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Low-energy transitions between excited states within theory of finite Fermi systems

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A new method for calculations of photon strength function in low energy region is developed. The main idea is to try to calculate E1 and M1 transitions between excited one-phonon states using the self-consistent theory of anharmonic effects developed within quantum many-body nuclear theory [1]. The approach involves a new type of ground state correlations, which originates from integration of three single-particle Green's functions. The Skyrme forces with known universal parameters are used so that both the HFB mean field and effective interaction between nucleons are calculated self-consistently. Our theoretical results for ^{208}Pb, ^{60}Ni, ^{70}Ni are compared with the experimental data of Oslo method [2, 3].

[1] S. P. Kamerdzhiev *et al.*, JETP Letters **106**, 139 (2017)

[2] S. N. Liddick *et al.*, Phys. Rev. Lett. **116**, 242502 (2016).

[3] T. Renstrøm *et al.*, arXiv:1804.08086 (2018).

Benchmarking mean-field and beyond-the-mean-field methods for calculating level densities

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Self-consistent mean-field approximations have been widely used in the calculation of level densities [1] but their accuracy has not been well studied. We discuss finite-temperature mean-field approximations to level densities, and benchmark them [7] against shell model Monte Carlo (SMMC) calculations that are accurate up to well-controlled statistical errors [3]. In particular, we discuss the finite-temperature Hartree-Fock (HF) and the Hartree-Fock-Bogoliubov (HFB) approximations. We present results for (i) a well-deformed heavy nucleus ^{162}Dy, for which the appropriate mean-field theory is the HF, and (ii) a spherical heavy nucleus ^{148}Sm, for which we use the HFB theory.

We identify the main weaknesses of the mean-field method for calculating level densities: (i) the extraction of level densities at fixed particle numbers from the grand-canonical ensemble of the finite-temperature mean-field approximation, and (ii) the symmetry breaking by deformation or by the pairing condensate. In a deformed nucleus, the entropy below the shape transition is underestimated since the mean-field approximation misses the contribution from rotational bands. Particle-number conservation is restored by particle-number projection after variation [4], which works well in deformed nuclei, but in the presence of a pairing condensate it leads to an unphysical negative entropy at low temperatures.

We also discuss and benchmark methods that take into account correlations beyond the mean-field approximation but are computationally more efficient than SMMC. In particular, we discuss the static path plus random-phase approximation (SPA+RPA), which includes large-amplitude static fluctuations around the self-consistent mean field and small-amplitude time-dependent quantal fluctuations around each static fluctuation [5].

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[2] Y. Alhassid, G .F. Bertsch, C. N. Gilbreth and H. Nakada, Phys. Rev. C **93**, 044320 (2016).

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[5] P. Fanto and Y. Alhassid, to be published.

Energy profile of laser Compton-scattered gamma rays generated at NewSUBARU

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We have measured photoneutron cross sections at the NewSUBARU synchrotron radiation facility within the PHOENIX (**PHO**ton **E**xcitation and **N**eutron em**I**ssion cross (**X**) sections) collaboration for the IAEA-CRP F41032. Quasi-monochromatic γ-ray beams are produced in collisions of laser photons with relativistic electrons. The energy distribution of the LCS γ-ray beam is essentially determined by the electron beam emittance involved in the collision and the size of the collimator which confines scattering angles. In this collaboration, we employed the Talon laser (532nm) and 10cm-Pb double collimators with 3 and 2mm apertures, respectively.

We measure response functions of a 3.5" × 4.0" $LaBr_3(Ce)$ detector to LCS γ-ray beams and determine the energy profile of the LCS γ-ray beam by best reproducing the response function with a GEANT4 code that incorporates the kinematics of the laser Compton scattering, transportation of γ-rays through the double collimators, and interactions of γ-rays with the $LaBr_3(Ce)$ detector. The energy spread of the LCS γ-ray beams is small under best accelerator conditions, being 1 - 3% in the full width at half maximum over the energy range from 6 to 40 MeV. In December 2017, however, we observed significant degradation of the energy profile of the LCS γ-ray beam, which is attributable to bad electron beam emittance in the GEANT4 simulation. We report the degradation effect of the electron beam emittance on the energy profile in comparison with best profiles.

Solving the statistical mysteries of ^{133}Xe with inverse-Oslo method

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When investigating statistical properties, the main route of investigation has been using a light ion beam on a stable target to produce the reaction of interest. This puts limits on the possible isotopes to explore. Using the Oslo method [1] it is then possible to extract the nuclear level density (NLD) and the γ-strength function (γ SF) for suitable targets. Alternatively, using the inverse-Oslo method, it is possible to study more exotic or unstable nuclei, using a heavy beam on a light target. A proof of principle experiment was performed in 2015 at iThemba LABS with a ^{86}Kr(d,p)^{87}Kr to determine the NLD and the γSF of ^{87}Kr [2].

In 2017, an experiment was carried out at iThemba LABS with ^{84}Kr and ^{132}Xe beams on a deuterated polyethylene target to undergo a (d,p) reaction, producing ^{85}Kr and ^{133}Xe. ^{133}Xe was produced by impinging a ^{132}Xe beam on a deuterated polyethylene target. NLD and γSF were extracted from the measured particle-γ coincidences. With the NLD and γSF, the nuclear structure of ^{133}Xe can be investigated to determine if there is a low energy enhancement (LEE) in the γSF, along with scissors and pygmy resonances. Due to its location relative to doubly-magic ^{132}Sn in the nuclear chart, ^{133}Xe has been predicted to have an especially large

LEE [3]. The statistical properties of ^{133}Xe are of interest for (n,γ) calculations. Highly excited ^{133}Xe* in high energy density plasmas has also been examined at the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory to examine changes in angular momentum due to nuclear-plasma interactions [4].

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Isospin effects and the electric dipole response in nuclei

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The study of the nuclear dipole response in nuclei is of great interest to understand the nature of excitation modes and their implications in nuclear astrophysics for nucleosynthesis and the modeling of neutron stars. Here a review is given of experimental work concerning isospin effects in nuclei as probed by gamma decay from the dipole excitations [1].

Particular attention is given to the experimental and theoretical efforts made to understand the nature and the specific structure of the low-lying dipole states (the Pygmy Dipole Resonance, PDR). In addition, the isospin mixing in nuclei at finite temperature and its relation with beta decay is here discussed.

All the experimental work addressing these topics here discussed uses the gamma-decay as a tool and reactions with light and heavy ions. It will be shown that an effective way to shed light on the underlying nature of the dipole excitation in the low energy region region is the comparison of their excitation with different reaction types.

Results, analysis methods and comparison with theoretical predictions will be presented both for the study of the pygmy states and for the isospin mixing in nuclei at finite temperature. Some possible future perspectives with AGATA will be also briefly illustrated.

[1] A.Bracco, E.Lanza, and A. Tamii *Isoscalar and isovector dipole excitations: Nuclear properties from low-lying states and from the isovector giant dipole resonance* Progress in Particle and Nuclear Physics 106 (2019) 360–433.

Quantum shape phase transitions and level densities in nuclei

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This contribution highlights a hitherto only partly recognized connection between the phenomenon of quantum shape phase transition (SPT) in nuclei and the nuclear level density (LD).

First, examination of experimentally determined level densities has shown that the well-known first order SPT taking place in rare earth nuclei (with $A \approx 150$) is accompanied by a maximum of the level density of the isotopes with Z = 60 to 67 at $N \approx 90$. The level density was examined within the BSFG (Back-shifted Fermi gas) model, taking its a-parameter as a measure of it. Both experimental level densities and those extrapolated to all nuclei (according to the procedure from [1]) show this maximum [2]. This behaviour is consistent with a phase coexistence phenomenon at the critical point. Thus, the level density is a useful indicator of SPTs. Unlike many other effective order parameters considered in different studies, it can be examined in any kind of nuclei (both even-even and with odd nucleon numbers) [2].

Second, it has been shown that the level density approach allows to disentangle the relationship between the shape coexistence (SC) and the SPT phenomena, an important question being whether SC is always present near a SPT [3]. For this, we have analyzed another well-known SPT region, that of the $A \approx 100$ nuclei around $N \approx 60$, by looking at extrapolated level densities (a values) for this region of neutron-rich nuclei. The behaviour of other key indicators of SPT, like the two-neutron separation energies S_{2n} or the mean square charge radii $< r^2 >$, shows a large similarity between the two SPTs [2]. By contrast, the level density analysis shows a certain difference between the two regions. There is no maximum in the LDs from the $A \approx 100$ region. This corroborates the experimental and theoretical findings that both before and after $N = 60$ these nuclei show SC phenomena. The rapidity of the transition, combined with the discrete character of N (the control parameter) makes it that in this region one does not see neither phase coexistence, nor nuclei with critical point symmetry properties, like in the $A \approx 150$ region.

In conclusion, the nuclear level density represents a good indicator for the first order SPT phenomenon, which is also sensitive to the eventual role played by shape coexistence near/throughout the SPT region.

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Constraining the cross section of ^{82}Se(n,γ)^{83}Se to validate the β-Oslo method

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The rapid neutron-capture process (r-process) is believed to be one of the major sources of the production of heavy elements, and the recent observations of a neutron star merger has further substantiated this theory. In order to better understand the r-process, nuclear physics properties of the nuclei involved are needed, including neutron-capture cross sections. Many r-process nuclei are not viable for direct measurements of neutron-capture rates due to short half-lives, so their neutron-capture cross sections are poorly known. This has led to the development of indirect measurement techniques such as the β-Oslo method, which uses β-decay to populate highly excited states of a nucleus. The resulting de-excitation via the emission of γ-rays is used to extract the nuclear level density (NLD) and γ-ray strength function (γSF) of the daughter nucleus. These nuclear properties are used as input in a Hauser-Feshbach reaction model to constrain the neutron capture cross section. This method will be validated in the A=80 region with the ^{82}Se(n,γ)^{83}Se reaction, where the neutron-capture product, ^{83}Se, can be accessed through the β-decay of ^{83}As, which has been studied at the NSCL with the total absorption spectrometer, SuN. The NLD and γSF of ^{83}Se has been extracted using the β-Oslo method and fed into TALYS, a statistical Hauser-Feshbach model, to constrain a neutron-capture cross section. The comparison of this constrained neutron-capture cross section to a direct measurement of the neutron capture on ^{82}Se using the Detector for Advanced Neutron Capture Experiments (DANCE) at Los Alamos National Laboratory will be presented.

