Shapes and Symmetries in Nuclei:

from Experiment to Theory

(SSNET'17 Conference)

Gif sur Yvette, November 6th – 10th, 2017

Book of Abstracts

Triaxiality in Neutron-Rich Mo-Ru Isotopes from Coulomb Excitation

Mitch Allmond

Oak Ridge National Laboratory, USA

Collective shape degrees of freedom have been a major direction in the study of the nuclear finite many-body problem for over 50 years. There is widespread evidence for quadrupole deformations, primarily of large prolate spheroidal deformation with axially symmetric rotor degrees of freedom. This naturally leads to the question of whether or not axially asymmetric rotor degrees of freedom are exhibited by any nuclei, with the implication of triaxial shapes. With respect to best cases for observation of triaxial shapes near the ground state, two regions stand out. The first is the Os-Pt region and the second is the neutron-rich Mo-Ru region, where low-energy 2^+_2 states are consistent with such an interpretation. Furthermore, the neutron-rich Mo-Ru region is expected to undergo a relatively rare instance of prolate-to-oblate shape evolution. Recent results from Coulomb-excitation and beta-decay studies of ^{106}Mo and ^{106,110}Ru will be presented. These experiments were conducted at the CARIBU-ATLAS facility of ANL using GRETINA-CHICO2. A survey of the equipment, techniques, and results will be presented.

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics.

Search for collective and non-collective band structures in ^{123}Xe

A. Basu[1], A.K. Singh[1], G.B. Hagemann[2], G. Sletten[2], B. Herskind[2], T. Døssing[2], S. Nag[3], I. Ragnarsson[4], H. Hübel[5], A. Bürger[5], S. Chmel[5], A.N. Wilson[6], J. Rogers[6], M.P. Carpenter[7], R.V.F Janssens[7], T.L. Khoo[7], F.G. Kondev[7], T. Lauritsen[7], S. Zhu[7], A. Korichi[8], P. Fallon[9], B.M. Nyakó[10], J. Timár[10]

[1] *Indian Institute of Technology, Kharagpur, India*
[2] *Niels Bohr Institute, Copenhagen, Denmark*
[3] *Department of Physics, NIT Raipur, India*
[4] *Division of Mathematical Physics, LTH, Lund University, Sweden*
[5] *Helmholtz-Institut für Strahlen- und Kernphysik, Universität Bonn, Germany*
[6] *R. S. P. E., ANU, Canberra, Australia*
[7] *Physics Division, Argonne National Laboratory, Argonne, USA*
[8] *CSNSM Orsay, France*
[9] *Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, USA*
[10] *Institute for Nuclear Research, Hungarian Academy of Sciences, Debrecen, Hungary*

Nuclei in the mass region A≃125 are transitional with respect to their shapes at low and high angular momenta as they lie between the spherical Tin nuclei (Z=50) and strongly deformed Cerium nuclei (Z=58). These nuclei are γ-soft at low and moderate spins and are also susceptible to polarization effects because of the excitations of individual quasinucleons. The unique parity $h_{11/2}$ intruder orbital is available for both protons and neutrons.The alignments of protons and neutrons, governed by the $h_{11/2}$ intruder orbitals, have opposite deformation driving effects. Protons drive the nucleus towards the prolate shape, whereas the oblate shape is by favoured by the neutrons. The presence of a lone neutron in the $h_{11/2}$ already drives the nucleus toward the oblate shape [1]. Therefore, the aftermath of this interplay makes this region very interesting to study the shape evolutions as we go from low spin to higher spin regions as the nucleus can have a prolate, an oblate or a triaxial shape depending on the alignment of nucleons [1]. As a result of limited number of valence particles outside the closed core with Z = 50 and N = 64, band termination occurs in which the rotational bands terminate when a nucleus with a specific configuration reaches the maximum spin. In addition to the presence of maximally aligned states, in which the spin vectors of all the valence nucleons outside the ^{114}Sn core are aligned, non-collective states with one or more anti-aligned particles can also be considered. All these have been identified in ^{121,123,125}I [2], [3], [4] and ^{122,124}Xe [5], [6]. High spin deformed bands, which extend upto $\sim 50\hbar$ and feed the non-collective bands at around $I \simeq 20-25\hbar$ spin, have been observed in ^{124,125,126}Xe [7], [8], [9]. Thus, all these interesting features have motivated the study of the ^{123}Xe isotope which has not been as exclusively explored as the other Xe isotopes. In order to investigate the high spin states of ^{123}Xe, an experiment involving a heavy-ion fusion evaporation reaction was carried out at the ATLAS accelerator in Argonne National Laboratory, USA where a ^{48}Ca projectile of 207 MeV beam energy and an intensity of 4 pnA was bombarded on a ^{80}Se target. The reaction ^{80}Se(^{48}Ca, 5n)^{123}Xe was used to populate the high spin levels of the ^{123}Xe isotope and the gamma ray coincidence data were recorded with the Gammasphere spectrometer array consisting of 101 Compton-suppressed Ge detectors. In the present work, the level scheme of ^{123}Xe, previously analysed by Schmidt, *et al* [10] has been extended and enriched with the placement of new structures. Spins and parities have been assigned based on angular distribution ratios and information from interband transitions. Cranked Nilsson-Strutinsky(CNS) calculations have been performed for comparison with the experimental results in order to assign configurations to the various bands wherever possible.

1. A. Granderath, *et al* 1996 Nucl. Phys. A**597** 427
2. E. S. Paul, *et al* 1993 J. Phys. G: Nucl. Part. Phys. **19** 913
3. P. Singh, *et al* 2008 Phys. Rev. C **85**, 034319
4. P. Singh, *et al* 2010 Phys. Rev. C **82**, 034301
5. J. Timár, *et al* 1995 J. Phys. G: Nucl. Part. Phys. A **21**, 783
6. A. Al-Khatib *et al* 2008 Eur. Phys. J. **36**, 21–29
7. S. Nag, *et al* 2016 Phys. Rev. C **94**, 034307
8. A. Al-Khatib, *et al* 2011 Phys. Rev. C **83**, 024306
9. C. R. Hansen *et al* 2007 Phys. Rev. C **76**, 034311
10. A. Schmidt, *et al* 1998 Eur. Phys. J. A **2**, 21–23

Perspectives for studies of extremely deformed nuclei near ^{40}Ca

Piotr Bednarczyk
IFJ PAN, Kraków, Poland

The medium light nuclei situated in the nuclear chart between the double magic nuclei ^{40}Ca and ^{58}Ni exhibit many features characteristic for well deformed heavier nuclei. Although in this regions close to the stability line the ground states are predominantly spherical or oblate, at higher values of spin well developed rotational bands are present. This happens in particular when the intruder $f_{7/2}$ or $g_{9/2}$ proton- and neutron- shells are partially filled. Such SD-like bands, resulted from the multiple particle-hole excitations across the magic *N,Z*=20 shells, were observed so far in several isotopes of Ar, Ca and Ti, but this knowledge is limited to rather moderate spins I ≤16. The effective interactions derived for the sdfp active orbitals allowed for reasonable description of the collectivity developed in these nuclei, up to the maximum aligned spin, within the spherical shell model. On the other hand, recent calculations performed in the framework of the EDF theory [1] foresee extremely deformed, high spin cluster states, that become *yrast* beyond the SD termination.

I will discuss plans to investigate the high spin states in these nuclei. The experiments will take advantage of the new detector systems as AGATA and PARIS at GANIL, or GALILEO and RFD at LNL.

[1] D. Ray and V. Afanasjev, Phys. Rev C **94**, 014310 (2016)

Attenuation of radiation with biological media

Ainouna Bouziane
Université des Sciences et de la Technologie d'Oran, Algeria

The probability of a photon interacting in a particular way with a given material, per unit path length, is usually called the linear attenuation coefficient (μ), and it is of great importance in biological media. Accurate determinations of μ are important to obtain representative values of biological media physical properties by gamma-ray attenuation technique. The aim of this study is to analyze possible variations of the theoretical and experimental biological media mass attenuation coefficient as a function of the chemical compositions.

Nuclear shape predictions with proxy-SU(3)

R. Burcu Cakirli
Istanbul University, Turkey

Using a new symmetry scheme, proxy SU(3), β and γ deformation variables are obtained. In this talk, experimental and theoretical results will be discussed including both prolate dominance and the prolate-oblate shape change transition around N~116 around Z~76 within the framework of the model. Details of the model will be introduced in another talk given by R.F. Casten.

A new approximate symmetry for heavy deformed nuclei - proxy - SU(3)

Richard F. Casten

Yale University and Michigan Sate University, USA

The use of structural symmetries has long been an important approach to the study and understanding of nuclear structure. An example is the group symmetry SU(3), pioneered by Elliott in the 1950's which had impressive early success in the study of light nuclei. This symmetry breaks down in heavy nuclei but a well-known approximate symmetry, pseudo-SU(3), recovers many desired features and has been actively studied for several decades. We have recently proposed a new approximate symmetry called a proxy-SU(3) symmetry that is applicable to heavy deformed nuclei. It was inspired by our earlier studies of the proton-neutron interaction and of the spatial overlaps of proton and neutron wave functions in a Nilsson model context. Like pseudo-SU(3) it is based on an orbit substitution but, in this case, the unique parity orbits are replaced by the highest j normal parity orbits from the next lower shell whose Nilsson quantum numbers differ from the original orbit by Nilsson quantum number differences 0[110]. This substitution recovers an approximate oscillator symmetry and therefore enables parameter-free predictions of the basic structure of heavy deformed nuclei. We will introduce this symmetry, vet its approximation, exhibit the main irreps that it leads to, outline how these can be used to make specific predictions, and discuss specific aspects of the approximations involved that point to the need for certain improvements to the model. A complementary talk at this conference will look at specific predictions for the structure of deformed nuclei, and discuss their comparison to the data.

Do we understand nuclear collectivity?

Bo Cederwall
Department of Physics, KTH Royal Institute of Technology, Stockholm, Sweden

In the simple and common picture of nuclear structure, when moving several nucleons or more away from "magic" neutron and proton numbers (which reflect major gaps in the energy level spectrum), an emergence of "collectivity", is expected. For even-even nuclei this is normally associated with a lowering of the first excited 2^+ state energy accompanied by an increase in the $2^+ \rightarrow 0^+$ transition strength, signaling that the wave function spreads to multiple coherent particle-hole components and opening the vibrational or rotational degrees of freedom. These quantities are hence important benchmarks for nuclear models. In particular, the reduced electric quadrupole transition probability, B(E2), connecting the lowest-lying excited states and the ground state directly probes the corresponding wave functions. Recent advancements of experimental techniques now enable us to study not only excited state energies but also electromagnetic transition strengths across long isotopic chains providing more stringent tests of theory. The results reveal some striking differences and deficiencies in the predictive power of current nuclear structure models.

Angular correlations of gamma rays from ^{206}Tl produced in thermal neutron capture

N. Cieplicka-Orynczak[1], S. Leoni[2], B. Fornal[1], D. Bazzacco[3], A. Blanc[4], G. Benzoni[2], S. Bottoni[2], A. Bracco[2], F. Crespi[2], G. de France[5], L. Iskra[1], M. Jentschell[4], U. Koester[4], C. Michelagnoli[4], P. Mutti[4], G. Simpson[6], T. Soldner[4], C.A. Ur[3], W. Urban[7]

[1] *Institute of Nuclear Physics, Polish Academy of Sciences, Kraków, Poland*
[2] *University of Milano and INFN, Milano, Italy*
[3] *INFN Padova, Italy*
[4] *Institut Laue Langevin, Grenoble, France*
[5] *GANIL, Caen, France*
[4] *LPSC, Grenoble, France*
[5] *University of Warsaw, Poland*

Nuclei from the regions of doubly-closed shells may be considered an excellent ground for studying both a) the couplings between valence nucleons - this provides information on the effective nucleonnucleon interaction and, b) couplings of the valence nucleons with core excitations, what may be used as a unique test of various effective interactions (Skyrme, Gogny, etc.) employed in mean-field based models. From a broader perspective, understanding the coupling of a single particle to vibrational motion in nuclei is of primary importance, as this coupling is responsible for the quenching of spectroscopic factors [1]; it is also the key process at the origin of the damping of giant resonances [2]. The vibrational phonons are best known from the spectroscopic studies of doubly-magic nuclei in which they appear, in general, as the lowest excited states. For example, in ^{208}Pb, the lowest excitation (at 2615 keV) is the 3^- octupole vibration with a large E3 transition strength of 34 W.u. ^{206}Tl has only one-proton-hole and one-neutron-hole with respect to the ^{208}Pb core. To reach the low-spin structure of this nucleus, we used a thermal neutron capture reaction ^{205}Tl(n,γ)^{206}Tl at Institut Laue-Langevin in Grenoble (France). Gamma rays from the capture state, which in ^{206}Tl is placed at 6.5 MeV, were detected in an array of 8 Ge clovers, named FIPPS. At the Conference, we are going to present the results of the double and triple-coincidence analysis which will allow to significantly extend the experimental information on the low-spin structure in ^{206}Tl. As the detectors of FIPPS were placed in one ring in octagonal geometry, double-coincidence data could be sorted into the matrices corresponding to different average angles between the crystals (up to 23 angles). The analysis of gamma-ray angular correlations will provide information about transitions multipolarities, which will significantly help with spin-parity assignments.
After extracting the information about spin and parity of the excited states in ^{206}Tl, the level structure of this nucleus will be compared to shell-model calculations results, as previously done in the case of the one-proton, one-neutron valence nucleus ^{210}Bi [3]. The large number of low-spin states populated in neutron capture reactions, which arises mainly from one proton-hole and one neutron-hole excitations, can be used as a very good testing ground for the old and newly developed shell model interactions in the south-west quadrant of the nuclear chart with respect to ^{208}Pb.

[1] A. Bohr, B.R. Mottelson, Nuclear Structure, vols. I and II, W.A. Benjamin, 1975.
[2] P.F. Bortignon, A. Bracco, R.A. Broglia, Giant Resonances: Nuclear Structure at Finite Temperature, Harwood Academic Publishers, New York (1998).
[3] N. Cieplicka-Orynczak et al., Phys. Rev. C **93**, 054302 (2016).

Different views of configuration mixing within Density Functional Theory

Gianluca Colò

Dipartimento di Fisica, Università degli Studi, and INFN, Milano, Italy

We have recently introduced a new approach, which is meant to be a first step towards complete low-lying spectroscopy of odd-mass nuclei.In the first applications, we have limited ourselves to a magic core plus an extra neutron or proton. The model does not contain any free adjustableparameter, but is based on a Hartree-Fock (HF) description of particle states and Random Phase Approximation (RPA) calculations for core excitations. The model is an extension of previous Particle-Vibration Coupling (PVC) calculations. However, at variance with these, it also includes the coupling with non-collective core excitations and can also describe states of shell-model type. At present, we apply this model by using Skyrme functionals, which is a specific realization of Density Functional Theory (DFT) in nuclei. We will show results in the neutron-rich region, around Ca and Sn isotopes. We would like to focus on the relationship between this model and other implementations of DFT that are based on the idea of symmetry breaking and restoration. In particular, relationships between this model and the standard multi-reference DFT for configuration mixing will be addressed.

