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Book of Abstracts

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Chaos and Pairing

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It is well known that pairing plays an important role in low-lying nuclear states, and that chaos plays an important role for highly excited states, as e.g. in the neutron resonance region. In the talk we shall discuss how these two parts combine.
In the nuclear ground-state region the mean field, deformed or spherical, provides a good approximation. The mean field then determines the dynamics of the system, and the connection classical/quantum chaos is well established. We show how the BCS pairing gaps respond differently on the dynamics of the mean field, and provide unique features through the gap fluctuations.

For the interacting many-body problem, where the two-body interaction is explicitly accounted for, chaos is usually found to appear with increasing excitation energy. This is understood as an effect of the two-body interaction, that plays a larger and larger role with increasing excitation energy. What happens if the two-body interaction is of pairing type? Will there be a transition to chaos for sufficiently large pairing strength? This is discussed based on a simple model system, that mimics a gas of ultracold fermionic atoms in a 2D confinement, subject to an attractive interaction of delta-type. It is found that with increasing strength of the pairing interaction, several chaos-like facets set in, although the system never becomes fully chaotic. For larger pairing strength the dynamics is found to revert, and the system becomes more and more regular as the interaction strength increases. We discuss differences in wave-functions emerging from a complex many-body system with a generic two-body interaction (as the nuclear shell model or even a random interaction), and from a many-body system with a pairing (delta) interaction.

1

Precision measurements for the cosmic rp-process.

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The explosive nuclear burning of hydrogen at high temperatures and densities on the surface of accreting white dwarfs and neutron stars, known as rp-process, gives rise to a number of observable phenomena like Novae or X-ray bursts. Recent astronomical observations provide unprecedented information, for example on atomic abundances in Nova ejecta and time structure in X-ray bursts. The interpretation of these data requires the understanding of the nuclear processes during the explosive events and therefore information on the structure of unstable, proton-rich nuclei.

Network model calculations show that the dominant burning processes, after breakout from the hot CNO cycles at sufficiently high temperatures, proceed via proton- and alpha-induced reactions. Since the reaction rates are very sensitive to the nuclear structure involved, shell- and statistical-model calculations are often not sufficient to predict the exact reaction paths of the rp-process.

Therefore, we have been conducting experiments using high-resolution spectrometers to search for possible reaction resonances that play a role in the rp-process and determine the nuclear-structure information, in particular the excitation energy, accurately above the proton- and alpha-thresholds. The techniques involving high resolution spectrometers at forward angles including 0 degree and examples of experimental results will be presented and discussed in the contexts of efforts to measure the reactions rates directly by applying measurements in inverse kinematics using existing and planned recoil separators.

2

Exploring the αp-Process with High Precision (p,t) Reactions

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Type 1 X-ray Bursts are identified as thermonuclear explosions on the surface of accreting neutron stars. These bursts can be observed and characterized through their bolometric luminosity curves. In a small number of type 1 X-ray bursts, a double peak structure in the light curve has been observed. This double peak structure lead Fisker et al to propose a nuclear waiting point impedance in the thermonuclear reaction flow of the αp-process, and conclude that uncertainties in (α,p) reactions rates on these potential waiting points can be directly observed in the structure of X-ray burst light curves [1]. (α,p) reaction rates on two possible waiting point nuclei, ²⁶Si and ³⁴Ar, were examined by investigating the level structure in the respective compound nucleus, ³⁰S and ³⁸Ca. This was done through high-precision measurements of ³²S(p,t)³⁰S and ⁴⁰Ca(p,t)³⁸Ca reactions utilizing the high energy-resolution zero-degree techniques with the K600 spectrometer at iThemba LABS [2]. States above the α-threshold have been identified and precise excitation energies were determined. These excitation energies, along with calculated level parameters were then used to determine the reaction rates for the ²⁶Si(α,p) and ³⁴Ar(α,p) reaction over stellar temperature ranges. Experimental excitation energies along with calculated reactions rates will be presented.

Ref.
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[2] R Neveling, H Fujita, F D Smit, T Adachi, G P A Berg, E Z Buthelezi, J Carter, J L Conradie, M Couder, R W Fearick, S V Fortsch, D T Fourie, Y Fujita, J Gorres, K Hatanaka, M Jingo, A M Krumbholz, C O Kureba, J P Mira, S H T Murray, P von Neumann-Cosel, S O'Brien, P Papka, I Poltoratska, A Richter, E Sideras-Haddad, J A Swartz, A Tamii, I T Usman, and J J van Zyl. High energy-resolution zero-degree facility for light-ion scattering and reactions at iThemba LABS. Nuclear Inst. and Methods in Physics Research, A, 654(1):29{39, October 2011.

3

Isoscalar and isovector spin-M1 transition strengths and tensor force effect in N=Z and even-even nuclei

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Gamow-Teller (GT) quenching problem, GT strength experimentally observed is missing in comparison with the model independent sum rule, has been a long standing problem. The missing strength has been found to be not due to excitations to Δ particle but due to excitations with 2-particle-2-hole configuration mixing mainly because of tensor force correlation. It is interesting if quenching phenomena is observed in isoscalar and isovector spin-M1 transition strengths because their transition operators are mediated by σ and στ_z, respectively, where the latter is analogous to the operator for GT transition.