Resolving discrepancies between $(\mathrm{p}, \mathrm{p}')$ and $(\gamma, x\mathrm{n})$ reactions

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A recent re-analysis of Livermore and Saclay $(\gamma, x\mathrm{n})$ photo-neutron data has suggested that systematic effects may have been introduced in these data as a result of the manner in which the data were processed to account for the neutron multiplicity of the events. Furthermore, discrepancies have been observed between equivalent photo-absorption cross sections for some neodymium and samarium isotopes obtained using $(\mathrm{p}, \mathrm{p}')$ data taken at iThemba LABS and the corresponding direct $(\gamma, x\mathrm{n})$ measurements obtained at Saclay. A measurement of two reference cases, ^{90}Zr and ^{159}Tb (both of which have been measured at Livermore and Saclay), will be useful to validate the agreement between $(\mathrm{p}, \mathrm{p}')$ and direct photo-absorption data and, furthermore, to ascertain whether the processing method of the $(\gamma, x\mathrm{n})$ data could explain the observed discrepancies. The proposed measurements of ^{90}Zr and ^{159}Tb will be presented along with a discussion on the discrepancies observed between $(\mathrm{p}, \mathrm{p}')$ and $(\gamma, x\mathrm{n})$ data.

Rotational enhancement of the nuclear level density in the static-path plus random-phase approximation

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Microscopic calculations of nuclear level densities are usually based on mean-field theories that ignore important correlations due to the residual nuclear interaction. The shell model Monte Carlo (SMMC) method includes such correlations but is computationally intensive. It is therefore useful to develop beyond-the-mean-field methods that account systematically for these correlations and are computationally efficient. The Hubbard-Stratonovich transformation for the nuclear partition function in the configuration-interaction shell model approach provides a useful framework for developing a hierarchy of approximations. In particular, the static-path plus random-phase approximation (SPA+RPA) includes large-amplitude static fluctuations and small-amplitude quantum fluctuations beyond the mean field. The SPA+RPA was shown to be a good approximation in solvable models [1, 2] and has been applied to study pairing correlations in physical systems [3, 4]. This method was applied to study level densities in Refs. [5, 6] but has not been systematically benchmarked in this context. We discuss the application of the SPA+RPA to the calculation of level densities in deformed nuclei, where mean-field approximations underestimate the density of states [7]. In particular, we study how much of the rotational enhancement of the level density can be recovered in the SPA+RPA for a shell-model Hamiltonian that includes a quadrupole-quadrupole force. We compare the SPA+RPA results with SMMC results, as well as with particle-projected finite-temperature Hartree-Fock calculations. Finally, we discuss plans to incorporate in the Hamiltonian a pairing force, as well as higher-order multipole-multipole forces.

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Production of PET generator radionuclides ^{72}Se and ^{68}Ge via ^{75}As(p,x) reactions in the energy range of E_p = 30-55 MeV

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The production cross sections for the medically-valuable PET radionuclides ^{72}Se and ^{68}Ge were measured through the irradiation of a stack of thin monoisotopic ^{75}As foils using a 55 MeV proton beam at the Lawrence Berkeley National Laboratory's 88-Inch Cyclotron. The metallic arsenic target foils were prepared through electrodeposition of As_2O_3 dissolved in aqueous HCl onto thin (25 μm) titanium backings. This work, for ^{75}As(p,x) reactions between 30-55 MeV, represents the most well-characterized measurement of the excitation function for ^{75}As(p,4n)^{72}Se and ^{75}As(p,np)^{74}As to date, the first measurement of the ^{75}As(p,x)^{68,69}Ge and ^{75}As(p,x)^{71,72,73}As reactions, and the characterization of ^{75}As(p,x)^{73,75}Se with improved precision compared with the body of previous measurements. This measurement was performed as part of a larger collaboration with Brookhaven National Laboratory and Los Alamos National Laboratory to extend cross section data up to 200 MeV. The ^{nat}Cu(p,x)^{62,63,65}Zn,^{58}Co and ^{nat}Ti(p,x)^{48}V,^{46}Sc monitor reactions were used to quantify proton fluence, using data from the IAEA monitor standards evaluation, with all activities measured using HPGe spectrometry. Along with the production of these medically-valuable radionuclides, the experiment provides unique opportunities to gain information about level density in highly excited nuclear states, through the first independent measurements of isomer-to-ground state branching ratios for ^{75}As(p,3n)^{73m}Se (J^π=3/2$^-$)/^{75}As(p,3n)^{73}Se (J^π=9/2$^+$).

Photoneutron cross section measurements with a direct neutron multiplicity sorting method

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Reliable measurements of total and partial photoneutron reactions cross sections in the Giant Dipole Resonance region provide a better understanding of the photoabsorption process and of the excited nuclear collective states decay, which is necessary for obtaining a good model description of observed cross sections over the complete range of nuclei. The International Atomic Energy Agency (IAEA) has launched a new Coordinated Research Project (IAEA CRP F41032) on Updating the Photonuclear Data Library and generating a Reference Database for Photon Strength Functions [1]. The PHOENIX collaboration*, led by Prof. Utsunomiya of the Konan University, has performed (γ, xn) with x=1-4 measurements for the IAEA-CRP at the γ-ray beam line GACKO (GAmma Collaboration hutch of KOnan university) of the NewSUBARU synchrotron radiation facility [2] in Japan. A new direct neutron multiplicity (DNM) sorting method based on a high-and-flat efficiency neutron detection system comprised of ^{3}He counters embedded in polyethylene moderator [3] has been applied. The ^{9}Be, ^{59}Co, ^{89}Y, ^{103}Rh, ^{139}La, ^{159}Tb, ^{165}Ho, ^{169}Tm, ^{181}Ta, ^{197}Au and ^{209}Bi [4] nuclei have been investigated between the neutron separation threshold up to $\sim$40 MeV incident photon energy. I will present the experimental technique, data analysis method and our current progress on ^{159}Tb, ^{165}Ho, ^{169}Tm (γ, xn) measurements.

* **Pho**ton **e**xcitation and **n**eutron em**i**ssion cross (**x**) sections, collaboration between Konan University, University of Oslo (UiO), "Horia Hulubei" National Institute for Physics and Nuclear Engineering, Moscow State University (MSU), and Shanghai Institute of Applied Nuclear Physics (SINAP).

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Investigating the fission process: a study of the prompt fission γ-rays from the fission of ^{241}Pu*

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In 2019 we celebrate 80 years since the discovery of fission, but still a lot of properties of fission are not understood. One of the least studied aspects of fission is the emission of so-called prompt fission γ-rays (PFGs) [1], which are photons emitted from the fission fragments as they de-excite. These photons carry valuable information about the fissioning system, and by studying them, useful insights can be obtained as we try to understand how fission unfolds.

The prompt fission γ-rays from the fission of ^{241}Pu* have been measured at the Oslo Cyclotron Laboratory, and preliminary results will be presented at this workshop. The (d,p) reaction was employed to induce fission, which enables the PFG characteristics to be extracted as a function of compound nucleus excitation energy. Furthermore, predictions of the ^{240}Pu(n,f) reaction were made with the Fission Reaction Event Yield Algorithm (FREYA), which provides a complete description of fission, where all physical quantities are conserved [2]. Comparing FREYA predictions to experimental results can give indications on whether the photon emission process is well understood.

The FREYA simulations reproduce the experimental photon spectrum for photon energies above 0.5 MeV, while for lower photon energies, there is a deviation. The total photon energy per fission calculated by FREYA increases as a function of excitation energy, a behaviour that was reported experimentally in the 1980s [3]. Several recent experiments [4, 5], including the present, could not validate this dependence on compound nucleus excitation energy. This suggests that the current description of photon emission from the fission fragments needs improvement.

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Theoretical description of the photon strength function and nuclear level densities

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Reliable theoretical predictions of nuclear dipole excitations and level densities in the whole nuclear chart are of great interest for different applications, including in particular nuclear astrophysics. We present here large-scale calculations of the E1 and M1 photoabsorption strength function obtained in the framework of the axially-symmetric deformed quasiparticle random phase approximation (QRPA) based on the finite-range D1M Gogny force. These calculations are complemented with simple expressions inspired from shell-model predictions to describe the de-excitation photon strength function at lowγ-ray energies. A thorough comparison with available experimental data is performed at GDR energies and below the neutron threshold. We show that a fairly good agreement is obtained. D1M+QRPA calculations are also used to derive simple expressions for the M1 spin-flip and scissors modes. Predictions of the dipole strength function for spherical and deformed nuclei within the valley of β-stability as well as in the neutron-rich region are discussed. The impact on the total radiative width as well as radiative neutron capture cross sections is studied.

Finally, the so-called HFB plus combinatorial model of nuclear level densities and its capacity to reproduce experimental data extracted from the Oslo method will be rapidly discussed. A special attention will be paid to the relevance of the combinatorial model to describe the low-energy level density in comparison with the constant temperature model.

Modifications to conventional Hauser-Fechbach calculations

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Hauser-Feshbach calculations are typically an important part of nuclear syntheses calculations in astrophysics. These calculations are usually based on widely available Hauser-Feshbach codes. Unfortunately, these codes typically do not include isospin or (for deformed nuclei) a deformation effect.

A summary of the changes resulting from inclusion of these effects in Hauser-Feshbach calculations for 20≤A≤35 will be presented. For some situations, isospin effects are small, nut in other cases changes as of much as 50% can occur. Among deformed nuclei, the effects of deformation also vary substantially for various nuclei but are particularly important for isomeric ratios.