Spectroscopic Factors in the Islands of Inversion: The Nilsson Strong Coupling Limit *

Heather Crawford

Nuclear Science Division, LBNL, Berkeley, USA

Guided by the formalism developed for studies of single-nucleon transfer reactions in deformed nuclei [1], we have analyzed spectroscopic factors data in the Islands of Inversion at N=8 and 20, in the rotational strong-coupling limit. Based on the fact that intruder deformed configurations dominate the low-lying structure of nuclei within the Islands of Inversion, the Nilsson formalism provides an intuitive and simple approach to obtain important structure information from direct reactions, and a complementary view to shell model calculations. We will present results for ^{10,11,12}Be and ^{32,33}Mg, showing good agreement with the experimental data, and discuss some predictions for other regions.

* This work is supported by the U.S. Department of Energy, Office of Nuclear Physics, under contract no DE-AC02-05CH11231.

[1] B. Elbek and P. Tjom, Advances in Nucl. Phys. Vol 3, 259 (1969).

Shape coexistence in gold, mercury and bismuth isotopes studied by in-source laser spectroscopy at RILIS-ISOLDE

James G. Cubiss*

University of York, United Kingdom

The competition between spherical and deformed nuclear configurations at low energy gives rise to shape coexistence in the neutron-deficient isotopes around Z~82 and N~104 [1]. Along the isotope chain of a number of elements this leads to an abrupt change in the mean-square charge radius of the nuclear ground state when entering the neutron-deficient region. The most notorious case is the shape staggering in the Hg isotopes [2]. An extended experimental campaign to study the mean-square charge radii of the ground and isomeric states of these nuclides, and thereby investigating such regions of nuclear shape changes, is being conducted at ISOLDE by the RILIS-Windmill-ISOLTRAP-IDS collaboration. The measurements rely on the high sensitivity achieved by combining in-source laser resonance ionization spectroscopy, ISOLDE mass separation, the Windmill spectroscopy setup [3], the Multi-Reflection Time-of-Flight (MR-ToF) mass separation technique [4], and the ISOLDE Decay Station (IDS) [5].

In this contribution, the systematics of charge radii and electromagnetic moments recently obtained at ISOLDE for the long isotopic chains of Au (IS534), Hg (IS598) and Bi isotopes (IS608) will be presented. For the lightest Au isotopes, a persistence of the strong deformation up to ^{180}Au was demonstrated for the first time, followed by what we call a 'jump back to sphericity', whereby ^{176mg,177,179}Au possess much lower deformation compared with strongly deformed $^{180\text{-}186}$Au. For the Hg chain, a termination of shape staggering and transition to more spherical shapes in the lightest $^{177\text{-}180}$Hg isotopes were deduced. A large odd-even shape staggering at $^{187\text{-}189}$Bi, similar to the well-known staggering in the Hg isotopes, was observed at the same neutron number. These three chains clearly demonstrate striking similarities in the shape staggering and shape changes when approaching the neutron mid-shell at N=104, while the lightest Au and Hg chains show the strong tendency towards the smooth nearly-spherical behavior.

[1] K. Heyde and J. Wood, Rev. Mod. Phys. 83, 1467 (2011).
[2] J. Bonn, G. Huber, H.-J. Kluge, L. Kugler, and E. Otten, Phys. Lett. B 38, 308 (1972).
[3] A.N. Andreyev et al,, Phys. Rev. Lett. 105, 252502,(2010).
[4] R. N. Wolf et al., Nucl. Instr. and Meth. A 686, 82-90 (2012).
[5] IDS collaboration, http://isolde-ids.web.cern.ch/isolde-ids/ (2017)

* *on behalf of Leuven-Gatchina-ISOLDE-Mainz-Manchester-York and RILIS-Windmill-ISOLTRAP-IDS collaboration*

Regularisation Methods to Stabilise Nuclear Inverse Problem via Physics-Based Improvements

I. Dedes, J. Dudek
IPHC Strasbourg, France

Consider a mathematical model $\hat{M}$ depending on optimised parameters p^{opt} generating the modelling results called data, *d*. In applied mathematics one usually writes $\hat{M}\, p^{opt} = d$; we say that we solved a direct problem. However, in order to be able to do this, we need to know the optimal parameters. They are obtained according to the *Inverse Problem Theory*, a quickly developing branch of *applied mathematics* by solving the so-called inverse problem, $\hat{M}^{-1} d = p^{opt}$. The main issue, and difficulty, is the determination of the $\hat{M}^{-1}$ or its equivalent so that the solutions for the parameters can be considered stable and the optimised model has some predictive power. In realistic modelling within nuclear physics such an operator is not known but the approaches which consist in bypassing the solution of the inverse problem, such as l^2-minimisation, lead to well known instabilities mainly due to parametric correlations within the model. Some standard methods' of stabilisation are developed in applied mathematics; they are known as *regularisation methods*, e.g. Tikhonov method. They consist in replacing the original problem by another one which is hoped to behave like the original one but does not produce destabilising singularities. We will propose a method which will consist in making the original Hamiltonian more realistic and at the same time much more stable - free from parametric correlations: In this sense we may say that we present a regularisation method by a better physics dictated choice.

Our illustrations will be based on the solutions of the realistic phenomenological mean-field Hamiltonian with the help of which the single-nucleon energies of the doubly-magic spherical nuclei will be calculated.

FRS Ion Catcher: Measurement of Isomers and Production of Isomerically Clean Beams

T. Dickel[1], S. Ayet[1], J. Bergmann[2], J. Ebert[2], H. Geissel[1], F. Greiner[2], E. Haettner[3], Ch. Hornung[2], W. Lippert[2], I. Miskun[2], S. Pietri[3], W. Plaß[1], S. Purushothaman[3], P. Reiter[2,4], A.-K. Rink[2], Ch. Scheidenberger[1], H. Weick[3], S. Bagchi[3], P. Constantin[5], M. Diwisch[2], A. Finley[4], S. Kaur[6], R. Knöbel[3], I. Mardor[7], B. Mei[5], I. Moore[8], J.H. Otto[2], A. Pikhtelev[9], I. Pohjalainen[8], A. Prochazka[3], Ch. Rappold[3], M. Takechi[3], Y. Tanaka[3], H. Toernqvist[3], J. Winfield[3], M. Yavor[10], X. Xu[3]

[1] GSI Darmstadt and JLU Giessen, Germany
[2] JLU Giessen, Germany
[3] GSI Darmstadt, Germany
[4] TRIUMF Vancouver, Canada
[5] ELI-NP Bucharest, Romania
[6] Saint Marys University, Halifax, Canada
[7] Tel Aviv University and Soreq NRC Yavne, Israel
[8] JYFL, University of Jyväskylä, Finland
[9] RAS Chernogolovka, Russia
[10] RAS St. Petersburg, Russia

The FRS Ion Catcher [1] at GSI enables precision experiments with projectile and fission fragments. The fragments are produced at relativistic energies in the target, spatially separated and energybunched in the fragment separator (FRS), and slowed-down and thermalized in a cryogenic stopping cell (CSC). A versatile RFQ beamline and diagnostics unit and a high-performance multiple-reflection time-of-flight mass spectrometer (MR-TOF-MS) [2] enable a variety of experiments, including highprecision mass measurements, isomer measurements and mass-selected decay spectroscopy. Access to millisecond nuclides has been demonstrated by the first direct mass measurement and mass-selected half-life measurement of ^{215}Po (half-life: 1.78 ms) The relative population of isomer and ground states and excitation energies of short-lived exotic nuclei have been determined at the FRS Ion Catcher.
The combination of a high density CSC with fast ion extraction (25 ms) and the MR-TOF-MS is an ideal tool to access isomers with half-lives as short as a few ms. This method is thus fully complementary to gamma-ray spectroscopy.
For the first time, an isomerically clean beam has been separated with an MR-TOF-MS, as demonstrated with ^{211}Po ions [3]. Results of isomeric-to-ground state ratios and excitation energies of uranium and xenon projectile fragments and uranium fission products measured with the MRTOF-MS will be presented. In total about 15 isomers were measured with a mass resolving power up to 450,000. Systematic investigation of the relative population of isomer and ground states and excitation energies were done with proton-rich indium isotopes. References:

[1] W.R. Plaß *et al.*, Nucl. Instrum. Methods B **317** (2013) 457
[2] T. Dickel *et al.*, Nucl. Instrum. Methods A **777**, (2015) 172
[3] T. Dickel *et al.*, Phys. Lett. B **744** (2015) 137-141

Effect of deformation on the broad structure of the Isovector Giant Dipole Resonance in $^{144\text{-}150}$Nd and ^{152}Sm

L.M. Donaldson[1], C. Bertulani[2], J. Carter[3], P. von Neumann-Cosel[4], V. Nesterenko[5], R. Neveling[1], P.-G. Reinhard[6], I. Usman[3], P. Adsley[7], J.W. Brummer[8], E.Z. Buthelezi[1], G. Cooper[3], R. Fearick[9], S. Fortsch[1], H. Fujita[10], Y. Fujita[10], W. Kleining[5], C.O. Kureba[3], J. Kvasil[11], K.C.W. Li[8], J. Mira[1], F. Nemulodi[1], P. Papka[8], L. Pellegri[1,3], N. Pietralla[4], A. Richter[4], E. Sideras-Haddad[3], F.D. Smit[1], J.A. Swarz[8], A. Tamii[10], G.F. Steyn[1]

[1] iThemba LABS, National Research Foundation, Somerset West, South Africa
[2] Texas A&M, University-Commerce, USA
[3] University of the Witwatersrand, South Africa
[4] TU Darmstadt, Germany
[5] JINR Dubna, Russia
[6] Universitat Erlangen, Germany
[7] IPN Orsay, Université Paris-Sud, France
[8] University of Stellenbosch, Matieland, South Africa
[9] University of Cape Town, South Africa
[10] RCNP Osaka, Japan
[11] Charles University, Prague, Czech Republic

High energy-resolution inelastic proton scattering experiments with Ep = 200 MeV were performed on ^{144,146,148,150}Nd and ^{152}Sm in the excitation-energy region of the Isovector Giant Dipole Resonance (IVGDR) using the zero-degree facility of the K600 magnetic spectrometer at iThemba LABS. The effect of deformation on both the broad and fine structure of the IVGDR in the rare-earth region was investigated. A goal of the present study was to investigate, for the first time, the IVGDRs of these isotopes with high energy-resolution and to confirm the *K*-splitting observed in previous photo-absorption measurements. The applicability of the photo-absorption data to the present study, owing to the poor energy resolution, is limited to broad structure comparisons only with the focus on the evolution of the shape of the IVGDR in the transition from spherical to deformed nuclei. Discrepancies were found which have implications for astrophysical applications. These results will be presented and discussed along with the comparisons to state-of-the-art theoretical predictions of the corresponding B(E1) strength functions.

In-beam spectroscopy of low-lying energy levels at extreme isospin at the RIBF

Pieter Doornenbal

RIKEN Nishina Center, Wako, Saitama, Japan

The presentation will address nuclear structure and shell evolution at extreme isospin values, studied via in-beam gamma-ray spectroscopy at intermediate energies. Besides an introduction of the setup, recent results will be presented. These include shape transitions and deformation at the N=60 island of deformation around ^{96}Kr, shell effects for N=70 isotones down to ^{110}Zr, and other topics.

Shell-structure evolution around ^{78}Ni

Gilbert Duchêne
IPHC and Université de Strasbourg, France

Based on experimental results, we will explore the evolution of the nuclear structure from the sub-shell N=40 to beyond the N=50 shell closure in the vicinity of ^{78}Ni. Experimental data have been obtained in ^{69}Ni at GANIL using (d,p) reactions, in neutron-rich isotopes for 30 < Z < 40 via multi-nucleon transfer and fusion-fission reactions with AGATA coupled to PRISMA (LNL) and VAMOS++ (GANIL), respectively. The N=40 region may be considered as an island of inversion similar to the one exhibited in the N=20 region which extends towards N=50 for Z < 28. On contrary, the N=50 gap for Z > 28 remains strong but collectivity develops rapidly for larger neutron numbers. Cases in Ge and Zn are considered. At LNL, lifetime measurements have also been performed.

Transfer reaction and ^{212}Po structure

Étienne Dupont
CSNSM Orsay, France

^{212}Po has been studied since 1916 and there have been numerous attempts to give a microscopic description of its structure. With only 4 nucleons more than the doubly-magic ^{208}Pb nucleus, the ^{212}Po is not well understood. Since the use of shell-model configurations failed to reproduce the large alpha-decay rate of the ground state, it has been completed by an alpha-cluster model. However this description fails to explain the lifetime of the 2^+_1 state recently measured [1].
At higher spins, more surprising results have been discovered: several states with non-natural parity have revealed very large B(E1)'s, which can only be explained, until now, by a high alpha-clustering with a vibration of the distance between the α-cluster and the ^{208}Pb core [2]. This very unique situation brought several questions, related to both the origin and the properties of this phenomenon. Is there a favored reaction mechanism and is there a favored energy for the population of these states? Are there still undiscovered cluster states in this nucleus?
During an experiment performed at Jyvaskyla with the JUROGAM2 gamma array, the reaction has been studied with two different beams and we got some information on the production of this nucleus and its neighbors that I will present. I will also show the on-going analysis of an experiment performed this year at GANIL with the germanium array AGATA to measure some lifetimes and to extract the excitation energy of ^{212}Po. A perspective to study the energy dependency in a dedicated experiment will also be presented.

[1] D. Kocheva *et al.,* Phys. Rev. C **96**, 044305 (2017)
[2] A. Astier *et al*., Eur. Phys. J. A **46**, 165–185 (2010)

Triaxiality and single-particle degrees of freedom

Stefan Frauendorf

University Notre Dame, USA

The experimental evidence for triaxiality is reviewed. Analysis of the γ-bands in terms of the collective model points to a soft large-amplitude mode. Evidence for transverse and longitudinal wobbling, and chiral vibrations is discussed. The phenomena are well accounted for by coupling quasiparticles to a rigid triaxial rotor core, as well as by the triaxial projected shell model, which assumes rigid deformation too. The physics behind the apparent more rigid triaxiality in the presence of quasiparticles as compared to the soft-mode γ band is analyzed.