We performed (p,p') measurement at 0^o on N=Z and even-even nuclei in the sd-shell region for investigation of spin-M1 transitions. Because target nuclei are T=0, isoscalar and isovector components can be separately observed. Angular distribution of differential cross section observed is compared with distorted wave impulse approximation calculation for assignment of 1+ transition and isospin. The differential cross section at 0o was converted to nuclear transition matrix element using a proportional factor, unit cross section, which was deduced from experimental data of β- or γ-decay life times in literature assuming isospin symmetry. Obtained matrix elements were accumulated up to 16~MeV in excitation energy for each nucleus. They were compared with the shell model calculation based on the USD, and the new USD interactions. A quenching factor, a ratio of the total experimental sum to the total calculation one, for isovector spin-M1 transition was 0.6, which is consistent with the quenching factor of GT transition obtained by the shell model calculation. However, the quenching factor for isoscalar spin-M1 transition was 1.0, which is inconsistent theories that have predicted 2-particle-2-hole configuration mixing as the GT quenching. Thus, it is suggested that we do not still fully understand the GT quenching problem. Combining the isoscalar and the isovector quenching factors, however, the experimental result may suggest tensor force effect in the ground state, which is consistent with the picture that the GT quenching is due to 2-particle-2-hole configuration mixing.

4

Exotic nuclei studied by direct reactions at low momentum transfer - recent results and future perspectives at FAIR

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Light-ion induced direct reactions, like for example elastic and inelastic scattering, transfer-, charge exchange-, or knock out-reactions, have been proved in the past, for the case of stable nuclei, to be powerful tools for obtaining nuclear structure information, and were also applied within the last two decades for the investigation of exotic nuclei with radioactive beams in inverse kinematics. In particular, it turned out that in many cases essential nuclear structure information is deduced from high-resolution measurements at low momentum transfer. For the case of inverse kinematics experiments with radioactive beams such measurements can be performed either by using the experimental technique of active targets, or, with even higher luminosities, in future with radioactive beams stored in storage rings, and interacting with thin internal targets. As an example for the application of the active target technique an overview on recent results on intermediate energy small angle elastic proton scattering, a meanwhile well established method for the investigation of nuclear matter distributions of halo nuclei, will be given. The experimental conditions at the future international facility FAIR will provide unique opportunities for nuclear structure studies on nuclei far off stability, and will allow to explore new regions in the chart of nuclides of key importance for nuclear structure and nuclear astrophysics. In particular, the predicted intensities of radioactive beams will allow for the investigation of direct reactions with stored and cooled radioactive beams interacting with internal H, He, etc. targets of the new storage ring NESR. This technique enables high resolution measurements down to very low momentum transfer and provides a gain in luminosity from accumulation and recirculation of the radioactive beams. The design of a complex detector setup is presently investigated by the EXL1 collaboration with the aim to provide a highly efficient, high resolution universal detection system, applicable to a wide class of reactions. It includes a detector array for recoiling target-like reaction products and gamma-rays, surrounding the internal target, as well as a forward detector for fast ejectiles, and an in-ring spectrometer for the detection of beam-like reaction products. A brief overview on the research objectives, the technical concept and the present status of the EXL project, as well as on feasibility studies and first experiments performed or planned at the present ESR storage ring, paving the way towards the full EXL experiment at FAIR, will be presented.

1 EXL: EXotic nuclei studied in Light-ion induced reactions at the NESR storage ring

5

Low-Energy Enhancement of the Photon Strength Function

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Over the last decade several measurements in light- and medium-mass nuclei have reported an enhanced ability for the absorption and emission of gamma radiation (photon strength function PSF) at low energies. The impact of this effect may have profound implications on neutron capture reaction rates which are not only responsible for the formation of elements heavier than iron in stellar and supernova environments [1] but are also of central importance for advanced fuel cycles in nuclear reactors [2]. The results were received with significant skepticism by the community mainly due to the lack of any known mechanism responsible for such an effect but also because another established experimental technique failed to confirm the measurement. Now, a new experimental method which is free of model input and systematic uncertainties has been developed to determine the PSF. It is designed to study statistical feeding from the quasi-continuum (below the particle separation energies) to individual low-lying discrete levels. A key aspect to successfully study gamma decay from the region of high-level density is the detection and extraction of correlated high-resolution particle-gamma-gamma events which is accomplished using an array of Clover HPGe detectors and large area segmented silicon detectors. The excitation energy of the residual nucleus produced in the reaction is inferred from the detected proton energies in the silicon detectors. Gating on gamma-transitions originating from low-lying discrete levels specifies the states fed by statistical gamma-rays. Any particle-gamma-gamma event satisfying these and additional energy sum requirements ensures a clean and unambiguous determination of the initial and final states of the observed gamma rays. With these constraints the statistical feeding to discrete levels is extracted on an event-by-event basis. In this talk the latest results for ⁹⁵Mo [3] are presented and compared to PSF data measured at the University of Oslo [4]. In particular, questions regarding the existence of the low-energy enhancement in the photon strength function will be addressed.

[1] M. Arnould, S. Goriely and K. Takahashi, Physics Reports 450, 97213 (2007).
[2] M.B. Chadwick et al., Data Nuclear Data Sheets 112, 2887 (2011).
[3] M. Wiedeking et al., Phys. Rev. Lett. 108, 162503 (2012).
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6

Do we understand gamma strength functions - the case of ⁹⁶Mo

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The gamma strength functions of ⁹⁶Mo derived from a variety of experimental methods show quite severe disagreement, in particular near the neutron threshold. We discuss a new experimental method, viz. relativistic proton scattering at extreme forward angles, which allows a consistent analysis of data below and above the particle threshold. E1 and M1 strength distributions can be determined by a multipole decomposition of angular distributions. The additional measurement of polarization observables provides an independent check of the method. First results from a recent experiment are presented.