Preliminary results for constraining i-process reaction rates

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Heavy element nucleosynthesis is one of the main focuses of the nuclear astrophysics community. The majority of elements heavier than iron are produced via neutron capture processes, the s-process (slow neutron capture) and the r-process (rapid neutron capture). However, certain astrophysical observations, such as Sakurai's object [1] and some carbon-enhanced metal-poor (CEMP) stars that show enhancement of s- and r-elements [2] cannot be described by either process or a combination of the two. The ”intermediate” i-process was proposed as a neutron capture process that proceeds at neutron densities between those of the s- and r-processes, in a region only several neutrons away from stability [3]. It is believed that the i-process can explain these anomalous abundance patterns [4]. Astrophysical models depend on nuclear physics input, particularly neutron capture rates. A sensitivity study was performed on the neutron capture rates of 52 unstable isotopes and their impact on the final abundance pattern [5]. Direct measurement of these reactions are not currently experimentally feasible, so indirect techniques are necessary to constrain the capture rate. The β-Oslo method will be used to determine the nuclear level density and γ-ray strength function for neutron-rich nuclei. The preliminary results of a recent experiment performed at the NSCL will be presented for ^{85}Br(n,γ)^{86}Br.

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Study of photon strength functions via $(\gamma, \gamma'\gamma'')$ reactions using quasi-monochromatic photon beams

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The photon strength function (PSF) serves as an essential input for nuclear astrophysical model calculations. It plays an important role in capture and photodisintegration reactions as well as in astrophysical scenarios describing the nucleosynthesis. In the past, different experimental methods and approaches have been used to study the PSF. In this contribution, we present a model-independent approach to extract the PSF in real-photon scattering experiments using quasi-monochromatic photon beams provided by the High Intensity γ-ray Source [1] at Duke University, Durham, NC, USA. After the nuclear excitation via resonant photoabsorption, the subsequent deexcitation via γ-emission from the target nuclei is measured with the γ-γ coincidence setup γ^3 [4]. This experiment allows to determine the PSF in two different ways. On the one hand side, it is possible to measure the photoabsorption cross section as a function of the excitation energy, which can be linked to the PSF build on the ground state. On the other hand, by extracting intensities from primary transitions to low-lying excited states, the PSF can be determined as a function of the γ-ray energy for different excitation energy regions. These two independent approaches enable to separately study the PSF in the excitation and the decay channel, respectively. The comparison of experimental data measured with ^{128}Te to statistical model calculations provides evidence, that the PSF extracted from the photoabsorption cross section is not in an overall agreement with the PSF determined from direct transitions to low-lying excited states [3]. The corresponding methods and results are presented and discussed.

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Investigating the influence of Nuclear deformation on the Pygmy Dipole Resonance

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The low-lying electric dipole (*E1*) response, referred to as the Pygmy Dipole Resonance (PDR) can be interpreted within the hydrodynamic model as an oscillation of excess neutrons against a proton-neutron saturated core [1, 2]. For deformed nuclei, it has been suggested that a splitting of the PDR response with respect to the K quantum number may occur, similar to that observed in the case of the Giant Dipole Resonance. In a preliminary ^{154}Sm(p,p') study performed at RCNP, evidence for a possible splitting in the PDR response was observed [3].

However, due to the PDR having both an isoscalar and isovector component, it is neccesary to investigate wether a splitting is observed when using an isoscalar probe. Therefore, (α,α'γ) inelastic scattering experiments on ^{144}Sm and ^{154}Sm were performed at iThemba LABS in South Africa. The K600 magnetic spectrometer was used in 0^{o} mode to measure the outcoming α-particles whilst BaGeL (**Ba**ll of **Ge**rmanium and **L**aBr detectors) detected the co-incident γ-particles. Preliminary results of this study will be presented in this talk.

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Nuclear shell model and the level density

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The nuclear level density is an important quantity for the description of properties of atomic nuclei. Its knowledge is crucial for understanding nuclear reactions, including formation of heavier, unstable nuclei through the r-process nucleosynthesis. A method that implements statistical approaches and uses configuration interaction Shell Model Hamiltonians to calculate nuclear level densities will be presented (moments method) and we will show results for selected *sd*- and *pf*-shell nuclei. Also, we will discuss the description of the level density by the effective temperature model, derived by fitting the results of the moments method for different isotopes, and dependence of the parameters on spin and various parts of the Shell Model Hamiltonian.

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Low Pressure Focal Plane Detectors for the K600:A design study

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Magnetic spectrometers have proven to be very useful in the world of experimental nuclear and astrophysics. The focal plane detection system instrumenting these spectrometers is instrumental in their success. A new focal plane detection system is envisaged for the K600 QDD magnetic spectrometer at iThemba LABS in Cape

Town, South Africa. The existing focal plane detection system, consisting of two multi-wire drift chambers (MWDCs) and plastic scintillators, is designed to detect light ions (H and He isotopes) at medium energies (50-200 MeV). The significant material budget of these detectors affects the low energy threshold for operation of the K600. A conceptual design for a new focal plane detection system will be presented.

Statistical gamma decay of ^{168}Er from resonance neutron capture

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One of the methods to study γ decay in heavy nuclei is analysis of γ-ray spectra following the slow neutron radiative capture. The Detector for Advanced Neutron Capture Experiments (DANCE) [1], located at Los Alamos National Laboratory, is well-suited for precise coincident detection of complete γ cascades thanks to its high segmentation, efficiency and solid angle coverage.

The DANCE detector was used for a measurement of γ-ray spectra following the radiative capture on well-isolated s-wave neutron resonances of ^{167}Er. The main topic of our interest is the nuclear level density and the photon strength functions – quantities that are used in description of the γ decay within the statistical model of the nucleus. The results were obtained by comparing the experimental spectra with statistical model simulations using DICEBOX code [2]. The photon strength functions describing the coincidence ^{168}Er spectra were found to be consistent with those reproducing such spectra in other well-deformed rare-earth nuclei [3, 4, 5].

Recently the $^{167}\text{Er}(n_{\text{res}}, \gamma)^{168}\text{Er}$ reaction was remeasured with a new data acquisition system in order to get more precise data on properties of the K-isomeric state at excitation energy 1094 keV, whose lifetime is approximately 100 ns [6]. The measured population of the state appears to be significantly higher than the population simulated within the statistical model using nuclear level density and photon strength functions models describing the γ cascades to the ground state. Results on the isomeric lifetime and population from the new measurement will be presented.

The study was supported by the Charles University, project GA UK No. 590218.

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Determining the Neutron Flux Spectrum for the Atlas of Gamma Rays

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The Atlas of gamma-ray spectra from inelastic scattering of reactor fast neutrons is a report by A. M. Demidov published in 1978.[1] The Atlas is a collection of gamma spectra measurements for the inelastic scattering of fast neutrons on a wide array of elemental and isotopic samples taken at the Baghdad Nuclear Research Institute. It was evaluated with ENSDF and compiled into a SQL database at Lawrence Berkeley National Laboratory.[2] The exponential neutron flux spectrum included in the Atlas report was not directly measured and produced a poor fit when used in model comparisons. A physically justifiable neutron flux spectrum was determined by comparing the ^{56}Fe data in the Atlas with partial cross section data measured by Negret.[3] The intensity ratios between each gamma and the strongest gamma were calculated for each data set. The flux spectrum was approximated as a Maxwell-Boltzmann distribution, and the optimal kT constant was determined to be 1.44 ± 0.03 MeV. A much better fit was demonstrated when comparing the Atlas to TALYS cross sections convoluted with the new flux spectrum. This result allows the Atlas to serve as a new and much-needed integral benchmark for the assessment of inelastic scattering model performance. Future investigations could use the Atlas to determine optimal values for model parameters, such as level density coefficients in TALYS.

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Constraints on the dipole γ-ray strength functions from multi-step cascade spectra

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Viable theoretical predictions of γ-ray strength functions (γSFs) covering the whole nuclear chart are of great interest for different nuclear applications, including in particular nuclear astrophysics. Recently a global microscopic γSF model consisting of axially-deformed HFB+QRPA calculations with the D1M Gogny interaction and a phenomenological low-energy contribution was proposed [1]. We tested this model predictions against previously published data from measurements of multi-step γ cascades following neutron capture on isolated resonances, see e.g. [2, 3], performed with the DANCE detector [4] on 15 isotopes ranging from Mo to U, including spherical, quasi-spherical and well-deformed nuclei. Such data present a stringent test of the γSFs models, in particular for the properties of the $M1$ scissors mode and the possible low-energy γSFs enhancement. This comparison indicates that the location and strength of the scissors mode is reasonably described by the HFB+QRPA approach. Moreover, a low-energy γSF contribution, not predicted by the HFB+QRPA calculation of the photo-absorption γSF, should be present in all nuclei. A systematics of this low-energy contribution, assumed in the $M1$ γSF, is proposed. A comparison with predictions of other phenomenological models [1, 6].

The work was performed within the IAEA CRP on "Updating the Photonuclear data Library and generating a Reference Database for Photon Strength Functions" (F410 32) and supported by FRS-FNRS, UNCE/SCI/013 and CSF 19-14048S projects.

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Estimation of Uncertainty in Calculated Gamma Cascades For Model Comparison

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A method is presented to estimate the uncertainty of discrete gamma intensities that are calculated by gamma cascade models where measured partial gamma cross sections are available. The method uses ratios of de-excitation gammas within the product nucleus to determine the consistency between the modeled gamma cascade and measured partial cross sections. The discrepancy between the calculated and measured ratios is treated as a bias that is converted into a 1-σ uncertainty on the calculated intensity of a chosen gamma, where the intensity is the calculated partial gamma cross section divided by the calculated channel cross section. The intensity uncertainty can be used to propagate modeling uncertainties onto reaction cross sections that are determined by combining measured partial gamma cross sections with modeled intensities. This method also allows for simple and informative comparisons of models, parameters, and structure data that are important to gamma cascade modeling, such as the spin and parity distributions of level density models. The use of ratios within a specific product nucleus reduces the influence of the competition between different reaction channels. An example is shown where the effects of changes to the level density models of ^{238}U on the inelastic scattering partial gamma cross sections are easily compared and assessed based on measured cross sections from Fotiades, *et. al.*[1]. This method provides a simple calculation that can be used to perform physically relevant evaluations of the ability of level density models and parameters to reproduce measured gamma cascade data.