Phase diagram of the extended Agassi model

José Enrique García Ramos[1], J. Dukelsky[2], J.M. Arias[3], P. Pérez-Fernández[3]

[1] University of Huelva, Spain

[2] IEM-CSIC Madrid, Spain

[3] Iuniversity of Seville, Spain

Algebraic models play a key role in Nuclear Physics since the pioneering works of Heisenberg (SU(2) model) and Wigner (SU(4) supermultiplet) in the 1930's and later on of Elliott (SU(3) model) in the 1950's. These models are characterized by an underlying Lie algebra that allow to solve the many-body Nuclear problem in a simple way, even analytically if a dynamical symmetry is realized. This simplicity makes algebraic models to act as excellent benchmarks for testing complex many-body approximations. In particular, the Lipkin model, which describes a two-level system with a monopole-monopole interaction, and the two-level pairing model have been used for years to calibrate the capability of certain approximations to provide accurate and reliable solutions.
In this contribution we consider the Agassi model, which is formulated as a combination of the Lipkin and the two-level pairing models through an so(5) algebra. We generalize the original Agassi model by adding an extra pairing contribution.

The main goal of this work is to obtain the phase diagram of the this generalized Agassi model in a three dimensional parameter space. To this end we work with a mean-field Hartree-Fock-Bogoliubov (HFB) approximation that allows to define the order parameters and phases of the model. We prove that HFB is exact in the thermodynamical limit by performing large scale diagonalizations and finite size corrections. We found a very rich phase diagram with regions where two and even three phases coexist: a symmetric or spherical phase, a parity broken phase related to the monopole interaction and a superconducting phase associated to pairing. Finally, we determine the order of the different phase transitions and the behavior of the order parameters across the phase diagram.

Recognizing structure in the Z = 50 region

Paul E. Garrett[1,2]

[1] *Department of Physics, University of Guelph, Canada*
[2] *University of the Western Cape, Bellville, South Africa*

Nuclei near stability in the Z = 50 region display a fascinating variety of structures at low energy. The presence of shape coexistence in the Cd and Sn isotopes, for example, has been well established, but is less so in the Pd and Te nuclei. The lack of high-precision data, or complementary data from a variety of probes, may cause the presence of shape-coexisting states to go unrecognized, leading to differing interpretations of the structure. The rich interplay between shape coexisting states and the "normally" deformed collective states will be discussed with a particular emphasis on the kind of data required for their identification.

Probing nuclear structure emerging from the interplay of single-particle and collective regimes

Tuomas Grahn
JYFL, Department of physics, University of Jyväskylä, Finland

When moving away from a shell closure, the nuclear structure starts to incorporate more collective features, as it is well known. However, especially in the vicinity of the magic numbers 82 and 126, the systematic data of the $B(E2;\ 2^+_1 \rightarrow 0^+_1)$ values are lacking. In order to probe the emerging collectivity in the neutron-deficient trans-Pb nuclei close to N = 126, we have measured the $B(E2;\ 2^+_1 \rightarrow 0^+_1)$ values in the ^{208,210}Rn and ^{206}Po nuclei by employing Coulomb excitation in inverse kinematics at CERN-ISOLDE using the MINIBALL γ-ray spectrometer [1]. These nuclei have been proposed to lie in, or at the boundary of the region where the seniority scheme should persist. However, contributions from collective excitations are likely to be present when moving away from the N = 126 shell closure. Such an effect is confirmed by the observed increased collective $2^+_1 \rightarrow 0^+_1$ transitions.

Another interesting region to probe the development of collectivity is the Os isotopes when approaching the N = 82 shell closure, where dramatic differences in the nuclear structure have been observed as a function of decreasing neutron number. The ^{168}Os nucleus, which lies between the rotational and vibrational isotopes, has been studied in detail at the Accelerator laboratory of the University of Jyväskylä [2]. In particular, the lifetimes of the excited states have been measured in Os nuclei using the recoil distance Doppler-shift method with the JUROGAM I and II γ-ray spectrometers combined with the RITU separator.

The results of these experiments, reflecting two different regions of the nuclear chart and structure evolution, will be discussed.

[1] T. Grahn et al., Eur. Phys. J. A **52**, 340 (2016)
[2] T. Grahn et al., Phys. Rev. C **94**, 044327 (2016)

A beyond-mean-field description for nuclear excitation spectra

Marcella Grasso
IPN Orsay, France

The second random-phase approximation (SRPA) is an extension of the standard random-phase approximation (RPA) where two particle-two hole (2p2h) are included together with the RPA one particle--one hole (1p1h) configurations. This beyond mean--field model allows us to provide reliable quantitative predictions for describing the widths and the fragmentation of excited states, due to the coupling between 1p1h and 2p2h elementary configurations. I will present the formal developments and practical applications that we have realized in the last years. A special accent will be put on a substantial implementation of the SRPA, based on a subtraction procedure. This subtraction method was tailored to cure double-counting problems encountered when effective interactions are used in beyond mean-field models, within energy-density functional theories. At the same time, this procedure cures all the instabilities and divergences present in the standard SRPA and produces renormalized single-particle excitation energies. The subtracted SRPA provides a well-defined theoretical framework for quantitative predictions on nuclear excitation spectra and several applications to low-lying states and giant resonances will be shown in the medium-mass region of the nuclear chart. A few words will we spent in the final part of this talk on the nuclear density functionals employed in beyond mean--field models.

Search for the nuclear chirality - a manual for experimenters

Ernest Grodner

National Centre for Nuclear Research, Otwock, Poland

2017 marks the twentieth anniversary of the nuclear chirality discovery. Over the years many theorists and experimenters have been involved in the exploration of this phenomenon. We now have a large amount of experimental data on the occurrence of nuclear chirality and new chiral candidates are continuously reported. However, there are still no definitive criteria to prove that candidates are representatives of the spontaneous chiral symmetry breaking phenomenon. An overview of the experimentally available observables and their relevance in the context of nuclear chirality will be presented.

Experimental information on axial symmetry breaking in heavy nuclei, data and calculations

E. Grosse[1], A.R. Junghans[2]
[1] *TU Dresden, Germany*
[2] *HZDR, Germany*

An increasing number of experimental data indicates the breaking of axial symmetry in many heavy nuclei and these are related to

1. Multiple Coulomb excitation of even nuclei analyzed using a rotation invariant formulation
2. Gamma transition rates and energies in odd nuclei
3. Mass predictions by the Thomas-Fermi (ETFSI) method
4. Collective enhancement of nuclear level densities
5. The splitting of Giant Resonances (IVGDR).

In our work on #4 we regard a transition from a superconducting phase to a Fermi-gas-scenario to obtain parameter free analytic predictions and for #5 we also focus on an extrapolation to low energy. In both topics, the quantum mechanical requirement of zero point oscillations and the distinction between static vs. dynamic symmetry breaking challenge experimentalist's data analysis and interpretation. For both again, nearly no parameters remain free to be adjusted by separate fitting, if previous information about nuclear masses, radii etc. are used to fix parameters for the Gogny force, the droplet model and the hydrodynamical surface dissipation model. For the IVGDR energies only an effective mass and for their strength the blocking of p-n pair absorption in nuclei has to be adjusted, when a triple Lorentzian (TLO) is used up to the pion threshold; for the level densities only shell and pairing effects as well as the shape symmetry have to be known, if ã from nuclear matter and the critical temperature Tc from Fermi gas theory are applied. In both analyses the axial symmetry breaking shows up already for heavy nuclei in the valley of stability and this indicates a nuclear Jahn-Teller effect -- mentioned in 1984 by Reinhard and Otten [NPA 420, 173]. In the same year a role of the order for the projection to angular momentum in relation to a Hartree Fock variation (PAV vs.VAP) was shown to be important for triaxiality by Hayashi, Hara and Ring [PRL 53, 337]. Cases for which experimental findings are not reproduced in microscopic calculations (HFB-RPA etc.) may thus challenge the often made axial approximation.

Advances in coupled-cluster computations of atomic nuclei

Gaute Hagen

Oak Ridge National Laboratory, USA

This talk reviews recent progress in coupled-cluster computations of atomic nuclei based on state-of-the-art interactions from chiral effective-field-theory. We made predictions for the neutron skin and dipole polarizability of ^{48}Ca, and showed that its neutron skin is smaller than previously thought. We performed coupled-cluster computations of neutron rich-nickel isotopes, and our results for the first 2^+ state in ^{78}Ni is consistent with it being doubly-magic. We also found that continuum effects play an important role on the level ordering of ^{79}Ni, with $1/2^+$ being the ground-state, indicating that there is a level inversion between the $5/2^+$ and $1/2^+$ states in the N = 51 isotones. I will also show preliminary results for neutron deficient tin isotopes, where in particular we make predictions for the structure and decay of ^{100}Sn from first principles.

Nuclear Shapes from the In-Medium Similarity Renormalization Group

Heiko Hergert
NSCL/FRIB Laboratory, Michigan State University, USA

The In-Medium Similary Renormalization Group (IMSRG) is one of a group of computationally efficient many-body methods tha have extended first-principles calculations of nuclei to nuclei as heavy as the tin isotopes. Moreover, it has allowed forays toward doubly open-shell nuclei, where intrinsic deformations arise. This is achieved in two complementary ways, either by direct calculations based on intrinsically deformed and angular-momentum projected reference states, e.g., from Generator Coordinate Method calculations, or by deriving valence-space Hamiltonians and operators for use in traditional nuclear configuration interaction calculations. I will present results for ground- and excited-state observablesf rom both approaches, and discuss their implications for the current state of the IMSRG and realted many-body methods. I will also briefly touch upon efforts to refine the nuclear interactions and transition operators, derived from chiral Effective Field Theory, which serve as inputs to our calculations.

Systematic study of Z = 83 nuclei: ^{193,194,195}Bi

Andrej Herzáň
Oliver Lodge Laboratory, University of Liverpool, United Kingdom

Two experimental studies have been performed with the aim to investigate the nuclear structure of three neutron-deficient Bi isotopes ^{193,194,195}Bi. The knowledge on these three isotopes is now considerably extended. Manifestation of shape coexistence is evident in all three cases. New high-spin isomeric states are identified, with their half-lives ranging from nanoseconds up to several seconds. Their feeding and decay paths have firmly been established. Many new rotational-like structures have been observed. They can be explained in terms of an unpaired proton coupled to the semi-magic lead core. At higher spins, 3-quasiparticle configurations can be attributed to these rotational bands. In some cases, an extra particle alignment is apparent at high excitation energies. Two $i_{13/2}$ neutron alignment seems to be dominant at low and moderate oblate deformations in this mass region. In all three Bi isotopes, some of the strongly coupled rotational bands are found to be built upon the isomeric states. Moreover, higher-spin members of the proton $i_{13/2}$ bands, above the band crossing, are also found to de-excite to the newly identified $29/2^+$ isomeric states in ^{193}Bi and ^{195}Bi. The ^{195}Bi nucleus is found to be the transitional nucleus in the neutron-deficient Bi isotope chain. Remarkable similarities between the two odd-A Bi isotopes are observed. Two superdeformed (SD) bands, one in each odd-A Bi isotope, have been identified. A possible linking transition has been observed for SD band in ^{193}Bi. Additionaly, a possible shears band is found in ^{195}Bi. It de-excites to the $(29/2^-)$ isomeric state. Combined with previous studies of neighbouring neutron-deficient Bi isotopes, these new results provide an important input for systematic studies of the evolution of shell structure, collectivity, deformation and nuclear isomerism in this mass region. These observations can therefore serve as a good testing ground for theoretical models and nuclei in the vicinity of Z = 82.

CAGRA Project at RCNP, Osaka University

Eiji Ideguchi
RCNP, Osaka University, Japan

We have started a CAGRA (Clover Array Gamma-ray spectrometer at RCNP/RIBF for Advanced research) project at RCNP, Osaka Univeristy. This project constructs a Compton-suppressed Germanium clover array (CAGRA) by an international collaboration (U.S.-Japan-China-Italy, . . .).
It consists of 16 Ge Clover detectors with BGO Compton shields. and a digital data acquisition system employing GRETINA digitizers is used, which enables high-rate data taking. At RCNP cylclotron facility, there are various experimental capabilities such as high-resolution spectrometer, Grand Raiden, low-energy RI beam facility, EN beam line, and the DC muon beam facility, MuSIC.
By combining the CAGRA with these devices, many physics opportunities will be provided. So far, CAGRA campaign experiments at EN beam line and Grand Raiden were successfully performed. It is also planned to bring the CAGRA array to RIBF for further experimental studies using unstable nuclear beams. In this talk, an overview of the CAGRA project and recent experimental results in the studies of mass 40 region obtained from the CAGRA experiment ar RCNP will be presented.

Spectroscopy of neutron-rich Y isotopes produced in fission induced by cold neutrons Onset and evolution of deformed structures

Ł.W. Iskra[1], B. Fornal[1], S. Leoni[2,3], G. Bocchi[2,3], A. Blanc[4], S. Bottoni[2,3], N. Cieplicka-Orynczak[1], M. Jentschel[4], U. Köster[4], C. Michelagnoli[4], P. Mutti[4], T. Soldner[4], G. de France[5], G. S. Simpson[6], C.A. Ur[3], W. Urban[7]

[1] *Institute of Nuclear Physics PAN, Krakow, Poland*
[2] *University of Milan, Milan, Italy*
[3] *INFN, Sezione di Milano, Milano, Italy*
[4] *Institut Laue-Langevin, Grenoble, France*
[5] *GANIL Caen, France*
[6] *LPSC Grenoble, France*
[7] *University of Warsaw, Poland*

In the isotopes of rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr) and niobium (Nb) (i.e., isotopes of nuclei with Z=37-41), a sudden change of the nuclear structure occurs when the number of neutrons reaches N=60. While the nuclei with N<60 exhibit spherical shape in their ground states, the isotopes with N_60 are significantly deformed. This phenomenon is considered the most dramatic shape change in the nuclear chart [1]. A question was raised of whether the deformed structures appear just at N=60 or they reside also in the lighter isotopes. Indeed, deformed rotational bands built on the excited isomeric states are placed in Rb, ^{96}Sr, ^{98}Y, $^{98\text{-}99}$Zr, i.e., at N=58 and 59 (e.g. [2]), however, nothing was known about location of such collective excitations at N<58. In our work, we have investigated the neutron-rich ^{94,96,97,98}Y isotopes in order to search for such deformed structures.

The data for the present study were obtained by employing highly efficient 48 HPGe array installed at the Institute Laue–Langevin in Grenoble, during the experimental campaign named EXILL [3]. The reactor neutrons were collimated forming a cold-neutrons beam with a flux of $10^8/(s \times cm^2)$ which induced fission of the ^{235}U and ^{241}Pu targets. During the off-line analysis, the data were sorted into the 2D and 3D histograms with various time windows. For the purpose of angular correlation study, the clover detectors were mounted in one ring with octagonal geometry.

