM04 conference.

Figure 1: Left: Collective path connecting the oblate and prolate shapes in ^{68}Se, which is determined by the ASCC method with the use of the P+Q interaction. Right: Collective Mass (Inertia) with respect to the geometrical length s in the (β, γ) plane is plotted as a function of the triaxiality parameter γ. The length s is given as a function of the collective coordinate q.

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Study of multi-quasiparticle isomers in deformed A~180 nuclei near and beyond the valley of stability*

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A characteristic feature of many axially symmetric, deformed nuclei near A~180 is the dominance of high-Ω orbitals in the vicinity of both the neutron and proton Fermi surfaces. This gives rise to the presence of multi-quasiparticle K-isomers with half-lives ranging from a few nanoseconds to hundreds of years [1]. Most of the studies so far have focused on neutron deficient structures that are accessible by heavy-ion fusion evaporation reactions. The information for nuclei near or on the neutron rich side of the valley of stability is very scarce despite the fact that this is the region where the longest lived isomers are known (and predicted) to reside, and hence, there is interest for various applications. The most notable examples include the $K^\pi=16^+$, 31 y isomer in ^{178}Hf and the $K^\pi=23/2^-$, 160 d isomer in ^{177}Lu. Spectroscopic studies in this region provide interesting nuclear structure information on the limits of existence of high-K isomeric states at the extreme of proton and neutron number, and on the seniority dependence of the major residual interactions in deformed nuclei. The interest is also motivated by the astrophysical relevance of ^{176}Lu as an *s*-process chronometer and thermometer. The feasibility of this application depends sensitively on details of the level scheme, that is so far not well established, in order to explain the coupling between the very long-lived ground state ($K^\pi=7^-$) and a short-lived, excited β^- decaying isomer ($K^\pi=1^-$) in a hot stellar environment.

We have pursued studies of lutetium nuclei around ^{176}Lu, and the neighboring ytterbium, hafnium and tantalum isotopes, that are located near and beyond the line of stability using the Gammasphere spectrometer in conjunction with time-correlated gamma-ray coincidence techniques. In a recent experiment, a 820 MeV pulsed beam (1 ns on/820 ns off) of ^{136}Xe from the ATLAS accelerator at Argonne National Laboratory was used to bombard several targets, including ^{174}Yb, ^{175}Lu and enriched ^{176}Lu. Many nuclei in the region near ^{176}Lu and ^{136}Xe were populated using so-called deep-inelastic and multi-nucleon transfer reactions.

Several new high-seniority isomers have been identified, including the predicted 5-quasiparticle $K^\pi=39/2^-$ isomer in ^{177}Lu [2] and the 7-quasiparticle $K^\pi=49/2^+$ isomer in ^{179}Ta that exhibits an unusually fast decay [3]. The ^{177}Lu isomer has the same configuration as that suggested by Al-Garni *et al.* [4] to be the source of a β^- decay to ^{177}Hf, but it has yet to be established that the same state is involved. A set of isomers and corresponding excited structures were also observed in neutron-rich nuclei near ^{136}Xe, including the semi-magic (N=82) ^{134}Te isotope. These results will be discussed with the emphasis on the properties of the isomers, the competition between collective and intrinsic excitation and the role played by various degrees of K-mixing on isomer decays.

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* This work was supported by the U.S. Department of Energy, Office of Nuclear Physics under Contracts No. W-31-109-ENG-38, the ANSTO program for Access to Major Research Facilities, grant No. 02/03-H-05 and the Australian Research Council projects DP0343027 and DP0345844.

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Nuclear Structure and Decay Data Evaluation*

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on behalf of the International Nuclear Structure and Decay Data Network#

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The expression ``Nuclear Structure and Decay Data'' refers to complex nuclear level schemes and tables of numerical values, which quantify fundamental nuclear structure information, such as level energies and quantum numbers, lifetimes, decay modes, and other associated properties. These data are not only at the core of basic nuclear structure and nuclear astrophysics research, but they are also relevant to 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 primary mission of the International Nuclear Structure and Decay Data Network is to evaluate, compile and disseminate nuclear structure and decay data for all known nuclei (more than 2900!). The principal effort of the network is devoted to maintain and update the two most complete and comprehensive databases in the field of nuclear physics: the Nuclear Science Reference (NSR) file and the Evaluated Nuclear Structure Data File (ENSDF). The performed evaluations are peer reviewed and published in the journal Nuclear Data Sheets. The corresponding data are disseminated to the Nuclear Physics community world-wide using the latest computer technologies. The research centers participating in the network are also involved in nuclear data measurements, analysis and modeling activities, as well as in development of new evaluation methodologies, that are relevant to basic science and applied physics research. In recent years, special attention has been given to specialized (horizontal) evaluations of specific nuclear properties that are useful to a broad range of nuclear structure physics and nuclear astrophysics communities.

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

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* This work is supported by the U.S. Department of Energy, Office of Nuclear Physics under Contracts No. W-31-109-ENG-38 and DE-AC02-98CH10886.
#A collaboration of scientists from Australia, Argentina, Belgium, Brazil, Bulgaria, Canada, China, France, India, Japan, Kuwait, Russia and United States under the auspices of the International Atomic Energy Agency.

^{135}Sb and the "new world" of exotic nuclei

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It is long predicted that the very neutron-rich medium-heavy nuclei represent a "new world" governed by a shell structure different to that established along the line of stability. The key to this region could be provided by ^{135}Sb, which has two neutrons and one proton above ^{132}Sn. It is the most exotic nucleus outside ^{132}Sn, for which some information exists on its excited states, and at the same time, which is a key condition, it can be modeled theoretically with high precision. The experimental information on this nucleus remains puzzling. The first excited state in ^{135}Sb (at 282 keV) has been interpreted as mainly due to the proton $d_{5/2}$ configuration [1,2]. Numerically such low excitation energy of the level requires a strong relative shift between the proton $d_{5/2}$ and $g_{7/2}$ orbits [3] just above ^{132}Sn, possibly due to the neutron diffuseness [2]. A critical verification can be obtained from the transition strength. The M1 transition is forbidden between the $d_{5/2}$ and $g_{7/2}$ single particle states, and the E2 collectivity is small in the shell model system. Thus in principle, a long lifetime in the nanosecond range would support the $d_{5/2}$ interpretation of the state and the monopole shift theory, while shorter lifetime in the sub nanosecond range would support mixing interpretation.

Following this idea, we have, recently, determined the lifetime of the 282 keV state in ^{135}Sb and found it exceptionally long at 6.0(7) ns. We have also measured the lifetimes of the first excited $5/2^+$ states in ^{137}I, which has two extra protons in comparison to ^{135}Sb, and in ^{131}Sb, which has two neutron-holes instead of two neutron particles. In both cases the M1 transition rates are about 10-20 times faster than for ^{135}Sb. Lifetimes for the 282 keV level in ^{135}Sb, 243 keV state in ^{137}I and for the 798 keV level in ^{131}Sb have been obtained using the Advanced Time-Delay $\beta\gamma\gamma(t)$ method [4] based on triple coincidences between the β, BaF_2 and Ge detectors. The experiment has been performed at the OSIRIS on-line fission product mass separator located at the R2-0 reactor in Studsvik. The levels in ^{135}Sb, ^{137}I, and ^{131}Sb were populated via β^- decay of ^{135}Sn, ^{137}Te and ^{131}Sn, respectively, produced in the thermal neutron induced fission of ^{235}U.

A discussion of the results will be provided within the framework of the shell model [2,5] including recent calculations. For example, in the preliminary realistic shell-model calculation, performed by the Naples group on ^{135}Sb, an effective two-body interaction was derived from the CD-Bonn nucleon-nucleon potential while the single-particle energies have been taken from the experimental spectra of ^{133}Sb and ^{133}Sn. A large configuration mixing was found for the $5/2^+$ state in ^{135}Sb, which was calculated at the excitation energy of 560 keV. In spite of the mixed nature of this state, its long lifetime can be reproduced by the theory if the g_l factor for neutrons is taken very large at about 0.8. Quite clearly further studies and in particular experimentally determined transition rates in the nuclei just above ^{132}Sn, like on ^{135}Te and ^{135}I, are strongly needed. Thus for now, ^{135}Sb remains an interesting puzzle.

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Recoil distance lifetime measurements in ^{118}Xe

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Lifetimes of the lower-excited states in ^{118}Xe are measured using the recoil-distance Doppler-shift technique. The reaction ^{93}Nb(^{29}Si,p3n)^{118}Xe at a beam energy of 135 MeV and was used for this experiment. The lifetimes of the 2^+, 4^+, 6^+, 8^+ and 10^+ states of the ground state band were extracted using the computer code LIFETIME which includes the corrections due to the side feeding and the nuclear deorienation effects. The present B(E2) values are in good agreement with the extracted B(E2) values from the Hartree-Fock-Bogoliubov calculation. The measured B(E2) values are also compared with the standard algebraic and the geometrical models. The B(E2) values for the 2^+ state for this nucleus and the other Xe nuclei as a function of the neutron number are well reproduced in the framework of the algebraic model IBA-1 with O(6) symmetry and the geometrical finite range model.

Exotic nuclei near ^{78}Ni in a shell model approach

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Neutron-rich nuclei in the vicinity of $^{78}_{28}$Ni$_{50}$ are currently in the focus of modern nuclear physics and astrophysics studies. The interest in this region is motivated by the doubly magic nature of $^{78}_{28}$Ni and understanding the way in which the neutron excess will affect the properties of nearby nuclei. The astrophysical importance is related to the understanding of the nuclear mechanism of the rapid capture of neutrons by seed nuclei through the r-process. The path of this reaction network is expected in neutron-rich nuclei for which there is little experimental data, and the precise trajectory is dictated by the details of the shell structure far from stability.

Recently, the $T = 1$ part of the effective interaction for the $p_{3/2}p_{1/2}f_{5/2}g_{9/2}$ model space has been derived from a fit to experimental data for Ni isotopes from $A = 57$ to $A = 78$ and $N = 50$ isotones from ^{79}Cu to ^{100}Sn for neutrons and protons, respectively. New interaction reveals some unusual properties of Ni-isotopes near ^{78}Ni and gives guidelines for future experiments on exotic nuclei.

This contribution reports on the next step towards full effective interaction. Detailed analysis of the available experimental data for the nuclei with active proton-neutron degrees of freedom in the $p_{3/2}p_{1/2}f_{5/2}g_{9/2}$ model space results in the determination of the $T = 0$ part of the effective interaction. Derived interaction is used for the studies of exotic Cu,Zn, Ga an Ge isotopes in the vicinity of ^{78}Ni. The issues of monopole shifts, evolution of single quasiparticle states, seniority isomers, development of collective features are addressed.

Di-neutron correlation in medium mass neutron-rich nuclei near drip-line

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Pairing correlation is one of the central issues for the structure problems in neutron-rich exotic nuclei, not only in the light Borromean halo nuclei, but also in heavier systems with more active neutrons. Particularly in nuclei near drip-line where the neutron threshold is very low, dramatic influence of neutron pairing on excitation mode can be expected. We predict that the neutron pairing exhibits a characteristic di-neutron correlation in unstable nuclei extending to medium mass region, and the di-neutron correlation manifests itself in the soft dipole excitation associated with neutron motion near the threshold.

In this theoretical prediction, we use the coordinate-space Hartree-Fock-Bogoliubov method and the continuum quasiparticle random phase approximation (QRPA)[1] to describe the pair correlation effects in the ground state and the soft dipole excitation. We perform all the calculations in the coordinate-space representation in order to make an exact treatment of the neutron continuum states, which play a central role near drip-line and above the threshold[1]. Focus is put on spherical O, Ca and Ni isotopes near neutron drip-line.

A clear di-neutron correlation shows up in the ground state (Fig.1 left). The soft dipole excitations calculated by the continuum QRPA exhibits also strong influence of the di-neutron correlation (Fig.1 right), which is directly visible in the large transition amplitude for the transfer of spin singlet neutron pair to the soft dipole excitation (equivalently, in the two-neutron emission from the soft dipole excitation). We point out that continuum single-neutron states play a critical role to produce the di-neutron correlation; the large effect emerges only by including configurations where two neutrons both occupy continuum single-particle orbits with large orbital angular momenta up to $l \sim 10$. This reflects directly the localized nature of the di-neutron correlation.

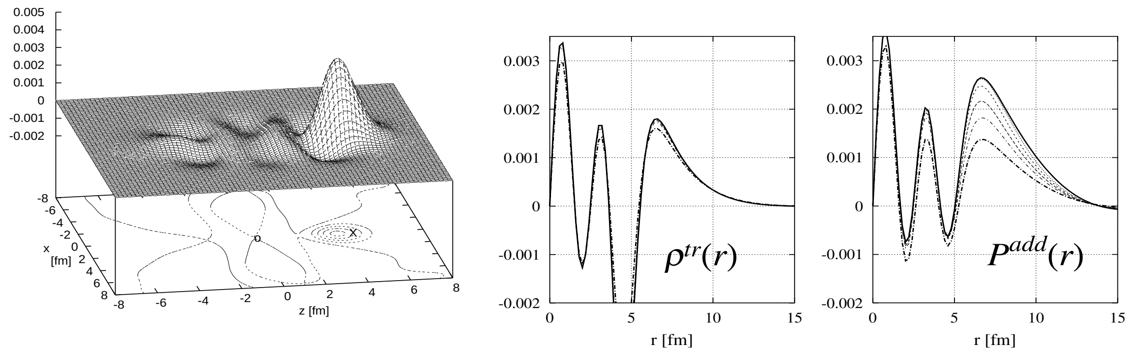

FIG. 1. (Left) Neutron two-body correlation density in the ground state of ^{54}Ca. (Right) The neutron particle-hole transition density $\rho^{tr}(r)$ and the pair transition density $P^{add}(r)$ for the soft dipole excitation in ^{84}Ni. Here the high-l contributions ($l = 5, 7, 9, 11$) are also shown.

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Gamow Shell-Model Description of Weakly Bound and Unbound Nuclear States

Nicolas Michel

Recently, the shell model in the complex k-plane (the so-called Gamow Shell Model) has been formulated using a complex Berggren ensemble representing bound single-particle states, single-particle resonances, and non-resonant continuum states. In this framework, we shall discuss binding energies and energy spectra of neutron-rich helium and lithium isotopes. The single-particle basis used is that of the Hartree-Fock potential generated self-consistently by the finite-range residual interaction.

Study of the (21^+) high-spin trap in ^{94}Ag

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A (21^+) isomer has recently been reported in the N=Z nucleus ^{94}Ag in measurements of β-delayed γ rays [1,2]. Large-scale shell model calculations including excitations of the ^{100}Sn core (up to 4p-4h) can reproduce the isomerism due to an E4 spin gap [2,3]. The isomer features the highest spin ever observed for β-decaying nuclei. We have further investigated the properties of this truly exotic state at the GSI online mass separator. Measurements of β-delayed protons and γ rays as well as proton-γ, proton-proton-γ and proton-γ-γ coincidences have been performed by using a high-granularity array of silicon and germanium detectors [4] as well as a total absorption spectrometry (TAS). The major part of the observed β decay involves the known (7^+) isomer in ^{94}Ag whose half-life is 0.57(6) s. High-spin states in ^{93}Rh populated by proton emission following the β decay of ^{94}Ag isomers have been observed for the first time. Even- and odd-parity yrast bands were identified with spin values up to of 39/2 by combining β-decay and in-beam data and comparing them with shell-model predictions. These results, together with the β-strength distribution of ^{94}Ag measured with TAS, confirm the (21+) assignment to the higher-lying isomer of ^{94}Ag and yield a value of 0.42(5) s for its half-life.
The β-decay energy of the (21^+) spin trap was deduced to be at least 16 MeV, which is in qualitative agreement with the (21^+) excitation energy of 6.3 MeV, predicted by shell-model calculations [2]. At this high excitation energy, the (21^+) isomer is expected be unbound to several exotic decay modes, such as direct (or Coulomb-delayed) one proton, two-proton or α emission to the ground state of the respective daughter nuclei: ^{93}Pd, ^{92}Rh and ^{90}Rh. The Q values estimated for these disintegration modes are 5.4, 1.8 and 3.8 MeV, respectively [5]. We have searched for the most intense 1097 and 985 keV γ-transitions in ^{93}Pd which may follow a direct proton emission. However, these lines have not been observed neither in proton-γ nor proton-γ-γ events. The corresponding upper-limit of the proton branching ratio amounts to 10^{-3}. We have also examined the possibility for direct two-proton radioactivity of the (21^+) isomer which is expected to be followed by the 235 keV γ-ray from ^{92}Rh. The non-observation of such a line in proton-proton-γ coincidences yields an upper limit of $4{\cdot}10^{-4}$ for the branching ratio of this decay mode. In addition, β-delayed two-proton and three-proton emissions from the ^{94}Ag isomers were investigated. We searched for γ rays from low-energy excited states in ^{92}Ru which may be populated in β-delayed two-proton emission from the ^{94}Ag isomers. A few events have been registered in proton-γ-γ coincidences related to a cascade of the lowest 866 and 991 keV γ-transitions in ^{92}Ru, resulting in a branching ratio of β-delayed two-proton emission of 0.2(2)%. Larger statistics are needed to firmly establish this decay branch. The 928 keV γ-ray from the $(15/2^+)$ state of ^{91}Tc following β-delayed three-proton emission was not seen in the proton-proton-proton-γ coincidence, the upper-limit of the respective branching ratio being $6{\cdot}10^{-4}$. The absence of any direct particle emission demonstrates the remarkable stability of the (21^+) isomer in ^{94}Ag making it a new textbook example of a high-spin trap.