7

The Pygmy Dipole Resonance - history and overview

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One of the currently most intensively debated phenomena in Nuclear Structure Physics is the existence of a new type of collective electric dipole excitation commonly denoted as Pygmy Dipole Resonance (PDR). It is located at energies around the particle threshold and is visualized in certain models as the oscillation of excess neutrons against an isospin saturated core. Recent results from magnetic spectrometers hint to an energetic splitting of the PDR. I will give an overview of the PDR from the first experiments to the present day status focusing on the possible contribution from different experimental probes.

8

On the nature of the Pygmy Dipole Resonance

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The investigation of the same nuclear excitation using different complementary probes can yield important details on the underlying structure of the excitation mode. In the case of the Pygmy Dipole Resonance (PDR) our experiments using the $(\alpha,\alpha'\gamma)$ reaction at $E\alpha$ = 136 MeV have revealed a structural splitting of the PDR when compared to corresponding (γ,γ') results: Whereas the low energy part of the E1 strength is excited by the (γ,γ') as well as by the $(\alpha,\alpha'\gamma)$ reaction, the high energy part is not excited in the α-scattering experiment [1,2,3]. This different excitation pattern is an experimental evidence for different structures of the two groups of 1− excitations. Corresponding investigations of the isoscalar and isovector E1 strength in QPM and RQTBA calculations show a qualitative agreement to these experimental observations and identify the lower energy E1 excitations as the neutron-skin oscillation often assigned to the PDR. The combined results of experiment and calculations thus provides for the first time an experimental identification of the E1 excitations showing the structure associated with the PDR picture of a neutron-skin oscillation [4]. This shows the importance of experimental investigations using complementary probes.

[1] D. Savran et al., Phys. Rev. Lett. 97 (2006) 172502
[2] J. Endres et al., Phys. Rev. C 80, 034302 (2009)
[3] J. Endres et al., Phys. Rev. Lett 105 (2010) 212503

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Overview of experimental conditions for (a,a'g) coincidence experiments

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The Pygmy Dipole Resonance (PDR) has been investigated systematically using different experimental methods within the last years. Especially the comparison of results obtained using complementary probes revealed a deeper insight into the structure of the PDR [1,2]. Therefore, (a,a'g) experiments have been conducted at the Kernfysisch Versneller Instituut (KVI) in Groningen, The Netherlands using a primary beam energy of 136 MeV. In order to detect the scattered a particles in coincidence with the emitted gamma rays, the Big-Bite Spectrometer (BBS) and an array of High-Purity Germanium (HPGe) detectors were used [3].
The experimental setup will be discussed in detail as well as the high selectivity and the analyzing power of this method.

[1] D. Savran et al., Phys. Rev. Lett. 97 (2006) 172502
[2] J. Endres et al., Phys. Rev. Lett 105 (2010) 212503
[3] D. Savran et al., Nucl. Instr. and Meth. A 564 (2006) 267

10

High energy-resolution measurements at RCNP

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At RCNP, we constructed in 2000 a beam line which can accomplish both the lateral and angular dispersion matching between the beam line and the magnetic spectrometer Grand Raiden.(GR). GR is characterized by its high resolving power of D/Mx=37,000 with the dispersion of D=15,451 mm. This large dispersion requires small energy spreads of the primary beam itself. Developments have been performed to deliver high quality beams on targets. No slits are installed in the beam line after the Ring cyclotron, because there are not enough spaces to cut beam halos generated by edge scatterings from slits. After the commissioning of the system, many experiments have been successfully

performed with such beams as protons, ³He, ⁴He, etc. I will present the design of the beam line and experiences and performances of the system so far.

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The K600 at iThemba LABS

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The investigation of medium-energy light-ion scattering and reactions at zero degrees has the advantage of being very selective to excitations with low angular momentum transfer. This simplifies analysis of the many contributions to the spectra due to the complex nature of the nuclear interaction. Only a few facilities exist worldwide where high energy-resolution measurements of this nature can be performed. The K600 Zero-Degree Facility at iThemba LABS was recently successfully developed. A high energy resolution of 37 keV (FWHM) was achieved for inelastic proton scattering measurements at an incident energy of 200 MeV, and 35 keV (FWHM) for the measurement of the (p,t) reaction at 100 MeV. An overview of the the facility and a short discussion on possible future developments will be presented.

12

Fine Structure of the Isovector Giant Dipole Resonance using the (p,p′) reaction at zero degrees: Effects of strong nuclear deformation

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The decay of giant resonances in nuclei is a prime example of how a well-ordered collective excitation dissolves into a disordered motion of internal degrees of freedom in fermionic quantum many-body systems. Fine structure of the Isovector Giant Dipole Resonance (IVGDR) for the neodymium isotope chain, ^{142,144,146,148,150}Nd, has been observed in high energy-resolution inelastic proton scattering experiments. The state-of-the-art K600 magnetic spectrometer of iThemba

LABS was used to perform these experiments at zero-degrees scattering angle with an incident proton energy of 200 MeV. The analysis of the measured (p,p′) energy spectra will yield insight into the transition from spherical (¹⁴²Nd) to highly deformed (¹⁵⁰Nd) nuclei and provide information about the dominant damping mechanisms. A comparison can be made to (γ,xn) data which clearly show a broadening and splitting of the IVGDR as deformation increases. Preliminary results will be discussed.