The analysis employed the delayed- and cross-coincident techniques [4] and allowed to extend the level schemes up to 5 MeV excitation energy. In the studied nuclei nearly 100 new gamma transitions were identified and spin-parities for most of the newly observed states were assigned. The partial results concerning the ^{94}Y isotopes were presented in the previous SSNET conference and showed the spherical character of this nucleus at medium energy and spin range [5]. In the case of more neutron-rich ^{97}Y and ^{98}Y species, the new results indicate the coexistence of both spherical and deformed configurations [6], however, the most interesting observation is the new isomer in 96Y isotope at 1655 keV and the possible rotational band built above [7,8]. This is the first evidence of the presence of deformation in the nucleus with N = 57.

Results of the present study concerning the four yttrium isotopes shed new light on the phenomenon of the onset of deformation in neutron-rich nuclei around N=60. They show that the deformed structures appear just after the subshell closure at N=56 and evolve smoothly when passing through N = 57-59 isotopes, to became ground state structures in the ^{99}Y isotope, i.e., at N=60.

[1] E. Chiefetz, R.C. Jared, S.G. Thompson, J.B. Wilhelmy, Phys. Rev. Lett. 25 (1970) 38.
[2] W. Urban et al., Nucl. Phys A 689, 605 (2001).
[3] M. Jentschel et al., EXILL technical paper, JINST (subm. 2017).
[4] Ł. W. Iskra et al., Phys. Rev. C 89, 044324 (2014).
[5] Ł. W. Iskra et al., subm. to Physica Scripta
[6] Ł. W. Iskra et al., to be published
[7] Ł. W. Iskra et al., Europhys. Lett. 117, 12001 (2017).
[8] Ł. W. Iskra et al., Acta Phys. Pol. B 48, 581 (2017).

Recent Results Selected results from in-beam and decay γ-ray spectroscopy in the ^{132}Sn region performed at RIKEN

Andrea Jungclaus

Instituto de Estructura de la Materia, CSIC, Madrid, Spain

In recent years a significant body of new experimental information with respect to the properties of neutron-rich nuclei around doubly-magic ^{132}Sn was obtained from experiments performed at the Radioactive Isotope Beam Factory at RIKEN (Tokyo, Japan). High-resolution γ-ray spectroscopy following isomeric and β decays has been performed within the EURICA project while for in-beam γ-ray spectroscopy using knockout reactions and Coulomb excitation the scintillator spectrometer DALI2 has been employed. In both cases the neutron-rich nuclei of interest were produced via projectile fission at relativistic energies taking advantage of the high intensity of the primary ^{238}U beam available at RIKEN and the very clean particle identification provided by the BigRIPS and ZeroDegree spectrometers.
In this contribution we will present selected examples of the obtained experimental results and discuss their relevance for the comprehension of the nuclear structure in this region of neutron-rich nuclei far-off the valley of stability.
This work was supported by the Spanish Ministerio de Ciencia e Innovación under contract FPA2011-29854-C04 and the Spanish Ministerio de Economía y Competitividad under contract FPA2014-57196-C5-4-P.

FIPPS - A new instrument for prompt gamma-ray spectroscopy at ILL

Yung Hee Kim

Institut Laue Langevin, Grenoble, France

The study of atomic nuclei levels and lifetimes provides new insights to understand and predict the evolution of nuclear structure and the emergence of new phenomena in exotic nuclei, as well as extraction of important quantities for nuclear applications. The prompt γ-ray spectroscopy of discrete states is a powerful method to address the above. Thermal neutron induced fission reaction can populate neutron-rich exotic nuclei at relatively large angular momentum. On the other hand, neutron capture reaction can access to states with low angular momentum near the valley of stability, which is difficult to access in other methods. Coupling of a high-efficiency Ge detector array with a well-collimated neutron beam provided by the ILL reactor, has been recently demonstrated by the EXILL (EXogam at ILL) campaign. Success of the campaign led to the installation of new permanent instrument setup FIPPS (FIssion Product Prompt Spectrometer) at ILL. In its first phase, it consists of a halo-free pencil neutron beam incident on a target surrounded by an array of 8 Ge clover detectors. This setup has been recently commissioned in Dec. 2016 to exploit a variety of spectroscopy from (n,γ) reaction. In a second phase of FIPPS it will be complemented with a recoil spectrometer based on a gas filled magnet. This will increase the sensitivity and selectivity for nuclear spectroscopy of fission products and enable fission studies of the correlation between excitation energy, angular momentum and kinetic energy. The description of the FIPPS instrument with present performance from commissioning run will be shown. A summary of the preliminary results from the first experimental campaign will be presented. Future perspectives and physics opportunities will be discussed.

Collective modes excited in inelastic scattering of fast protons studied at Cyclotron Center Bronowice (CCB)

M. Kmiecik[1], A. Maj[1], B. Wasilewska[1], M. Ciemała[1], J. Łukasik[1], P. Pawłowski[1], M. Ziębliński[1], P. Bednarczyk[1], J. Grebosz[1], F.C.L. Crespi[2;3], A. Bracco[2;3], S. Brambilla[3], N. Cieplicka[1], B. Fornal[1], Ł. Iskra[1], M. Matejska-Minda[4], K. Mazurek[1], P. Napiorkowski[4], M.N. Harakeh[5], M. Lewitowicz[6], A. Tamii[7], J. Issak[7], et al.

[1] *IFJ PAN Krakow, Poland*
[2] *University of Milano, Italy*
[3] *INFN Milano, Italy*
[4] *SLCJ Warsaw, Poland*
[5] *KVI Groningen, Netherlands*
[6] *GANIL Caen, France*
[7] *RCNP Osaka, Japan*

The new proton beam facility at the Institute of Nuclear Physics Polish Academy of Sciences Poland, the Cyclotron Center Bronowice (CCB) offers, except its primary objective which is proton cancer therapy, the possibility of using proton beams for nuclear physics investigations. The first experiment concerning study of the nuclear structure by means of proton induced excitations of the nuclei has been performed in March 2017. The aim of the measurement was investigation of collective modes in stable nuclei ^{208}Pb. It focuses on the study of the gamma decay from high-lying states below and above the particle binding energy excited via proton inelastic scattering. Above particle binding, the giant resonances (mainly the giant quadrupole resonance, GQR) decay has been studied. The region below the particle binding energy where, among others, the pygmy dipole states (PDR) are present, was explored as well. Experimental set-up required detectors for high-energy gamma rays and scattered protons coincidence measurements. To measure the high-energy gamma rays with high efficiency the HECTOR array [1] was used. It consists of 8 big BaF_2 detectors (14.5 cm of diameter × 17.5 cm of length). They are characterized by high relative efficiency of 10% at 15 MeV for full energy peak. The good timing of BaF_2 detectors of the HECTOR array (≈1 ns) was exploited to define well the coincidence condition and thus to reduce the accidental coincidences and other sources of background. Additionally, the cluster of PARIS type phoswiches (9 $LaBr_3$-NaI or $CeBr_3$-NaI crystals) [2] and one large volume $LaBr_3$ scintillator were used for high energy gamma rays detection. For the measurement of protons with a well-defined scattering angle and energy the KRATTA array [3] was employed. It consisted of 24 triple telescopes made of silicon detectors and two CsI crystals (2.5 and 12.5 cm long) each. The array can measure proton energy from 2.5 to 260 MeV with the resolution of 2 MeV. The KRATTA detectors were placed at forward angles while HECTOR was mounted at backward direction and PARIS at 90 degrees, both outside the vacuum scattering chamber where target was installed. The first experiment aiming at study excitation of ^{208}Pb was preceded by several test measurements done as a preparation of detectors for coincidence measurement. During the talk obtained results as well as experimental method will be discussed.

[1] A. Maj et al., Nucl. Phys. A571, 185 (1994).
[2] A. Maj et al., Acta Phys. Pol. B40, 565 (2009).
[3] J. Łukasik et al., NIM A709, 120 (2013).

Elimination of the spurious admixtures in the QRPA E0, E1, E2 and M1 excitations of deformed nuclei

J. Kvasil[1] , A. Repko[1] , V. Nesterenko [2]

[1] *Inst. for Particle and Nuclear Physics, Charles University, Prague, Czech Republic*

[2] *Institute of Physics, Slovak Academy of Sciences, Bratislava, Slovakia*

[2] *Laboratory of Theoretical Physics, JINR, Dubna, Russia*

Theoretical analysis of the low-lying intrinsic nuclear excitations is substantially complicated by the presence of the spurious modes related to the violation of the conservation laws and corresponding symmetries (translation and rotation invariance, conservation of the nucleon numbers, etc) [1]. These spurious modes are connected with a motion of the whole nucleus in the external laboratory frame and they do not represent real intrinsic excitations of the intrinsic degrees of freedom. It is known that the Quasiparticle Random-Phase-Approximation (QRPA) method allows in principle to remove spurious modes from the solutions of the RPA equations [1]. During last decades, various techniques were proposed for this aim, see e.g. [2, 3, 4]. However, in a practical realization, these techniques quite often are not universal enough or require an impressive computational effort. The latter is quite undesirable for deformed heavy nuclei where self-consistent QRPA calculations need a huge configuration space and thus are already very time consuming. In this contribution, we propose a general method for elimination of various spurious modes and their admixtures from physical QRPA excitations of axially deformed nuclei. The method is an extension and modification of the technique implemented for E0 excitations in Ref. [2]. Here the method is generalized for excitations of any type and multipolarity in axially deformed nuclei. The efficiency of the method is demonstrated in the framework of the Skyrme QRPA approach for E0, E1μ, E2μ, and M1μ isoscalar and isovector excitations in axially deformed nucleus ^{154}Sm.

[1] P. Ring, and P. Schuck. The Nuclear Many-Body Problem (Springer-Verlag N.Y., Heidelberg, Berlin, 1980).
[2] Jun Li, G. Colo, and J. Meng, Phys. Rev. C 78, 064304 (2008).
[3] J. Terasaki, J. Engel, M. Bender, J. Dobaczewski, W. Nazarewicz, and M. Stoitsov, Phys. Rev. C 71, 034310 (2005).
[4] J. Terasaki, and J. Engel, Phys. Rev. C 82, 034326 (2010).

Nature of the doublet bands generated in the particle-rotor model

Elena Lawrie
iThemba LABS, South Africa

A rotating triaxial nucleus is expected to wobble. Recently it was suggested that odd-mass triaxial nuclei may show transverse wobbling and ^{135}Pr was proposed as such a nucleus [1,2]. In order to describe transverse wobbling two approximations were included in the particle-plus-triaxial rotor (PTR) model [1]. The first approximation was that the particle occupies a single $h_{11/2}$ orbital with largest angular momentum projection along the short axis and this angular momentum remains frozen as the rotational frequency increases. The second approximation is that the angular momentum projection along the short and intermediate axes is much smaller than the total angular momentum. The latter allows to approximate the three-dimensional rotation of a triaxial nucleus with a rotation along the intermediate axis coupled with wobbling vibrations. In this work the validity of the second approximation is examined, and is found unsatisfactory. The solutions of the PTR model with and without this approximation are studied and the nature of the predicted bands in odd-mass nuclei is investigated. Furthermore these results have a direct impact on the interpretation of the two-quasiparticle doublet bands in some doubly-odd nuclei as chiral partner bands.

[1] S. Frauendorf and F. Dönau, Phys. Rev. C 89, 014322 (2014)
[2] J. T. Matta, Phys. Rev. Lett. 114, 082501 (2015)

Nuclear structure and reactions from lattice simulations

Dean Lee

North Carolina State University, USA

I describe recent progress and future directions for lattice simulations of nuclear structure and reactions. Some of the topics include the adiabatic projection method for scattering and reactions and the connection between nuclear forces and nuclear structure.

First-order quantum phase transitions between spherical and γ-unstable deformed nuclear shapes

A. Leviatan, N. Gabrielov

Racah Institue of Physics, The Hebrew University, Jerusalem, Israel

Shape-phase transitions between spherical [U(5)-like] and γ-unstable deformed [SO(6)-like] nuclei have been studied extensively and interpreted as a second-order quantum phase transition (QPT). The latter isassociated with a Landau potential $V(\beta;\lambda)$ in which a spherical minimum evolves continuously into a deformed minimum, upon variation of a coupling constant λ in the Hamiltonian.In the present contribution, we address the possibility that such QPT is of first-order, where $V(\beta;\lambda)$ develops multiple minima that coexist in a range λ values and cross at the critical-point. We present a complete classical phase diagram of the underlying symmetric sextic ($\beta 6$) and γ-independent potential in a finite system, obtained by the use of number-conserving coherent states. The quantum analysis involves investigating the properties of a bosonic Hamiltonian with cubic terms, constructed from U(5) and SO(6) invariants. Special attention is paid to identifying signatures of the QPT along the critical-line in the calculated spectrum and electromagnetic transition rates, for low and high barriers separating he coexisting shapes.

Manifestation of triaxiality in ^{135,136}Nd: Chirality and Wobbling

Bingfeng Lv
CSNSM Orsay, France

The existence of triaxially deformed nuclei is a long standing debate. According to the theory there are two unique fingerprints of a triaxial nuclear shape: wobbling and chirality. The wobbling is characterized by $\Delta I=1$, E2 transitions between the bands, and a decrease in the wobbling energy confirms it's transverse nature.
The wobbling bands are expected to exist in ^{135}Nd, with a configuration involving one $\nu h_{11/2}$ hole coupled to a triaxial core, and also in ^{136}Nd with a configuration involving two $\pi h_{11/2}$ particles. The connecting transition between the one and zero-phonon wobbling bands are predicted to have a predominant E2 character.
Therefore, to prove the wobbling character of a band precise angular distribution and polarization measurements are needed. The JUROGAM II array composed of tapered and clover detectors organized on rings with high efficiency, is an ideal setup for measuring in the same experiment both the angular distribution and the polarization of the transitions of interest.

Rotation induced shapes and collective phenomena in excited atomic nuclei - an overview of studies coordinated by groups from IFJ PAN Krakow and HIL Warsaw

A. Maj[1], M. Kmiecik[1], B. Wasilewska[1], M. Ciemała[1], P. Bednarczyk[1], K. Mazurek[1], P. Napiorkowski[2], K. Hadyńska-Klęk[2], J. Srebrny[2], E. Grodner[2], A. Bracco[3], J. Dudek[4] et al.