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High Spin Shape Isomers and Nuclear Jahn-Teller Effect

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High-spin isomers in N=83 isotones have been systematically studied[1]. Their spin-parities are $49/2^+$ and 27^+ for odd and odd-odd nuclei, respectively. Life times of these isomers range between ∼10ns and ∼μs. Excitation energies of high-spin isomers are between 8.5 and 9.0MeV for N=83 isotones with $60 \leq Z \leq 66$. High-spin isomers have stretch coupled configurations breaking a neutron magic 82 core. Resulting configurations are such as $[\nu(f_{7/2}h_{9/2}i_{13/2})\ \pi h_{11/2}{}^2]_{49/2^+}$ for odd nuclei and $[\nu(f_{7/2}h_{9/2}i_{13/2})\ \pi(d^{-1}_{5/2}h_{11/2}{}^2)]_{27^+}$ for odd-odd nuclei. Experimental results were compared with those calculated by a deformed independent particle model (DIPM)[2].

High-spin isomers in N=83 isotones have oblate shape. The deformation parameter β of the high-spin isomer in ^{147}Gd was experimentally determined to be −0.19 based on the measurements of the static quadrupole moment by O. Häusser et al. and E. Dafni et al.[3]. The deformation parameters β of yrast states deduced by the DIPM calculation for N=83 isotones are nearly −0.05 up to the 49/2 state and larger values than −0.16 for yrast states above this spin. This indicates that high-spin isomer may be caused by the sudden shape change from near spherical to oblate shape. These isomers are considered to be shape isomers. It is difficult to understand these high-spin isomers to be K-isomers, although these isomers have large K-quantum number. A hindrance factor F_W is expressed to be $logF_W = 2(|\Delta K| - \lambda)$ by K selection rule[4]. The values of ΔK is 49/2−7/2=21 which leads F_W to be 10^{38}∼10^{40} for λ of 1∼3. As the maximum hindrance factor for observed transitions directly deexciting the high-spin isomers is ∼10^{10}, these isomers do not follow the K-selection rule. Therefore, high-spin isomers in N=83 isotones could be categorized to be high-spin shape isomers. High-spin isomers appeared in N=83 isotones may be good examples of nuclear Jahn-Teller effect[5].

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The problem of superheavy hydrogen isotope ^{6}H

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During a few past years the evidence of existing of superheavy unstable hydrogen isotopes ^{5}H and ^{7}H was obtained [1,2]. So together with the known for a long time ^{4}H, three hydrogen nuclides beyond the neutron drip-line are identified. Rather intriguing their decay energies seem not change strongly with the neutrons number though the accuracy of the data is far from satisfactory. The same can be said about the widths of the ground states, which are known with even less reliability, but the very fact of the observation of the abovementioned nuclides means that they do not exceed ~ 3 MeV. It is natural to revise the question of existing of ^{6}H, whose observation was claimed some time ago [3]. ^{6}H was identified as a broad resonance in an inclusive spectrum of ^{8}B residuals in the $^{7}Li(^{7}Li,^{8}B)$ reaction at E_{lab} = 82 MeV. The $^{6}H \rightarrow {}^{3}H + 3n$ decay energy was determined to be Q = 2.7 MeV and width $\Gamma \sim 1.8$ MeV in accordance with those of the other unstable hydrogen isotopes. Though the result [3] was confirmed in another inclusive experiment [4] some doubts remain, and additional studies of the subject are desirable.

Some non-direct evidence came recently from the calculations [5] of the hypernuclei $^{6}H_{\Lambda}$ mass. Basing on the mass of ^{5}H [1] $^{6}H_{\Lambda}$ is predicted to be stable against neutron emission by a few MeV depending on the role of ΛNN forces. Keeping in mind that the experimental difference $^{4}H - {}^{4}H_{\Lambda}$ is about 4 – 5 MeV, one can expect the similar value for the $^{6}H - {}^{6}H_{\Lambda}$ difference, which is qualitatively consistent with the ^{6}H decay energy observed in [3].

The conclusion is that there are serious arguments in favor of existing of unstable ^{6}H. The proposal of its search using ^{8}He beam is submitted to RIKEN.

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Light exotic nuclei studied with the parity-projected Hartree-Fock method

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The Skyrme-Hartree-Fock (SHF) method has been successful to describe ground-state properties of nuclei for a wide mass region. We have extended the SHF method to describe odd-parity excited configurations in the variation after parity projection procedure (Parity-Projected Skyrme-Hartree-Fock method = PPSHF) [1]. Furthermore, we achieve the angular momentum projection after variation. To solve the self-consistent equation, we employ the imaginary time procedure in the three-dimensional Cartesian mesh representation. In the present formalism, the odd-parity excited configurations can be calculated without any assumptions on the nuclear shape and orbital properties.

The appearance of the cluster structure is intimately related to the correlation energy induced by the restoration of spatial symmetries, especially the spatial inversion. The PPSHF method is capable of describing clustering states of light nuclei. We have obtained the $\alpha{-}^{16}O$ configuration for ^{20}Ne and the 3α for ^{12}C, both in the ground and excited states [1]. Now the method is being applied to exotic nuclei. As an example, we show here even- and odd-parity states in ^{32}Mg nucleus, calculated with the SLy4 parameter set. The calculated spectra are shown in Fig. 1.

We have found nearly-degenerate two solutions with even parity, one of which is deformed in a prolate shape ($\beta \sim 0.4$) and the other is almost spherical ($\beta < 0.1$). Although the deformed even-parity state is slightly higher in energy before the angular momentum projection, the projection brings down the deformed state to the ground state. The ground-state band is qualitatively reproduced in the calculation, although the spin of 4^+ state is not confirmed in the experiment [3]. However, the angular momentum projection seems not to be very successful for the state with a nearly spherical shape. Since the intrinsic state consists mainly of a $J^\pi = 2^+$ component, the low-spin states projected on good J^π (0^+ and 2^+) appear in reversed order in the spectra. Despite of this deficiency in the projection from a "spherical" state, the calculation, at least, may suggest the existence of a low-lying even-parity state.

For the odd-parity sector, we have also found two solutions: The lowest state has a large prolate deformation, $\beta \sim 0.5$, and the other has $\beta \sim 0.25$. The calculation predicts a "superdeformed" rotational band with $K^\pi = 1^-$ whose band head is located around 2.5 MeV in excitation energy (see Fig. 1).

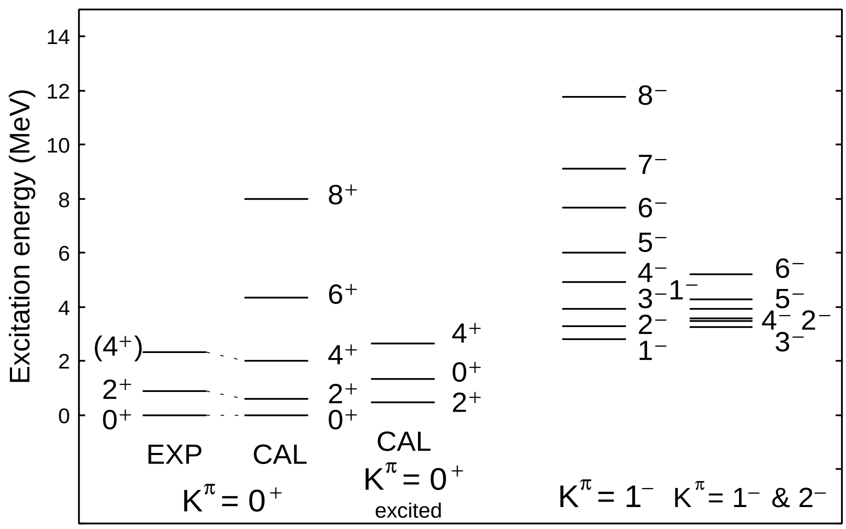

FIG. 1. Calculated and experimental [2,3] spectra in ^{32}Mg.

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Mixed-symmetry states in $^{93}_{41}Nb_{52}$ *

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The simplicity of the assumptions on which the Interacting Boson Model-2 is based does not inhibit it from predicting some remarkable results for collective nuclear excitations. In the IBM-2 [1], valence neutrons and valence protons are distinguishable and coupled in pairs only to angular momentum 0, s-states related to the residual interaction, and to angular momentum 2, d-states related to the quadrupole interaction. One of the great achievements of the IBM-2 was to predict the so-called mixed-symmetry (MS) states by relating symmetry changes to enhanced M1 strength [2]. Recently, MS states have also been explained by means of the more precise shell model [3], where large isoscalar E2 matrix elements have been found between states with MS assignments, and interpreted as states with similar proton-neutron symmetry.

Experimentally, MS states were first identified in the rotational nucleus, ^{156}Gd [4], where the large B(M1;$1^+ \rightarrow 0^+_{gs}$) was identified as the 1^+ scissor mode excitation predicted by Iudice and Palumbo [5] and soon after discovered in a wider range of deformed nuclei [6]. In the vibrational U(5) limit of the IBM-2, the lowest MS states predicted have $J^\pi = 2^+_{1,ms}$ coupled to the first 2^+_1 phonon structure by an M1 transition and have been also identified in the so-called vibrational A$\sim$110 region [7,8]; however, it was not expected that MS states might be identified in nuclei without a clear rotational or vibrational pattern. Nevertheless, MS states have been recently identified in the even-even nuclei $^{92}_{40}Zr_{52}$ [9], $^{94}_{42}Mo_{52}$ [10] and $^{96}_{41}Mo_{52}$ [11]. In order to search for MS states in an odd-A neighbor, $^{93}_{41}Nb_{52}$ was studied at the University of Kentucky with the (n,n'γ) reaction and at the University of Cologne by using the ^{94}Zr(p,2nγ)^{93}Nb reaction. Excitation functions and lifetimes were obtained from the former, whereas spin assignments and mixing ratios were obtained from the latter.

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*This work was supported by the U. S. National Science Foundation under grant No. PHY-0098813.

Triaxiality vs K-quantum number in ^{128}Xe.

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An extended decay scheme for ^{128}Xe has been constructed. Bands have been identified as being built on proposed $K^{\pi}=5^{-}$ and $K^{\pi}=6^{-}$ intrinsic states at 2228.4 keV and 2499.8 keV, respectively, and on a previously assigned $K^{\pi}=8^{-}$ intrinsic state at 2786.3 keV. The half-lives of these states have been measured as 5(1), 6(1) and 73 (5) ns, respectively. Theoretical calculations have been performed using the configuration-constrained blocking method based on a non-axial Woods-Saxon potential. Large variations of γ-deformation and γ-softness are predicted for the ground state and the $K^{\pi}=5^{-}$, $K^{\pi}=6^{-}$ and $K^{\pi}=8^{-}$ two-quasiparticle configurations. The values of the hindrance factors for E1 transitions depopulating the intrinsic states and the rotational behaviour of the bands built on these intrinsic states show that the K-quantum number still influences the decay properties of this largely triaxial nucleus.

γ-ray spectroscopy of the $T = 2$ nucleus ^{22}F

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Because they require a good understanding of interactions involving several major shells, intruder states present a particularly stringent test for nuclear models. The lowest energy intruder configurations are expected when a single particle or hole is promoted across a major shell leading to an opposite-parity state. The gaps between major shells generally lead to a substantial energy cost for cross shell excitations and to relatively high excitation energies for intruder states. However, deformation and some other nuclear structure effects can sometimes reduce the effective shell gaps and lower intruder state energies. A particularly striking example of this reduction is the 109 keV $1/2^-$ state in ^{19}F. While a PSD interaction was adjusted to fit ^{19}F intruder states[1,2], it is still important to investigate how this interaction, and other models, fit isotopes with increasing neutron excess. Prior experiments, using both β^- delayed γ rays, and charge exchange reactions indicate the possibility of three excited states below 1 MeV in ^{22}F[3,4,5,6]. The *s*-*d* shell model using the well-established USD interaction only predicts two, at 192 and 713 keV. The current psd interaction places the first negative parity state at 2322 keV. To investigate the possibility of an extra low-lying state in ^{22}F, we used the reaction of a radioactive, but long-lived, ^{14}C beam with a long-lived radioactive ^{10}Be target.

The experiment was performed at Florida State University, using an enriched $Fe_3^{14}C$ target in a SNICS source to produce the ^{14}C beam. The ^{10}Be target was one of three made by Goosman[7] and was 113 μg/cm^2 thick. The evaporated charged particles were detected using a segmented particle telescope subtending 430 msr at 0° relative to the beam. The prompt γ rays were detected using three four-crystal Clover type detectors and six single particle detectors. It is worth noting that even with the neutron excess of the beam and target, ^{22}F could only be observed through particle-γ and particle-γ-γ coincidences. Analysis of the ^{10}Be(^{14}C,d)^{22}F data reveals many previously unobserved γ rays and several previously unknown levels in ^{22}F and establishes several previously unknown spins. It also verifies the existence of a state at 311 keV which cannot be accounted for in the *s*-*d* model space using the USD interaction. These results will be compared with recent shell model calculations using several different effective interactions. This work was supported in part by the US NSF under Grant No. 0139950 and the state of Florida.

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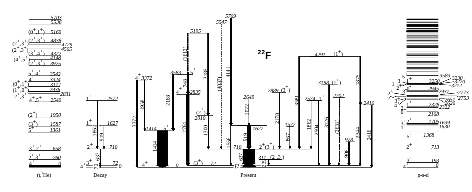

FIG. 1: A summary of ^{22}F from the (t,^{3}He)[4], β^- decay[6], present, and calculations using the psd interaction.

Systematics in the structure of low-lying, non-yrast bandhead configurations of strongly deformed nuclei *

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The systematic application of the pseudo-*SU(3)* model for a sequence of deformed nuclei from the rare earth region that is considered, demonstrates that there is an overarching symmetry that can be used to predict the onset of deformation as manifested through low-lying, non-yrast collective bands. The results show that it is possible to obtain an accurate and unified description of not only the yrast states but also the $K^{\pi} = 2^{+}$ and $K^{\pi} = 0^{+}_{2}$ states, by using a classification scheme based on the occupation numbers in the valence shells. The classification scheme utilizes an overarching *sp(4,R)* algebraic framework. The nuclei considered in this article belong to the $F_0 = 0$ symplectic multiplet of the (50,82|82,126) shell structure.

* Support from the U.S. National Science Foundation, Grant No. PHY-0140300, and the Southeastern Universities Research Association is gratefully acknowledged.

Shape transitions and triaxiality in neutron-rich Y and Nb isotopes

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Intensive studies of shape transitions, shape coexistence and onset of deformations including triaxiality have been carried out in neutron-rich even-even nuclei with A ~ 100[1, 2, 3]. However, there is less published for odd-Z nuclei. Following our work on Rh (Z=45)[4] and Tc (Z=43)[5] we now propose new level schemes of ^{99,101}Y and ^{101,105}Nb based on our fission gamma data accumulated with ^{252}Cf in Gammasphere in 2000.

Quadrupole deformation may peak at N = 60 in the Y (Z=39) isotopic chain and at N = 62 in the Nb (Z=41) chain. Quadrupole deformation decreases with increasing Z between 39 and 45. Pronounced differences in structure are seen between Y and its Nb, Tc, Rh, Ag isotones. Very small signature splitting is observed in ^{99,101}Y, in contrast to the very large ones in Tc, Rh and Ag isotones, with splittings of ^{101,103,105}Nb at intermediate values. The signature splitting indicates triaxial deformation in the Tc, Rh and Ag nuclei[4, 5]. Distinct differences are also seen in moments-of-inertia $J^{(1)}$ and $J^{(2)}$ between Y and Tc, Rh isotones similar to those between Zr and Mo isotones, which was attributed to the triaxial degree of freedom in Mo (Z=42) and axially-symmetric shape in Zr (Z=40) isotopes[3].

A sideband built on an excited $11/2^+$ state with a high excitation of 1654.7 keV is observed in ^{99}Y, and its decay-out transition predominantly feeds the $7/2^+$ level of the yrast band, in contrast to the low excitation and very small E2 strength in Tc, Rh and Ag isotopes[4, 5]. The latter was ascribed to triaxiality in Z = 43 – 47 isotopes. It is suggested that Y isotopes have axial symmetry, while there is triaxiality in Tc, Rh and Ag, with Nb isotopes having an intermediate transitional structure with regard to triaxial deformation.