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Effects of nuclear deformation on the fine structure of the Isoscalar Giant Quadrupole Resonance of even-even neodymium isotopes using proton inelastic scattering

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Fine structure has been observed in the region of the Isoscalar Giant Quadrupole Resonance (ISGQR) in ¹⁴²Nd, ¹⁴⁴Nd, ¹⁴⁶Nd, ¹⁴⁸Nd and ¹⁵⁰Nd target nuclei using high energy-resolution proton inelastic scattering. The 200 MeV proton beams were delivered by the Separated Sector Cyclotron (SSC) and measurements were made using the K600 Magnetic Spectrometer of iThemba Laboratory for Accelerator Based Sciences, a facility which is situated at Faure near Cape Town, South Africa. Nuclei with mass number A ≈ 150 and neutron number N ≈ 90 are of special interest since they occupy that region of the nuclide chart wherein the onset of permanent prolate deformation occurs. The stable neodymium (Z = 60) isotopes have been chosen in the present study, in order to investigate the effects accompanying the onset of deformation, on the excitation energy spectra in the ISGQR region (9 ≤ E_x ≤ 15 MeV), since they extend from the semi-magic N = 82 nucleus (¹⁴²Nd) to the permanently deformed N = 90 (¹⁵⁰Nd) nucleus. In order to enhance the ISGQR in the excitation energy spectra measured, a Discrete Wavelet Transform (DWT) background subtraction was carried out. The resonance width extracted shows a systematic broadening of the ISGQR, moving from spherical to highly deformed nuclei as has already been observed for the Isovector Giant Dipole Resonance (IVGDR) excited by γ-capture. Energy scales were extracted for the resonance region using the Continuous Wavelet Transform (CWT) technique. Experimental details, data extraction and analysis techniques, together with preliminary results will be presented.

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Investigation of fine structure of the Isovector Giant Dipole in nuclei across the periodic table using proton inelastic scattering at zero degrees.

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A survey of the fine structure phenomenon of the Isovector Giant Dipole Resonance (IVGDR) was carried out, using proton inelastic scattering at an incident energy of 200 MeV for a wide target-mass range of closed and near-closed shell nuclei: ²⁷Al, ⁴⁰Ca, ⁵⁶Fe, ⁵⁸Ni and ²⁰⁸Pb. The data obtained will provide an unique insight into the role of different damping mechanisms contributing to the decay of the IVGDR. A comparison between the present data and photo-absorption cross-sections will be done in order to check for consistency. Absolute cross-sections together with systematic predictions on the position and width (Γ) of the IVGDR in a given nuclei will be presented. The presence of other multipole admixtures, such the Isoscalar Giant Quadrupole Resonance (ISGQR) and Isovector Giant Quadrupole Resonance (IVGQR), were found in the obtained spectra in some of the target nucleus investigated. Such information led to the confirmation of their respective resonance widths, centroids and strengths for each identified giant resonance. Experimental results from other probes exciting the IVGDR will also be compared to this present work and the corresponding correlations extracted. Characteristic energy scales from the experimental data will be extracted using the wavelet analysis technique, an unique technique that has been able to provide a solution to the long-standing search for experimental signatures of scales associated with the coupling between collective states and internal degrees of freedom.

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Overview of experiments on the fine structure of isoscalar giant quadrupole resonance at iThemba LABS

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The K600 Magnetic Spectrometer of iThemba LABS is a unique facility world-wide for the study of nuclear structure and reactions mechanisms at intermediate energies using light-ion projectiles. In particular, high energy-resolution experiments on nuclei in the region of giant resonances present a powerful tool to extract information about the dominant processes leading to equilibration. Proton inelastic scattering on nuclei spanning the periodic table from light to heavy-mass nuclei (sup>12</sup>C to ²⁰⁸Pb) has established fine structure as a global phenomenon for the Isoscalar Giant Quadrupole Resonance (ISGQR). In addition, it has been possible to extract level densities in the nuclear continuum very reliably for use in astrophysical calculations. Experimental results and recent developments in maximising the capability of this unique facility will be presented.

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Dipole polarizability of Ca-48

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Inelastic proton scattering at extreme forward angles is a powerful tool to investigate electric dipole and magnetic spin excitations with a high energy resolution. It is possible to separate E1 from M1 contributions to angular distributions as demonstrated in the cases of Pb-208 and Zr-90. Data from a proton-scattering experiment on Ca-48 are currently analyzed. The excitation energies range from 4 MeV to 26 MeV. Due to this broad energy range almost the complete E1 strength can be extracted. The dipole polarizability has been suggested [1] as a new measure of the neutron skin from a strong correlation of both quantities found in virtually all RPA calculations. A precise value for the polarizability has been extracted from the experiment on Pb-208 [2]. However, while the correlation is observed in all models, absolute values for the derived neutron skin dier considerably. Thus, further data are necessary to constrain the models. The case of Ca-48 was found to be of special interest [3]. Further-more, microscopic coupled cluster or no-core shell model calculations are able to relate 3N forces to the neutron skin thickness in Ca-48 [4].