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Properties of neutron-rich ^{71,72,73}Ni

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The rapid neutron capture process (r-process) is responsible for the synthesis of approximately half of the abundance of the heavy elements. The recent LIGO and Virgo gravitational-wave detection from two colliding neutron stars combined with the wealth of electromagnetic follow-up measurements across the electromagnetic spectrum demonstrated the production of heavy nuclei in an r-process. Despite knowing at least one location for the r-process, many open questions remain. The uncertainties in the nuclear physics inputs present a large barrier to accurately model the abundance distributions in large-scale nucleosynthesis calculations. In particular, neutron-capture rates are the most uncertain theoretical input and the most difficult to measure directly. The β-Oslo method is one indirect approach for constraining the neutron-capture cross section. The β decay of a short-lived nucleus is used to populate the high-energy states in a daughter nucleus and the subsequent photon deexcitation is monitored and used to infer the nuclear level density (NLD) and the γ-ray strength function (γSF). The NLD and γSF are then input into a Hauser-Feshbach model to constrain the neutron capture cross section. A series of experiments have been performed at the National Superconducting Cyclotron Laboratory (NSCL) along the Ni elemental chain to obtain the NLD and γSF for a variety of isotopes. The preliminary results obtained for ^{71,72,73}Ni will be presented and compared with ^{69,70}Ni.

Extension of the β-Oslo method: Preliminary results for constraining rp-process reaction rates

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X-ray bursts are one of the most common explosive phenomenon in the universe. They provide observational information into the composition of the surface and crust of neutron stars, providing a wealth of information on one of nature's most dense objects. The nuclear reactions of the rapid proton capture process, or rp-process power the light-curves of Type-I X-ray bursts. While past model calculations have successfully reproduced observed properties for particular X-ray bursts [1], sensitivity studies have demonstrated the substantial impact of certain reaction rates on the resultant X-ray burst light curve and on the abundances of the burst ashes [2]. Of the reactions identified, ^{59}Cu(p,γ)^{60}Zn was one of the most influential nuclear reaction rates on the shape of the X-ray burst light curve. Presently, this key reaction rate is beyond the reach of direct measurement techniques, so indirect methods have been employed to constrain the calculated reaction rate. The β-Oslo method was performed for the first time on a proton-rich nucleus at the NSCL. The preliminary results of the deduced nuclear level density and γ-ray strength function for ^{59}Cu(p,γ)^{60}Zn the will be presented.

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Investigating the M1 scissors resonance in well deformed Samarium isotopes

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The rare-earth isotopic chain of Samarium provides an excellent opportunity to systematically investigate the evolution of nuclear structure effects from the near spherical (β_2=0.00) ^{144}Sm isotope to the well-deformed system (β_2=0.27) ^{154}Sm. As the nuclear shape changes, statistical properties such as the nuclear level density (NLD) and γ-strength function (γSF) are expected to be affected. In particular resonance modes, such as the Pygmy Dipole (PDR), Scissors Resonance (SR) and the recently discovered Low-Energy Enhancement (LEE) in the rare-earth region may reveal interesting features when their evolution is investigated across several nuclei in an isotopic chain. Most reliable knowledge can be obtained when results from several different experiments are compared. We performed an experiment in September 2016 at the Oslo Cyclotron Laboratory (OCL) where a NaI(Tl) γ-ray detector array, silicon particle telescopes and 6 high-efficiency $LaBr_3$:Ce detectors were utilized to measure particle-γ coincidence events. The deuteron beams with 13 and 15 MeV energies were used to populate excited states in ^{154,155}Sm through the inelastic scattering (d,d'γ) and the transfer reaction (d,pγ). From particle-γ coincidence events, the NLDs and γSFs were simultaneously extracted below the neutron separation energy, Sn, using the Oslo Method [1]. The results from our measurements are used to investigate the evolution of nuclear structure effects in ^{154,155}Sm by comparing to those in other Sm isotopes. Further, our data set provides complementary information to the ^{154}Sm(p,p')^{154}Sm measured at RCNP, Japan [2] and ^{154}Sm($\alpha, \alpha'\gamma$)^{154}Sm measured at iThemba LABS [3]. I will present results from this investigation of the ^{154,155}Sm NLD and γSF and compare to other measurements in ^{151,152,153}Sm isotopes.

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Evolution of the pygmy dipole strength in Sn isotopes

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The pygmy dipole resonance is the prominent feature in the nuclear response function to electromagnetic absorption and emission. In contrast to the isovector giant dipole resonance centered at relatively high energies around 12-15 MeV, the pygmy dipole resonance arises from the group of E1 transitions in the vicinity of neutron separation energy. Appearance of the PDR might significantly affect neutron capture cross sections and is directly linked to the concept of neutron skin of nuclei, thus being applicable for understanding abundances of astrophysical processes and applicable to the equation of state for neutron rich matter [1]. Tin isotipic chain is one of the interesting subjects of investigation in this scope. The previous measurements of γ-strength function of $^{116-119,121,122}$Sn in (^{3}He,^{3}He' γ) and (^{3}He,α γ) reactions at the Oslo Cyclotron Laboratory revealed the significant enhancement at $\approx$ 8 MeV corresponding to the PDR in these nuclei as well as an increase of centroid energy with increasing neutron number [2]. The enhancements were also observed for heavier Sn isotopes including the ^{124}Sn isotope using both isoscalar and isovector probes for the investigation of the PDR structure [3].

In this contribution the preliminary results on study of ^{124}Sn isotope recently carried out at the Oslo Cyclotron Laboratory are presented. The level density and γ-strength function of ^{124}Sn will be subsequently extracted from proton-γ coincidences of the ^{124}Sn$(p, p'\gamma)$ reaction with the 16 MeV proton beam used.The particle-γ coincidences are studied by means of OSCAR scintillator array and Siri E-ΔE particle telescope placed in the 126-140° backward angles. The increased precision of current $(p, p'\gamma)$ measurement and comparison with the previous OCL data will significantly contribute to our knowledge of the PDR properties and evolution in the Sn isotopic line.

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Development of the Fast Loading User Facility for Fission Yields

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The Fast Loading User Facility for Fission Yields (FLUFFY) is a new experimental capability being developed at the 88-Inch Cyclotron at Lawrence Berkeley National Laboratory. Using a high-flux tunable neutron source, FLUFFY enables cyclical irradiation and counting of fissionable samples, facilitating the measurement of independent yields of short-lived ($\leq$1 s) fission products. FLUFFY will utilize a pneumatic system to rapidly transport a capsule containing fissionable samples and monitor foils from the irradiation site to a high-purity germanium clover detector array for observation of decay gamma-rays. The data from FLUFFY will be part of an integrated experiment/modeling program that will lead to a new fission yield evaluation, which in turn will improve reactor antineutrino calculations, criticality safety, and nuclear safeguards. A report on the technical operation of FLUFFY and results from an April 2019 commissioning experiment will be presented.

Consolidating the concept of low-energy magnetic dipole decay radiation

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We have made a thorough study of the low-energy behavior of the γ-ray strength function within the framework of the shell model. We have performed large-scale calculations spanning isotopic and isotonic chains over several mass regions, considering 283 nuclei in total, with the purpose of studying the systematic behavior of the low-energy enhancement (LEE) for $M1$ transitions. There are clear trends in the calculations: From being nearly absent in the lowest mass region, the LEE becomes steeper and more pronounced as the mass number increases, and for a given mass region it further increases toward shell closures. Moreover, the LEE is found to be steeper in regions near doubly magic nuclei where proton particles couple to neutron holes. These trends enable us to consolidate several previous works on the LEE into a single, consistent concept. We compare the inferred trends to the available experimental data from the Oslo method, and find support for the systematic behavior.

Measurement of ^{139}La(p,x) Cross Sections from 35–60 MeV by Stacked-Target Activation

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A stacked-target of natural lanthanum foils (99.9119% ^{139}La) was irradiated using a 60 MeV proton beam at the LBNL 88" cyclotron. ^{139}La(p,x) cross sections are reported between 35–60 MeV for nine radionuclides. The primary motivation for this measurement was the need to quantify the production of ^{134}Ce. As a positron-emitting analogue of the promising medical radionuclide ^{225}Ac, ^{134}Ce is desirable for *in vivo* applications of bio-distribution assays for this emerging radio-pharmaceutical. The results of this measurement were compared to the nuclear model codes TALYS, EMPIRE and ALICE (using default parameters), which showed significant deviation from the measured values.

Multimessenger area: Opportunities for future experiments at ISAC-II, TRIUMF

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The recent observation of neutron star mergers indicate the presence of the r-process in those events, but the precise elemental composition can not be deduced from the multimessenger observations. Detailed information about the heavy, neutron-rich nuclei involved are needed in order to pin down the origin of heavy elements in the universe. The next-generation radioactive ion beam facility ARIEL at TRIUMF soon will start delivering intense and clean post-accelerated RIBs.

The new TI-STAR silicon tracker detector, under development in an international collaboration at the University of Guelph and TRIUMF, is designed for experiments with heavy, exotic beams at the future ARIEL facility. TI-STAR will contain a hydrogen, deuterium or helium gas target to gain a factor 20-100 in luminosity for direct reaction experiments compared to experiments using target foils. One major goal of TI-STAR is constraining neutron-capture rates of r-process nuclei in the key A=130 region around ^{132}Sn. Calculations indicate that uncertainties of neutron capture rates are typically one order of magnitude, and can be responsible for current disagreements between predicted and measured abundance distributions. TI-STAR coupled to the TIGRESS array of HPGe detectors and the new EMMA recoil separator will offer populating the r-process nuclei via one-neutron transfer reactions. Reconstruction of excitation energies and gamma ray decay scheme will allow to determine the neutron capture rates via the Oslo method. I will present the status of our experimental program related to Oslo-type experiments at TRIUMF and will discuss the challenges and opportunities of the ARIEL and TI-STAR projects.