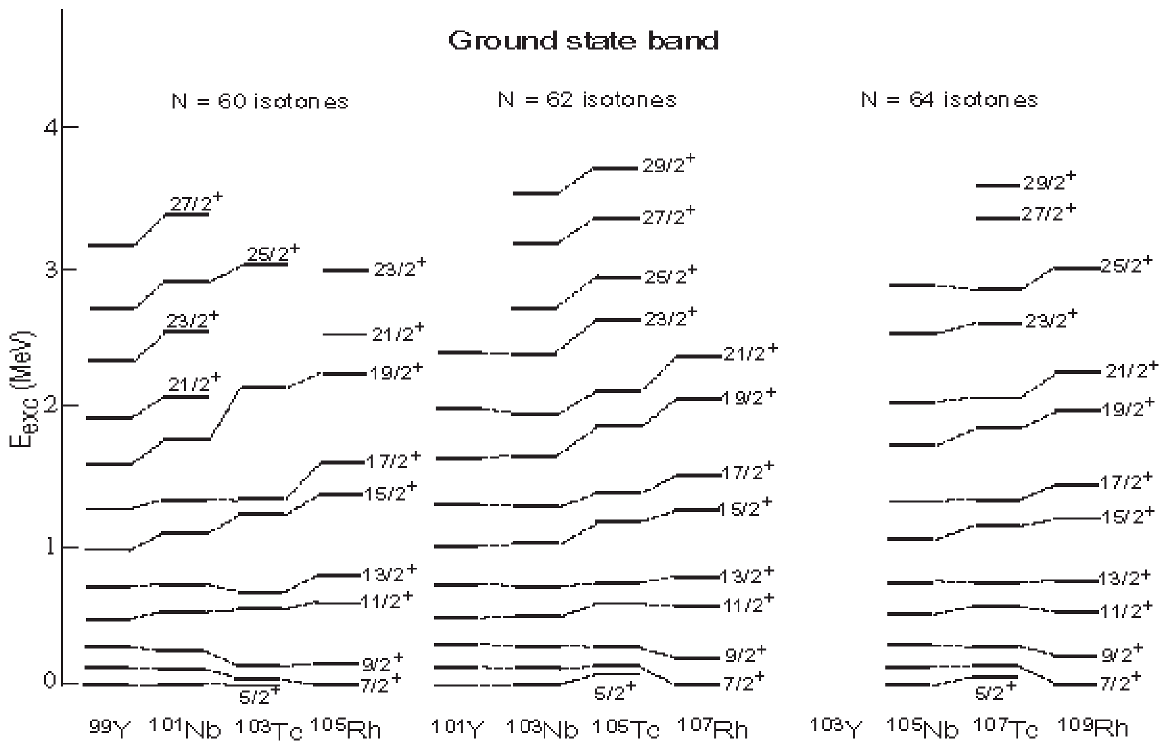

FIG. 1. Level systematics of the ground state bands in N = 60, 62 and 64 isotones with Z = 39 – 45.

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*This work was supported by the U.S. Department of Energy under Grant No. DE-FG05-88ER40407 and Contract Nos. W-7405-ENG 48, DE-AC03-76SF00098, and DE-AC07-99ID13727.

Triaxiality in neutron-rich Tc and Rh isotopes

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Shape transition and coexistence are of current interest for neutron-rich nuclei with $39 \le Z \le 47$. Study of triaxiality has drawn much recent attention. The $g_{9/2}$ proton and $h_{11/2}$ neutron orbitals are especially involved, and their interplay results in rich structure, implying various nuclear shapes, including triaxiality.

High-spin level schemes of neutron-rich odd-Z nuclei in this region have been proposed by our GANDS2000 collaboration based on our fission gamma data accumulated with Gammasphere in 2000. Especially in Tc, Rh and Ag has the even-parity system revealed collective band families and gamma-transition branching ratios indicative of triaxial shapes. Bands built on various even-parity proton orbitals, including intruder orbitals from the major shell above, and band crossings related to $h_{11/2}$ neutron-pair alignment are observed in Tc and Rh.

Triaxial-rotor-plus-particle model calculations performed with $\beta = 0.34$ and $\gamma = 22.5^0$ on the prolate side of maximum triaxiality yielded the best reproduction of the excitation energies, signature splittings and branching ratios of the Tc isotopes (see figure below). The calculations gave the best fit to those of Rh isotopes at near maximum triaxiality with $\gamma = 28^0$. A side-band built on an excited $11/2^+$ state with low excitation energy predominantly feeding the $9/2^+$ state of the yrast band also provides evidence of triaxiality in Tc, Rh and Ag isotopes. The E2 strength to the $7/2^+$ is mainly dictated by the diagonal E2 reduced matrix element, which vanishes for $\gamma = 30^0$.

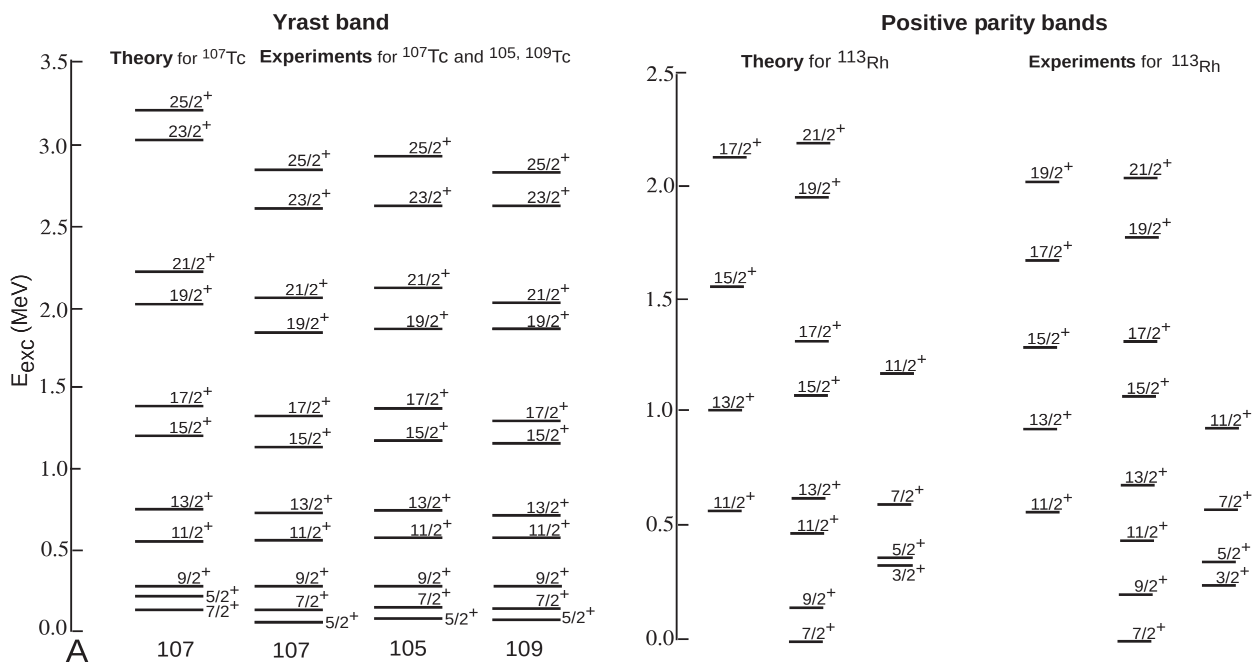

FIG. 1. Fits of the yrast bands in Tc and positive-parity bands in Rh isotopes by triaxial-rotor-plus-particle model.

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*This work was supported by the U.S. Department of Energy under Grant No. DE-FG05-88ER40407 and Contract Nos. W-7405-ENG 48, DE-AC03-76SF00098, and DE-AC07-99ID13727.

Discovery of a new 2.5 s isomer in the neutron rich nucleus ^{174}Tm*

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Nuclei far from stability are produced at the ISAC facility sited at TRIUMF using 500 MeV proton-induced reactions on ^{181}Ta targets. The exotic nuclei thus produced are extracted using a surface ionization source, and accelerated to an energy of 30 keV. A high resolution mass analyzer separates species with different mass number , which are then transported to the experimental stations such as the 8π γ-ray spectrometer. The 8π γ-ray spectrometer is an array of 20 Compton suppressed high purity Germanium detectors. When coupled with the moving tape transport facility it serves as a powerful tool to study levels populated in the decay of nuclei far from stability.

The close proximity of high-K states near the Fermi surface of the neutron rich A=170-190 nuclei makes this region very attractive to search for high-K isomers. Nilsson-BCS calculations[1] do predict low lying intrinsic states with large K-values. We report here the discovery of a 2.5 sec isomer in the neutron rich ^{174}Tm nucleus. The A =174 beam was implanted onto a moving tape transport facility, with beam-on/beam-off cycling times of 2s/2s, 3s/3s, 10s/10s and 100s/50s. Gamma-rays emanating from the implanted radioactivity are detected with the 8pi array. The data were sorted off-line into two fold γ–γ and γ–time matrices. The prominent γ-rays observed in the spectra had energies of 100 keV and 152 keV and were known from a previous β–decay study of ^{174}Er [2], which has a half life of 3.3 min. Interestingly, in the present experiment, from the γ–time matrices a half life of 2.5 s could be deduced for these two γ-transitions. The short half life coupled with the high intensity of the two γ–transitions, and compared to the intensity of levels populated in the β–decay study of ^{174}Er [2], establishes that the origin of 2.5 s half life arises from an isomer in ^{174}Tm. Fully aligned proton-neutron orbitals giving rise to an 8^- state are predicted in ^{174}Tm [2], which can be a candidate for the new isomer. The observation of the 100 keV and 152 keV γ–transitions in the ^{174}Tm isomer decay as well as the ^{174}Er [2] β–decay, gives rise to a interesting scenario about the existence of a β–decaying high spin isomer in ^{174}Er .

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*This work was supported by the EPSRC, UK, NSERC, Canada, Brookhaven Technology Group, USA, U.S. Department of Energy.

Structure of doubly-even Cd nuclei studied by β^- decay*

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Even-mass Cd nuclei have an interesting structure that is indicative of the coexistence of quadrupole anharmonic vibration and proton particle-hole intruder excitations. The quadrupole vibration character of Cd nuclei is fulfilled by observations of multiphonon states and the one quadrupole phonon transition strengths (*e.g.* Refs. [1-3]), in accordance with the quadrupole vibrator model. On the other hand, the (^{3}He,n) two-proton transfer reaction measurements on ^{108}Pd and ^{110}Pd targets have shown the evidence of proton-pair excitations across the major shell gap [4]. These are followed by the observation of a rotational-like intruder band built on top of the probable 2*p*-4*h* 0^+ state in doubly-even ^{110}Cd to ^{116}Cd nuclei (*e.g.* Ref. [5]). The low-lying level structures of near neutron midshell nuclei ^{112}Cd and ^{114}Cd are thus well described by employing a configuration mixing of the quadrupole anharmonic vibration and intruder excitations [6].

The structures of doubly-even $^{116\text{-}120}$Cd nuclei have been recently studied at the IGISOL facility of the University of Jyväskylä, by β^- decay of neutron-rich Ag isotopes [7,8]. The on-line mass-separated Ag activities were produced by 30 MeV proton induced symmetric fission of natural uranium and the ion-guide technique. The existence of a higher-spin β-decaying isomer in doubly-odd Ag isotopes allows for the population of the low and medium-spin states in Cd daughter nuclei. The new data have extended the available systematics for the three-phonon states to more neutron-rich Cd nuclei, see Fig. 1.

For continuation of these studies, new experiments are in progress at IGISOL in Jyväskylä and at ISOLDE, CERN. These experiments are aimed at the structures of more neutron-rich doubly-even $^{122\text{-}128}$Cd nuclei by β^- decays of Ag isotopes using different spectroscopic setups. These detailed studies will extend the knowledge of two and three-phonon multiplets and intruder states to the heaviest Cd isotopes up to ^{128}Cd.

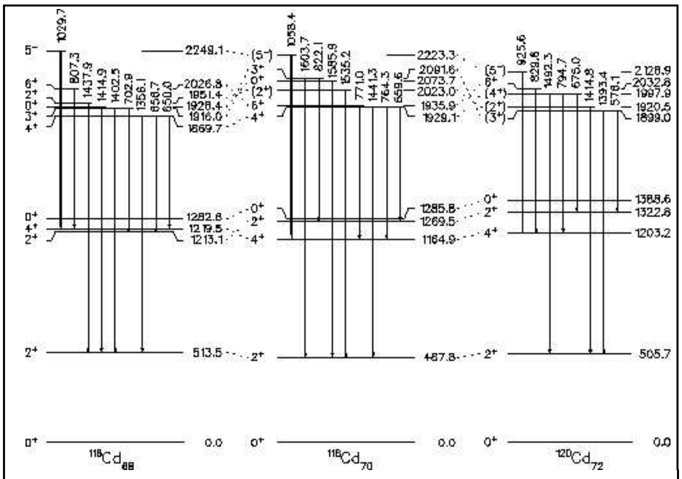

Fig. 1. The three-phonon states in ^{116,118,120}Cd nuclei populated in β^- decay.

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*This work has been supported by the Academy of Finland under the Finnish Center of Excellence Program 2000-2005 (Project No. 44875, Nuclear and Condensed Matter Programme at the JYFL)

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Using high-spin data to constrain spin-orbit term and spin-fields of Skyrme forces: The need to unify the time-odd part of the local energy density functional*

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In this work we want to pursue a novel method to study the ℓs-potential. It has it's roots solely in high-spin physics [1] and is based on a direct comparison of excitation energies of terminating states [maximum-spin states within a given single-particle configuration] for two selected configurations. Herein we will demonstrate the reliability of the concept for $A{\sim}40$, $20 \leqslant Z < N \leqslant 24$ nuclei. The configurations of interest are $d_{3/2}^{-1} f_{7/2}^{n+1}$ and $f_{7/2}^{n}$. The difference, E, between the excitation energies of these two terminating configurations is dominated by the size of the magic gap 20 which, in turn, is governed by the strength of ℓs-potential. Within the Skyrme-Hartree-Fock (SHF) approach which is used here, E depends also on time-odd fields, in particular spin fields. Within the SHF, the strength of these fields is almost purely accidental. Indeed, an unification of them (see [2]) leads to a relatively consistent description of E for various Skyrme forces as shown in Fig. 1. The remaining discrepancy, Fig. 1, which is still at the level of ∼10% (except for SkM* and SkP forces where it reaches unacceptable level) signals most likely problems pertaining to the ℓs-potential and can be used to adjust its strength.

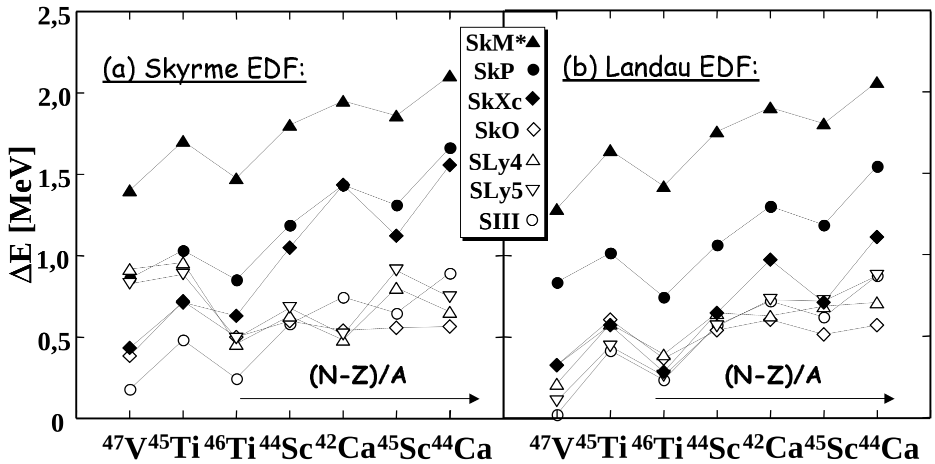

FIG. 1: Calculated energy differences for terminating states $\Delta E_{th} = E[d_{3/2}^{-1} f_{7/2}^{n+1}] - E[f_{7/2}^{n}]$ relative to the experimental data $\Delta E \equiv \Delta E_{exp} - \Delta E_{th}$. Left panel shows SHF calculations for various parametrizations while right part illustrates calculations using an unified description of the spin fields, see Refs. [1],[2].

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* This work was supported by the Polish Committee for Scientific Research and by the Göran Gustafsson Fundation.

Particle-Core Coupling in the Transitional Proton Emitters ^{145,146,147}Tm*

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In recent years, proton emitters have become a testing ground for nuclear structure far from the line of stability. The discovery of the deformed proton emitters ^{131}Eu and ^{141}Ho [1] and the proton-decay fine structure in ^{131}Eu [2] initiated detailed studies of the role of deformation in proton decay. The observation of excited states in ^{141}Ho elucidated the role of the Coriolis interaction in proton decay [3].

In this work, excited states in the moderately deformed proton emitters ^{145,146,147}Tm were studied using the Recoil-Decay Tagging method. Prompt γ rays were detected in the GAMMASPHERE Ge array. The γ rays were tagged by proton decays observed in a Double-Sided Si Strip Detector placed at the focal plane of the Argonne Fragment Mass Analyzer. Excited states in ^{147}Tm have been studied previously using a modest Ge array [4]. Due to a much larger γ detection efficiency the ^{147}Tm ground-state band was significantly extended and evidence was found for the unfavored signature partner band. The ^{146}Tm proton emitter exhibits a complex proton-decay level scheme. At least 4 proton lines have been associated with this nucleus [5]. In this work prompt γ-ray spectra correlated with the individual ^{146}Tm proton lines were obtained. The ^{145}Tm ground state decays primarily to the 0^+ ground state in the daughter ^{144}Er. A branch to the 2^+ state has been observed recently [6]. The cross section for producing ^{145}Tm is about 200 nb. The ^{145}Tm half-life is only 3 μs. To avoid pileup of protons with implants, fast delay-line amplifiers were developed. They allowed the observation of protons with decay times as short as 1 μs. As a result, the ground-state band was clearly observed in ^{145}Tm. In addition, coincidences between the proton fine structure line and the $2^+ \rightarrow 0^+$ γ-ray transition in ^{144}Er were detected at the focal plane of the FMA. This is the first time that coincidences between proton decays and γ rays have been seen.