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Spectral distributions of E1 and M1 strengths at PDR energies

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We present systematic theoretical investigations of electromagnetic response functions where new modes of nuclear excitations are explored. The approach incorporates density functional theory and QRPA plus multi-phonon coupling. This allows for a consistent microscopical description of dierent complex excitations in stable and exotic nuclei [1, 2].
The analysis of QRPA transition densities and currents at low energies reveal a clear indication of specic signals of nuclear skin oscillations which are distinct from other surface vibrations and the giant resonances known from stable nuclei. These signals are found as well in dipole and quadrupole response functions and they are related to pygmy dipole and quadrupole resonances [1, 2]. Even though the pygmy dipole strength is mostly of electric character [3], the presence of skins is found to in uence also M1 strengths. In this aspect investigations of the ne structure of M1 spectral functions are discussed in comparison with experimental data [4]. The new observations contribute to the understanding of the spin dynamics of the nucleus in the presence of skin.

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Experimental results on double-beta decay matrix elements, or what did we learn after so many years of charge-exchange reactions

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Charge-exchange reactions of (n,p) and (p,n) type at intermediate energies are a powerful tool for the study of nuclear matrix element in double-beta decay. The present contribution reviews some of the most recent experiments in this context. Here, the (n,p) type reactions are realized through (d,²He), where ²He refers to two protons in a singlet 1S0 state and where both of these are momentum analyzed and detected by the same spectrometer and detector. These reactions have been developed and performed exclusively at KVI, Groningen (NL), using an incident deuteron energy of 183 MeV. Final state resolutions of about 100 keV have routinely been available. On the other hand, the (³He,t) reaction is of (p,n) type and was developed at the RCNP facility in Osaka (JP). Measurements with an unprecedented high resolution of 30 keV at incident energies of 420 MeV are now readily possible. Using both reaction types one can extract the Gamow-Teller transition strengths B(GT₋) and B(GT₊), which define the two "legs" of the 2-neutrino double-beta decay matrix elements. The high resolution available in both reactions allows a detailed insight into the excitations of the intermediate odd-odd nuclei and, as will be shown, some rather unexpected features are being unveiled. Special emphasis will be placed on the double-beta decay nuclei ⁷⁶Ge, ⁹⁶Zr, ¹⁰⁰Mo, ^{128,130}Te and ¹³⁶Xe. The data are being reviewed and some important conclusion may now be drawn about the particulars of the nuclear structure of each system and their impact on the nuclear matrix elements.

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Search for the 0+ 5 alpha cluster state in 20Ne

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Multi-alpha particle clustering in light nuclear matter has received much attention from recent theoretical investigations [1,2]. This topic of research has profound implications to the fields of both nuclear structure and nuclear astrophysics [3,4].

The primary aim of this experimental investigation was to search for the elusive 0+ 5 alpha cluster state in ²⁰Ne, which is expected to be found at a few hundred keV above the threshold for 5 alpha breakup in ²⁰Ne (Ex = 19.17 MeV) [5]. It would be an analogue to the Hoyle state in 12C, which has a well established 3 alpha cluster structure [1,6]. The secondary aim was to search for new low spin states at high excitation energy in 20Ne. During four weekends between April and July of 2012, the ²²Ne(p,t)²⁰Ne reaction was investigated with the iThemba LABS K600 light ion spectrometer. A 60 MeV proton beam impinged upon a ²²Ne gas target at lab angles of θLAB = (0˚, 7˚, 16˚, 27˚) .

Performing this experiment at 0˚ with the (p,t) reaction provides a selective, background-free probe with adequate resolution to search for the low spin states of interest. Measurements at larger angles were necessary to characterize the spin-parities of the observed states.
Preliminary results from the analysis of these data will be presented.

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Summary:

Alpha cluster models predict that 20Ne will have a 0+ 5 alpha cluster state above the threshold for 5 alpha breakup at 19.17 MeV. The primary aim of this experiment was to search for this state using the 22Ne(p,t)20Ne reaction at 60 MeV, employing the zero degree mode of the iTL K600 spectrometer. A 22Ne gas cell target was used.

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magnetic spectrometer measurements for double beta decay

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Neutrinoless double beta decay is of outmost importance for neutrino physics. This mode violates lepton number by two units and thus would open the door to physics beyond the Standard Model of Particle physics. It requires that neutrinos are their own antiparticles and a non-vanishing rest mass of the neutrino, which is linked to the measurable half-life. In the conversion from half-life to neutrino mass and also in the Standard model process including the emission of 2 anti-neutrinos nuclear matrix elements occur. Their determination is a major theoretical challenge and activities were started some years ago to provide more experimental data. Especially important are nucleon transfer reactions and charge exchange reactions.
The talk will give an introduction of the current situation, reviews measurements done in the last years and and outlook what should be done.