Experimental constraints on level densities through cross-section correlations

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Accurate prediction of cross sections depend significantly on the level densities (LD) of all nuclei produced through the different reaction channels. Several of the most common models aiming to describe LD make simplified assumptions regarding the overall behavior of the total LD and the intrinsic spin and parity distributions of the excited states. Despite their direct impact in cross sections, very few experimental constraints are taken into account in these models: the density of levels at the neutron separation energy of the compound nucleus (D_0) whenever it has been previously measured, and the sometimes subjective extrapolation of discrete levels. These, however, constrain the LD only in the asymptotic regions of low and high excitation energies. Measurements of particle evaporation spectra must assume nuclear equilibirum and are not very sensitive to details of LD. For this reason, in nuclear reaction data evaluations it is very common that LD models serve as starting point but then have their model parameters adjusted, often beyond reasonability, with the purpose of obtaining the best cross section agreement possible. Many experiments aiming to directly measure level densities convoluted with gamma strength function have been made. However, in order to extract the LD, model assumptions are made. Additionally, when such data are finally used in reaction calculations they are normally forced to be fitted by pre-defined exponential functionals, which may lead to the dilution or loss of experimental information.

This work addresses the issue of the lack of experimental constraints in LD by establishing quantitative correlations and sensitivities between cross sections at specific neutron incident energies and LD at ranges of excitation energy, allowing fitting and the determination of structures in LD which are constrained by experimental cross-section data. For this we use the microscopic Hartree-Fock-Bogoliubov (HFB) LD as a starting point as the HFB-LD provide a more realistic spin and parity distributions than phenomenological models such as Gilber-Cameron (GC). We then associate variations predicted by the HFB model with the observed double-differential cross sections at low outgoing neutron energy, region that is dominated by the LD input, as well angle-integrated cross sections for reactions such as (n,p). With this approach we are able to perform fits of the LD based on actual experimental data, constraining the model and ensuring its consistency. This approach can be particularly useful in extrapolating the LD to nuclei for which high-excited discrete levels and/or values of D_0 are unknown. It also predicts inelastic gamma (n,n$'\gamma$) cross sections that in some cases can differ significantly from more standard LD models such as GC.

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The implementation of electric dipole transition strength in constraining the relativistic energy density functional

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The electric dipole transition strength in nuclei provides a valuable constraint on the effective nuclear interactions. Recently a novel relativistic energy density functional has been constrained by the ground state properties of atomic nuclei along with the isoscalar giant monopole resonance energy and dipole transition strength in nuclei, i.e. dipole polarizability in ^{208}Pb [1]. A unified framework of the relativistic Hartree-Bogoliubov model and random phase approximation based on the relativistic density-dependent point coupling interaction has been established in order to determine the DD-PCX parameterization by χ^2 minimization. This procedure is supplemented with the co-variance analysis in order to estimate statistical uncertainties in the model parameters and observables. The effective interaction DD-PCX accurately describes the nuclear ground state properties including the neutron-skin thickness, as well as the isoscalar giant monopole resonance excitation energies and dipole polarizabilities. The implementation of the experimental data on nuclear excitations allows constraining the symmetry energy close to the saturation density, and the incompressibility of nuclear matter by using genuine observables on finite nuclei in the χ^2 minimization protocol. Over the past years the energy density functionals have been extensively used in nuclear physics research; there are more than 240 nonrelativistic Skyrme parametrizations and 263 relativistic-mean-field (RMF) models introduced so far. However, all of them are optimized by the nuclear ground state data only, often supplemented with pseudo-observables in order to set the nuclear matter (equation of state) properties. However, our recent work [1] introduced for the first time a method that constrains the energy density functional simultaneously by the ground state properties, dipole transition strength (i.e., the dipole polarizability) and isoscalar giant monopole resonance, in order to determine the properties of finite nuclei and nuclear equation of state around saturation.

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Dipole strength of ^{164}Dy below the neutron separation threshold

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The E1 strength of atomic nuclei is dominated by the isovector giant dipole resonance (IVGDR). For axially deformed nuclei, a separation (K-splitting) into two parts has been observed, corresponding to the nucleus' symmetry axes. In heavy nuclei, residual E1 strength situated on the low-energy tail of the IVGDR is frequently addressed as pygmy dipole resonance [1] (PDR) and often attributed to a neutron-skin oscillation. Similar to the IVGDR, a sensitivity to the nucleus' symmetry axes is expected, suggesting the possibility of a similar kind of K-splitting [2, 3]. However, data are sparse for such deformed nuclei, and so far, no conclusive observations exist.

Nuclear resonance fluorescence experiments allow for a selective study of the nuclear dipole response. In experiments performed at the γ^3 setup [4] at the High Intensity γ-ray Source (HIγS), the dipole strength above 4 MeV of the well-deformed nucleus ^{164}Dy was studied using a completely polarized, quasi-monochromatic γ-ray beam. This allows for a model-independent investigation of E1 and M1 strength contributions.

At low energies, level densities are sufficiently small to allow for the analysis of individual levels. For higher energies up to the neutron separation threshold, average quantities such as branching ratios are extracted, yielding insights into the decay properties of dipole-excited states. The results are presented and compared to statistical model calculations.

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What do we know about the Pygmy Dipole Resonance and what can we still learn?

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The electric dipole response of nuclei in the vicinity of the neutron separation threshold has a strong impact in the calculation of the photo-disintegration reaction rates in astrophysical scenarios. For this reason and for nuclear structure interests the study of the low-energy part of the E1 response, the so-called Pygmy Dipole Resonance (PDR), has received a considerable attention in the past 20 years [4, 2]. The PDR was observed in several neutron-rich nuclei in different mass region and it's connected to the excitation of the neutron excess. Another important characteristic of these states is their isospin mixed nature that was revealed by comparison between measurements performed with isovector and isoscalar probes and supported by theoretical calculations. Even if a consistent effort was put to understand this excitation mode, its nature and behaviour with neutron excess and deformation defy interpretation, especially concerning the predictive power for exotic nuclei. While these previous studies have provided a wealth of information on the PDR, they have been mostly concentrated on spherical nuclei, and hence the role that nuclear deformation plays on the PDR is yet to be understood. Experiments to study this aspect were performed at iThemba LABS using $(\alpha,\alpha'\gamma)$ reactions. In this talk, an overview on the PDR will be presented. Particular attention will be given to recent results on deformed nuclei and future possibility for these studies at iThemba LABS.

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Neutron-capture cross sections for *i*-process nuclei, ^{102,103}Mo

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Neutron-capture nucleosynthesis occurs via a variety of processes depending on the astrophysical sites and conditions. Recent observations and stellar evolution models suggest that an intermediate process, known as the *i*-process, exists between the slow (*s*-process) and rapid (*r*-process) neutron-capture processes, and is necessary to explain abundances in the Ge-Te region [1]. The abundance patterns of *i*-process nuclei are affected by various nuclear inputs including neutron-capture cross sections, the uncertainties of which limit, at present, the predictive power of *i*-process simulations. Direct neutron-capture measurements are only feasible for long-lived nuclei, while for short-lived nuclei, indirect techniques are required. One such technique is the β-Oslo method in which the nuclear level density (NLD) and gamma-ray strength function (γSF) are extracted following the β-decay of a neutron-rich parent and are used in a statistical reaction model to constrain the neutron capture cross section [2]. In this work, ^{103,104}Mo were studied at the NSCL via the β-decay of ^{103,104}Nb and detected using the Summing NaI(Tl) (SuN) total absorption spectrometer. Results on the NLD, γSF, and neutron-capture cross sections of ^{102}Mo(n,γ)^{103}Mo and ^{103}Mo(n,γ)^{104}Mo using the β-Oslo method, and preliminary *i*-process calculations from the Nucleosynthesis Grid (NuGrid) Collaboration will be presented.

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Fast Neutron Yeilds and Spectra as a Function of Angle from 33 MeV Deutrons Breakup on Beryllium

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In recent years, there has been growing interest in the production of medical isotopes via (n,x) reactions induced by high-energy (>5 MeV) neutrons. One way to produce energetic neutrons involves the breakup of deuterons on low-Z targets. However, the neutron yield from thick target deuteron breakup as a function of both the energy and angle of the outgoing neutron remains largely unmeasured.

We will report on a thick target neutron yield experiment performed at the 88-Inch cyclotron at LBNL where a 33 MeV deuteron pencil beam of 4mm in diameter was made incident on a thick beryllium breakup target. Monitor foil packs containing iridium, copper, nickel and iron were placed at the angles of 0, 7, 10, 15, 20, 25, 35, 45, 60 degrees with respect to the incident deuteron beam and their activation used to infer the the incident neutron flux as a function of energy. We will present results from this experiment and discuss plans to further quantify the neutron spectrum from deuteron breakup at the cyclotron.

Study of excitation energy and angular momentum dependence of the level density parameter

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The density distribution of nuclear levels has been a matter of investigation over a long time, and remains an active area of research. In the Fermi gas type level density formulation [**?**] which is the most widely used analytic form of nuclear level density (NLD); the most significant factor is the level density parameter (LDP), a. Since a is directly related to the density of single particle states near the Fermi energy, its variation as a function of excitation energy and angular momentum can provide important information on the underlying microscopic structure of the nucleus. Furthermore, precise determination of a is crucial for the quantitative description of nuclear reactions under the statistical model framework. A number of experiments have recently been performed at the Variable Energy Cyclotron Centre (VECC), Kolkata using ^{4}He-ion beams to investigate the excitation energy (temperature) and angular momentum (spin) dependence of a. Angular momentum gated kinetic energy spectra of light particles (n, p, and αparticles) were experimentally measured and compared with the statistical model (SM) calculations to extract the value of a at different temperature and spin region. It was observed that for several medium mass nuclei (A$\sim$ 70 - 120) the level density parameter is enhanced at higher spins (J $\sim$10 - 25 $\hbar$) beyond the present theoretical predictions [**?**, **?**]. However, the results in case of the heavier systems (A$\sim$ 170 - 200) were found to be in good resemblance with the existing theoretical picture [**?**].