The calculated deformation changes rapidly from oblate in ^{147}Tm (β_2=-0.18) to prolate in ^{145}Tm (β_2=0.25) [7]. On the other hand, the ^{145}Tm proton-decay rate and the branching ratio to the 2^+ state have been reproduced using the particle-vibrator model [8]. The decay rates in ^{147}Tm are consistent with the assumption of spherical shape. The dominant γ-ray sequences feeding the ground states in ^{147}Tm and ^{145}Tm have properties of decoupled $\pi h_{11/2}$ bands. The yrast sequence observed in ^{146}Tm resembles the ground-state band in ^{147}Tm. The energies of the $15/2^- \rightarrow 11/2^-$ transitions indicate deformation lower than calculated for both ^{145}Tm and ^{147}Tm. The $E(19/2^-)/E(15/2^-)$ ratio, equivalent to $E(4^+)/E(2^+)$ for the even-even core, is about 2.5, which is characteristic of a γ-soft rotor, and is greater than 2.2 for a typical harmonic vibrator, but below the rotor value of 3.33. This suggests an alternative way of viewing the proton decay in ^{145,146,147}Tm as emission of the $h_{11/2}$ proton aligned with the angular momentum of the γ-soft deformed core. Different scenarios can be described in the frame of the core quasi-particle coupling model and compared with the data.

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*This work supported by U.S. DOE under Contract No. W-31-109-ENG-38

Symmetry of randomly interacting fermions and bosons *

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The quantum many-body system is one of the most interesting topic in physics. One of the most useful ways to study it is to apply the matrix comprised of random numbers as the Hamiltonian matrix. Recently, C.W. Johnson and his collaborators discovered the "$J=0$ dominance" [1] of ground states for even-even nuclei by random two-body interaction, and the study of random interaction becomes more fascinating topic.

The $J=0$ dominance means that the angular momentum, J, of the ground state of even-even nuclei obtained by a random Hamiltonian matrix favors zero, although the subspace having $J=0$ is very small in comparison with the entire Hilbert space. All the realistic even-even nuclei are known to have $J=0$ ground states experimentally, and its origin is considered to be the pairing correlation and time reversal symmetry. However, the random interaction without time reversal symmetry was shown to reproduce the $J=0$ dominance [2]. This result shows that the case of random interaction is very different from the case of realistic nuclei, and the origin of the $J=0$ dominance has not yet been understood clearly in spite of many efforts. We aim to discuss the properties of ground states obtained by the random matrices, and to reveal the origin of $J=0$ dominance.

It was appeared that the ground states tend to have not only spin-0, but also isospin-0 and parity-positive [3,4]. The ground states provided by the random matrices seem to favor the highest symmetries. We discuss how these symmetries occur and, in addition, the difference between the case of fermion system and the one of boson system. According to our work, many terms of random interactions mix with each other and cause quantum chaotic mixing [5]. We report the relation between the quantum chaotic mixing and the symmetries which the ground states obtained by the random interactions have.

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*This work was supported by a Grant-in-Aid for Specially Promoted Research (Grant No. 13002001) from the Ministry of Education, Science and Culture in Japan.

Effective Operators in the NCSM Formalism

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No-core shell model (NCSM) calculations using *ab initio* effective interactions are very successful in reproducing the experimental nuclear spectra [1, 2]. While a great deal of work has been directed toward computing effective interactions from bare nucleon-nucleon (NN) and three-nucleon forces, less progress has been made in calculating the effective operators. Thus, except for the relative kinetic energy, the proton radius, and the NN pair density, all investigations have used bare operators (e.g., Refs. [1, 2]). We apply the Lee-Suzuki procedure [3] to general transition operators, investigating the importance of the approximations involved. In particular, we concentrate on the validity of the two-body cluster approximation, by performing calculations in restricted model spaces.

I.S. and B.R.B acknowledge partial support by NFS grants PHY0070858 and PHY0244389. The work was performed in part 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. P.N. received support from LDRD contract 04-ERD-058. C.W.J. acknowledges support by USDOE grant No. DE-FG02-96ER40985.

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Study of the $N = 77$ Isotones Near the Proton Drip Line *

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The odd-odd $N = 77$ isotones near the proton drip line are located in the region of expected deformation changes between the prolate and oblate shapes. Some of these nuclei might have non-axial shapes and chiral bands[1,2]. An unbound $N = 77$ isotone ^{146}Tm is the only known odd-odd nucleus exhibiting fine structure in proton emission[3,4]. The structure of low-energy states is governed by the $s_{1/2}$, $d_{3/2}$, and $h_{11/2}$ orbitals close to the Fermi surface - the same orbitals for neutrons and protons for these proton-rich nuclei.

Our studies of the $N = 77$ isotones, a first one on ^{140m}Eu[5] and the following ones on ^{142m}Tb and ^{144m}Ho, were focused on structure resulting from the proton-neutron coupling. Studies on these nuclei were also done by other groups[2,6,7]. In all of these studies, including ours, the spin and parity assignments were not certain. In some cases they differed from one another.

The present experiments at the Recoil Mass Separator (RMS) at Oak Ridge National Laboratory (ORNL) are aiming at a determination of the multipolarities of the transitions following the isomeric decays. The measurements utilized the high-resolution conversion electron spectrometer BESCA with a 5 mm thick, LN2 cooled, SiLi crystal, one LOAX detector, and two segmented Ge clover detectors. All the detectors were mounted around a moving tape. A thin, 0.001 inch, Cu degrader was placed just before the tape to prevent deep ion implantation in the tape material. This minimizes the amount of energy an electron will have to loose before reaching BESCA. It was a first use of BESCA facing the recoil implantation point at the RMS final focus. The digital electronics[8] allowed us to reduce the blocking of the electron detection caused by the radiation flash occurring during the implantation of energetic recoils into the tape. The data will be presented with a discussion of the evolution of p-n states in this region.

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*This work was supported by the U. S. Department of Energy under contract numbers DE-AC05-00OR22725, DE-FG02-96ER40983, DE-FG05-88ER40407, DE-FG02-96ER40978, DE-FG02-96ER41006, and DE-AC05-76OR00033.

Chirality in real nuclei *

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Chirality in nuclear rotation is a novel collective feature predicted for odd-odd nuclei from angular momentum coupling considerations [1]. Many theoretical and experimental efforts have been dedicated to the study of that interesting phenomenon. In the work [1], it is pointed out that the rotation of triaxial nuclei may lead to the appearance of chiral doublet bands. Interacting boson fermion-fermion model calculations [2] also reproduced well the level schemes of the chiral candidates, as for instance these in ^{134}Pr. In addition, crucial experimental observables for the understanding of nuclear structure and for checking the reliability of the theoretical models are the electromagnetic transition probabilities.

For the first time, the lifetimes of the levels of the doublet bands in ^{134}Pr were measured by means of the recoil-distance Doppler-shift and Doppler-shift attenuation methods using the multidetector array Euroball and Cologne coincidence plunger device. The excited states of ^{134}Pr were populated via the reaction ^{119}Sn(^{19}F,4n)^{134}Pr at a beam energy of 88 MeV. We have used advanced methods [3,4] for the analysis of the γ-ray line-shapes observed in RDDS and DSAM measurements of nuclear lifetimes. In the case of the RDDS measurement, the finite slowing-down time of the recoils in the stopper was taken into account in the lifetime determination. Ten lifetimes in the g.s.b. and five in the second chiral candidate band were determined.

These are the first experimentally obtained absolute transition strengths which allow a check of the existence of chirality of nuclear rotation. For both B(M1) and B(E2) values, the obtained experimental absolute transition strengths are in qualitative agreement with the predictions of the theory of Döenau and Frauendorf. In this theory, the left- and right-handed solutions give rise to two near degenerate ΔI = 1 bands of the same parity with suppressed electric quadrupole transitions between them [5]. The behavior of these strengths with spin is also very similar in the two chiral bands. Thus, chirality in nuclear rotation is confirmed for the first time by the experimental electromagnetic transition strengths.

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*This research has been supported by a Marie Curie Fellowship of the European Community programme IHP under contract number HPMF-CT-2002-02018.

First observation of a scissors mode to γ-band decay in ^{164}Dy *

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Since the discovery of a scissors-like counter-oscillation of valence protons against valence neutrons, the scissors mode (SM) [1,2,3], in the rotational nucleus ^{156}Gd [4], a decay of this excitation to the γ-band was never observed in well-deformed rotors. Thus, the question was left unanswered whether such decay is forbidden due to its two-phonon transition character (annihilation of the SM and excitation of a γ-vibration), or it is allowed as it is even predicted in the algebraic IBM [3].
A puzzling situation with ambiguously placed γ-transitions was left for ^{164}Dy in the early 90's [5,6,7], as it is depicted in Figure 1. Some γ-transitions that were observed might have been transitions from a main SM fragment to the 2^+_γ state, and from a so far unobserved state.

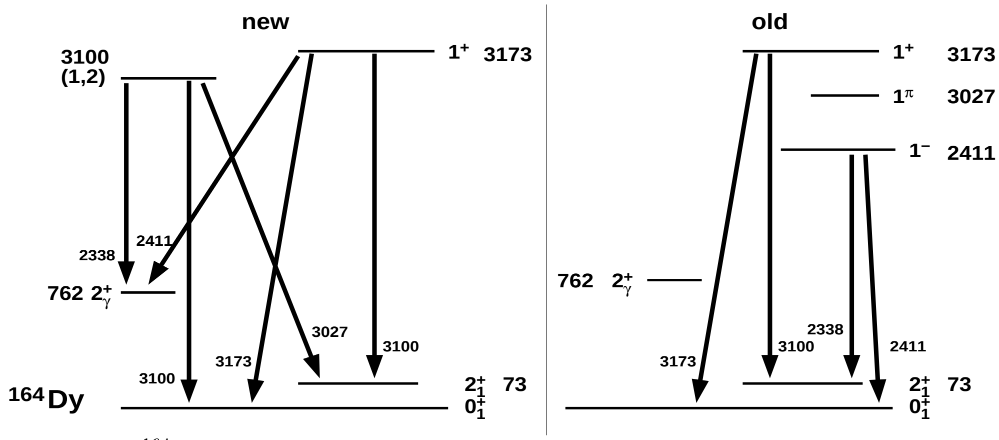

FIG. 1. Part of the ^{164}Dy level scheme. The left hand side shows the placement of γ-rays and levels due to the new data. On the right hand side the so far ambiguous placements are shown.

The unique features of a free electron laser (FEL) as monochromacity, high photon flux, and complete polarization, recently brought this technique also into discussion for future plans involving stored ion beams at the GSI. The existing FEL at Duke University was used for an experiment that proves, in combination with data from a traditional highly sensitive (γ,γ') experiment at Stuttgart University, the existence of a decay of the SM to the 2^+_γ state, and the existence of an additional, very short-lived state, probably 2^+, around the excitation energy of the SM of roughly 3 MeV.

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*This work was supported by the DFG under contracts Br799/11-1, Kn153/31-2, and Pi 393/1-2.

Pairing effects on the collectivity of quadrupole states around ^{32}Mg

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The observations of the anomalous $E2$ properties in neutron rich $N = 20$ nuclei, the large $B(E2)$ values and the low excitation energies in ^{32}Mg and ^{30}Ne [1,2], are clear evidences of the vanishing of the $N = 20$ shell closure. These anomalous $E2$ properties are usually explained by deformation effects, however the experimental evidence is not well established. The energy ratios of the first 4^+ and 2^+ states, $E(4_1^+)/E(2_1^+)$, are 3.0 in ^{24}Mg and 3.2 in ^{34}Mg [3], and these values are very close to the rigid rotor limit 3.3. On the other hand, the ratio is 2.6 in ^{32}Mg, and this value is in between the rigid rotor limit and the vibrational limit 2.0. Moreover, the $B(E2)$ value 15.0 ± 2.5 (in single-particle units) in ^{32}Mg [1] is smaller than the values in other deformed Mg isotopes, 21.0 ± 5.8 in ^{24}Mg and 19.2 ± 3.8 in ^{34}Mg [4].

The purpose of this study is to emphasize the importance of neutron pairing correlations. Generally speaking, neutron 2p-2h configurations across the $N = 20$ shell gap can originate not only from deformation, but also from neutron pairing correlations. The shell model calculations have shown the importance of neutron 2p-2h configurations to describe these anomalous $E2$ properties [5]. It was not clear, however, which effect is more essential. We have performed Skyrme-HFB plus selfconsistent QRPA calculations for the first 2^+ states in $N = 20$ isotones including neutron rich ^{32}Mg and ^{30}Ne [6]. Spherical symmetry is imposed to emphasize the roles of neutron pairing correlations. The $B(E2)$ values and the excitation energies are well described not only qualitatively but also quantitatively with the experimental results. If the neutron pairing is dropped, we cannot get the correct $E2$ properties.

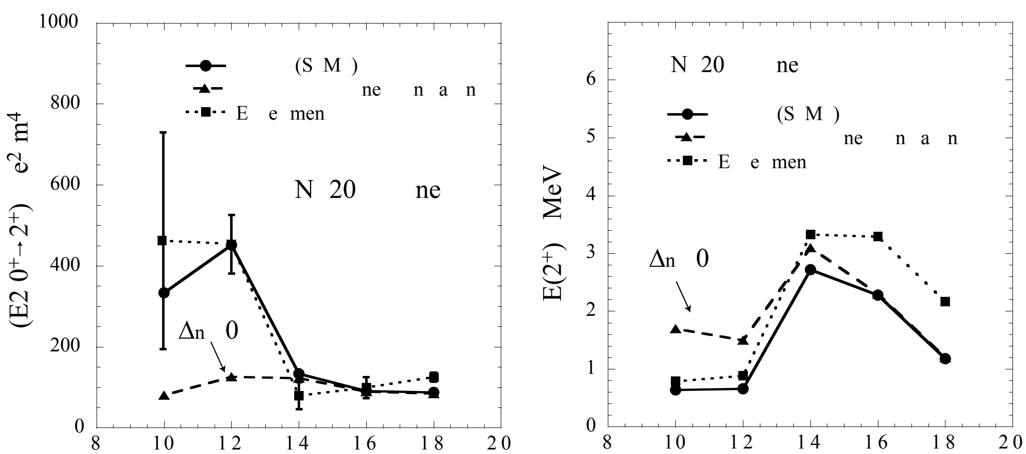

Figure 1: The $B(E2, 0_1^+ \to 2_1^+)$ values and the excitation energies of the first 2^+ states in $N = 20$ isotones calculated by Skyrme-HFB plus selfconsistent QRPA with/without neutron pairing correlations. The available experimental data are also shown [1,2].

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Microscopic Structure of Negative-Parity Vibrations built on Superdeformed States in Sulfur Isotopes close to the Neutron Drip Line

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New features, such as neutron skin and shell structure near the continuum, of unstable nuclei close to the neutron drip line are nowadays under active discussions both theoretically and experimentarily. Because properties of low-frequency collective vibrational modes are quite sensitive to surface effects and details of shell structure, we expect that new kinds of collective excitations might emerge under such new situation of nuclear structure. We have been investigating such possibilities by means of the selfconsistent RPA based on the Skyrme-Hartree-Fock (SHF) mean-field. Although such RPA calculations for unstable nuclei are available, most of them are restricted to the case of spherical nuclei and low-frequency RPA modes in deformed unstable nuclei remain largely unexplored. In order to clearly see the deformation effects, Inakura et al.[1] investigated properties of negative-parity collective excitations built on superdeformed (SD) states in neutron-rich Sulfur isotopes by means of the the mixed representation RPA[2], and found many low-energy modes possessing strongly enhanced mass octupole transition strengths. Quite recently, we have made a detailed analysis of microscopic structure of these negative-parity excitations with the use of the deformed Woods-Saxon potential and the conventional A, B matrix formulation of the RPA in the Cartesian coordinate mesh representation[3], and found a number of new features of these excitation modes. Figure 1 illustrates one of the interesting example: In the neutron drip-line nucleus ^{50}S, the large mass-octupole transition strength is caused by a specific particle-hole excitation consisting of a resonance-like neutron particle near the centrifugal barrier top and a weakly bound neutron hole. Due to the dominant contribution from the region outside of the root mean-square radius, this specific particle-hole excitation has a large matrix element and brings about the enhancement of the transition strength.

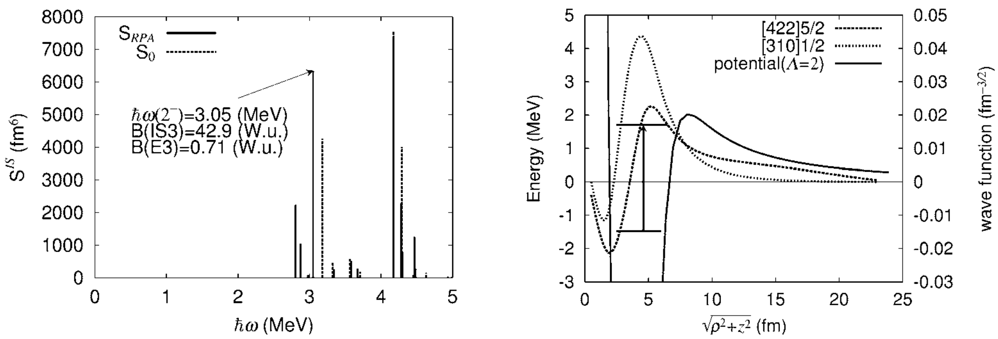

Figure 1: Left: Mass octupole strengths (intrinsic transition matrix elements squared) obtained in the RPA calculation for $K^{\pi} = 2^{-}$ excitations on the SD ground state of ^{50}S. The solid and dotted bars indicate the RPA and unperturbed particle-hole strengths, respectively. Right: A particular neutron particle-hole excitation near the barrier contributing to the strongly enhanced transition strength of the $K^{\pi} = 2^{-}$ state at 3.05 MeV. The particle and hole states are labeled by asymptotic quantum numbers. Their wave functions are drawn by dotted curves. The solid curve denotes the neutron single-particle potential including the centrifugal barrier for $\Lambda = 2$.