21

Characterization of the 2+ excitation of the Hoyle state in 12C

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For many years there has been a question mark over the location of the 2⁺ excitation of the Hoyle state in ¹²C. Several measurements were performed to search for this state. A measurement which published in 1971 showed the existence of a 11.16 MeV 2⁺ state in ¹²C. This state was assumed to be a candidate for the 2⁺ excited state of the Hoyle state. However, the existence of this state was not confirmed by other studies. Recent measurements to search for the 2⁺ excited state of the Hoyle state indicated that a 2⁺ state may exist around 10MeV, which is in contradiction with the 1971 measurements. In 2004, Itoh et al. published (α,α') data that showed that there is strong evidence for a 2⁺ state in ¹²C lie at 10 MeV region. Since then there have been several other measurements which supported these claims. With interest in locating the 2⁺ excitation of the Hoyle state growing rapidly, it was considered important to perform a set of experiments with improved equipment and analysis techniques available today, to provide answers regarding these contradicting claims about the location of this state. The first experiment was performed at iThemba LABS with the high energy resolution K600 magnetic spectrometer to investigate the ¹¹B(³He,d)¹²C reaction for an incident beam energy of 44 MeV to search for the 2⁺ state in the 11.16 MeV region. These experimental conditions mirrors those used in the 1971 study. Measurements were performed at the three spectrometer angles where a clear signature was reported in the previous measurement. The results from the recently published data analysis will be presented.

The second experiment intended to search for the 2⁺ excitation of the Hoyle state in the 10 MeV region was recently completed. The experiment was also performed at iThemba LABS with the high energy resolution K600 magnetic spectrometer using the ¹⁴C(p,t)¹²C reaction with a 66 MeV proton beam. Data analysis of these measurements is underway. Preliminary results will be presented in this talk.

22

Electric Dipole Response of ²⁰⁸Pb: PDR, Neutron Skin, and Symmetry Energy

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ponses of atomic nuclei to an external field. Most of the E1 strength is carried by a giant dipole resonance (GDR), which is described as a dipole oscillation between protons and neutrons. Recently a sizable E1 strength concentration has been found in several nuclei at the region of neutron separation energy below GDR, which is called low-lying dipole strength or a pygmy dipole resonance (PDR). The nature of the PDR is not known well but might be explained as a dipole oscillation of neutron skin against an isospin-saturated core. The properties of the PDR may shed light on the formation of neutron skins, symmetry energy and equilibrium properties of neutron stars. In addition, recent studies on energy density functionals using Skyrme forces suggest dipole polarizability, which is an inversely energy-weighted sum-rule of the E1 strength, as an alternative observable to constrain both neutron skin and symmetry energy. Thus complete determination of the E1 response is quite important.

A case of special interest is the doubly magic nucleus 208Pb. We have performed a high-resolution proton inelastic scattering measurement from ²⁰⁸Pb at very forward angles including zero-degrees. The data were taken at the Research Center for Nuclear Physics (RCNP), Osaka University, employing a polarized proton beam at 295 MeV. Differential cross sections were measured at 0-6 degrees and polarization transfer coefficients at 0-2.5 degrees. The measured excitation energy region is 5-22 MeV, which completely covers the GDR and PDR strengths.

We have obtained an accurate E1 strength distribution including the PDR region. The dipole polarizability has been determined up to 130 MeV by combining our data and existing data. The measured dipole polarizability and the E1 strength distribution are compared with theoretical models to discuss the neutron skin thickness and the symmetry energy of the nuclear equation of state.

In the workshop, I will explain the overview of the experimental methods and will discuss the results on behalf of the RCNP-E282 collaboration.

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23

The complexity of low-lying 0+ excitations

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Remarkable measurements with the (p,t) reaction using the Q3D magnetic spectrograph at the University of Munich MP tandem accelerator revealed many 0+ excitations lying at relatively low excitation energies in rare earth region nuclei. A total of 11 excited 0+ states were observed in ¹⁵⁸Gd below an excitation energy of about 3.1 MeV. This abundance of 0+ states in a single nucleus provides significant new information on this poorly understood phenomenon. Theory, however, predicts less 0+ states than those experimentally characterised. The combination of Coulomb-excitation, electron-conversion, (p,t) and (³He,n) transfer reactions at iThemba LABS will provide a means to characterise the nature of these exciting 0+ states.

24

Measurement of radiative widths of excited states above the alpha-decay threshold in ¹²C

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In the normal sequence of stellar evolution,¹²C synthesis ordinary proceeds through the 0₂⁺ excited state at Ex = 7.65 MeV, so-called triple alpha process. At very high temperature (T9 > 1) such as supernova explosion, the 3₁⁻ state at Ex = 9.64 MeV also plays an important role. But the 3₁⁻ radiative decay width is still unknown and only the upper and lower limit is provided at present. For this reason, it is very important to measure the radiative width of 3₁⁻ state at Ex = 9.64 MeV for better understanding of triple alpha process. In order to determine this width, we have proposed a new experiment at RCNP. In this experiment, we perform the inverse kinematics measurement

of inelastic proton scattering from ¹²C at an incident energy of E = 20.8 MeV/u. We have already performed the test experiment. We present the results of the test experiment and the prospects of a new experiment.

25

Fine structure and 1⁻ level densities in the GDR region in light <i>N=Z</i> nuclei.

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We report on a study of the isovector giant dipole resonance (GDR) in light <i>N=Z</i> nuclei. Inelastic scattering of 295 MeV protons was measured at close to zero degrees at the Grand Raiden spectrometer at RCNP, at resolutions of 20-40 keV FWHM, for selfconjugate target nuclei from ¹⁶O to ⁴⁰Ca with strongly varying ground-state structure (H. Matsubara, A. Tamii).
The GDR is clearly revealed in the spectra, and fine structure is observed across the range of nuclei. Characteristic scales of fine structure in the region of the GDR have been extracted using a continuous wavelet technique. Level densities were extracted using an autocorrelation analysis following a background subtraction using a discrete wavelet technique.