On the other hand, the temperature dependence of a studied in the range of T$\sim$ 0.7 - 1.5 MeV was found to be reasonably explained by the empirical relation $k(U) = k_0 + \kappa(U/A)$ where k is the inverse level density parameter and U is the thermal excitation energy. The temperature dependence of a can primarily be accounted for by the temperature dependence of the effective nucleon mass [**?**].

The experimental studies have recently been extended to a higher temperature and angular momentum range using heavy-ion induced reactions. Neutron evaporation spectra at various laboratory angles (45^0 180^0) were measured in coincidence with

the low energy γ-rays in case of ^16O, ^20Ne + ^27Al, ^58Ni, ^93Nb reactions. The experiment will allow us to understand the variation of NLD in the temperature and angular momentum range of T $\sim$ 2.5 - 4.0 MeV and J $\sim$ 20 - 45 ?, respectively. The detailed analysis of the experimental data is in progress. The results will be compared with the SM calculations.
The specific motivations, the methodology of the study and the detail experimental results will be presented in the workshop.

A thermodynamic approach to nuclear level densities in the framework of Skyrme energy density functionals

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The calculation of level densities have followed three main approaches: phenomenological models, microscopic mean-field methods and the shell model Monte Carlo (SMMC) approach [1]. The SMMC method has the advantage that correlations are fully accounted for. Given a model space and a Hamiltonian, the calculated level densities are exact up to well-controlled statistical errors. However, SMMC calculations are computationally intensive and the corresponding shell model Hamiltonian is specific to the mass region under consideration. Mean-field calculations based on self-consistent energy density functionals (EDF) require only a moderate computational cost and can be applied across the table of nuclei. EDF parameterizations, adjusted to a large volume of experimental data, have been used to model globally nuclear masses, fission barriers, level densities and other observables [2]. Nevertheless, the state-of-the-art calculations of level densities still contain phenomenological ingredients, such as the collective enhancement factors.

A thermodynamic approach to level densities based on finite-temperature self-consistent mean-field theories was recently benchmarked against exact SMMC calculations using the same model space and Hamiltonian [3], and particle-number projection was implemented in Ref. [4]. We are exploring the generalization of this thermodynamic mean-field approach to level densities using the framework of EDFs. In particular, the advanced Skyrme EDF solver MOCCa [5] has been extended to allow for finite temperature and for the inclusion of the particle-number projection method of Ref. [4]. We will show first results obtained in this framework and compare, when possible, to other microscopic calculations of level densities.

The finite-temperature mean-field level densities exhibit singularities at the shape and pairing transition temperatures. We will explore the inclusion of thermal fluctuations of the order parameters of the corresponding transition (e.g., the quadrupole deformation parameters for a shape transition) [6, 7] to smooth those singularities. We also plan to explore other corrections such as rotational enhancement.

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Radiative proton-capture reactions as a tool to study averaged partial γ-decay widths

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Nuclear reaction rates are one of the main ingredients for the understanding of nucleosynthesis processes in stellar environments [1, 2]. For isotopes heavier than iron, reaction rates are widely calculated within the Hauser-Feshbach statistical model [3]. The accuracy of the predicted reaction rates strongly depends on the uncertainties of the nuclear-physics input-parameters such as nuclear-level densities and γ-ray strength functions.

Via high-resolution γ-ray spectroscopy of radiative proton-capture reactions at the Cologne HORUS γ-ray spectrometer [4], information on the total as well as the partial γ-ray decay widths of the compound nucleus at different excitation energies can be obtained.

The precise measurement of total and partial reaction cross-sections at sub-Coulomb energies are used to constrain or exclude different nuclear-physics models. Especially the comparison of partial cross-section to predictions from the statistical-model can yield valuable information on the γ-ray strength function [5]. Moreover, $\gamma\gamma$-coincidence data can be used to study the statistical γ-decay behavior to final states with different spin and parity in much more detail.

This talk is going to present recent experiments performed at the Cologne 10 MV FN-Tandem accelerator and the high-efficiency HORUS γ-ray spectrometer. The experimental technique as well as recent results on the ^{63}Cu(p,$\gamma\gamma$) and ^{65}Cu(p,$\gamma\gamma$) reactions to study the γ-ray strength in ^{64,66}Zn will be shown.

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Development of E1 and M1 strengths in ^{54}Fe and ^{66}Ni

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We studied dipole excitations in the $N = 28$ nuclide ^{54}Fe and the $N = 36$ nuclide ^{66}Zn in photon-scattering experiments using bremsstrahlung at the γELBE facility of Helmholtz-Zentrum Dresden-Rossendorf [1] and using quasi-monoenergetic, polarized γ beams at the HIγS facility of the Triangle Universities Nuclear Laboratory in Durham [2]. We identified intense E1 as well as M1 transitions to spin-1 states up to about 10 MeV. The development of E1 and M1 strengths with increasing neutron number is discussed.

In the second part, possibilities of studying the low-energy enhancement of dipole strength in photon-scattering experiments are considered on the basis of levels and transition strengths calculated using the shell-model code NuShellX@MSU [3]. The nuclide ^{64}Ni, in which the low-energy enhancement was recently observed in an experiment at the Oslo cyclotron [4], was taken as an example. Gamma-ray cascades depopulating 1^+ states around 7.5 MeV and feeding the 2_1^+ state were constructed and used to simulate the shapes of spectra in coincidence with the $2_1^+ \rightarrow 0_1^+$ transition in experiments using quasi-monoenergetic γ beams.

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Level densities of pf-shell nuclei by large-scale shell-model calculations

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We report recent developments of shell-model studies concerning nuclear level densities and giant dipole resonances of pf-shell nuclei. We developed a new shell-model code "KSHELL" which enables us to obtain a large number of eigenstates efficiently with the thick-restart block Lanczos method utilizing state-of-the-art supercomputers [1].

In order to calculate the level density based on the shell model efficiently, we introduced a stochastic estimation method: we stochastically estimate the level densities, namely eigenvalue densities of the Hamiltonian matrix whose M-scheme dimension reaches $O(10^{10})$. We perform the contour integral of the matrix element of a resolvent to count the number of the eigenvalues of the matrix in a certain energy range. The shifted block Krylov subspace method enables its efficient computation. We obtain the level densities of both positive-parity and negative-parity states of pf-shell nuclei. The shell-model study successfully reproduces the parity equilibration of the $J^\pi = 2^+$ and $J^\pi = 2^-$ level densities of ^{58}Ni and shows the importance of adopting realistic interaction [2].

We also report the systematic studies of the photoabsorption cross sections and the pygmy resonances of Ca isotopes [3].

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abstract

Photon strength function of ^{196}Pt extracted from neutron radiative capture measured with DANCE detector

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The ^{195}Pt (n,γ) reaction was measured with the γ calorimeter DANCE (Detector for Advanced Neutron Capture Experiments) consisting of 160 BaF_2 scintillation detectors at the Los Alamos Neutron Science Center. The cascades of gamma-decay from isolated compound-states of ^{196}Pt nucleus were simulated by the DICEBOX statistical model code and were transformed with the GEANT4 code simulating response of the detector into the form allowing direct comparison with experimental data and the comparison has then been made for several different models of level density (LD) and photon strength functions (PSF) models.

The comparison confirms the presence of a pygmy resonance at 5.6 MeV in photon strength function of ^{196}Pt reported earlier [1, 2]. Our simulations indicate that there is a significant contribution of the M1strength in this gamma-ray energy region. Our analysis also indicates that a finite value of the PSF strength at very low energy. On the other hand, data are also inconsistent with predictions with any strong low-energy PSF enhancement below about 3 MeV.

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Systematic study of the level density and γ-ray strength function of samarium isotopes

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The Hyperion array at Texas A&M University consists of fourteen Compton suppressed germanium clover detectors and a ΔE-E telescope for particle identification and energy measurements. Particle-gamma coincidences from Hyperion allow for building a E_X vs E_γ matrix that can be used for Oslo-type analysis. In this work, the γ-strength functions and level densities of in the quasi-continuum of ^{147,149,151,153}Sm isotopes will be discussed.

A beam of 28 MeV protons was impinged on higly enriched Sm targets and the compound nuclei of interest were populated via (p,d) reactions. The measurements allow for systematic investigation of the properties of the level densities and γ-ray strength functions across the Sm isotopes of varying deformation. An upbend in the γSF was observed in all the Sm isotopes and the scissors mode was present for the deformed nuclei. The total γ-ray strength at low γ-ray energies remains nearly constant as predicted by shell model calculations. The results are in a good agreement with shell model calculations.

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Present status of the ELIGANT setups for photonuclear reaction studies above the neutron threshold

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The Extreme Light Infrastructure – Nuclear Physics (ELI-NP) facility that is under implementation in Măgurele in Romania is projected to provide the European community with the highest brilliance gamma beam to date for physics experiments utilizing photonuclear reactions.

One of the set of instruments being developed with a specific focus on measuring combined neutron and γ production in γ-ray induced reactions is the ELI Gamma Above Neutron Treshold (ELIGANT) setup. ELIGANT consists of three complementary setups: ELIGANT Thermal Neutron (ELIGANT-TN) [1] for being an array of ^{3}He counters embedded in a polyethylene matrix; ELIGANT Gamma Neutron (ELIGANT-GN) [1, 2] comprising EJ-309 liquid scintillator detectors and GS20 ^{6}Li glass detectors fast neutrons, and a mixed array of $CeBr_3$ scintillators and $LaBr_3$:Ce scintillators for γ rays. In addition to these setups a new configuration, ELIGANT Gamma Gamma (ELIGANT-GG), has also been realized for weak γ coincidence measurements using the $CeBr_3$ scintillators and thick lead shielding. These detector system will be read out by a large-scale analogue and digital data acquisition systems.