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Shell model study of nuclei around mass 130 in the pair-truncated model

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Nuclei around mass $A = 130$ have many interesting features such as high-spin isomers, backbending phenomena, even-odd energy staggering of quasi-γ band caused by a soft triaxial deformation, and features recently referred to as "chiral doublet bands". Moreover, the beta-decay rates in this region provide us with necessary information for predicting the abundance of nuclei in the environment of super-nova explosions. The nuclei in this region are neither vibrational nor rotational. Thus it is very difficult to treat them in terms of conventional mean field theories. Therefore, theoretical studies of the even-even nuclei with $A \sim 130$ were carried out in terms of the various collective models.

The properties of the even-even nuclei in the $A \sim 130$ mass region are discussed by Casten and von Brentano [1], where these nuclei are well described by the O(6) dynamical symmetry of the IBM-1 Hamiltonian. Furthermore the low-lying states in these nuclei were extensively studied in terms of the IBM-2 [2,3], and the energy spectra and electromagnetic transitions were also well approximated in the O(6) dynamical symmetry of the IBM Hamiltonian. However, the model has deficiencies that structure of pairs is fixed irrespective of dynamics and that the contribution of single-particle energies is a constant.

Recently, we have carried out systematic studies for Xe, Ba, Ce and Nd isotopes within the framework of the *SD* version of the pair-truncated shell model [4]. This calculation uses the single particle orbitals $0g_{7/2}$, $1d_{5/2}$, $1d_{3/2}$, $0h_{11/2}$ and $2s_{1/2}$ for both neutrons and protons, and the pairing plus quadrupole type interactions are employed. It is found that energy spectra of the yrast and quasi-γ are nicely reproduced along with interband and intraband $E2$ transitions. The results of this calculation will be presented and discussed.

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First Coulomb Excitation Experiment Using Odd-A Neutron-Rich Radioactive Beams *

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To extend the scope of our Coulomb excitation (Coulex) experiments [1] using neutron-rich radioactive ion beams (RIBs), we recently carried out the first Coulomb excitation experiment using odd-A neutron-rich RIBs. Coulomb excitation of odd-A and odd-odd nuclei is in general more difficult than that of an even-even nucleus. The non-zero spin of the ground state in an odd-A nucleus results in a much more complicated level structure, B(E2) strength is fragmented in an odd-A or odd-odd nucleus, and excitations of interest often involve unstretched E2 transitions. Such complications add additional changes to experiments involving RIBs. However, it is important that we expand our neutron-rich RIBs Coulex studies to odd-A and odd-odd nuclei. This is because odd-mass nuclei often can provide unique information on nuclear structure that cannot be obtained from even-even nuclei.

As the first experiment to Coulomb excite an odd-A radioactive beam, we took a 400-MeV A=129 radioactive beam provided by the Holifield Radioactive Ion Beam Facility, and bombarded it onto ^{50}Ti targets with thicknesses of 1 and1.5 mg/cm^2. The CLARION Ge detector array was used to detect the γ rays, the Hyball CsI detector array (absorbers removed) was used to detect scattered beams and recoiling target ions, and a Bragg detector was used to monitor the beam composition. Doppler corrected (event-by-event) γ rays that are correlated with the ^{50}Ti ions are shown in Figure 1. Almost all peaks in this spectrum can be identified as in ^{129}Te or ^{129}Sb, which are the main components of the mixed beam. Gamma-gamma coincidence data also indicated presence of new levels in ^{129}Te that were not previously established. Preliminary data analysis yielded a B(E2, $7/2^+ \rightarrow 11/2^+$) in ^{129}Sb (ground state I^π = $7/2^+$) that is about ten times smaller than the B(E2, $0^+ \rightarrow 2^+$) values in its even-even neighbors. Data are also being analyzed to extract B(E2)'s of about 10 other transitions (both stretched and unstretched E2 transitions) in ^{129}Sb and ^{129}Te. The results from the present experiment, as well as the planned future experiments to Coulex odd-A and odd-odd neutron-rich RIBs, could provide fresh insight to our understanding of nuclear structure near ^{132}Sn, especially concerning the coupling of single-particles to corresponding even-even cores.

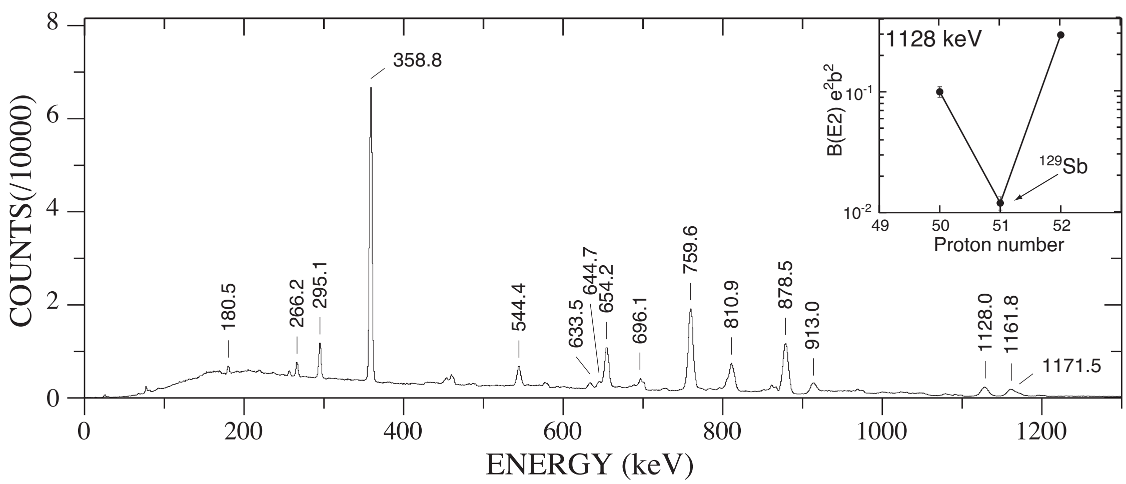

FIG. 1. Spectrum of gamma rays in coincidence with the ^{50}Ti target recoils from the Coulomb excitation of A=129 neutron-rich RIBs. The inset shows the preliminary B(E2, $7/2^+ \rightarrow 11/2^+$) value deduced for the 1128-keV transition in ^{129}Sb compared to the B(E2, $0^+ \rightarrow 2^+$)'s [2] in its even-even neighbors.

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*This work was supported by the U.S. OE under contracts DE-AC05-76OR00033

Simplified Expressions for Pair Transfer, especially N=Z Nuclei

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In the single j shell approximation a wave function of a state of total angular momentum I in an even-even Ti isotope can be written in terms of a column vector with entries D(J_p,J_n) where D is the probability amplitude that the protons couple to angular momentum J_p and the neutrons to J_n. For I = 0 which we here consider $J_p = J_n =$ J. We address the problem of obtaining the number of n-p pairs in a given Ti isotope with angular momentum J_a, where J_a can range from zero to 2j. Normally, to get an expression for the number of n-p pairs we require a 9j symbol to bring together the neutron and the proton, as well as coefficients of fractional parentage to single out one neutron from the rest. However, we can with some tricks get the following simplified expressions for the members of n-p pairs for a Ti isotope with n neutrons, using any isospin conserving 2 body interaction:
For $T = T_{min} = (N - Z)/2$

Number of pairs($J_a = 0$) = 2 D(0,0)^2/n   Number of even pairs = n-1

For $T = T_{min} + 2$

Number of pairs($J_a = 0$) = 2 n D(0,0)^2 Number of even pairs = 2n

(The corresponding numbers for odd pairs are (n+1) and zero).

For an N = Z nucleus e.g. radioactive ^{44}Ti we find number of n-p pairs with even angular momentum J_a = D(J_a,J_a)^2 where for ^{44}Ti J_a can be 0,2,4, or 6. This is the same as the number of nn pairs and of pp pairs.

As an example for ^{44}Ti, using an interaction obtained for the spectrum of ^{42}Sc, the values of D(J,J) for J = 0,2,4 and 6 are respectively 0.7878, 0.5617, 0.2208 and 0.1234.

If we had no interaction the average number of J_a pairs for J_a = 0 to 7 would be respectively 0.750, 0.432, 0.861, 0.902, 0.750, 1.000, 0.639 and 0.667. However, with an interaction obtained from the spectrum of ^{42}Sc the corresponding values are 1.862, 0.675, 0.946, 0.271, 0.146, 0.159, 0.046, 1.895

We see that the interaction enhances the number of pairs with J_a =0,1,2 and 7 and depletes the number of pairs with J_a = 3,4,5 and 6 (total number of pairs must be 6).

Counting pairs is of course important for 2 nucleon transfer reactions, and for determining, for example if there is J = 1 T = 0 pairing in N = Z nuclei. We find the following interesting relation for $T = T_{min}$

$$D(00) = \frac{n}{(2j+1)} \sum_J D(JJ)(j^{n-1}jj|\}j^n J)\sqrt{(2J+1)} \tag{1}$$

Collaborators on these works include E. Moya de Guerra, A. Raduta, P. Sarriguren, A. Escuderos, S.J.Lee and A. Mekjian.I acknowledge grant support DOE-FG01-04ER04-02.

Fission
and
Superheavy Elements

Posters - Heavy Elements and Fission

Number/Session	Name/email	Institution	Title
141/ Tuesday	Adamyan, Gurgen adamian@thsun1.jinr.ru	Bogoliubov Lab. of Theoretical Physics	Possibilities of production of new heaviest nuclei
148/ Tuesday	Gridnev, Konstantin gridnev@nuclpc1.phys.spbu.ru	St.Petersburg University	Alpha-particle correlations and nuclear binding energies
144/ Tuesday	Kadmensky, Stanislav kadmensky@phys.vsu.ru	VSU	Quantum Dynamics and P-odd, P-even and T-odd Correlations for Binary and Ternary Fission
145/ Tuesday	Mazurek, Katarzyna kasiam@kft.umcs.lublin.pl	Maria Curie-Sklodowska University	Quadrupole and hexadecapole non-axialities and life-times of Cf-Ds nuclei region.
146/ Tuesday	Patin, Joshua jbpatin@llnl.gov	Lawrence Livermore National Laboratory	Random Probability Analysis of Recent ^{48}Ca Experiments
Number/Session	Name/email	Institution	Title

POSSIBILITIES OF PRODUCTION OF NEW HEAVIEST NUCLEI

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The experimental evaporation residue cross sections in cold (^{208}Pb- and ^{209}Bi-based) and hot (actinide-based) fusion reactions leading to the production of heavy and superheavy nuclei are well reproduced in the dinuclear system model of fusion [1-3]. In the cold fusion-evaporation reactions the dependence of the yield of heaviest nuclei on the isotopic composition of the projectile nucleus is studied. Projectiles with a larger number of neutrons are not expected to increase always the production cross section of superheavy nuclei. For the first time, the optimal excitation energies and the combinations of the colliding nuclei, such as ^{67,68}Zn, ^{73,74}Ge+^{208}Pb, are suggested for future experiments. The systematical experimental study of these reactions is needed to reveal the role of the subshell at N=162 for Z >110. Our results favour the use of ^{67,68}Zn and ^{73,74}Ge beams on ^{209}Bi target in the production of the 113 and 115 elements, respectively.

As main important outcome we found that in ^{48}Ca-induced hot fusion-evaporation reactions the actinide targets with smaller neutron excess are even more favorable within certain intervals than those with larger neutron excess. Therefore, our results could motivate the experimentalists to produce superheavies with more efficient target-projectile combinations.

For the first time, we show that the actinide-based reactions with stable projectiles heavier than ^{50}Ti projectile are not much promising for further synthesis of superheavies. New isotopes of superheavy nuclei with Z=110, 112, 114 and 115 could be produced in the reactions ^{40,42}Ar,^{50}Ti+^{238}U, ^{50}Ti+^{228,229,231}Th,^{235}U and ^{46}Ar,^{47}K+^{248}Cm.

A new method is suggested for calculating the charge and mass distributions of quasifission products [4]. The quasifission is treated within a transport model describing the evolution of a dinuclear system in charge (mass) asymmetry and the decay of this system along the internuclear distance.

The production of unknown isotopes of heaviest nuclei in the incomplete fusion reactions is treated.

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Alpha-Particle Correlations and Nuclear Binding Energy

K. A. Gridnev[1], S. Yu. Torilov[1], D. K. Gridnev[1], V.G. Kartavenko[2], W. Greiner[3] and J. Hamilton[4]
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[3] *Frankfurt University and*
[4] *Vanderbilt University*

We consider the nucleus taking for building blocks the alpha-particles. The interaction between alpha-particles is taken of the Lennard-Jones type, which has a repulsive core. Due to the repulsive core one can construct the nuclear matter from alpha-particles, with the nucleus gaining volume and nearly constant binding energy per alpha-particle. The binding energy of a nucleus in this model is calculated through counting bonds between alpha-particles. This gives binding energies that for the first 26 alpha-particles agree within 0.99-1.025 with respect to experimental values. The counting of bonds proceeds as follows. First, one seeks the configuration which minimizes the potential energy of the system and then one counts bonds in this particular configuration. The binding energy has the expression

$$E_B = A(N_\alpha + 6n_\alpha) + C \tag{1}$$

where A determines the energy of interaction, N_α is the number of bonds between alpha-particles, n_α is the number of alpha-particles in the nucleus and C is the Coulomb energy. The model shows very well appearance of shell structures and predicts an island of stability for $Z = 120$, which agrees with with predictions based on Hartree-Fock calculations. The model provides reasonable matches of alpha-particle separation energies, as shown in Fig. 1

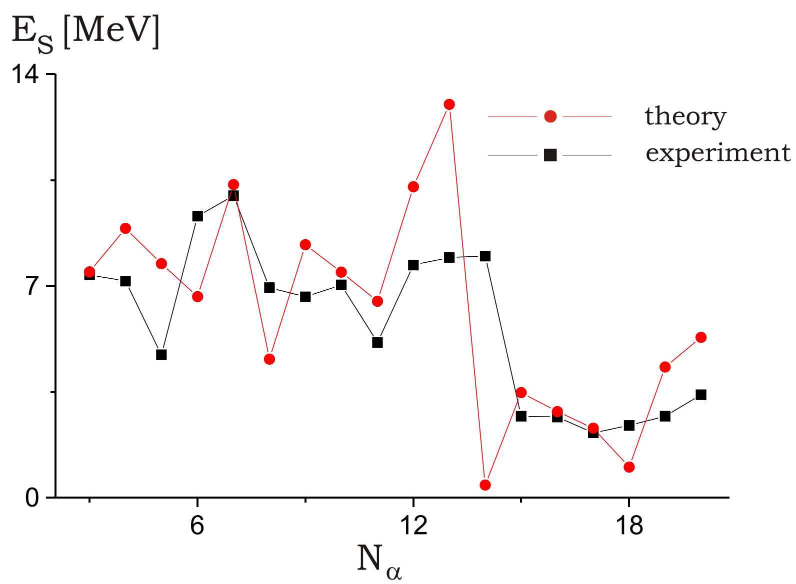

FIG. 1: Separation energy of an alpha-particle as a function of the number of alpha-particles in the nucleus

Quantum Dynamics and P-odd, P-even and T-odd Correlations for Binary and Ternary Fission*

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In the frame of the quantum theory of spontaneous and low-energy induced binary and ternary fission of axially symmetric nuclei [1] the role of Coriolis interaction uniformly mixing of nuclear spin's projections onto symmetry axis for excited nuclear states with big energy density because of dynamical enhancement effect [2] is analyzed. It is shown that the agreement of A. Bohr concept of transitional fission states [3] with the properties of Coriolis interaction is possible if the fissile nucleus near scission point is cold in spite of nonadiabatic character of nuclear deformation parameters changes.

On the basis of this condition the mechanism of the generation of big values of relative orbital moments and spins of fission fragments connected with the strong nonspherity of interaction between fission fragments is proposed. The comparison of experimental and theoretical angular distributions for fragments of even-even actinides subbarier photofission gives the possibility to see the deviations from A. Bohr formula predictions and to obtain the maximal value of relative orbital moment of fission fragments: Lm"30. This value is in good agreement with experimental measurements of multiplicities and multipoles of gamma-quanta emitted from fission fragments.

The calculated on the basis of the quantum theory [1] the angular distributions of ternary fission products taking into account the strong coupling of fission channels and the mechanism of pumping of relative orbital moments of ternary particles and fission fragments by nonspherical Coulomb and nuclear potentials are in good agreement with corresponding experimental distributions. The calculated values of P-odd and P-even correlation coefficients for ternary particles in induced by cold polarized neutrons ternary fission agree with one-step mechanism of ternary fission and substantiate the necessity of new more precise experiments. It is shown that T-odd correlations in ternary fission found in work [4] are defined by Coriolis interaction between ternary particle orbital moment and fissile nucleus spin [5] and that the angular and energy dependences of T-odd correlation coefficients agree with corresponding experimental data [4].

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* This work was supported by INTAS (grant 03-51-6417) and RFFI (grant -03-02-17469).

Quadrupole and hexadecapole non-axialities and life-times of Cf-Ds nuclei region.