[1] IFJ PAN Krakow, Poland
[2] SLCJ Warsaw, Poland
[3] University of Milano, Italy
[4] University of Strasbourg, France

Nuclear rotation at sufficiently high spins, may induce important (in particular shape) changes in the nucleus. At sufficiently high temperatures the nuclear shell-effects can be considered negligible and the nuclear behavior resembles that of a liquid drop. When angular momentum increases, the nucleus changes its shape, from spherical to oblate one, and at some critical spin, the nucleus may undergo a sudden change of shape – from oblate to very elongated prolate. This is the phenomenon in known as Jacobi shape transition. In between those two extremes, oblate and strongly elongated prolate shapes, the nucleus usually undergoes a sequence of triaxial shapes. The latter, in turn, may lead to the phenomenon of chirality, wobbling, etc. In my lecture, I will focus on selected achievements of Polish experimental groups from Institute of Nuclear Physics (IFJ PAN) in Krakow and Heavy Ion Laboratory (HIL) in Warsaw exploring the collective properties of rotating nuclei. I will discuss the results of research on the phenomenon of rapid change of shape of the rotating nucleus from the flattened to the elongated ellipsoid (Jacobi transitions). Such studies were carried out for A=40 and A=90 nuclei, by measuring the gamma decay of the Giant Dipole Resonance (GDR). In addition, I will present related studies of the Coulomb excitations, which revealed the possible existence of tri-axial super-deformed shape in A = 40 mass region. I will also demonstrate the results of the research that have shown that rotating tri-axial nucleus may exhibit nuclear chirality. Finally, I will present the status of the construction of a novel array for measuring high energy gamma-rays, PARIS, and in the context of using PARIS, I will discuss the possible perspectives of the studies of rotation induced shapes and collective phenomena.

Effects of reflection-asymmetric shapes on nuclear collective and isomeric properties

Nicolay Minkov
INRNE, Bulgarian Academy of Sciences, Sofia, Bulgary

We present current advances of a research project in the field of nuclear shape dynamics based on combined collective (geometric) and intrinsic (single-particle) model approaches aiming to reveal the rôle of reflection-asymmetric deformations such as the axial quadrupole-octupole (QO) one in the forming and manifestation of specific nuclear properties such as alternating-parity and quasi-parity-doublet spectra, isomer excitations and related electromagnetic features. We briefly review a model formalism for coherent QO motion (CQOM) [1] connected to reflection-asymmetric deformed shell model (DSM) with pairing correlations of BCS type and Coriolis interaction [2]. We exemplify its applications to octupole spectra and high-K isomeric states in heavy and super heavy nuclei [3] and illustrate a particular model prediction made for a radiative decay of the 7.8 eV isomer in ^{229}Th [4]. On this basis we give an idea for possible relation of some of the observed phenomena with a genuine symmetry inherent for the coherent QO mode which could allow their interpretation in terms of the supersymmetric quantum mechanics (SUSY-QM).

[1] N. Minkov et al., Phys. Rev. C 73, 044315 (2006); 76, 034324 (2007); 85, 034306 (2012);
88, 064310 (2013).
[2] N. Minkov, Phys. Scripta T154, 014017 (2013).
[3] P. M. Walker and N. Minkov, Phys. Lett. B 694, 119 (2010); N. Minkov and P. M. Walker, Eur. Phys. J. A 48: 80 (2012); Phys. Scripta 89, 054021 (2014).
[4] N. Minkov and A. Palffy, Phys. Rev. Lett. 118, 212501 (2017).

Erosion by neutron emission of Coulomb effects on the charge distribution of final fragments from low energy fission of ^{234}U and ^{236}U

Modesto Montoya, Arnold Rivera

Universidad Nacional de Ingeniería, Lima, Peru

In the cold region of low energy fission of ^{233}U and ^{235}U, respectively, between two isobaric primary fragmentations having similar Q-values, the more asymmetric charge split has the higher yield. This property called the Coulomb effect was possible to discover because, in that cold region, corresponding to windows of the highest values of kinetic energy of fragments, there is no neutron emission, so that the final and primary masses of fragments are the same [1]. As the kinetic energy windows of the final fragments are lowered, the preference is reversed in favor of less asymmetric fragmentations [2,3]. In this work, using the Monte Carlo simulation method, we show that this anti Coulomb effect in final fragments is due to neutron emission. As input data for the simulation we take (i) the primary mass yield Y (A); ii) the average and standard deviation of the kinetic energy of the fragments as a function of mass A; iii) the number of neutrons emitted as a linear function of the kinetic energy, with zero value for the maximal kinetic energy, and equal to the neutron multiplicity for the average value of the kinetic energy iv) a distribution of charges equal to corresponding to the cold fission. As a result of the simulation we obtain that the average charge is a decreasing function of light fragment kinetic energy. This result suggests that the Coulomb effect is also produced outside cold fission, but that the emission of prompt neutrons does not allow to observe it in the final fragments reaching detectors. To explain anti Coulomb effect, we must remember that i) the lower the kinetic energy the higher the excitation energy and the higher the number of neutrons emitted by the corresponding fragment and ii) primary fragments with A higher than m have an average charge higher than those corresponding to fragments with primary mass A=m. In consequence the fragments ending with lower kinetic energy will have higher average of charge. Nevertheless, the anti Coulomb effect is modulated by the average kinetic energy dependence of primary fragment mass. The above analysis is valid for the light fragments in the mass region where kinetic energy is almost constant. For regions of heavy mass fragments, the effects of neutron emission are varied, there are even regions where the effects are contrary to those observed in the light fragments. In this region, new technologies in the measurement of charge distribution [4] could verify these results of a Monte Carlo simulation.

[1] M. Montoya, R.W. Hasse and P. Koczon, Z. Phys. A – Atoms and Nuclei **325** (1986) 357-362.
[2] U. Quade et al.: Nucl. Phys. A**487** (1988) 1-36.
[3] W. Schwab et al.: Nucl. Phys. A**577** (1994) 674-690.
[4] P. Grabitz et al.: Journal of Low Temperature Physics, **184** (2016) 944–951.

Do Quarks Play Explicit Role in Nuclear Structure?

Genis Musulmanbekov
JINR Dubna, Russian Federation

Starting with the quark model of nucleon structure in which valence quarks are strongly correlated within a nucleon, light nuclei are constructed by assuming the similar correlations of the quarks of neighboring nucleons [1]. Application of the model to larger collections of nucleons reveals the emergence of the face-centered cubic (FCC) symmetry at a nuclear level where nucleons are arranged in alternating spin--isospin layers. The FCC model of nuclear structure, which is isomorphic to the shell model and, moreover, composes the features of the liquid drop and cluster models, has been proposed by N.Cook about 30 years ago [2]. Binding of nucleons in stable nuclei are provided by quark loops which form three and four nucleon correlations. On a quark level the nuclear shell closures correspond to the octahedral or truncated tetrahedral symmetry. Thus all nuclei even with closed shells are non-spherically symmetric. The quark loop that can be identified with three nucleon force results in a "pairing" effect. And namely quark loops leading to four-nucleon correlations are responsible for the binding energy enhancement in even-even nuclei which are formed by virtual alpha-clusters. For medium and heavy nuclei the arrangement of nucleons is modified by Coulomb repulsion of protons. This effect together with quark/nucleon correlations leads to deviation from the shell model expectations. The model can predict the boundary of the maximal numbers of proton and neutron excess, i.e. proton and neutron drip lines. Moreover, the quark loops are responsible for formation of exotic (borromean) nuclei [3]. These loops corresponding triangular nucleon configurations ^{3}H and ^{3}He are building blocks of both stable and borromean nuclei. In borromean nuclei possessing maximal deformation, these configurations are weakly bound. The proposed model provides predictions for specific nuclear configurations and their shapes. According to our approach, there is a depression of nuclear matter in the central part of ^{4}He. The model predicts the maximally possible neutron excess in helium isotopes is 4, i.e. the last helium bound state is ^{8}He, and a bound state of ^{10}He does not exist

[1] G. Musulmanbekov, *AIP Conf. Proc.*, **675**, 358 (2004).
[2] N.D. Cook, *Models of Atomic Nuclei*, Springer, (2006) and references therein.
[3] G. Musulmanbekov and N.D. Cook, *Phys.Atom.Nucl.* **71**, 1226 (2008).

Shell-model investigation of even and odd nuclei above ^{132}Sn

H. Naidja[1,2], F. Nowacki[1]
[1]*IPHC, IN2P3-CNRS et Université de Strasbourg, Strasbourg, France*
[2] *LPMPS, Université Constantine 1, Constantine, Algeria*

The investigation of neutron rich nuclei in the vicinity of the robust ^{132}Sn core are currently an active subject on nuclear structure research. Recent advances in radioactive-ion-beam facilities and detection systems provide access to many exotic nuclei in this region. At the same time the progress in the development of the effective interactions has opened up a new era of successful theoretical approaches, to explore and gain more information from this region of heavy mass nuclei.In our earlier shell-model works [1,2,3] the low-lying state energies and isomeric transitions of the tin isotopes ^{134,136,138,140}Sn are investigated using realistic interaction. In this presentation, this study will be extended by exposing the recent results of chains of even [4,5] and odd nuclei with $50 \leq Z \leq 82$, where the low-lying states energies, E2 and M1 transitions will be discussed. Special attention is devoted to N=86 and 88 isotones [6], where we noticed collective features with signature of triaxial γ−bands.

[1] G. S. Simpson and *al.*, Phys. Rev. Lett 66, 054313 (2013).
[2] H. Naïdja, F. Nowacki, K. Sieja, J. Phys: Conf. Series 580, 012030 (2015).
[3] H. Naïdja, F. Nowacki, K. Sieja, Acta. Phys. Pol. B 46, 669 (2015).
[4] H. Naïdja and F. Nowacki, Acta. Phys. Pol. B 48, 587 (2017).
[5] H. Naïdja, F. Nowacki {\it et al.} Phys. Rev. C 95, 064303 (2017).
[6] H. Naïdja and F. Nowacki submitted in Eur. Phys.J conf (2017).

The second gamma-ray spectroscopy campaign with GRETINA at NSCL

Yuichiro Nagame

Japan Atomic Energy Agency, Japan

The first ionization potential (IP_1) is one of the most sensitive atomic properties which reflect the outermost electron configuration. Precise and accurate determination of IP_1 of heavy elements allows us to give significant information on valence electronic configuration affected by relativistic effects.

The IP_1 values of heavy elements up to einsteinium (Es, Z = 99), produced in a nuclear reactor in macroscopic quantities, were successfully measured by resonance ionization mass spectroscopy (RIMS). IP_1 values of heavy elements with $Z \geq 100$, however, have not been determined experimentally, because both half-lives and production rates of nuclides of still heavier elements are rapidly decreasing, which forces us to manage elements on an atom-at-a-time scale.

In the present study, we report the determination of the IP_1 values of heavy actinides from Fm through Lr using a surface ionization technique source installed in JEA−ISOL (Isotope Separator On−Line) was applied for measuring the ionization of the short-lived nuclides ^{256}Lr ($T_{1/2}$= 27s), ^{257}No ($T_{1/2}$= 24.5s), ^{251}Md ($T_{1/2}$= 4.27min), and ^{249}Fm ($T_{1/2}$= 2.6min) that were produced in the ^{249}Cf+^{11}B, ^{248}Cm+^{13}C, ^{243}Am+^{12}C, and ^{243}Am+^{11}B reactions, separation was determined by alpha−particle spectroscopy to evaluate ionization efficiencies. The IP_1 values of these elements were determined by the prescription in Ref. [1]. The obtained results are in good agreement with relativistic calculations as well as with the early prediction. The contribution will present experimental details and results obtained in this study.

[1]. T. K. Sato *et al.*, *Nature* **520**, 209 (2015).

Bound and unbound light nuclei from ab initio theory

Petr Navratil
TRIUMF, Vancouver, Canada

In recent years, significant progress has been made in *ab initio* nuclear structure calculations employing Hamiltonians constructed within chiral effective field theory based on symmetries of QCD. One of the newly developed approaches is the No-Core Shell Model with Continuum (NCSMC) [1,2], capable of describing both bound and scattering states in light nuclei starting from chiral two- (NN) and three-nucleon (3N) interactions. I will present latest NCSMC calculations of weakly bound states and resonances of exotic halo nuclei such as ^{6}He and ^{11}Be and discuss strong E1 transitions and photo-dissociation of ^{11}Be. I will also present our results for unbound nuclei such as ^{7}He, ^{9}He and ^{11}N and highlight the role of chiral NN and 3N interactions. Finally, I will review our recent results for A=12 nuclei with ^{12}N calculated including its ^{11}C+p breakup channel, and discuss the role of E1 excitations in ^{12}C in experimental determination of its 2^{+} quadrupole moment.

[1] S. Baroni, P. Navratil, and S. Quaglioni, Phys. Rev. Lett. **110**, 022505 (2013);
Phys. Rev. C **87**, 034326 (2013).
[2] P. Navratil, S. Quaglioni, G. Hupin, C. Romero-Redondo, A. Calci,
Physica Scripta **91**, 053002 (2016).

Pigmy resonance in soft nuclei measured through excitation of spin isomers

Vladimir Nedozerov
INR RAS, Russia

New experimental results on excitation of Cd and In isomers at photon energies from 5 to 8.5 MeV are presented. Measurements have been performed using the INR electron linac-8.5 MeV and, in parallel, the femtosecond laser facility of the Moscow State University. A detailed comparison between two experimental methods including the GEANT-4 simulation code is done. The obtained data are discussed in the frames of the phenomenological model which allows the theoretical evaluation of the isomeric ratio in this energy region. The model based on the well known structure of the excited levels of the studied nucleisatisfactorily describes the threshold value, the amplitude and width of the resonance observed. Dependence on the dipole and quadrupole mode contributions is studied.
The signatures for exotic nuclear excitations are not found.

Single-particle states vs. collective modes: friends or enemies?

Takaharu Otsuka
Department of Physics, University of Tokyo, Japan

I will present a new mechanism, called "quantum self-organization", and will illustrate that this is an underlying-mechanism to govern various types of low-energy collective modes of atomic nuclei. Let me explain this by taking an example. Many nuclei are deformed to ellipsoids rather than being spherical. This deformation is primarily due to the quadrupole component of nuclear forces. We recently found that the actual deformation is determined not only by the effect of this quadrupole interaction but also by the balance from the resistance power against the deformation. Historically, the pairing interaction was known to contribute to the resistance, reducing the moment of inertia of rotational band. We point out that the single-particle energies are another major resistance power. The bound quantum system is characterized by discrete single-particle energies. If they are split strongly (e.g., nuclear spin-orbit splitting), the deformation is hindered. This is common in collective motions based on the Jahn-Teller effect. We shall present that the nuclear force, particularly its monopole component, can organize (effective) single-particle energies so as to be more favorable for a given collective mode, by choosing optimum configurations of protons and neutrons over various orbitals. This mechanism is called quantum self-organization. In short, once the nucleus "decides" to have an ellipsoidal shape, the nucleus self-organizes its single-particle structure in a favorable way. This can be a general feature in many-body quantum systems, where "many-body" is a crucial key word. I will explain that this is a revision of Landau's Fermi liquid picture of atomic nuclei, and will present concrete examples from stable and exotic nuclei, including quantum phase transition, shape coexistence, shell evolutions and shape transitions, by utilizing results from Monte Carlo Shell Model calculations.