The planned physics cases for ELIGANT span over a large area of subfields within nuclear physics ranging from photonuclear data on high-priority nuclei as identified by the International Atomic Energy Agency for energy applications, nuclear astrophysics and p-process nucleosynthesis. Notable day-one experiments as defined in the technical design-report (TDR) [1] are the cross sections for the p-process reactions $^{180}\mathrm{Ta}(\gamma,\mathrm{n})^{179}\mathrm{Ta}$ and $^{138}\mathrm{La}(\gamma,\mathrm{n})^{137}\mathrm{La}$ with ELIGANT-TN and a detailed nuclear structure study of the giant dipole resonance (GDR) in ^{208}Pb with ELIGANT-GN. With the newest addition of the ELIGANT-GG configuration a long-running experiment is already ongoing for detailed studies of the rare competitive double-γ ($\gamma\gamma/\gamma$) decay mode recently observed in ^{137}Ba [3].

In this contribution we will present the current status of the implementation of the different subsystems of ELIGANT and the outlook for the future.

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Test of Practical Expressions for E1 Photon Strength Functions on Photoabsorption and Photodecay Data

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The description of photoabsorption and photodecay data by closed-form Lorentzian models of photon strength functions (PSF) for electric dipole gamma-rays is considered. The experimental photoabsorption data are compared with theoretical calculations for even-even nuclei using criteria of minimum of least-square factor and root-mean-square deviation factor. The following models are used: Standard Lorentzian, Simplified Modified Lorentzian model, Generalized Lorentzian model [1], [2] and Triple Lorentzian Model [3]. The experimental OSLO data on photodecay [4] are compared with calculations within above mentioned models with allowance for M1 transitions [5]. For test of photoabsorption description, new database on experimental E1 PSF was prepared using photoabsorption cross-sections from EXFOR database. Experimental data for photoabsorption cross-sections in the energy intervals (dE) just above neutron separation energies do not include contribution of the cross-sections from gamma-gamma channels. The absence of this contribution leads to incorrect values of the PSF [1] extracted from photodata in such gamma-ray energy range. In this contribution, the intervals dE for all isopopes were calculated using simulations of the photo cross-sections by the nuclear reaction code TALYS 1.6 with SMLO model for PSF. These intervals were found from the condition of ten percent contribution of the cross-section from gamma-gamma transitions to total photoabsorption cross-section. New database for E1 PSF was prepared with systematic uncertainty less than 10 %. It was shown that the Simplified Modified Lorentzian model can be considered as the best one for simulating of the E1 PSF at the gamma-ray energies below $\sim$ 30 MeV for simple description of photoabsorption data. This work is partially supported by the IAEA through a CRP on Updating the Photonuclear Data Library and generating a Reference Database for Photon Strength Functions (F41032).

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Nucleosynthesis around ^{60}Fe via indirect neutron-capture reaction studies

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Active nucleosynthesis in our galaxy can be observed directly through the detection of long-lived radioactivities. Isotopes such as ^{18}F, ^{22}Na, ^{26}Al, ^{44}Ti and ^{60}Fe have been identified as a live signature of nucleosynthesis by high-resolution γ-ray observatories such as COMPTEL, RHESSI and INTEGRAL [1, 2]. The direct observation of these isotopes offers a unique opportunity to better understand nucleosynthesis processes, but this is only true if the reactions responsible for producing and destroying them are well understood. In the case of ^{60}Fe, the relevant reactions are a series of (n,γ) reactions starting from the stable isotope ^{58}Fe, namely ^{58}Fe(n,γ)^{59}Fe(n,γ)^{60}Fe(n,γ)^{61}Fe. The first and last reactions are well constrained by direct measurements [3, 4]. Therefore, the main remaining uncertainty in the production/destruction of ^{60}Fe is coming from the unknown rate of the ^{59}Fe(n,γ)^{60}Fe reaction. A recent publication constrained the γ-ray strength function of ^{60}Fe above the neutron separation energy (8.8 MeV) [5], however no constraints exist on the nuclear level density or on the γ-ray strength function at low energies. Here we will present the first measurement of the nuclear level density and the γ strength function of ^{60}Fe using the β-Oslo method [3]. The experiment was performed at the National Superconducting Cyclotron Laboratory, at Michigan State University using the Summing NaI(Tl) (SuN) detector. A ^{60}Mn beam was implanted at the center of SuN and levels in the compound nucleus of interest, ^{60}Fe, were populated up to the β-decay Q-value (8.4 MeV). We will present first results of the experiment and discuss the implications on the synthesis of ^{60}Fe in the Universe.

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Nuclear Level Density and γ-Decay Strength for ^{93}Sr

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The ability to quantitatively model (n,γ) reactions on neutron-rich nuclei, such as fission fragments, is extremely limited, in part due to a limited understanding of the nuclear properties used as input for statistical model calculations. This data deficiency leads to reaction-rate uncertainties up to several orders of magnitude [1]. To address this deficiency in the neutron-induced cross section data for the A=95 fission fragment mass range, an experiment was recently performed utilizing a ^{93}Rb beam provided by the NSCL facility to populate the ^{93}Sr compound nucleus. In the experiment, the γ rays emitted from highly excited nuclear states were measured using the Summing NaI (SuN) detector and a plastic scintillator barrel (fiber detector) surrounding the implantation point for β-particle detection [2]. A tape transport system (SuNTAN) was employed to remove daughter activity. The β-Oslo method is used in the ongoing data analysis to extract the level density and γ-decay strength, two key ingredients for calculating (n,γ) reactions rates [3]. Preliminary analysis of measured γ-ray spectra will be presented here. The results will also provide crucial tests for model input to infer the (n,γ)^{95}Sr reaction rate, which is a high-yield fission product.

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Gamma decay of the isovector giant dipole resonance in ^{90}Zr: the damping mechanism and the fine structure

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The Isovector giant dipole resonance (IVGDR) is a collective vibrational excitation that commonly exists in all the atomic nuclei, and is macroscopically described as a dipole oscillation between the neutrons and protons. Gross properties like excitation energy and strength are well reproduced by microscopic models. The width of the IVGDR is, however, not yet fully explained owing to the complex damping mechanism. A pronounced fine structure is observed in heavy nuclei in recent high-resolution experiments [1, 2]. The present research is focusing on the damping mechanism and the fine structure of the IVGDR with the scope for an extension to other types of collective modes in near future.

The key point of the present study is the measurement of the gamma-decay branching ratio (BR) of the IVGDR. By measuring the gamma-decay BR to the gound state (g.s.), (Γ_{γ_0}/Γ), the total width (Γ) that includes the contribution of all the decay channels can be studied. The measured quantities are also relevant to the study on the gamma-strength function, level density, and the gamma-decay properties.

We have measured gamma decay from the IVGDR in ^{90}Zr as a pilot experiment by employing the high-resolution Grand Raiden magnetic spectrometer at RCNP, Osaka University. The target nucleus was excited by proton scattering at 392 MeV and at a scattering angle of zero degrees. The gamma rays were detected by a gamma-ray detector array, Scγlla, which consists of eight large-volume LaBr3:Ce detectors [3] from Milano. The target thickness was 20 mg/cm^2. The beam intensity was 2 nA. The measured excitation energy, 7-32 MeV, fully covers the IVGDR as well as the low-lying E1 strength that is discussed in terms of the Pygmy Dipole Resonance (PDR). The gamma decay of IVGDR to the g.s. was successfully observed in spite of its small BR of 1%. We will report on the experiment, preliminary results, and future plans in the conference.

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Fine structure of the pygmy quadrupole resonance

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The electric quadrupole response in the neutron-excess ^{112,114}Sn nuclei is investigated by energy-density functional (EDF) and three-phonon quasiparticle-phonon model (QPM) theory [1] with special emphasis on 2^+ excitations located above the first collective quadrupole state [2] . The theoretical results are compared to two high-resolution (p, p' γ) Doppler-shift attenuation (DSA) coincidence experiments. Our analyses give further evidence for a new mode of nuclear excitation in those two nuclei, i.e. the pygmy quadrupole resonance (PQR)[3, 4, 5], observed as a clustering of 2^+ states below the particle emission threshold. The origin of the PQR is explained suggesting two-quasiparticle neutron excitations related to neutron-skin oscillations. Our results for neutron-skin thickness in ^{112,114}Sn show a close relation of the calculated total PQR strength with the neutron excess and the neutron skin thickness. This is further confirmed in the studies of neutron and proton transition densities which indicate isoscalar and isovector contributions to PQR excited states. Furthermore, a substantial contribution from low-energy multi-phonon states induces additional E2 strength in the PQR region. From these studies it is also observed that the low-energy PQR strength is strongly fragmented. Detailed information on the fine structure of PQR mode could be obtained from branching ratios of the excited 2^+ states to the ground state and other excited states [2]. In addition, the theoretical results and experimental data show that branching ratios give useful information on the fine structure of the PQR and a strong evidence on the existence of multi-phonon excitations in the PQR energy region.

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Gamma-ray strength function for Ni, Ba, and Tl isotopes along the s-process path

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Photoneutron cross sections were measured for ^{58,60,61,64}Ni, ^{137,138}Ba, and ^{203,205}Tl at energies below two-neutron threshold using quasimonochromatic γ-ray beams produced in laser Compton scattering at the NewSUBARU synchrotron radiation facility. The photoneutron data are used to constrain the γ-ray strength function on the basis of the Hartree-Fock-Bogolyubov plus quasi-particle random phase approximation using the Gogny D1M interaction. Supplementing the experimentally constrained γ-ray strength function with the zero-limit E1 and M1 contributions which are unique to the deexcitation mode, we discuss radiative neutron capture cross sections and the Maxwellian-averaged cross sections for Ni isotopes, including a branching-point nucleus ^{63}Ni along the weak s-process path [1], Ba isotopes in the vicinity of the neutron magic number 82 [2], and Tl isotopes, including a branching-point nucleus ^{204}Tl in the context of the ^{205}Pb - ^{205}Tl chronometry [3].

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Recent development of DICEBOX code

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Analyses of γ decay of excited levels in the region of high nuclear level density (NLD) in medium and heavy nuclei are often carried out by comparing the experimental observables with outcomes from simulations. It turns out that the main obstacle of these simulations is the correct treatment of expected fluctuations in positions of individual levels and individual transitions intensities (and any derived experimental observables).