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Large scale calculations in a multidimentional space of deformation parameters allow us to investigate the influence of quadrupole and hexadecapole non-axialities on parameters of the life time estimation of nuclei. The macroscopic-microscopic method gives the total energy surfaces combined with the newest Lublin-Strasbourg Drop (LSD) [1] macroscopic energy. The microscopic part based on the single particle energy spectra of the Woods-Saxon single particle potential with the universal set of parameters in every point of the five - dimensional space of deformation parameters for each of around 200 even-even isotopes. The influence of axial quadrupole, octupole and other multipole deformation parameters on nuclear total energy surfaces is very well known. It was calculated with different macroscopic-microscopic and with self-consistent methods. Our aim is to obtain the total energy surfaces by minimisation in the multidimensional space of deformation parameters paying special attention to non-axial quadrupole and hexadecapole parameters $\alpha_{20}, \alpha_{22}, \alpha_{40}, \alpha_{42}, \alpha_{44}$ and to compare them with the total energy surfaces obtained by minimisation in the axially symmetric space $\alpha_{20}, \alpha_{40}, \alpha_{60}, \alpha_{80}, \alpha_{100}$ for of Cf-Ds or even heavier nuclei.

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Random Probability Analysis of Recent ^{48}Ca Experiments

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During the past few years, numerous experiments have been performed at the Dubna U400 Cyclotron Facility bombarding various actinide targets (^{238}U, ^{242,244}Pu, ^{243}Am, ^{245,248}Cm, & ^{249}Cf) with ^{48}Ca aimed at producing isotopes of elements 112-118. Recent independent data analysis of the information gathered during these experiments was performed at LLNL and corroborated the results observed at FLNR. The Monte Carlo random probability analysis developed at LLNL for such heavy element experiments was performed for all of the data and the implications from such analysis will be presented.

Much of the support for the LLNL scientists was provided by the US DOE under Contract W-7405-Eng-48.

Nuclear Moments
and
Radii

Posters - Nuclear Radii and Moments

Number/Session	Name/email	Institution	Title
31/ Tuesday	Fukuda, Mitsunori mfukuda@phys.sci.osaka-u.ac.jp	Osaka University	Density Distribution of Proton Drip-Line Nucleus ^{17}Ne
32/ Monday	Gridnev, Konstantin gridnev@nuclpc1.phys.spbu.ru	St.Petersburg University	About a stability of nuclei with neutron excess.
33/ Tuesday	Huyse, Mark mark.huyse@fys.kuleuven.ac.be	K. U. Leuven	Shape evolution in the neutron-deficient lead isotopes measured by in-source laser spectroscopy
34/ Monday	Kumar, Ashok ashok@pa.uky.edu	University of Kentucky	Lifetime measurements and low lying structure in ^{112}Sn
35/ Tuesday	McCutchan, Libby elizabeth.ricard-mccutchan@yale.edu	Yale University	Ground State Properties and Phase/Shape Transitions in the IBA
41/ Tuesday	Werner, Volker vw@ikp.uni-koeln.de	University of Cologne	A measure for triaxiality from K invariants
37/ Tuesday	Yamaguchi, Yoshi yamaguch@cns.s.u-tokyo.ac.jp	University of Tokyo	Halo structure of ^{17}B studied via its reaction cross section measurement
Number/Session	Name/email	Institution	Title

Density Distribution of Proton Drip-Line Nucleus ^{17}Ne

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Studies of a proton halo structure in contrast to neutron halos are valuable for elucidation of roles of Coulomb effects or isospin symmetry in the mechanism of development of halos in loosely bound nuclei [1]. The ground state of ^{17}Ne (I^{π}=1/2$^-$) is attractive as a subject of such studies, because relatively large interaction cross sections at high energies for ^{17}Ne were reported by Ozawa et al. [2]. Some experimental works for ^{17}Ne were carried out to clarify the halo structure, though the conclusions of the works conflict with each other [3, 4]. On the interest whether or not the new magic number 16 found for some neutron rich nuclei is applicable also for proton rich side, ^{17}Ne is a quite interesting nucleus. In order to make clear the halo structure of ^{17}Ne, we derived the density distribution of ^{17}Ne through the energy dependence of reaction cross sections (σ_R).

In this study, σ_R for ^{17}Ne were measured at ~ 60*A* and ~ 40*A* MeV on ^{9}Be, ^{12}C, and ^{27}Al targets at RIKEN Accelerator Research Facility with the transmission method with an accuracy within 2 %. These energies were chosen because σ_R becomes sensitive in this energy range to the thin density part due to the large NN cross sections.

The σ_R is connected with a density distribution of nuclear matter through the optical limit of the Glauber theory (OL). We deduced the density distribution of ^{17}Ne by a fitting procedure with the present σ_R data and the high-energy σ_I measured by Ozawa [2]. In this procedure, free parameters in the functional form of the density distribution were optimized to fit the calculated σ_R to the experimental σ_R. Corrections for a low-energy Glauber calculation [1] and a few-body effect [6] are included in the procedure.

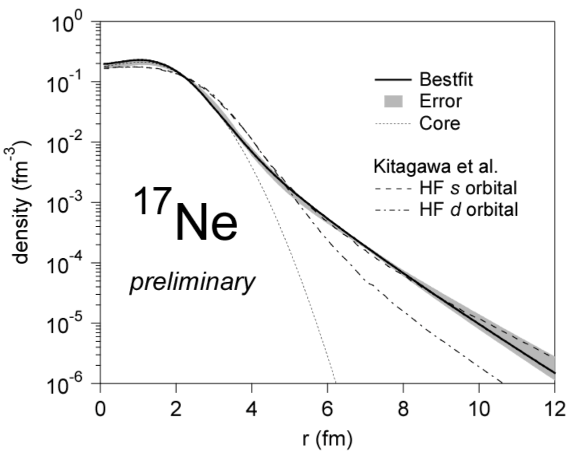

FIG. 1. Density distribution of ^{17}Ne.

FIG. 1 shows the preliminary result of the deduced density distribution. Theoretical densities calculated by Kitagawa et al. with the Hartree-Fock model in which two-valence protons occupy the $2s_{1/2}$ orbital or the $1d_{5/2}$ orbital are also shown for comparison [7]. The present density distribution of ^{17}Ne has a long tail consistent with the theoretical density that the two-valence protons are in the $2s_{1/2}$ orbital. Interestingly, this result suggests the level inversion between the $2s_{1/2}$ and the $1d_{5/2}$ in ^{17}Ne, and it is a first sign of the new magic number 16 for the proton-rich side.

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About a stability of nuclei with neutron excess.

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Using the Hartree-Fock method with the Skyrme effective interaction, we investigated ground state properties of the oxygen isotopes ($^{16\text{-}30}O$) and calcium ($^{40\text{-}70}Ca$). In particular we calculated dencity distribution of protons and neutrons, rms-radii for protons and neutrons, two-neutrons separation energies and quadrupol momenta. The nuclear stability limits (NLS) with respect to the nucleon emission are calculated with a few types of interactions. It is occured that the NLS position is weakly dependent on a choice of the Skyrme parameter set.

Shape evolution in the neutron-deficient lead isotopes measured by in-source laser spectroscopy

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Mean-square charge radii and magnetic moments have been measured for the neutron deficient lead isotopes, $^{183-188}$Pb.
The measurement was performed at the ISOLDE online mass separator, using the in-source laser spectroscopy technique. The laser wavelength of the first excitation step in the resonance ionization laser ion source (RILIS) [*e.g.* 1] is scanned over the resonance(s) and the α-line intensity of the Pb α-decay is monitored as a function of the wavelength. The isotope shift and, in the case of odd-A isotopes, the hyperfine splitting are deduced.
Considerable improvement of the laser frequency stabilization has been made and resulted in an improved reliability of this technique. In combination with its large sensitivity, this technique has become an efficient tool in atomic spectroscopy, especially in the regions of heavy nuclei furthest away from stability, where the isotope production steeply drops.
As a test case ^{190}Pb was remeasured: good agreement was obtained with the earlier, collinear laser spectroscopy measurement of Dutta *et al.* [2].
The observed behaviour of the rms-charge radii as a function of the mass, follows the smooth trend of the heavier isotopes, down to and even below the neutron mid-shell, where the excitation energy of the oblate intruder 0^+ state in the even isotopes reaches its minimum. This finding evidences a spherical shape of the lead ground states and a limited mixing with the deformed configurations, present at higher energy in the excitation scheme.
In addition, the magnetic moments have been deduced from the hyperfine splitting in the odd-A isotopes.

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Lifetime measurements and low lying structure in ^{112}Sn

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Abstract

The stable Sn isotopes provide a valuable testing ground for examining the role of valence neutrons in nuclear structure. The nucleus ^{112}Sn has had the least study of structure character and collectivity of these isotopes. The spins, parities and especially lifetimes can provide information about collectivity, and a good base for nuclear model tests. The aim of the present work is to study the low energy levels and decays from them, and lifetimes. We first measured gamma-ray yields as a function of incident neutron energy to fix thresholds and the energy dependence of yields above threshold. These energy dependencies limit possible spin assignments. An angular distribution has been measured to determine spins, lifetimes, and obtain some multipole mixing ratios. Large M1 amplitudes, if they exist, could indicate mixed-symmetry states, found in other nuclei in this mass region [1,2]. Several new levels and new gamma rays have been observed, that clarify the level scheme. Further analysis is in progress. This work is supported by the U. S. National Science Foundation under Grant No. PHY-0098813.

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Ground State Properties and Phase/Shape Transitions in the IBA*

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The nature of phase/shape transitions as nuclei evolve from spherical to deformed shapes is a fundamental subject and recently, has been the focus of many theoretical and experimental investigations. The study of phase transitional behavior in nuclei can easily be accomplished using the Interacting Boson Model (IBA) [1], where a study of the total energy surface of the IBA Hamiltonian has shown [2] that first and second order phase transitions occur as a function of the IBA parameters.

In terms of spectroscopic quantities, very basic observables can point to phase transitional behavior. Some examples include the energy ratio of the first 4^+ state to the first 2^+ state, the $R_{4/2}$ ratio, as well as the electromagnetic transition rate B(E2; 2_1 0_1). The evolution of the $R_{4/2}$ ratio as a function of increasing neutron number for the Sm isotopic chain is illustrated in Fig. 1(a), and, a sharp rise in the ratio is observed at the phase transitional point, N = 90.

Signatures of phase transitions can also be observed in the evolution of observables related to the masses and radii of nuclei. Intuitively, one would expect these quantities to prove the most obvious evidence for phase/shape transitional behavior since they are closely connected to the shape of the nucleus. Observables such as two neutron separation energies [2] and the isomer shift [3] have provided experiment evidence of phase transitions. The two neutron separation energies for the Sm isotopic chain are illustrated in Fig 1(b) and a deviation from linear behavior is observed again for N = 90.

In order to understand the evolution of these quantities within the framework of the IBA and their connection to actual nuclei, we have preformed detailed fits to nuclei in the rare earth region using the IBA-1 model. Using a simple, two parameter Hamiltonian, parameters for entire isotopic chains were extracted by considering a combination of several basic spectroscopic observables. The resulting parameters were then used to calculate two neutron separation energies, isomer and isotopic shifts for each chain. The resulting predictions agree very well with the available data and provide an additional signature for phase transitional behavior.

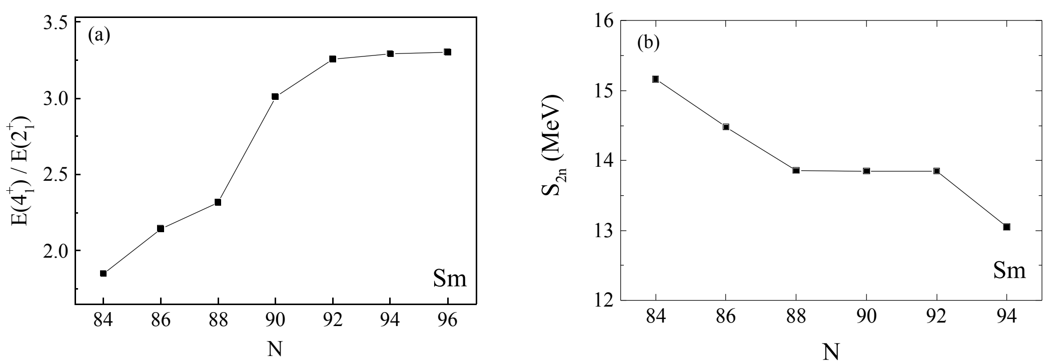

FIG. 1. Evolution of (a) $R_{4/2}$ and (b) S_{2n} as a function of N for the Sm isotopes.

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*This work was supported by the U.S. Department of Energy under grant DE-FG02-91ER-40609.

A measure for triaxiality from K invariants *

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The deformation parameters β and γ from the geometrical model are not easy to define in all cases, *e.g.*, in vibrational nuclei. An alternative approach to nuclear deformation are quadrupole shape invariants [1,2]. They are defined by $K_n = q_n/(q_2^{n/2})$ [3], with higher order moments of the quadrupole operator in the ground state of the type $q_n = \langle 0_1^+ | [\underbrace{Q \ldots Q}_{n}]^{(0)} | 0_1^+ \rangle$.

The invariants q_2 and K_3 are directly connected to the geometrical deformation parameters. They can be translated to effective deformation parameters by

$$q_2 = \left(\frac{3ZeR^2}{4\pi}\right)^2 \langle \beta^2 \rangle = \left(\frac{3ZeR^2}{4\pi}\right)^2 \beta_{\rm eff}{}^2 \qquad \text{and} \qquad K_3 = -\frac{\langle \beta^3 \cos 3\gamma \rangle}{\langle \beta^2 \rangle^{3/2}} = -\cos(3\gamma_{eff}) \ ,$$

while K_4 and K_6 give measures for fluctuations in β and γ in the non-rigid case. For the rigid rotor K_3 gives the known geometrical γ-value, while it provides a measure for triaxiality also for vibrational or γ-soft nuclei. In general, a measurement of K_3 affords measuring a large set of E2 matrix elements. Nevertheless, applying the Q-phonon scheme [4] and it's $\Delta Q = 1$ selection rule for E2 transitions, the number of needed matrix elements reduces drastically and we get an approximative formula for K_3:

$$K_3^{appr} = \sqrt{\frac{7}{10}}\, \text{sign}(Q(2_1^+)) \left(\sqrt{\frac{B(E2;2_1^+ \to 2_1^+)}{B(E2;2_1^+ \to 0_1^+)}} - \frac{\sqrt{B(E2;2_2^+ \to 0_1^+) \cdot B(E2;2_2^+ \to 2_1^+)}}{B(E2;2_1^+ \to 0_1^+)} \right) \ .$$

Only the B(E2) strengths from the first and second 2^+ states are needed, as well as the (still not easy to measure) quadrupole moment of the 2_1^+ state, for brevity given as the usual $Q(2_1^+)$, and as $B(E2;2_1^+ \to 2_1^+) = 1/5\ \langle 2_1^+ || Q || 2_1^+ \rangle^2$. The latter was shown [5] to be obtainable from

$$B(E2;2_1^+ \to 2_1^+) + B(E2;2_2^+ \to 2_1^+) = B(E2;4_1^+ \to 2_1^+) \ .$$

The approximation to K_3 was tested to hold to a good extent within the Davydov model of a triaxial rotor, and within the IBM. K_3^{appr}-values are given for a variety of nuclei, as well as effective γ-deformation values. Three examples are given below, where in the fourth and fifth columns upper and lower limits for K_3 are given, obtained from a simple two parameter fit within the IBM-1.

	K_3^{appr}	γ_{eff}^{appr}	K_3^{fit} limits upper	K_3^{fit} limits lower
^{188}Os	-0.63(5)	17(1)	-0.65	-0.76
^{192}Os	-0.28(11)	25(3)	-0.48	-0.71
^{156}Gd	-0.97(5)	5(4)	-0.86	-0.98

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*This work was supported by the DFG under contract number Br799/11-1.

Halo structure of ^{17}B studied via its reaction cross section measurement

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The investigation of unstable nuclei has been extended with rapid progress involving a radioactive ion–beam technique during the last few decades. After the neutron halo structure in ^{11}Li was discovered for the first time, [1] the existence of a neutron halo structure in some neutron–rich light nuclei was confirmed or suggested up to now. Recently, the neutron–rich nucleus ^{17}B has been recognized to be a two–neutron halo nucleus due to its weak binding energy of the valence two–neutron ($S_{2n} = 1.39 \pm 0.14$ MeV) [2], the large *r.m.s.* matter radius ($\tilde{r}_m = 2.90 \pm 0.06$ fm) [3], and the narrow momentum distribution of ^{15}B fragments ($\Gamma = 80 \pm 10$ MeV/c) [4] from the breakup of ^{17}B.

Motivated by the measurements mentioned above, we studied the density distribution of ^{17}B, which is one of the most important issue so as to argue a halo structure. We measured the reaction cross section (σ_R) for ^{17}B on a carbon target (377 mg/cm^2) at an energy of 77 *A*MeV by a transmission method, in order to deduce the density distribution. We did find a large enhancement of σ_R for ^{17}B, compared with that predicted by a phenomenological formula, proposed by Kox *et al*, shown in Fig. 1. The enhancement of σ_R measured at present energy is much larger than that at high–energy (880 *A*MeV). This fact suggests the existence of a low–density tail at a large distance from the center of the nucleus, since lower the beam energy, thus the larger the elementary NN cross section, is the smaller overlapped density is probed.