Effective field theories for collective excitations of nuclei

T. Papenbrock[1], E.A.O. Pérez[2]

[1] *University of Tennessee, USA*

[2] *TU Darmstadt, Germany*

We re-examine nuclear vibrations and rotations with the tool of effective field theory (EFT). For nuclear rotation, the EFT is based on the emergent breaking of rotational symmetry and on its Nambu-Goldstone realization. Its leading order recovers well-known collective models, and higher-order corrections correctly describe the faint inter-band transitions. The EFT suggest that some transitions would merit a re-measurement or re-evaluation. The EFT for nuclear vibrations is based on the usual Wigner-Weyl realization of rotational symmetry. Expanding Hamiltonians and transition operators consistently, and employing Bayesian uncertainty quantification, we arrive at a consistent description (within theoretical uncertainties) of spectra and electromagnetic transitions in ^{62}Ni, $^{98, 100}$Ru, $^{106, 108}$Pd, $^{110, 112, 114}$Cd, $^{118, 120, 122}$Te, and some of their odd-mass neighbors.

Shape coexistence and beta decay in proton-rich A~70 nuclei within beyond-mean-field approach

Alexandrina Petrovici
IFIN-HH, Bucharest-Magurele, Romania

Recently obtained self-consistent results on coexistence phenomena in A~70 nuclei comparing nicely with the experimental data [1-4] are extended to the investigation of shape coexistence effects on superallowed Fermi and Gamow-Teller beta decay of odd-odd nuclei. Beta decay properties of the N=Z nucleus 70Br explored within the beyond-mean-field complex Excited Vampir variational model using an effective interaction obtained from a nuclear matter G-matrix based on the charge-dependent Bonn CD potential and an adequate model space will be presented. Results on superallowed Fermi beta decay of the ground state and Gamow-Teller decay of the 9^+ isomer in ^{70}Br correlated with the shape coexistence and mixing effects on the structure and electromagnetic properties of the populated states in the daughter nucleus ^{70}Se will be compared with available data.

[1] A. Petrovici, Phys. Rev. C 91, 014302 (2015).
[2] A. Petrovici and O. Andrei, Phys. Rev. C 92, 064305 (2015).
[3] A. Petrovici, J. Phys. Conf. Ser. 724, 012038 (2016).
[4] A. Petrovici, Phys. Scr. 92, 064003 (2017).

Possible decay chains of superheavy nuclei in forthcoming experiments

D.N. Poenaru[1] , R.A. Gherghescu[1] , S. Hofmann [2]

[1] *IFIN-HH, Bucharest-Magurele, Romania*

[2] *GSI, Darmstadt, Germany*

Production of superheavy (SH) nuclei with Z>118 is the next goal of several laboratories who have been active until now in this field, e.g. GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany, JINR Dubna, Russia, Nat. Livermore Lab., USA, and RIKEN Japan. We would like to investigate the competition of three decay modes, α~decay (αD), cluster radioactivities (CR), and spontaneous fission (SF) of the following nuclides: $^{297,299,300}119$ and $^{299,300,301,302}120$. The most reliable method to identify a new SH is by αD chains leading to well known final nuclei. Nevertheless, sometimes the main decay mode could be SF, and this may comnplicate the experiments. For heavier SHs, e.g. Z>120 it is possible that even CR [1] may compete [2]. We are using mainly the following models: ASAF (Analytical Super-Asymmetric Fission); UNIV (Universal Formula), and semFIS (Semi-empirical formula based on Fission Theory) to study αD. ASAF and UNIV are useful for CR. A dynamical model based on cranking inertia tensor allows us to calculate SH half-lives. Strutinsky's macroscopic-microscopic method with Yukawa-plus-exponential (Y+EM) liquid drop and the best two-center shell model [3] are necessary to calculate the total deformation energy. For pairing we have to solve the BCS system ot two equations. For ^{38}Sr cluster radioactivity of $^{300,302}120$ we predict a branching ratio relative to α~decay of -0.10 and 0.49, respectively, meaning that it is worth trying to detect such kind of decay modes in competition with α~decay. Whenever possible we calculate the Q-values by using the latest experimental evaluation of the masses [Chinese Physics C 41 (2017) 030003]. Otherwise the W4 atomic mass model [Phys. Lett. B 734 (2014) 2215] is our choice.

[1] Encyclopaedia Britannica Online. Web \http://www.britannica.com/EBchecked/topic/465998/
[2] D.N. Poenaru, R.A. Gherghescu, and W. Greiner, Phys. Rev. Lett. **107**, 062503 (2011).
[3] R.A. Gherghescu, Phys. Rev. C {\bf 67} 014309 (2003).

Potential energy surfaces of superheavy nuclei in the 4D Fourier parameter space

Krzysztof Pomorski[1] , B. Nerlo-Pomorska[1] , C. Schmitt [2] , J. Bartel[2]
[1] *Maria Curie Sklodowska University, Lublin, Poland*
[2] *IPHC and Universite de Strasbourg, Strasbourg, France*

Potential energy landscapes of super-heavy nuclei were analysed in a four dimensional deformation parameter space. The elongation, neck, mass-asymmetry, and nonaxial modes are taken into account [1,2]. The potential energy surfaces (PES) are calculated within the macroscopic-microscopic model based on the Lublin-Strasbourg Drop (LSD) [3], the Yukawa-folded (YF) single-particle potential (details in Ref. [4]) and a monopole pairing force. The PES are presented and analysed in detail for the even-even nuclei from Z=100 to 128 and N-Z=40 to 74, i.e. for 258 isotopes in the mass range from 240 to 324. The ground and shape-isomeric states energies and multipole moments as well as the fission barrier heights were evaluated. The valleys leading to the symmetric or/and asymmetric fission are traced for each isotope (see also [4])

[1] K. Pomorski, B. Nerlo-Pomorska, J. Bartel, C. Schmitt, Acta Phys. Pol. B Supl. 8, 667 (2015).
[2] C. Schmitt, K. Pomorski, B. Nerlo-Pomorska, J. Bartel, Phys. Rev. C 95, 034612 (2017).
[3] K. Pomorski and J. Dudek, Phys. Rev. C 67 , 044316 (2003).
[4] A. Dobrowolski, K. Pomorski, J. Bartel, Comp. Phys. Comm. 199, 118 (2016).

Some spectroscopic properties of odd well-deformed nuclei in the rare-earth region

Meng Hock Koh[1], Philippe Gaston Quentin[2], Hervé Molique[3], Johann Bartel[3], Ludovic Bonneau[2], N.M. Nor[1]

[1] *Universiti Teknologi Malaysia, Malaysia*

[2] *CENBG Bordeaux, France*

[3] *IPHC Strasbourg, France*

The region of well-deformed rare-earth nuclei provides a valuable testing ground to assess both single-particle (s.p.) and pairing properties, the latter being of course partly contingent on the former. Calculations of even-even, odd-even and odd-odd nuclei have been performed within a standard self-consistent Skyrme-Hartree-Fock plus seniority force BCS approach (with self-consistent blocking and taking into account time-reversal breaking effects for odd isotopes). We emphasize here the study of the influence of pairing properties on some spectroscopic properties. To that effect, we chose a parametrization of the Skyrme interaction which has proven to provide reasonable s.p. properties in general [1] and in particular in this region [2], namely the well established Skyrme SIII force [3].

The neutron and proton parameters of the seniority force (only n-n and p-p correlations are considered here) have been fitted from 3-points odd-even mass differences (centered on odd nuclei) for 16 odd-N and 14 odd-Z rare-earth isotopes yielding r.m.s energy differences from the experimental data [4] of 75 and 122 keV respectively, quantities which are of the same order as the standard deviation of the experimental values (averaging around 600 keV).

With the so-defined Hamiltonian we have calculated for a wide sample of well-deformed even-even nuclei in this region, moments of inertia within the M(Q) Inglis-Belyaev approximate ATDHFB ansatz [5] corrected as in [6] for the so-called Thouless-Valatin self-consistency effects. The spectroscopy of band-heads of the seniority-one type (evaluated as it has been done in [7] for a few actinide nuclei) has also been yielded and compared with experimental data, particularly around the ^{178}Hf region. Finally spectroscopic quadrupole moments and magnetic dipole moments have been evaluated for some of the above considered odd-N and odd-Z nuclear states.

[1] L. Bonneau et al., Phys. Rev. C 76, 024320 (2007)
[2] N. Pillet et al., Nucl. Phys. A 697, 141 (2002)
[3] M. Beiner et al., Nucl. Phys. A 238, 29 (1975)
[4] G. Audi et al., Chinese Phys. C 41, 030001 (2017)
[5] E. Kh. Yuldaeshbaeva et al., Phys. Lett. B 461, 1 (1999)
[6] J. Libert et al., Phys. Rev. C 60, 054301 (1999)
[7] Meng-Hock Koh et al., E. Phys. J. A. 52, 3 (2016).

Study of vibrational to rotational region by use of affin su(1,1) algebra in the sdg-IBFM framework

R. Zeinab, M. Ghapanvari, M.A. Jafarizadeh

Universiy of Tabriz, Iran

Algebraic method which is simpler and also easier in compare to numerical methods is offered for complicated sdg interacting boson-fermion model Hamiltonian. In this method, solvable transitional Hamiltonian which is based on SU(1,1) algebra is used for transitional sdg interacting boson-fermion model Hamiltonian to provide an investigation of quantum phase transition (QPT) between the spherical and deformed gamma unstable shapes in odd-A nuclei. Some observables such as BE(4) which exhibits a necessity of inclusion of g boson in the sd IBM and cannot be explained in the sd boson model is calculated and better interpretation of this observable is achieved. Energy spectra, quadrupole electromagnetic transitions, hexdacapole electromagnetic transitions, an expectation value of the g-boson number operator and level crossing are presented. Energy spectra, BE(2) ,and BE(4) are determined via the Bethe-Ansatz method and compared with the experimental data. An acceptable degree of agreement was achieved based on this new procedure.

Symmetric/asymmetric transition of fission yields studied with the time-dependent generator coordinate method

D. Regnier[1], M. Verrière[2], N. Schunck[3], N. Dubray[2]

[1]*IPN Orsay, France*

[2] *CEA, DAM, DIF, Arpajon, France*

[3] *Nuclear and Chemical Science Division, Lawrence Livermore National Laboratory, Livermore, USA*

The concept of shapes in the atomic nucleus has historically been connected to the fission process. This phenomenon is still widely pictured as an evolution of the nuclear shape coupled to some internal degrees of freedom that eventually leads to the production of two fragments. The variety of its applications ranging from the formation of elements in the r-process to fuel cycle optimization in nuclear energy is an incentive to develop microscopic approaches to fission, rooted in the framework of energy density functional. One of the most promising theoretical frameworks in this direction is the time dependent generator coordinate method (TDGCM) applied under the Gaussian overlap approximation (GOA). Previous studies reported promising results by numerically solving the TDGCM+GOA equation for the fission of a few actinides. However, due to the computational cost of this method, it has not yet been applied to more exotic systems and its reliability in other regions of the nuclear chart is yet to be demonstrated. To cast a new light on this topic, we computed systematically the fragment mass distributions produced by low energy fission of even systems in the Fm and Th isotopic chain. These two isotopic chains present a particular interest for fission theory as experimental data emphasize transitions from mostly symmetric to asymmetric mass split. In this talk, we briefly present the latest improvements to the numerical tools used to solve the TDGCM+GOA equation. We emphasize the fission fragment yields obtained for the Fm and Th isotopic chains. Eventually, we discuss the limitations of the TDGCM approach for fission as well as some perspectives to go beyond.

Coulomb excitation of ^{132}Sn with MINIBALL at HIE-ISOLDE

Peter Reiter
for the MINIBALL collaboration
Institute of Nuclear Physics, University of Cologne, Cologne, Germany

The MINIBALL spectrometer utilizes successfully the huge variety of post-accelerated radioactive ion beams provided by the new HIE-ISOLDE accelerator at CERN. In-beam gamma-ray spectroscopy after Coulomb excitation (CE) or transfer reactions is performed with optimized setups of ancillary detectors for particle detection. Especially the enlarged availability of exotic heavy ion beams and the higher beam energies of HIE-ISOLDE enable unique studies of collective properties up to the actinide region. Promising first results were obtained by employing a ^{132}Sn ion beam with an energy of 5.5 MeV/u. The vibrational first 2^+ and 3^- states of the doubly magic nucleus ^{132}Sn were excited via safe Coulomb excitation after bombardment of a thin ^{206}Pb target. The high beam energy, the high-energy resolution and good efficiency of the HPGe © spectrometer provide a favourable combination to master the measurement characterized by small cross sections of the high lying states with excitation energies above 4 MeV. The results on excited collective states in ^{132}Sn provide crucial information on 2p-2h cross shell configurations that are expected to be dominated by a strong proton contribution. The experimental results are compared to large-scale shell model calculations and new mean field calculations.

Studies of shape coexistence with the Coulomb excitation in the light mercury isotopes

Kseniia Rezynkina*
IKS, KU Leuven, Belgium

In the neutron-deficient $^{182\text{-}186}$Hg isotopes the so-called intruder states come down in excitation energy to the vicinity of the spherical states, yielding the low-lying non-yrast energy levels [1]. The mixing between the states of the coexisting configurations gives rise to transitions with a strong electric monopole component, often referred to as a fingerprint of shape coexistence.
Coulomb excitation studies have been performed at the ISOLDE facility on even mass mercury isotopes and reveal the coexistence of the prolate and the weakly-deformed oblate configurations in these nuclei [2].
Recent data from decay spectroscopy at ISOLDE indicates very high internal conversion coefficients (ICC) for the $2^+ \rightarrow 2^+$ transitions [3], suggesting the strong mixing between the two shape configurations. These new spectroscopic data (i.e. the ICC and the branching ratios) are used in a re-analysis of the Coulomb excitation yields from REX-ISOLDE, providing a unique opportunity to extract the transitional matrix elements, the spectroscopic quadrupole moments Q_s and the electric monopole transition strengths $\rho(E0)$.
The new results from the GOSIA calculations for ^{182}Hg and ^{184}Hg will be presented, compared with theory and interpreted in a two-level mixing model. The future Coulomb excitation and decay spectroscopy experiments at ISOLDE will also be discussed.