The extracted scales of fine structure have been compared to those extracted from RPA calculations with a realistic nucleon-nucleon interaction derived by the unitary correlation operator and similarity group renormalization methods, which have recently been extended to deformed nuclei. The analysis permits a test of the importance of Landau damping in explaining the fine structure of the GDR in light nuclei.

26

Dynamical correlations in nuclear spectra

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Nuclear correlations caused by coupling between single-particle and collective degrees of freedom are discussed. It is shown how the nucleon self-energy containing temporal and spatial non-localities provides fragmentation of the quasiparticle states, compared to the mean-field picture. The nucleon-nucleon effective interaction, derived from this self-energy, acquires an energy dependence which causes the fragmentation of collective modes of excitation like giant resonances and soft modes, compared to the random phase approximation. The "time blocking" approximation to the Bethe-Salpeter equation with singular kernels allows a very elegant treatment of the energy-dependent effective interaction including terms with "backward-going" diagrams and opens a way for inclusion of correlations of growing complexity. Comparison of the calculated strength functions to spectral data allows identification of the nature and mechanisms of formation of various collective and non-collective excited states in nuclei.

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Nuclear structure made clear by Gamow-Teller transitions

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Gamow-Teller (GT) transitions are caused by the sigma; tau; operator. Therefore, they reflect the uniqueness of nuclei that consist of two types of Fermions "protons and neutrons" with "spin-degree" of freedom. In addition, GT transitions are the most common nuclear weak transitions that are active all over the Universe. Most direct information on GT transition strength B(GT) can be derived from beta-decay measurements, but they cannot access highly excited states. In the 1980s, it was found that p,n) charge-exchange (CE) reactions at intermediate energies (E_p > 100 MeV) and 0-degrees are sensitive to the sigma; tau; response of nuclei. Thus, they became the break through against the Q-value limitation in the beta-decay study. In the late 1990s, (³He, t), CE reaction at 0-degrees was introduced, in which a magnetic spectrometer was used for the analysis of tritons. By the realization of beam matching conditions for the high-dispersive beam line WS course and the Grand Raiden spectrometer, high energy-resolutions of 30 keV or even better were achieved at the incoming ³He energy of 140 MeV/nucleon. The overview of the study of GT transitions at RCNP, Osaka [1] are presented for p-shell, sd-shell, pf-shell, and also for heavier mass A nuclei.We see that they are the transitions with full of personality.

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28

Time scales in nuclear giant resonances

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We propose a general and schematic approach to characterize fluctuations of measured cross sections of nuclear giant
resonances. Cross sections are obtained from simulated, yet representative, forms for the self-energy which contains
information about fragmentations. Using a wavelet analysis, we demonstrate the extraction of time scales of cascading decays of the resonance into configurations of increasing complexity. We argue that the spreading widths of collective excitations in nuclei are determined by the number of fragmentations as seen in the power spectrum. An analytic treatment of the wavelet analysis using a Fourier expansion of the cross section confirms this principle. A simple rule for the relative lifetimes of states with different complexity is obtained.

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Search for alpha condensed state in ²⁴Mg

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Recently we performed a high-resolution measurement of alpha;
inelastic scattering from ²⁴Mg to search for the alpha; condensed states with the configuration of 6alpha; or 2alpha;+¹⁶O. The alpha; inelastic scattering had been demonstrated as a useful probe to search for alpha; cluster states in the previous work. We also measured decaying particles from the excited states in coincidence with the inelastically scattered alpha; particles to clarify the alpha; cluster structure in ²⁴Mg. It is naturally expected that alpha; cluster states should prefer to decaying into alpha; emission channels while single-particle states should prefer to decaying into proton or neutron decay channels. In the present talk, we will present the experimental details and
preliminary results on the alpha; condensed states in ²⁴Mg.

30

Cluster-induced reactions in astrophysics

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Nuclear processes driving the energy production and nucleosynthesis in stars often cannot be studied directly in the laboratory. In many cases the reactions involve short-lived nuclei and are hindered by the Coulomb repulsion of the nuclei, making direct observation of the reactions difficult or even impossible. This is particularly true for reactions related to the breakout from the Hot-CNO cycle in for example X-ray bursts, a nuclear run-away on the surface of neutron stars. These reactions are triggered by the absorption of an alpha-cluster, and are therefore hindered by a large Coulomb barrier. Since the reactions involve the radioactive ¹⁴O, ¹⁵O, and ¹⁸Ne isotopes, direct measurements of the reactions are furthermore impeded by the difficulty in producing sufficiently intense beams of the involved isotopes.

The alpha-induced reactions are therefore best studied through indirect means using a combination of nuclear reactions with beams of both stable and radioactive nuclei. Through such reaction studies the nuclear properties that influence the astrophysical processes are measured, and the impact on stellar explosions determined. The presentation describes a research programme towards the measurement of the key breakout reaction, ¹⁵O(alpha;,gamma;)¹⁹Ne. The planned measurements include: indirect studies of the reaction using alpha-particle transfer; detailed studies of the mirror reaction; as well as a study of the alpha emission from the excited 19Ne states that determine the reaction rate. The programme utilises a combination of radioactive and stable ion beams with measurement of the reactions in high-resolution spectrometers and highly-segmented silicon arrays.