The density distribution of ^{17}B was deduced through the energy dependence of σ_R together with high–energy data using a finite–range Glauber–model calculation under an optical–limit approximation and a few–body treatment. [5] The existence of the neutron–tail structure in ^{17}B as well as the amplitude of the tail and the s–wave spectroscopic factor will be discussed.

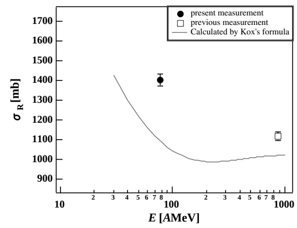

FIG. 1. The reaction cross sections for ^{17}B.

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Radioactive Ion Beam Production

Posters - Radioactive Ion Beam Production

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153/ Monday	Joinet, Angelique angelique.joinet@cesr.fr	CESR	Yields and release of radioactive ion beams of tin
79/ Tuesday	Köster, Ulli Ulli.Koster@cern.ch	CERN	From ^{199}Fr via ^{232}Fr to neutron-magic ^{213}Fr: ISOLDE beams of francium isotopes
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155/ Tuesday	Penttilä, Heikki heikki.penttila@phys.jyu.fi	Univeristy of Jyväskylä	Performance of IGISOL 3
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158/ Monday	Tarasov, Oleg tarasov@nscl.msu.edu	NSCL / MSU	LISE++ development: application to projectile fission at relativistic energies
159/ Tuesday	Tengblad, Olof imtot4a@iem.cfmac.csic.es	Instituto de Estructura de la Materia - CSIC	TARGISOL an ISOL-Database on the web
Number/Session	Name/email	Institution	Title

Design Studies for the RIA Fragment Separators

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The Rare Isotope Accelerator, RIA, facility has been named the highest priority for major new construction by the nuclear science community in the US. Among the key components in the RIA design are the two fragment separators, each with a distinct purpose, one providing secondary beams directly to experiments and the other serving a gas stopping cell to provide species for reacceleration. The goal is to have the separators collect nearly 100% of fragments produced by fragmentation and in-flight fission reactions, and allow the use of thick production targets where secondary production will also contribute to the yields of very exotic fragments. This will require large acceptances where higher order aberrations are a problem. A high resolving power must be maintained in order to purify the fragments and minimize the stopping volume in the gas cell. Specific aspects of the preliminary designs will be discussed, as well as some ion-optical and Monte Carlo simulations performed to date to verify the desired optical qualities.

RFQ cooler and buncher at IMP *

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The study of nuclides far from the valley of stability in recent years, with various spectroscopic methods, sets new demands for the handling of the ion beams. A relative old technique that was first proved to be feasible by Paul and his coworkers [1] has been revived by using electromagnetic fields to prevent the low energy ions from losing in the gas. In the past few years, emittance improvement of low-energy radioactive ion beams has gained a lot of interest and several devices for an emittance improver and buncher have been constructed [2-6].

RIBLL (Radioactive Ion Beam Line in Lanzhou) [7] produces radioactive ions by in-flight fragmentation of the primary beam, the energy spread of the secondary beam is about 10% and its dimension about 10-30 mm diameter varying in different cases. Although it is enough for some rough experiments, it is far from requirement for those experiments which need precise beam energy and ion position. To improve the beam quality a RFQ cooler and buncher is planned to be installed. A same type of RFQ cooler and buncher is also being planned to be used in the new designing spectrometer for super-heavy nuclides research.

Compared to the existing devices [2-6] around the world, the new designing RFQ cooler and buncher becomes much bigger in dimensions. The distance between opposite rods is 120 mm and the total length of the rod structure is about 1500 mm. This device is planned to work in a much higher helium pressure with about 5-10 mbar rather than about 0.1 mbar. The radioactive ions with energy of about 5 MeV will be stopped in the helium buffer gas directly and then cooled and bunched in the rest part of the RFQ structure. The device is being simulated by using the SIMION code and the prototype will be constructed soon.

In this report the setup will be shown and the simulation results will be discussed.

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*This work was supported by the Chinese Academy of Sciences.
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Yields and release of radioactive ion beams of tin*

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Radioactive tin isotopes were produced at ISOLDE by bombarding uranium carbide/graphite and lanthanum carbide/graphite targets with high energy protons (1.0 and 1.4 GeV). They were selectively ionized with the resonance ionization laser ion source (RILIS). The yields and release curves of the tin isotopes from ^{104}Sn to ^{138}Sn were determined. Compared with a "hot plasma source", the RILIS provides a strong suppression of isobaric contaminations from elements with high ionization potential. This enhanced beam purity allowed e.g. to determine more precisely the branching ratio for beta-delayed neutron emission of ^{134}Sn.

Another way to produce pure ISOL beams is the separation of an abundantly populated molecular sideband. Adding a sulphur-containing compound (like SO_2) will lead to the creation of tin sulphide molecules [1] which are much more volatile than atomic tin [2]. The formation of sulphide molecules allowing to translate Sn towards a region with less background, has been studied at ISOLDE during off-line and on-line experiments.

Release measurements of tin from various prospective target materials were performed off-line with radioactive tracers at CERN-ISOLDE and on-line with a stable tracer beam at GSI-ISOL [3].

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*This work was supported by the EU RTD projects EURISOL (HPRI-CT-1999-50001) and TARGISOL (HPRI-CT-2001-50033).
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From ^{199}Fr via ^{232}Fr to neutron-magic ^{213}Fr: ISOLDE beams of francium isotopes*

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Francium is one of the seven so-called "NuPECC reference elements" which serve as benchmark for radioactive ion beam facilities. Isotope yields and release properties of these elements have been studied in detail from various ISOLDE targets for a reliable yield extrapolation to the future EURISOL facility [1].
The most neutron-deficient francium isotopes were produced with similar yields from high-energy proton induced spallation of $^{232}ThC_x$ and $^{238}UC_x$ targets respectively. ^{199}Fr was observed and for ^{200}Fr the yield was sufficiently high to derive in a high-statistics run a precise half-life [2], which differs significantly from former measurements at in-flight separators.
For heavier francium isotopes the yields are more than one order of magnitude higher for ThC_x targets compared to UC_x targets, due to the more favorable cross-sections for ^{232}Th(p,4p*x*n) spallation reactions versus ^{238}U(p,6p*x*n). Finally, beyond ^{229}Fr (*N*=142) only $^{238}UC_x$ targets can be used. The energy increase of the CERN-PSB proton driver from 1.0 to 1.4 GeV gave a clear increase of the production rates of the most neutron-rich francium isotopes. Hence, ^{232}Fr beams could be used for beta-gamma and gamma-gamma spectroscopy, yielding an improved half-life measurement and the determination of the ground state band of ^{232}Ra.
Due to the selective surface ionization, the francium beams are generally quite pure. Only for the heavier masses background from radium isobars and alkaline earth halogenides (RaF^+, $BaBr^+$,...) becomes noticeable. In fact, one of these beam contaminations, $^{213}RaF^+$, served even to obtain new nuclear structure information: the EC decay of 1/2⁻ ^{213g}Ra allowed to deduce via gamma-gamma spectroscopy the low-spin structure of neutron-magic ^{213}Fr.

[1] http://www.ganil.fr/eurisol
[2] H. De Witte et al., Eur. Phys. J. A, submitted.

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*Supported by the EU-RTD projects EURISOL (HPRI-CT-1999-50001) and TARGISOL (HPRI-CT-2001-50033).

GANIL and the Spiral2 project

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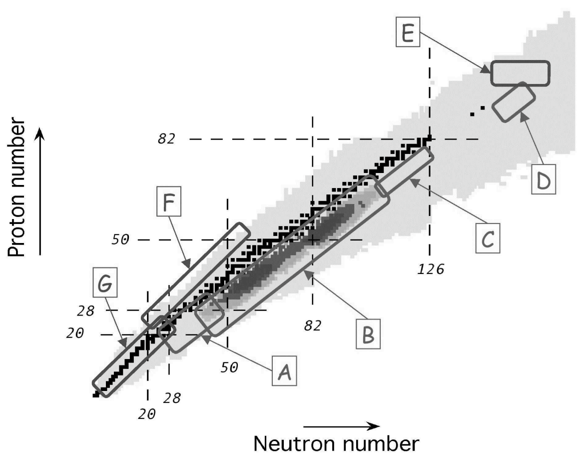
Based on the LINAG Phase 1 conceptual design [1] and the European RTD program [2], a two years detailed design study of a facility for the production of high intensity secondary beams, mainly by the Isol method, named SPIRAL2, was started in 2003. The multibeam driver will allow various production modes to reach various regions of the nuclear chart (see figure 1). Radioactive isotope beams can be produced via the fission process, with the aim of 10^{13} fissions/s, induced in a UC_x target by fast neutrons from a C converter [3] using a 5mA deuteron beam of 40MeV. With the use of high density UC_x the fission rate can reach 10^{14}/s. In this case the fission products are coming from^{239}U at an excitation energy of about 25MeV, that is optimal for the production of neutron rich nuclei in the main fission bumps(region B of figure 1). Higher excitation energy fission products that populate a much broader range, including region A on the chart can be obtained by direct bombardment of a fissile target with a heavier beam, such as He,Li,C,... The driver consists in high-performance ECR sources, an RFQ cavity and independent phase superconducting resonators. Energies up to 14.5MeV/nucleon and intensities of 1mA will be possible for A/Q=3. As it is a linear accelerator, further upgrade will be possible.



The recently commissioned cyclotron CIME will perform the post acceleration in the SPIRAL2 project. It allows acceleration of heavy ions in the energy range of 1.7A MeV and 25A MeV, depending on the q/A. For fission fragments and with present performances of an ECR charge booster, optimal energies would be of the order of 8A MeV. Yield calculations of fission fragments with the LAHET+MCNP+CINDER code for a 5 mA deuteron beam of 40 MeV energy in a carbon converter, followed by a UC_x target have been performed(see e.g. [4]). The expected radioactive beam intensities (after diffusion, effusion, ionisation and acceleration) are for some examples: ^{78}Zn,8.10^6/s; ^{91}Kr,8.10^{10}/s; ^{94}Sr,10^{10}/s; ^{123}Cd,10^9/s; ^{132}Sn,3.10^9/s; ^{140}Xe,8.10^{10}/s. The intarget production yields are those calculated using the 11 g/cm3 UC_2. The Arrhenius coefficients used in this calculation were supposed to be the same as for C and Ta, both tabulated in the literature. The assumed 1+ and 1+/N+ ionisation efficiencies are adopted as 90% (1+) and 12% (1+/N+) for Kr and Xe, 30% (1+) and 4% (1+/N+) for Zn, Sr, Sn, I and Cd. The assumed acceleration efficiency in the CIME cyclotron is 50%. The region N=Z (region F on figure 1) will be accessible via the fusion-evaporation process, using the high intensity heavy ion beams of the LINAG. Light radioactive nuclei (region G) can be produced using either neutron induced reactions or appropriate light heavy ion induced reactions. It was estimated that 10^{13}/s of ^6He can be produced. Regions C,D,E will come in reach using fusing fusion evaporation reactions with secondary beams. A decision on the project is expected for mid-2004.

[1] LINAG Phase I, a technical report, version 1.3, GANIL, June 27, 2002, GANIL R 02 08.
[2] M.G. Saint Laurent et al., SPIRAL phase II European RTD report, GANIL R 01-03 2001.
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Performance of IGISOL 3*

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The ion guide technique was developed in Jyväskylä during the early 1980's. Its success has had an important impact on planned concepts of future radioactive beam facilities, such as the radioactive ion acceleration project at Texas A&M University, EURISOL and the Rare Isotope Accelerator RIA.

The IGISOL upgrade project was launched a few years ago after it had become clear that the new ion beam handling techniques such as the radiofrequency quadrupole ion cooler [1] and the mass purification Penning trap [2] would soon make the front end of the IGISOL mass separator the weakest link of the facility. Also, the need of selective ionization techniques such as laser ionization was recognized and technical requirements for such a system were taken into account in the new front end design. The main goal of the upgrade was to increase the isotope separator beam intensity by means of higher pumping efficiency and better radiation shielding to fully benefit from the high intensity light ion beams now available at the K130 cyclotron. [3]

The first tests of the upgraded IGISOL facility with a light ion induced fusion ion guide showed that the goal was met. Typically, the yields normalized by the primary beam intensity are at least three times higher than before the upgrade. First experiments with proton induced fission, for which the largest improvement is expected [3], are scheduled in late May 2004. Their outcome, as well as the ion yields from fusion reactions, will be summarized.

In addition, with the help of an instrumentation grant from the Academy of Finland, we have already been able to start a new project that aims to laser ionize neutral atoms in the gas jet leaving the ion guide and guide them with a radiofrequency field to the extraction stage of the isotope separator. A report of this project will also be given.

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*This work was supported by the Academy of Finland under the Finnish Centre of Excellence Programme 2000-2005 (Project No. 44875, Nuclear and Condensed Matter Physics Programme at JYFL)
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Production of beams of neutron-rich nuclei between Ca and Ni using the ion-guide technique

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Since several neutron-rich nuclei between Z = 20 - 28 are refractory in their nature, they are rarely available as low energy Radioactive Ion Beams (RIB) in ordinary Isotope Separator On-Line (ISOL) facilities. Despite this, the main ISOL work in this region of the chart of nuclei has been done using solid catchers at GSI [1-3]. At GSI, quasi- and deep-inelastic reactions were used for production. Recently, at the ISOLDE PSB facility at CERN, Mn beams were developed [4]. There, the production was based on reactions induced by the 1 GeV proton beam hitting the 52 g/cm^2 thick UC_x/graphite target. At the Leuven IGISOL facility, the beta-decay of $^{68-74}$Ni was studied [5]; the Ni isotopes were produced by fissioning ^{238}U using 30 MeV protons. Of these ISOL-facilities, only at CERN is it possible to perform precision studies of nuclear ground-state properties and measurements of atomic masses using laser spectroscopy and ion trapping. The latest mass measurements in this region of the chart of nuclei were done in Los Alamos at 1994 with a typical mass-resolving power (m/Δm) of about 3850 [6].

Based on the information above, studies of these nuclei at Jyväskylä using the fast (delay-times of a few ms) and chemically unselective IGISOL facility [7], coupled to a double Penning trap ($m/\Delta m=10^7$-10^8) and a laser spectroscopy installation, is a very attractive idea. Also, standard beta-decay studies using isobarically purified IGISOL beams are possible. We are now presenting initial results from the production studies of these beams at the Jyväskylä IGISOL facility using quasi- and deep-inelastic (^{65}Cu (403 MeV) + ^{197}Au → X + Y) and heavy-ion induced fission reactions.

In general, the main complication with quasi- and deep-inelastic reactions, from the IGISOL point of view, is the high kinetic energy of the projectile-like products, since they are finally thermalized into a relatively small volume filled with He-gas. As a result, the energy and angular distributions of the projectile like products were studied in advance at Lawrence Berkeley National Laboratory (LBNL), USA. For the fission approach, the 130 MeV ^{4}He + ^{139}La reaction was used. From the fragment energetics point of view, this reaction is comparable to the proton induced fission of U which means that standard IGISOL fission chamber could be used [7].

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[2] E. Runte et al., Nucl. Phys A441 (1985) 237.
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Preparation of cooled and bunched ion beams at ISOLDE-CERN

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ISCOOL (ISolde COOLer) is the new Radio Frequency Quadrupole ion Cooler and Buncher (RFQCB) for ISOLDE that will deliver ion beams from the High Resolution Separator (HRS) (see refs. [1] and [2]). ISCOOL will be completely integrated into ISOLDE and will have to provide all experiments working with HRS, with all different ion beams coming out from the target ion source. Unlike other existing similar devices around the world with more specific working conditions, ISCOOL can be defined as a general purpose ion trap for the preparation of cooled and bunched radioactive ion beams. Together with the requirements of full integration into ISOLDE, it implies that both flexibility and reliability of the device have to be stressed.

The design of such a device means that the mechanical design has to allow for flexible modifications. For example, as was already discussed in ref. [2], a new electrodes package structure has been designed which fulfills these specifications. In addition, other systems that are important to keep the flexibility and reliability are the electronics, the control or the vacuum systems. They have already been designed to assure also the successfully integration of ISCOOL into ISOLDE. Realization of these systems will be described.

To minimize the disturbance for the normal operation of ISOLDE-facility, the construction and testing phase of the RFQCB will be performed off-line. The off-line laboratory is equipped with an ion source which provides stable alkali and noble gases ion beams at 60 keV*, and a diagnostics setup following the RFQCB. With such a test bench, the operational parameters of ISCOOL can easily be verified.

ISCOOL will be an important step forward for ISOLDE ion beam properties. Furthermore, the new device will contribute to the set-up of a new collinear laser spectroscopy experiment at ISOLDE, similar to one experiment running at JYFL, see ref. [3]. Moreover and not least important, other experiments at ISOLDE will benefit from the improved properties of the ion beam coming from the new device. For example, at REX-ISOLDE, the efficiency of REXTRAP and REXEBIS will be increased since the bunched ion beam delivered directly from ISCOOL will fit better the acceptance requirements and will improve the global efficiency. In this contribution, some of the physics applications of RFQCB will be outlined and off-line tests reported on.

References

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[3] A. Nieminen et al., Phys. Rev. Lett. 88 (2002) 094801.