[1] K. Heyde, J. L. Wood, Rev. Mod. Phys. **83**, (2011) 1467
[2] N. Bree et al., Phys. Rev. Lett. **112**, 16 (2014), 162701
[3] E. Rapisarda et al., J. Phys. G: Nucl. Part. Phys. **44** (2017) 074001

* for the IS452 and IS563 collaborations

Shapes describing the fusion, fission and fragmentation phenomena and alpha molecules

G. Royer, J. Jahan , N. Mokus
Subatech, UMR 6457: IN2P3/CNRS, Université, IMT, Nantes, France

In nuclear and particle physics, molecular physics, astrophysics, and mechanics, physical leptodermous (thin skin) distributions of matter or charge are often simulated by geometric shapes and it is necessary to know their main characteristics such as center of inertia, volume, surface, curvature, moments of inertia, quadrupole moment, ... Assuming volume conservation and constant density during the deformations the spherical form minimizes always the surface energy but maximizes the Coulomb repulsion (as in nuclei) or the gravitational attraction (as in stars and planets). The rotation of these physical objects or/and shell effects induce often large ellipsoidal prolate or oblate deformations (ground state nuclear deformations, super and hyperdeformations in rotating nuclei, planets, and galaxies,...). Transition from one-body to two-body or several body shapes may also be induced by very rapid rotation or decay of excited nuclear systems (binary and ternary fission, fragmentation in heavy-ion reactions at intermediate energies,...). Conversely, initially separated nuclei or astrophysical objects may also fuse (fusion of two ions, fusion of three alpha particles submitted to high pressure in stars,...). The purpose of this presentation is to provide geometric shapes [1-2] and to give their main characteristics in order to determine the energy and the dynamics of reactions such as the nuclear fusion [3], fission [4-5], fragmentation processes [6] and alpha emission [7]. After recalling general definitions, the following shapes will be successively studied: ellipsoids, symmetric and asymmetric elliptic and hyperbolic lemniscatoids, prolate symmetric and asymmetric compact ternary shapes, toroids and bubbles. Other planar and three-dimensional multibody shapes such as linear chain, triangle, square, tetrahedron, pentagon, trigonal bipyramid, square pyramid, hexagon, octahedron, octagon and cube used to describe some light nuclei as alpha molecules will be also shown as the associated potentials [8].

[1] G. Royer, N. Mokus, and J. Jahan, Phys. Rev. C (2017) in press.
[2] R. W. Hasse and W. D. Myers, 1988, Geometrical Relationships of Macroscopic Nuclear Physics, (Springer verlag, Berlin, 1988).
[3] G. Royer and J. Gaudillot, Phys. Rev. C 84, 044602 (2011).
[4] G. Royer, M. Jaffré, and D. Moreau, Phys. Rev. C 86, 044326 (2012).
[5] G. Royer, F. Haddad, and J. Mignen, J. Phys. G: Nucl. Part. Phys. 18, 2015 (1992).
[6] C. Fauchard and G. Royer, Nucl.Phys. A 598, 125 (1996).
[7] G. Royer, Nucl. Phys. A 848, 279 (2010).
[8] G. Royer, G. Ramasamy, and P. Eudes, Phys. Rev. C 92, 054308 (2015).

The Evolution of Shapes and Collectivity with Increasing Angular Momentum

J.S. Baron[1], M.A. Riley[1], J. Simpson[2], E.S. Paul[3], D.J. Hartley[7], R.V.F. Janssens[4], X. Wang[1], A.D. Ayangeakaa[5], H.C. Boston[3], M.P. Carpenter[4], C.J. Chiara[4,6], U. Garg[5], D. Judson[3], F.G. Kondev[8], T. Lauritsen[4], J. Matta[5], S.L. Miller[1], P.J. Nolan[3], J. Ollier[2], M. Petri[9], J.P. Revill[3], L.L. Riedinger[10], S.V. Rigby[3], C. Unsworth[3], K. Villafana[1], S. Zhu[4], and I. Ragnarsson[11]

[1] *Department of Physics, Florida State University, Tallahassee, USA*
[2] *STFC Daresbury Laboratory, Warrington, United Kingdom*
[3] *Department of Physics, University of Liverpool, United Kingdom*
[4] *Physics Division, Argonne National Laboratory, Argonne, USA*
[5] *Physics Department, University of Notre Dame, Notre Dame, USA*
[6] *Dept. of Chemistry and Biochem., Univ. of Maryland, College Park, USA*
[7] *Department of Physics, United States Naval Academy, Annapolis, USA*
[8] *Nuclear Engineering Division, Argonne National Laboratory, Argonne, USA*
[9] *Nuclear Science Div., Lawrence Berkeley National Lab, Berkeley, USA*
[10] *Dept. of Physics and Astronomy, University of Tennessee, Knoxville, USA*
[11] *Div. of Mathematical Physics, LTH, Lund University, Sweden*

The light rare-earth nuclei near N = 90, are textbook examples of the evolution of nuclear structure with excitation energy and angular momentum. They display a variety of different phenomena, such as, multiple backbends, dramatic prolate to oblate shape changes associated with band termination plus a spectacular return to collectivity extending discrete gamma-ray spectroscopy into the so-called ``ultrahigh-spin regime`` (I = 50-70).

Band termination represents a clear manifestation of mesoscopic physics, since the underlying finite-particle basis of the nuclear angular momentum generation is revealed.
In ^{158}Er, terminating states at values $I^{\pi} = 40^{+}, 43^{-}, 46^{+}, 48^{-}$, and 49^{-}, have been observed, Other neighbouring nuclei have also been found to exhibit similar fully aligned states providing stringent tests of nuclear models since the wavefunctions for these special states are extremely pure.

The present work has been triggered by a comprehensive high-spin analysis of data from Gammasphere on ^{157}Ho$_{90}$ which showed remarkable similarities to the known band termination states in ^{158}Er$_{90}$. A systematic analysis of favoured band terminations in neighboring nuclei has subsequently been carried out and will be discussed.

Towards symmetry unrestricted Skyrme-HFB calculations: Rotation of exotic shapes

M. Bender, W. Ryssens
IPNL, Lyon, France

The concept of intrinsic symmetry breaking is central to the mean-field description of nuclei: it allows for the inclusion of correlations beyond the independent-particle picture at modest computational cost. Restriction of the rotational symmetry to one Cartesian axis (instead of three) is a prime example of intrinsic symmetry breaking in many mean-field approaches; limiting rotational symmetry this way gives access to the description of axial deformations. Time-reversal symmetry is another example, its breaking allowing for the description of collective rotation and odd numbers of nucleons. While in many applications axial (and to a lesser extent, triaxial) deformations are considered, there remain a number of significant additional symmetries that are assumed to be conserved in many approaches. These assumptions are usually made for two reasons: every conserved intrinsic symmetry eases the computational burden and facilitates the physical interpretation of the results. However, an important downside of conserving additional symmetries is the limitation of the variational space and a loss of generality: the description of exotic geometries is often impossible. An example is reflection symmetry: while assumed to be conserved in many cases, it is necessarily broken for nuclear configurations exhibiting octupole or tetrahedral deformation. With the advent of tracking-γ-ray spectroscopy, experiments become more and more able to resolve the rich structure of rotational bands in numerous nuclei. More and more data becomes available on bands that are associated in a mean-field context with exotic geometries of the nucleus. To provide a satisfactory mean-field description of such bands, just allowing for axial (or even triaxial) deformations is not sufficient. To improve the description of such states, we have developed a new framework for self-consistent mean-field calculations, using effective Skyrme interactions in a coordinate-space representation. The MOCCa code [1] is a generalization of the principles of the EV8 code [2,3], allowing its user for significant freedom concerning symmetry assumptions of the nuclear configuration and a more general treatment of pairing correlations. We will present the first results obtained within this framework, specifically focusing on the rotational properties of exotic shapes. Octupole deformed shapes, breaking reflection symmetry, are a first candidate: recent experimental data [4] offer new insight into the structure of ^{223}Th. A transition between static octupole deformation at low spins to reflection-symmetric shapes at higher spins is suggested by experiment and predicted by a cranked Woods-Saxon calculation [5]. The description of an even-odd system, coupled with the breaking of time-reversal and reflection symmetries, make this application a technical challenge. Breaking signature symmetry is also possible within the framework of MOCCa, allowing more degrees of freedom for the orientation of the angular momentum relative to the nucleus. This freedom opens up the possibility to study wobbling and shears modes [6] as well as chiral rotation. The latter of these phenomena has recently garnered significant experimental interest, especially the detection of multiple chiral doublet (MχD) bands [7,8]. First results of mean-field explorations using MOCCa in the A~130 region of such features will be presented.

[1] W. Ryssens, PhD Thesis, Université Libre de Bruxelles (2016).
[2] P. Bonche et al., Comput. Phys. Commun. 171, (2005).
[3] W. Ryssens et al., Comput. Phys. Commun. 187, (2015).
[4] G. Maquart et al., Phys. Rev. C textbf{95}, 034304 (2017).
[5] W. Nazarewicz et al., Phys. Rev. Lett. textbf{52}, 1272 (1984).
[6] S. Frauendorf, Rev. Mod. Phys. 73, 463 (2001).
[7] I. Kuti et al., Phys. Rev. Lett. Textbf{113}, 032501 (2014).
[8] A.D. Ayangeakaa et al., Phys. Rev. C textbf{93}, 054317 (2016).

Evidence of rotational behavior in ^{120}Te isotope

M. Saxena[1], P. Napiorkowski[1], R. Kumar[2], L. Prochniak[1], A. Stolarz[1], S. Dutt[3], K. Wrzosek-Lipska[1], M. Matejska-Minda[1], M. Palacz[1], J. Srebrny[1], H.J. Wollersheim[4]

[1] Heavy Ion Laboratory, University of Warsaw, Poland
[2] Inter University Accelerator Centre, New Delhi, India
[3] Department of Physics, Aligarh Muslim University, India
[4] GSI, Darmstadt, Germany

In recent years the region in the vicinity of tin isotopes has been intensively investigated both from experimental and theoretical perspectives. In particular, the excitation energies and the reduced transition probabilities across the Z=50 chain has been examined in detail. The Te nuclei with 52 protons lies in the transitional region between the spherical nuclei at Z = 50 and deformed Xe and Ba nuclei. For the mid-shell ^{120,122,124}Te nuclei the partial level show the expected vibrational like structure with equal energy spacing between the phonon states [1]. This observation is quite in contrast to the measured quadrupole moments Q_{2+} for the doubly even Te isotopes [2, 3]. These quadrupole moments can reach 60% of the one predicted by the symmetric rigid rotor.
In our recent Coulomb excitation experiment [4] at IUAC, New Delhi we used 58Ni beam @ 175MeV to excite ^{120,122,124}Te isotopes. In these measurements the scattered particles were detected at forward angles. The B(E2; $0^+ \rightarrow 2^+$) value in ^{120}Te was re-measured with a much higher precision to allow a comparison with the predictions of the large scale shell model calculations (LSSM). Based on all experimental findings including the excitation of higher excited states for ^{120,122,124}Te one obtains the best agreement with an asymmetric rotor behavior. Calculations were performed using the Davydov-Filippov model which reproduce the reduced transition probabilities with β=0.19 and γ~27°. But, microscopic calculation (using the Skryme effective interaction) performed point towards a vibrational structure with a mean value of γ~30°. The most sensitive probe to characterize a nuclear excitation is via the measurement of quadrupole moments. Therefore, to further investigate the second order effects (diagonal matrix elements) in ^{120}Te, an experiment was performed at Heavy Ion Laboratory, Warsaw, where particle detectors are in the backward direction enabling a more precise and sensitive measurement of the quadrupole moments. The measurement was carried out using a highly enriched ^{120}Te target and a ^{32}S beam @ 100 MeV from the U-200P cyclotron at HIL.
A multi-step Coulomb excitation of ^{120}Te was observed up to 4^+ state in the g.s. band. Along with second 0^+ and second 2^+ states were also populated. The relative signs and magnitude of the transitional matrix elements between populated states were determined. The diagonal matrix element for the 2^+ state was determined and has significant value different from zero with a negative sign, which shows a rotational character of the collective structure of ^{120}Te. The results will be interpreted with the collective models of nuclear structure.

[1] http://www.nndc.bnl.gov/ensdf.
[2] A. Bockisch and A. M. Kleinfeld, Nucl. Phys.A**261** 498-510 (1976).
[3] J. Barrette et al., Phys. Rev. C **10**, 3 (1974)
[4] M. Saxena et al., Phys. Rev. C **90**, 024316 (2014).

Restoration of symmetries in time-dependent calculations. Josephson effect in reactions below the barrier

G. Scamps, Y. Hashimoto
CCS Tsukuba University, Tsukuba, Japan

Heavy ion transfer reactions are an ideal tool to study the pair correlations. New experimental data show that the probability to transfer a pair of neutrons is enhanced compared to the expected value in the uncorrelated limit or pure sequential transfer [1,2]. This enhancement is expected to be due partially to the Josephson effect. This effect is well understood in macroscopic systems where the transfer arises from systems with a define gauge angle. Nevertheless, in nuclear reactions, the initial particle number of both fragments is a good quantum number and so the symmetry of the relative gauge angle must be restored. In order to study the transfer reaction, we use the Time-dependent Hartree-Fock-Bogoliubov (TDHFB) theory. The calculation is done with a Gogny interaction in a hybrid basis of two-dimensional harmonic oscillator eigenfunctions and a one-dimensional Lagrange mesh. With that model, the Josephson effect is quantitatively described in the reaction $^{20}O+^{20}O$ and $^{14}O+^{20}O$ as well as the dependency of the Nucleus-Nucleus potential with respect to the Gauge angle [3].

The restoration of the gauge angle symmetry is then studied with a projection method. This calculation consists in making several TDHFB calculations with different initial relative gauge angle. The final observable is then obtained by a triple projection method, that include the calculation of overlap between final state of the different TDHFB calculations. The Pfaffian method is used to compute the overlap between the quasiparticle vacuum states. The accuracy of this method is discussed in a simple model [4] and then applied to the realistic model [5].

[1] L. Corradi et al., "Single and pair neutron transfers at sub-barrier energies", Phys. Rev. C **84**, 034603 (2011).
[2] K. Hagino and G. Scamps, "Enhancement factor for two-neutron transfer reactions with a schematic coupled-channels model", Phys. Rev. C**92** 064602 (2015).
[3] Y. Hashimoto and G. Scamps, "Gauge angle dependence in time-dependent Hartree-Fock-Bogoliubov calculations of 20O+20O head-on collisions with the Gogny interaction", Phys. Rev. C **94**, 014610 (2016).
[4] G. Scamps and Y. Hashimoto, "Superfluid effects in collision between systems with small particle number", arXiv:1704.00930.
[5] G. Scamps and Y. Hashimoto, "Transfer probabilities for the reactions 14,20O+20O in terms of multiple time-dependent Hartree-Fock-Bogoliubov trajectories", arXiv:1708.01994.