31

Fine structure of pygmy resonance.

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Quasiparticle-phonon model will be briefly outlined. Fragmentation of the electric dipole strength below and above neutron separation energy will be considered from calculations within this model. Differences in response to isoscalar and isovector external fields will be addressed.

32

Future Development of iThemba LABS

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iThemba LABS, based around the Separated Sector Cyclotron (SSC), is already the premier nuclear particle accelerator laboratory in Africa and indeed in the Southern Hemisphere. It proposes to address Grand Challenges identified by the DST, i.e. Energy Security and Space Sciences by building a radioactive-ion beam facility to bring South Africa to a position of international leadership in the fields of nuclear physics and material sciences. Internationally, interest in nuclear physics is focusing on the study of the so-called 'terra incognita' – the unknown part of the table of nuclides – which includes the unstable 'neutron-rich' nuclei that cannot be produced using beams of stable atoms. This region holds the key to our understanding of nuclear forces and the origin of the elements of which the Universe is composed. Neutron-rich nuclei can only be created and studied in the laboratory by using beams of artificially produced radioactive-ion beams from an accelerator such as a cyclotron. Furthermore, radioactive probe ions are of particular use in the development of advanced materials. Measurements of the decay of the probe ion give direct evidence on the site of the implanted ion, on the nature of the site, and on diffusion characteristics of the dopant ions.

iThemba LABS proposes a staged development of a radioactive-ion beam facility:

1. The first stage would see the addition of a high-current, 70-MeV cyclotron to iThemba LABS.

This cyclotron would take over the production of radioisotopes, 24 hours a day, thus releasing the existing SSC to be dedicated to physics research – mainly pure and applied nuclear physics – and to neutron radiotherapy. The capacity for physics training would be more than doubled and the links with international collaborations would be considerably strengthened owing to the increased availability of beam time, currently restricted to weekends only. (Proton therapy is assumed to be transferred to the proposed iThemba Particle Therapy Centre, a private-public partnership which is currently under consideration by the minister.)

1. The second stage would see the production of radioactive-ion beams, bringing nuclear and materials research and training in South Africa to the international forefront.

Since two H– ion beams can be extracted simultaneously from the proposed new 70-MeV cyclotron, one of these will be used to produce radioactive ions via the Isotope-Separation-On-Line (ISOL) method. These ions will then be formed into a beam which can then be post-accelerated by the existing SSC for use in nuclear physics experiments.

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Small resonances on the tail of the Giant Dipole Resonance

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The nuclear physics group at the Oslo Cyclotron Laboratory has developed a unique technique to extract simultaneously the level density and γ-strength function from primary γ-ray spectra [1]. These are fundamental properties of the atomic nucleus and important input parameters in reaction cross-section calculations, used in reactor physics simulations and astrophysics models of formation of heavy elements in explosive stellar environments. I will give a short description of our facility and the Oslo method. Then the latest result from experiments done in Oslo will be presented, including resent data on actinide nuclei, relevant for the Thorium fuel cycle, where we observe a large orbital scissors strength for several actinide nuclei [2]. We have also observed another resonance around 7-9 MeV in Sn isotopes which might be due to neutron skin oscillations [3]. Both these resonances increase the gamma decay probability and should be included in neutron capture cross-sections calculations. Finally an unexpected enhancement of the γ-strength function at low gamma energy has been observed in several nuclei [4]. This low energy enhancement has the potential of increasing neutron-capture rates with up to two orders of magnitude if also present in very neutron-rich nuclei [5]. The present status of the low-energy enhancement will be presented.

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34

Unique Information on Proton-Neutron Structure of Nuclear States from Combined Electromagnetic and Hadronic Scattering Experiments

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A consequence of the formulation of the proton-neutron version of the Interacting Boson Model [1] is the occurrence of low-energy mixed-symmetry states with boson couplings that are partially non-symmetric with respect to proton and neutron boson labels. This results in enhanced M1 gamma-ray transitions to lower-lying fully symmetric states that dominate the low-energy M1 strength function in heavy nuclei. The existence of mixed-symmetry states have later-on been verified experimentally. Their properties are uniquely sensitive to the effective proton-neutron interaction in the valence shell. Electromagnetic probes such as photon scattering, electron scattering, or projectile-Coulomb excitation on light targets have proven themselves as powerful methods for the identification and quantitative investigation of the fundamental building block of quadrupole-collective mixed-symmetry structures of heavy nuclei, the one-phonon mixed-symmetry 2+1,ms state. A complete set of data on the 2+1,ms state has been obtained [2-4] on stable even-even isotopes of the A=130 mass region on the basis of absolute M1 transition rates. For the case of ¹³²Te the method of projectile-Coulomb excitation has produced first solid evidence for a mixed-symmetry state of a radioactive nuclide [5], too. Information on the dominant single-particle components involved in the formation of quadrupole-collective one-phonon states of vibrational nuclei has recently been obtained [6] from a comparison of inelastic electron-scattering and proton-scattering cross sections. Quantum interferences in charge- or matter-transition densities enable one to determine whether a proton boson or a neutron boson couples antisymmetrically within the mixed-symmetry wave function [6]. New data [7] on that phenomenon will be presented and discussed. The topic represents a strong physics case for a continued collaboration between TU Darmstadt and iThemba Labs.

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