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* We would like to thank CRNS (Orsay) for the support in the construction of the off-line test beam line.
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LISE++ development: application to projectile fission at relativistic energies

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The program LISE++[1] is intended to calculate the transmission and yields of fragments produced and collected in a fragment separator at medium-energy and high-energy facilities (fragment- and recoil-separators with electrostatic and/or magnetic selections). The projectile fragmentation and fusion-evaporation [2] assumed in this program as the production reaction mechanism allows to simulate experiments at beam energies above the Coulomb barrier.

High-energy secondary-beam facilities such as GSI, RIA, and RIBF provide the technical equipment for a new kind of fission experiment [3]. Fission properties of short-lived nuclei can be investigated in inverse kinematics. A new model of fast analytical calculation of fission fragment transmission through a fragment separator has been developed in the framework of the code LISE++.

The electromagnetic excitation cross section calculation procedure (see Figure) is based on work of C.Bertulani [4] and LisFus evaporation model [2]. The calculation of nuclide production yields of fissile nuclei have been incorporated from work of J.Benlliure [5]. High-energy fission ("abrasion-fission") is under construction and is expected to be finished soon.

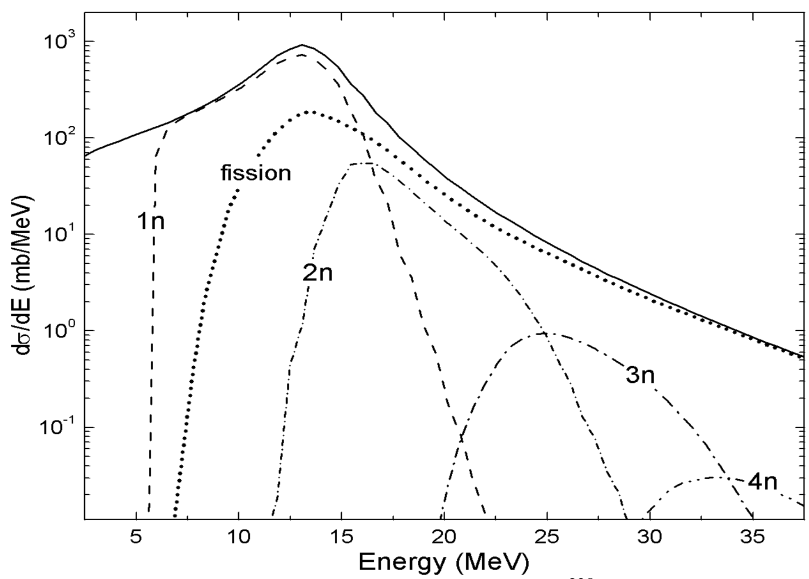

FIG. 1. The differential cross section of electromagnetic excitation in ^{238}U on a lead target at 920 MeV/u (solid curve). Deexcitation channels for excited ^{238}U nuclei as a function of excitation energy are denoted by letters on figure.

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TARGISOL: an ISOL-database on the web *

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The production of radioactive isotopes is getting more and more difficult the further out from stability the scientific interest is moving. Also as the more easily produced elements have been studied the interest is moved to elements, which, due to their specific chemical properties, are difficult to release from the production target and thus presently are too scarce for making experiments possible. There are in the world several ongoing projects studying the next generation Radioactive Nuclear Beam facilities, see [1] for details. These new facilities will have higher primary beam energies and intensities in order to reach further away from stability and to increase the production yields. However, in order to be able to study more exotic (i.e. very short lived) and presently unreachable elements one have to optimise not only the production but also the release of the produced isotopes out of the target matrix and to have an efficient transport up to the experiment.

In the case of ISOL facilities a requisite for the efficient delivery of short- lived nuclei to the experiment is the fast release of the radioactive ions from the target-ion source-system. The experimentally determined release curves of different elements from specific targets contain components due to the container surface sticking time as well as due to the diffusion out of the target material. The development of analytical methods to simulate this release allows us to understand and if possible determine the relative contribution of each mechanism to the final release. For such a release optimisation a database of diffusion and effusion data is required.

The TARGISOL-database [2] contains a collection of tables connected in a series of relationships that, in the case of producing radioactive ion beams (RIBs), reflects the process and the delay parameters to produce intense beams of rare isotopes. The data of the database are collected from literature and from several research organizations under the criteria of being refereed and published in order to maintain the quality of the stored information. The database is managed by a relational database management system, RDBMS, and can be accessed through the user-interface both by a retrieval system and/or applications programs. An internet browser-based user interface to the Oracle Relational Database, Rdb, has been created to provide a quick and simple querying procedure. To enhance communication with the database a Web application has been integrated. Standard HTML pages and embedded PL/SQL code constitute an Oracle PSP file. The PSP files are actually stored in the Oracle Rdb and provide query access to it, why the process to retrieve information is quick and secure. The HTML pages use forms that include test entries, check boxes, and radio buttons. These graphical tools provide the interactive interface to the user. The PSP files contain server-side script commands that build an SQL search string based on the user selection and input. After an user submits a query request from the web page, the PSP script commands execute on the database via the PL/SQL gateway, the database retrieves the data which uses the PL/SQL Toolkit to return the data in HTML format. Graphical representations of retrieved data is embedded in the HTML page using Java Applets.

The structure of the database and the user interface are reviewed, as well as the Internet software developer tools used to create the online interface. Future plans for its upgrading are also presented.

[1] R. Bennet *et al.*, "Radioactive Nuclear Beams Facilities", NuPECC Report, April 2000.
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*This work was supported by the European Union under contract HPRI-CT-2001-50033

Fundamental Symmetries

Posters - Fundamental Symmetries

Number/Session	Name/email	Institution	Title
131/ Monday	Beck, Marcus Marcus.Beck@fys.kuleuven.ac.be	Katholieke Universiteit Leuven	Recoil Spectrometry with the WITCH Experiment
132/ Monday	Chuvilskiy, Yurii tchuvl@nucl-th.sinp.msu.ru	Skobeltsyn Institute of Nuclear Physics	Search for P-odd Time-Reversal Noninvariance in Nuclear Processes
134/ Monday	Koike, Takahisa tkoike@riken.jp	RIKEN	Electron screening effect during the cascade of kaonic nitrogen atoms
135/ Monday	Rodriguez, Daniel rodriguez@lpccaen.in2p3.fr	LPC-ENSICAEN	Measurement of the beta-neutrino correlation in ^{6}He using a transparent Paul trap
Number/Session	Name/email	Institution	Title

Recoil Spectrometry with the WITCH Experiment

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The WITCH experiment (Weak Interaction Trap for CHarged particles, [1] [2]) has been set up at the ISOLDE facility at CERN to investigate the weak interaction with beta decay. It measures the energy spectrum of the recoil ions after beta decay using a Penning trap and a retardation spectrometer. This recoil energy spectrum, which until recently could only be measured in dedicated experiments for specific isotopes, is sensitive to many characteristics of beta decay like F/GT mixing ratios, the V-A structure of the electroweak interaction, or deviations from it, and the beta-energy dependence of the ionisation probability of the daughter nucleus. Furthermore, EC-decay results in a monoenergetic peak in the recoil energy spectrum and can consequently be investigated with much more ease with the WITCH experiment than with conventional experiments.

A major advantage of the WITCH experiment is the use of a Penning trap to store the radioactive ions in vacuum. This avoids scattering and energy loss of the recoil ions in the source which otherwise would disturb the recoil energy spectrum. It also allows to store any isotope with disregard of its atomic or chemical properties. Together with the capability of ISOLDE to produce a wide variety of isotopes this enables the WITCH experiment to use the best suited isotope for a given topic.

The first goal of the WITCH experiment is to search for a contribution of scalar interaction to the V-A structure of the standard electroweak interaction. This test of the Standard Model can be performed by extracting the beta-neutrino angular correlation from the recoil energy spectrum of a pure Fermi decay.

The WITCH experiment is scheduled to take first radioactive beam in October 2004. This beamtime will be used as proof-of-principle. In this contribution the experimental principle, the set-up and the present status of WITCH will be described shortly and some of the physics topics, that can be investigated with the WITCH experiment, will be explained.

[1] M.Beck *et al.*, Nucl. Instr. and Meth. A **503** (2003) 567
[2] http://www.fys.kuleuven.ac.be/iks/ko/research/witch/index.phtml

Search for P-odd Time-Reversal Noninvariance in Nuclear Processes

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Search for parity as well as time-reversal (PT) fundamental symmetry violation effect is an outstanding question of modern physics. There are grounds to assume that the major contributor to this effect is placed beyond the standard model. An investigation of the effect in nuclear processes is considered as a promissing source of the information which is complementary to that obtained from K- and B-meson experiments and measurements of the electric dipol moments of elementary particles and atoms because the mechanisms specific for PT-symmetry violation in NN-interaction (isovector part of meson exchange amplitude for example) turn out to be essential or even dominating in the discussed case.

Last two decades the researches of PT-noninvariance in nuclear processes were concentrated on the sole case, namely on the case of $\vec{n} +^{139} \vec{La}$ collision. Nevertheless there is no exciting progress on this way up to now.

In the present talk the results of the analysis of capability of the wide range of experimental schemes are presented. This analysis demonstrates the significant advantage of the scheme based on the measurement of linear polarisation of gamma radiation of oriented (by a preceeding nuclear transformation or by criogenic means) sample. Both in-beam experiments and measurements using long-lived radioactive sources are discussed.

Electron screening effect during the cascade of kaonic nitrogen atoms *

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The charged kaon mass is one of the fundamental constants in any physics concerning the charged kaon. The Particle Data Group assigned 493.677 ± 0.013 MeV to it[1]. This value is a weighted-average of six measurements, in which the most two recent measurements using the kaonic atom x-rays differ by about 60 keV, although the errors for both measurements is ∼10 keV[1]. Therefore, the further precise mass measurement is necessary to establish the kaon mass within the uncertainty less than ∼10 keV.

Recently, the kaonic nitrogen atom x-rays in gaseous target is firstly obtained by DEAR (DAΦNE Exotic Atom Research) group at the DAΦNE of Frascati, and the precise charged kaon mass measurement is also planned in future by using them[2]. In order to deduce the kaon mass from the kaonic atom x-ray, the x-ray energy must be calculated with sufficient accuracy including various corrections. Among the corrections, the electron screening effect is difficult to estimate correctly, because it needs the knowledge of the electron populations at the moment of x-ray emission, which depends on the balance between Auger electron emission and electron refilling during the atomic cascade process.

For the forthcoming kaon mass measurement, we developed the atomic cascade code for the kaonic nitrogen atom, which enables us to determine the electron fraction at each atomic level of kaon. By reproducing the x-ray yields observed at DAΦNE, it is found that the K-shell electron population at $n = 6$ is estimated to be 1 to 3% within the experimental errors of x-ray yields. Fig.1 shows the calculated K-shell electron populations as a function of principal quantum number n of kaon orbits. By using these results, the electron screening effect for the observed x-ray energy can be calculated with sufficient accuracy. We will report the details of calculation and discuss about the precision of charged kaon mass. This work is the extension of the theoretical part on the atomic cascade calculation in Ref.[2] by one of authors.

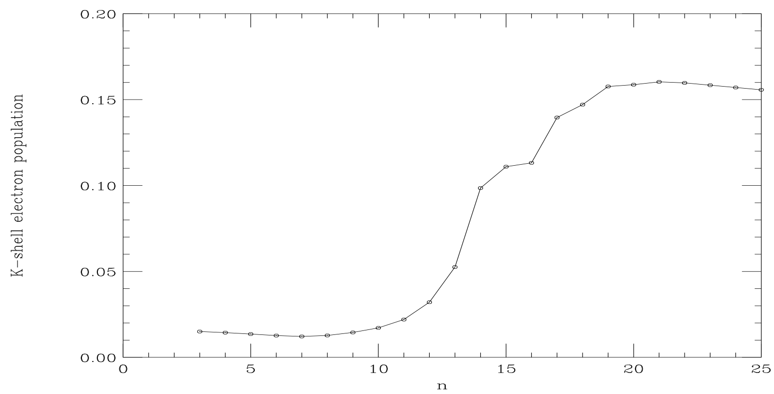

FIG. 1. K-shell electron populations for kaonic nitrogen atom in gaseous target as a function of n.

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*This work is supported by the Special Postdoctoral Researchers Program from RIKEN.

Measurement of the β-ν correlation in ^{6}He using a transparent Paul trap *

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In the framework of the Standard Model, nuclear β-decay is described in terms of current-current couplings, either vector or axial-vector. Other couplings such as scalar, pseudoscalar or tensor, are permitted by Lorentz invariance but forbidden within the Standard Model. The search for the contribution of such interactions requires high-precision experiments, directed to determine unambigously predicted properties. Here, we address the precise experimental determination of the β-ν angular correlation coefficent a by studying the decay of ^{6}He. This is a pure Gamow-Teller decay and according to the Standard Model, a must be $-1/3$. Up to date, the most precise measurement of the β-ν angular correlation coefficient in the decay of ^{6}He has led to $a = -0.3308 \pm 0.0030$ [1,2]. A more precise value of a, by a factor of two improved accuracy ($\delta a = 0.0015$), could reveal the presence of tensor like contributions in the weak interaction.

Experimentally, a is determined by measuring the energy or momenta of the recoiling ions in coincidence with the β particles. The measurements will be considerably enhanced if the decaying source is held almost at rest in a well controlled environment as such provided by a trap. To this aim, a new facility called LPCTrap was constructed and tested during the last five years. The facility has been recently coupled to the low energy beam line of SPIRAL/GANIL. The LPCTrap comprises two key elements: 1) a segmented ion cooler, to reduce the time structure, emittance, and energy of the incoming ion beam, and 2) a transparent Paul trap to confine the decaying source. The coincidence-detection system consists of sets of MCP's detectors and a β-telescope. For the first time, a Paul trap with a novel geometry has been coupled to a radioactive ion beam facility for high-precision nuclear physics experiments. The results achieved along the commissioning stage show the feasibility to pursue the proposed experiment [3]. In this contribution, we will give a status report of the project underlining the highlights achieved so far and the potential of this novel experimental arrangement in nuclear physics.

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*This work has been supported by the European Commission within the RTD project EXOTRAPS under contract number HPRI-CT-1998-00018, and is supported within the NIPNET network under contract number HPRI-CT-2001-50034.

G-Parity Irregular Term in the Weak Nucleon Current Extracted from the Alignment Correlation Term in the Mass $A = 8$ System

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The G parity holds in the nuclear β-decay process, if the strong interaction exactly holds SU(2) symmetry. So that, the G-parity irregular term in the weak nucleon current, which is the induced tensor term, allows us to know how much the fundamental symmetry is broken in nuclei. The induced tensor term may give, for instance, the difference between the up and down quarks in the usual nuclei. For the mass $A = 8$ system, the β-α angular correlation was observed in 1980 by McKeown et al. to test the existence of the induced tensor term[1]. However, due to the contribution from the second-forbidden matrix elements, it is difficult to extract the induced tensor term only from the β-α angular correlation. To extract purely the induced tensor term, in the present study, the alignment correlation terms in the β-ray angular distributions of the spin aligned ^{8}Li and ^{8}B were precisely determined.

A deuteron (^{3}He) beam with the 3.5 MeV (4.7 MeV) was provided by the Van de Graaff accelerator at Osaka University. The ^{8}Li (^{8}B) nuclei were produced through the reaction ^{7}Li(d,p)^{8}Li, (^{6}Li(^{3}He,n)^{8}B), and the nuclear polarization was produced by selecting the recoil angle of the reaction product. The polarized nuclei were implanted in the single crystal of Zn (TiO_2), which was placed in an external magnetic field $H_0 = 2.3$ kOe (600 Oe) to maintain the polarization and to manipulate the nuclear spins by use of the RF magnetic field. The obtained polarization was converted into the positive and negative alignments applying the NMR technique. The β-ray energy spectra from the aligned nuclei were precisely observed.

The alignment correlation terms were extracted from the mirror pair ^{8}Li and ^{8}B, and the difference is shown as a function of β-ray energy in Fig. 1, together with the β-α angular correlation [1]. The average of these two kinds of difference data is given by the sum of the induced tensor term and the weak magnetism without the forbidden matrix elements. The obtained average was well reproduced only by the weak magnetism [2], which suggests that the induced tensor term is very small for the mass $A = 8$ system.

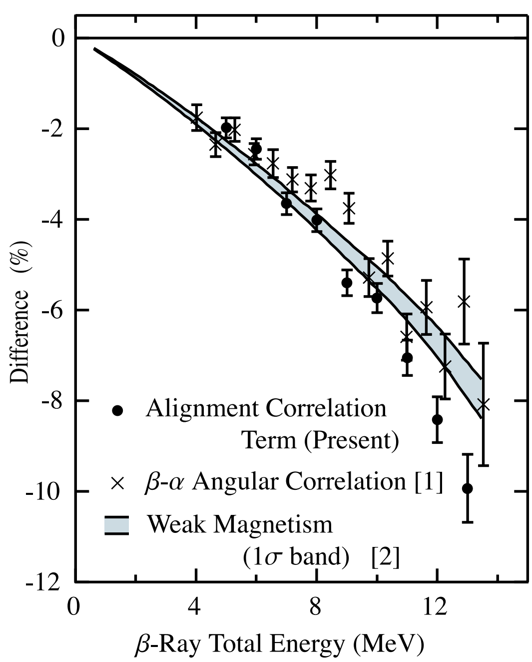

FIG. 1: Difference of the alignment correlation terms and that of the β-α angular correlation [1] between the mirror decays. The average of two differences was well reproduced only by the weak magnetism [2] without the induced tensor term.

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