More than 20 years ago a Monte-Carlo based code for simulation of γ decay known as DICEBOX [1] was introduced. Throughout the years DICEBOX has been developed by the Prague group and was recently made publicly available at IAEA website [2]. The DICEBOX code has been used in many works for several different purposes. In majority of cases it was exploited for description of the statistical γ decay following the slow neutron radiative capture with aim to study quantities governing the decay – the NLD and photon strength functions (PSFs), see Ref. [3] and references therein. Others checked the population of low-lying levels [4, 5]. In addition, the predictions of the code were used in analyses of (γ, γ') reaction [6, 7] and γ decay from charged-particle induced reactions [8].

Significant modifications have been incorporated into the code since late 90's, including the introduction of the so-called nuclear suprarealizations. This addition enables to distinguish between different sources of fluctuations and was recently used in the analysis of MSC spectra of dysprosium isotopes measured at DANCE [3].

In this contribution we shall give details on the present version of the algorithm, discuss different fluctuations as sources of uncertainties in simulated quantities, and show examples illustrating importance of correct treatment of the Porter-Thomas fluctuations on predictions of the γ-decay related observables. The main differences to other algorithms – DECAYGEN/CAPTUGEN [9], CoH_3 [10] and γDEX [11] – and DICEBOX successors – FIFRELIN [12] and RAINIER [13] – will be presented.

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Recent Results with the Fission Event Generator FREYA

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The state of the art for handling fission in transport codes long involved sampling from average distributions. Such "average" fission models have limited capabilities because energy is not explicitly conserved and no correlations are available: all particles are emitted isotropically and independently. However, in fission events, the energies, momenta and multiplicities of emitted particles are correlated.

Several Monte Carlo codes have become available that calculate complete fission events. Event-by-event techniques are particularly useful because one can obtain the fission products as well as the prompt neutrons and photons emitted during the fission process, all with complete kinematic information. It is therefore possible to extract any desired observables, including correlations, see the review in Ref. [1].

The fast event-by-event fission code FREYA (Fission Reaction Event Yield Algorithm) generates large samples of complete fission events [2, 3] and employs only a few physics-based parameters. We discuss recent results on optimization of these parameters for spontaneous fission and compare results with the optimized parameters to available data on prompt neutron and photon emission [4]. We will also discuss preliminary results on optimization for neutron-induced fission and how more data, over a range of energies, can improve fission modeling in codes, such as FREYA.

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Level densities for nuclei from 70-80 mass region from different experiments

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New data on level densities of ^{69,71}Ga obtained from proton evaporation spectra of lithium induced reactions on ^{63,65}Cu targets will be presented. Level densities and their parameterizations will be compared with our previous data on ^{74,76}Ge nuclei and with level densities obtained from neutron resonance counting. The results indicate the discrepancy between level densities obtained from particle evaporation technique and from analysis of neutron resonance spacings, specifically in this mass region. Possible reasons of discrepancy and suggestions on future experimental and theoretical efforts will be discussed.

Gamma Strength Functions and Level Densities along the Stable Tin Isotope Chain

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Polarized proton scattering at energies of a few 100 MeV and extreme forward angles including 0° is a well-established tool to extract the complete E1 response in nuclei up to excitation energies of about 20 MeV [1]. In particular, this method provides information on the poorly determined B(E1) strength below and around neutron threshold in heavy nuclei [2, 3, 4, 5]. One can also extract the spin-M1 resonance and the analog B(M1) strength [6] and from the combined information on B(E1) and B(M1) the gamma strength function [7]. The high energy- resolution achieved in the experiments additionally enables the extraction of level densities in the energy region of the GDR with a fluctuation analysis [8]. The combined information allows tests of the Brink-Axel hypothesis in the astrophysically relevant energy region of the pygmy dipole resonance by comparison with results of Oslo-type experiments in the same nucleus [7, 10]. Here we present results from a systematic study of the stable even-even tin isotopes 112-124 serving as a test case to single out the role of neutron excess, since their underlying nuclear structure shows little changes.

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Testing of the Brink-Axel Hypothesis in ^{208}Pb using fast protons at the CCB facility in Krakow

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A very first experiment in the field of nuclear structure at the Cyclotron Centre Bronowice (CCB) facility in Krakow, Poland has been performed recently. The medical cyclotron IBA Proteus C-235 located at CCB produces proton beams in the energy range of 70-230 MeV, that can be used for experimental purposes as well[1]. In the reported measurement, the energy of scattered protons at the incident beam energy of 85 MeV and emitted γ rays from the excited ^{208}Pb target were measured in coincidence.

The set-up consisted of three detectors' arrays. For inelastically scattered protons, the KRATTA array[3] – a set of 24 triple telescopes made of three photodiodes and two CsI:Tl crystals – was used, while the γ-ray energy was measured with 8 large BaF2 crystals of the HECTOR array[2] and a cluster of the PARIS calorimeter[4].

During the experiment, excitations in the energy region of the Giant Quadrupole and Dipole Resonances, as well as, the Pygmy Dipole States were observed. By applying different conditions on the data, spectra corresponding to γ decays of excited states to selected low-lying levels in ^{208}Pb were obtained, allowing a look into the Brink-Axel hypothesis.

In the course of the talk, the experimental set-up will be presented and methods of analysis will be discussed in detail. Obtained results will be shown along with the tentative interpretation. Future experimental plans and an upgrade of the set-up will be introduced.

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New Measurements and Prospects of Normalization of Photon Strength Functions

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Significant developments on the African LaBr3:Ce (ALBA) and Clover+BGO (AFRODITE) gamma-ray arrays have taken place at iThemba LABS. The increases in detection efficiencies significantly improve and make possible new-type of measurements of nuclear properties. For instance, the development of the inverse-Oslo method [1], to extract the photon strength function (PSF) and nuclear level density (NLD) from inverse kinematic reactions, provides a powerful and complementary tool to study statistical properties for a wide range of nuclei, which were previously inaccessible at stable and radioactive ion beam facilities. Several such PSF and NLD measurements on Ni, Kr, and Xe isotopes have already been performed. Other interesting spectroscopy techniques are currently also being investigated at iThemba LABS to measure the PSF using high-intensity proton beams or the K600 magnetic spectrometer. Such measurements may provide much-needed constraints on the normalization of the PSF. The normalization is an outstanding problem when investigating nuclei away from the line of stability where results from direct measurements are not available. In this presentation, I will focus on new experimental results from our inverse kinematic measurements, as well as on a new program to measure PSFs using alternative techniques. The prospect of normalizing the PSF for nuclei away from stability will also be discussed.

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E1 strength in ^{70}Ni Nucleus

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The Coulomb excitation of the neutron rich nucleus ^{70}Ni was measured in inverse kinematics at 260 *A*MeV bombarding energy and with a ^{197}Au target. The beam energy allowed to study the dipole response around the neutron separation energy (up to about 12 MeV). The experiment was performed at the RIKEN Radioactive Isotope Beam Factory (RIBF). The γ-decay from the scattered ^{70}Ni ions at around zero degree was measured with a scintillator detection system composed of large volume $LaBr_3$:Ce detectors (HECTOR$^+$ array) and NaI(Tl) detectors (DALI2 array). Results were obtained for the E1 strength in the region where the dipole response is characterized by the presence of the Pygmy Dipole Resonance (PDR). The measured E1 strength is found to be larger as compared with that of ^{68}Ni below the neutron binding energy. The measured E1 strength as a function of energy is compared with available predictions based on relativistic and non relativistic approaches and only in some cases theory gives a reasonable account of the data.

Investigation of the γ-ray strength function of ^{87}Rb

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About half of the elements heavier than iron are produced in the slow neutron-capture process (s-process) and the reaction path is close to the valley of stability. For this production process the beta-decay rate λ_b is usually dominating over the neutron-capture rate λ_N. When $\lambda_b \approx \lambda_N$ the s-process can branch [1]. In the s-process nucleosynthesis such a branching-point nucleus is ^{86}Rb bypassing the s-only nuclei ^{86}Sr/^{87}Sr. Hence, to precisely understand the production of ^{86}Sr/^{87}Sr during the s-process, the radiative neutron-capture rate λ_N of ^{86}Rb is of utmost importance. Since ^{86}Rb has a half-life of only $T_{1/2} = 18.7\ d$, the direct measurement of the neutron-capture cross section $^{86}\text{Rb}(n,\gamma)^{87}\text{Rb}$ is experimentally not feasible [2]. Within the framework of the Hauser-Feshbach Statistical model theoretical calculations of neutron-capture cross sections can be performed [3]. For these calculations a precipse knowledge of the γ-ray strength function (γSF) of the product nucleus (^{87}Rb) is crucial.

To experimentally determine the γSF, real photon scattering experiments are a very powerful tool [4]. Several (γ, γ') experiments have been performed on ^{87}Rb so far. Bremsstrahlung experiments with different electron energies have been done at the Stuttgart Dynamitron facility (4 MeV [5]) and the γELBE facility [6] (8.5 MeV and 13 MeV) to investigate photoabsorption cross sections.

The bremsstrahlung measurements have been extended by a complementary measurement at the High Intensity Gamma-ray Source (HIγS) at TUNL, Durham, USA. Here, almost monoenergetic, linear polarized γ-ray beams are provided by the Laser-Compton backscattering technique [7, 8]. A complex energy scan from 5 MeV to 15 MeV with 26 energy settings has been performed. Deexciting γ rays were detected with the high-efficiency setup γ^3 (4 HPGe detectors and 4 LaBr detectors) [9]. At HIγS, absolute values for elastic and inelastic photoabsorption cross sections are investigated also aggregating unresolved transitions [10].

Moreover, the linear polarized beam enables the direct measurement of electromagnetic type of radiation. For non-zero groundstate-spins, angular distributions are less distinct, but still measurable with high accuracy for the $3/2^-$ groundstate in ^{87}Rb.

In this contribution, the experimental setups will be presented and results regarding the dipole response of ^{87}Rb will be shown and discussed.

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