"Stiff" Deformed Nuclei and the β and γ Degrees of Freedom

John Sharpey-Schafer

University of the Western Cape, South Africa

Although four decades ago it had been conclusively shown [1] that the first excited 0^+_2 state in $^{156}_{66}Dy^{90}$ was a pairing isomer, the lessons of this identification has taken a long time to connect with the Nuclear Structure Community. The 0^+_2 states that can be populated significantly with two particle neutron transfer, all have large enough cross-sections to demonstrate that simple monopole pairing in theoretical descriptions will be insufficient. The conclusion that these states cannot be associated with time-dependent "β" vibrations of the nuclear shape is also supported by their very weak excitation in inelastic scattering processes such as (d,d') [2]. Blocking of the coupling of the single particle neutrons in odd nuclei to the 0^+_2 states near N=90 have shown that a major part of their configurations is a pair of neutrons in the [505]11/2$^-$ Nilsson orbit [3]. This high-K orbit is extruded from the $h_{11/2}$ shell to the Fermi surface by the increasing deformation caused by adding neutrons outside the N=82 core. These data confirm the separation of prolate-prolate and oblate-oblate pairing suggested by [4] and used in the model of [5] by [1]. At iThemba LABS we have used conventional γ-ray spectroscopy to investigate structures in the pairing gaps of even-even nuclei in the ranges Z=62-70 and N=88-92, in particular to study the systematics of the excited Kπ = 0^+_2 and 2^+_γ positive parity bands. We find that the 02+ bands all have moments-of-inertia that are greater than those of the ground state 0^+_1 bands, in complete contradiction to the predictions of all Interacting Boson Models (IBM) [6]. The larger moments-of-inertia for 0^+_2 bands are consistent with reduced pairing due to the low density of oblate (high-W) orbitals near the Fermi surface. The odd spin members of the γ bands all track the ground state bands while the even spin members can mix with the 0^+_1 and 0^+_2 bands. Indeed the γ bands and 0^+_2 bands cross and interact strongly affecting the signature splittings S(I) observed in the γ bands. The systematic data will be discussed in terms of the Triaxial Projected Shell Model (TPSM) [7] and the 5-Dimensional Collective Model (5-DCM) [8].

[1] J. J. Kolata and M. Oothoudt, Phys. Rev. C**15**, 1947 (1977).

[2] B. Bloch, B. Elbek and P. O. Tjøm, Nucl. Phys. A**91**, 576 (1967).

[3] J. F. Sharpey-Schafer et al., Eur. Phys. J. A **47**, 6 (2011).

[4] R. E. Griffin, A. D. Jackson and A. B. Volkov, Phys. Lett. B**36**, 281 (1972).

[5] W. I . van Rij and S. H. Kahana, Phys. Rev. Lett. **28**, 50 (1972).

[6] W.-T. Chou, Gh Cata-Danil, N. V. Zamfir, R. F. Casten and N. Pietralla, Phys. Rev. C**64**, 057301 (2001).

[7] J. A. Sheik, G. H. Bhat, G. B. Vakil and R. Palit, Phys. Rev. C**77**, 034313 (2008).

[8] Z. P. Li, T. Nikšic, D. Vretenar, J. Meng, G. A. Lalazissis and P. Ring, Phys. Rev. C**79**, 054301 (2009).

Phase diagram of the extended Agassi model

Krzysztof Starosta[1], Q. Chen[2], T. Koike[3]

[1] Simon Fraser University, Burnaby, Canada
[2] IEM-CSIC Madrid, Spain
[3] Iuniversity of Seville, Spain

Algebraic models play a key role in Nuclear Physics since the pioneering works of Heisenberg (SU(2) model) and Wigner (SU(4) supermultiplet) in the 1930's and later on of Elliott (SU(3) model) in the 1950's. These models are characterized by an underlying Lie algebra that allow to solve the many-body Nuclear problem in a simple way, even analytically if a dynamical symmetry is realized. This simplicity makes algebraic models to act as excellent benchmarks for testing complex many-body approximations. In particular, the Lipkin model, which describes a two-level system with a monopole-monopole interaction, and the two-level pairing model have been used for years to calibrate the capability of certain approximations to provide accurate and reliable solutions.

In this contribution we consider the Agassi model, which is formulated as a combination of the Lipkin and the two-level pairing models through an so(5) algebra. We generalize the original Agassi model by adding an extra pairing contribution.

The main goal of this work is to obtain the phase diagram of the this generalized Agassi model in a three dimensional parameter space. To this end we work with a mean-field Hartree-Fock-Bogoliubov (HFB) approximation that allows to define the order parameters and phases of the model. We prove that HFB is exact in the thermodynamical limit by performing large scale diagonalizations and finite size corrections. We found a very rich phase diagram with regions where two and even three phases coexist: a symmetric or spherical phase, a parity broken phase related to the monopole interaction and a superconducting phase associated to pairing. Finally, we determine the order of the different phase transitions and the behavior of the order parameters across the phase diagram.

New experimental data relevant to the shape change in the A~100 region

Waldemar Urban

Faculty of Physics, University of Warsaw, Poland

The shape change around the Z=40 proton and N=60 neutron numbers continues to attract the attention. Recent shell-model calculations, performed in a large base of single-particle orbits, have offered a new explanation of the effect as due to significant rearrangements of positions of these orbits [1]. While the results are in many respects similar to conclusions based on the Nilsson scheme, there are also some differences, studying of which may help better understanding of the phase transition at Z=40, N=60.

One of these differences concerns the role of the neutron $9/2^+[404]$, extruder orbital, which is important in the Nilsson picture, in accord with its observation near the Fermi level in Sr and Zr isotopes around N=60 (see Ref. [2] and references therein). This orbital is, however, neglected in the shell-model approach, because of the $\nu g_{9/2}$ shell being located well below the valence shells. Another difference is related to the, generally, more important role of proton excitations in the shell-model picture in contrast to the employment of low- neutron subshells in the deformed, mean-field approach [3, 4].

It is clear that further detailed experimental search for proton and neutron excitations in the region is needed. Our previous works have shown the presence of low-Ω subshells of the $\nu h_{11/2}$ orbital [5] and the $\nu 9/2^+[404]$ orbital [2] past the N=56 subshell closure. Less is know about the spherical $g_{7/2}$ and h11/2 neutron orbitals in the 50_N_56 range as well as about low-Ω subshells of the $\pi g_{9/2}$ orbital above the N=56 subshell closure.

Our recent studies of nuclei from the discussed region, utilizing the data measured with the Eurogam, Gammasphere, EXILL and FIPPS arrays of Ge detectors, the Lohengrin fission fragmen separator and the JYFYLTRAP Penning trap provided new data on the subject, which will be presented and discussed in this paper.

[1] T. Otsuka, and Y. Tsunoda, J. Phys. G **43**, 024009 (2016).

[2] W. Urban, J.A. Pinston, J. Genevey, T. Rz¸aca-Urban, A. Z lomaniec, G. Simpson, J.L. Durell, W.R. Phillips, A.G. Smith, B.J. Varley, I. Ahmad, and N. Schulz, Eur. Phys. J. A **22**, 241 (2004).

[3] T. Werner, J. Dobaczewski, M.W. Guidry, W. Nazarewicz, and J.A. Sheikh, Nucl. Phys. A **578**, 1 (1994).

[4] J. Skalski, S. Mizutori, and W. Nazarewicz, Nucl. Phys. A **617**, 282 (1997).

[5] W. Urban, J.L. Durell, A.G. Smith, W.R. Phillips, M.A. Jones, B.J. Varley, T. Rz¸aca-Urban, I. Ahmad, L.R. Morss, M. Bentaleb, and N. Schultz, Nucl. Phys. A **689**, 605 (2001).

Mean Field Description of Exotic Nuclear Systems from Chiral NN and ΛN potentials

Petr Vesely, J. Pokorny, J. Mares

Nuclear Physics Institute, Czech Academy of Sciences, Rez, Czech Republic

In this work we construct a self-consistent mean field of hypernucleus from the realistic chiral nucleon-nucleon (NN) N^2LO_{opt} [1] and Λ-nucleon (ΛN) LO [2] interactions. The mean-field model based on the realistic baryon-baryon forces was recently introduced and applied on both nuclear [3] and hypernuclear [4] systems. We discuss the spin-orbit splitting of the single particle energies of Λ in $^{13}{}_{\Lambda}C$ and $^{17}{}_{\Lambda}O$ and its dependence on the tensor term. Additionally we implemented the Λ-neutron TDA method to calculate the low-lying spectra of the hypernuclei $^{12}{}_{\Lambda}C$ and $^{16}{}_{\Lambda}O$. The obtained results are compared with the experimental data. We discuss possible extensions of the formalism to include the Λ particle-core polarization effects.

[1] A. Ekstrom, G. Baardsen, C. Forssen, G. Hagen, M. Hjorth-Jensen, G. R. Jansen, R. Machleidt, W. Nazarewicz, T. Papenbrock, J. Sarich et al., Phys. Rev. Lett. 110, 192502 (2013).
[2] H. Polinder, J. Haidenbauer, U.-G. Meissner, Nucl. Phys. A 779, 244 (2006).
[3] D. Bianco, F. Knapp, N. Lo Iudice, P. Vesely, F. Andreozzi, G. De Gregorio, A. Porrino, J. Phys. G: Nucl. Part. Phys. 41, 025109, (2014).
[4] P. Vesely, E. Hiyama, J. Hrtankova, J. Mares, Nucl. Phys. A 954, 260, (2016).

The second gamma-ray spectroscopy campaign with GRETINA at NSCL

Dirk Weisshaar

NSCL/Michigan State University, USA

In July 2017, the second NSCL fast-beam gamma-ray spectroscopy campaign with the Gamma-Ray Energy Tracking In-beam Nuclear Array GRETINA set up in front of the S800 magnetic spectrograph was concluded. Fast beams of rare isotopes provided at the Coupled Cyclotron Facility of the National Superconducting Cyclotron Laboratory (NSCL) impinged on a reaction target located at the center of GRETINA. Reaction residues were detected in the spectrograph in coincidence with gamma rays in GRETINA. The high spatial resolution of GRETINA enabled accurate event-by-event Doppler-shift reconstruction of the gamma-ray energies emitted by the reaction residues in flight, at velocities typically exceeding 30% of the speed of light. GRETINA's tracking capability allows to acquire gamma-ray data of high spectral quality. This presentation will summarize the performance of GRETINA in this powerful configuration for fast-beam spectroscopy and give an overview of the physics program addressed in this second campaign of GRETINA at NSCL.

Probing Low-Spin Nuclear Structure with Fast Neutrons

Steven Yates
University of Kentucky, USA

The inelastic neutron scattering (INS) reaction can be used to populate nuclear levels non selectively (statistically), and the decays of low-spin, non-yrast states can be observed. Lifetimes in the femtosecond regime can be determined and transition probabilities can be extracted [1]. These measurements permit the characterization of low-spin levels at low excitation energies particularly well and provide structural information for comparison with theoretical nuclear structure calculations.

In experiments performed at the University of Kentucky Accelerator Laboratory, INS reaction studies have been applied to a variety of nuclear structure problems with recent work focusing on (a) obtaining new information relevant to the calculation of the nuclear matrix elements for neutrinoless double-beta decay [2-4], (b) characterizing the nuclear shape transition in the stable xenon nuclei [5], and (c) examining the role of collective vibrational excitations in the medium-mass region [6]. In each of these studies, many new low-spin levels were identified. Moreover, evidence for a number of previously suggested levels in these nuclei was not found and they were eliminated. Level lifetimes, multipole mixing ratios, transition probabilities, and other properties were determined.

This material is based upon work supported by the U.S. National Science Foundation under Grant No. PHY-1606890.

[1] T. Belgya, G. Molnár, and S. W. Yates, Nucl. Phys. **A607**, 43 (1996).
[2] S. Mukhopadhyay *et al.*, Phys. Rev. C **95**, 014327 (2017).
[3] S. Mukhopadhyay *et al.*, to be published.
[4] E. E. Peters *et al.*, to be published.
[5] E. E. Peters *et al.*, Phys. Rev. C **94**, 024313 (2016).
[6] F. M. Prados-Estévez, *et al.*, Phys. Rev. C **95**, 034328 (2017).

Studying the nuclear g factor and quadrupole moment of the isomeric 1^+ state of ^{34}Al via the beta-NMR technique

Z. Xu[1], H. Heylen[1], K. Asahi[2], F. Boulay[3], J.-M. Daugas[4], R. De Groote[1], W. Gins[1], O. Kamalou[3], A. Koszorus[1], M. Lykiardopoulou[5], T.J. Mertzimekis[5], G. Neyens[1], H. Nishibata[2], R. Orset[4], T. Sato[2], C. Stodel[3], J.-C. Thomas[3], M. Vandebrouck[6], X. Yang[1]

[1] *IKS, KU Leuven, Belgium*
[2] *RIKEN Nishina Center, Japan*
[3] *GANIL Caen, France*
[4] *CEA/DAM/DIF, Arpajon, France*
[5] *University of Athens, Greece*
[6] *CEA/SPhN, Saclay, France*

Nuclei far from the β-stability line are of great interest for their unique properties compared to those of stable nuclei. One of the archetypical examples is called the ''island of inversion" around ^{32}Mg (Z = 12), where the ground states of nuclei are strongly deformed despite the neutron shell closure at N = 20 [1]. In the framework of the shell model, these deformed ground states are dominated by intruder configurations, in which two neutrons are excited from the normal *sd* shell to the *pf* shell (2*p*2*h*) owing to a reduced N = 20 shell gap and strong quadrupole correlations. Since the neutron-rich Al isotopes (Z = 13) are located at the northern border of the island of inversion, strong competitions between the normal and intruder configurations are anticipated in their ground and low-lying states. Thus, they can provide a stringent test for various theoretical models to understand the underlying nucleon-nucleon interactions and the driving force of deformation in the island of inversion.

For ^{34}Al (N = 21), a previous g-factor measurement suggests a large mixing of 2*p*2*h* configurations into the 4^- ground state [2]. Later, a 1^+ isomer was discovered based on the β decay of ^{34}Al, proposed to be a intruder state dominated by 1*p*1*h* configurations [3]. In a recent ^{34}Mg β-decay study, the excitation energy of this intruder isomeric state have been measured, closely above the ground state [4]. In this contribution, we will present the first g-factor and quadrupole-moment (Qs) measurements of this isomer, ^{34m}Al, using the β-detected nuclear magnetic/quadrupole resonance (β-NMR/NQR) technique. The obtained g factor is found to be very close to that of the 1^+ ground state of ^{32}Al, confirming the 1*p*1*h* nature of the isomer. The quadrupole moment, on the other hand, is increased by 50% from ^{32}Al to ^{34m}Al, evidencing directly the increase in deformation due to a 1*p*1*h* excitation. The new results are well reproduced by the large-scale shell-model calculations using effective interactions developed for this mass region.

[1] E.K. Warburton *et al.*, Phys. Rev. C **41**, 1147 (1990)
[2] P. Himpe *et al.*, Phys. Lett. B **658**, 203 (2008)
[3] F. Rotaru *et al.*, Phys. Rev. Lett **109**, 092503 (2012)
[4] R. Lica *et al.*, Phys. Rev. C **95**, 021301(R) (2017)