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Book of Abstracts

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Vladimir Zelevinsky

(pdf, ppt, wmv, mp4)

National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, MI

Many-body quantum chaos and exponential convergence of large Hamiltonian matrices

With excitation energy and level density growing, the quantum states of a realistic quantum many-body system become exceedingly complicated superpositions of simple particle-hole excitations. As confirmed by data and shell-model calculations, this structure is close to the extreme chaotic limit of random matrix theory. Transforming the ideas of quantum chaos into a practical tool, one can use these chaotic properties to estimate the influence of highly excited configurations onto observable properties of low-lying states. In particular, we will show that a sequence of regular truncations of huge Hamiltonian matrices leads to the exponential convergence of the observables. This is important for practical calculations of level densities, binding energy, position of drip lines, astrophysical cross sections etc.

Mihai Horoi

(pdf, ppt, wmv, mp4)

Central Michigan University, Mt. Pleasant, MI

Accurate description of the spin- and parity-dependent nuclear level densities

We developed a methodology of calculating the the spin- and parity-dependent nuclear level density using the interacting shell model technology. We also proposed new techniques based on nuclear statistical spectroscopy to calculate the spin and parity projected moments of the nuclear shell model Hamiltonian, that can be further used to obtain an accurate description of the nuclear level densities up to about 15 MeV excitation energy. These techniques were fully tested for the sd-shell nuclei and some light fp-shell nuclei, by comparing with the level density obtained from exact shell model diagonalization. We will present for the first time comparisons with the exact shell model diagonalization for nuclei around and heavier than ^{56}Ni, using a new shell model code that works in a coupled-J scheme. The ratio of nuclear level densities of opposite parities will be also discussed. This historical breakthrough was possible due to a new and very efficient nuclear shell model code, NuShellX, that can provide a large number of states of given spin and parity in very large model spaces.

Hiroaki Utsunomiya

(pdf, ppt, wmv, mp4)

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Photodisintegration and nuclear statistical quantities in astrophysics

Nuclear statistical quantities such as γ strength function (γSF) and nuclear level density (NLD) are important nuclear ingredients in Hauser-Feshbach model calculations of neutron capture and photodisintegration cross sections for the s-, r-, and p-process nucleosynthesis of heavy elements. Photonuclear reactions that play a primary role in the p-process nucleosynthesis can take place on excited states in stars that are in thermal equilibrium with the ground state. Since GRD is built on excited states as well as on the ground state [1], the γ strength function near, both above and below, the neutron separation energy (S_n), is a key ingredient in (γ,n) reactions [2,3]. On the other hand, in (n,γ) reactions, the γ-decay process of compound nuclear states populated just above S_n by neutron capture is very sensitive to both γSF and NLD below S_n. Recently the nuclear statistical quantities near S_n have been experimentally investigated in the photoneutron channel with quasi-monochromatic γ rays produced in laser inverse Compton-scattering at the National Institute of Advanced Industrial Science and Technology (AIST) in Japan. I present results of our recent investigations of γSF with multipolarity E1 for ^{181}Ta [4] and M1 for zirconium isotopes (^{91,92,94}Zr) [5] and of NLD for the only naturally-occurring isomer ^{180}Ta$^{\mathrm{m}}$ [6].

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Peter von Neumann-Cosel

(pdf, ppt, wmv, mp4)

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Level densities and γ strength functionsfrom the fine structure of giant resonances

High-resolution experiments performed with a variety of probes show that giant resonances generally exhibit fine structure. I will discuss methods to derive spin- and parity-resolved level densities from this fine structure by means of a combination of a wavelet analysis and a fluctuation analysis. These results allow, for example, to test recent theoretical claims of a parity dependence of level densities in the fp-shell region. Recent experiments demonstrate that intermediate-energy inelastic proton scattering may serve as a tool to study the complete E1 upward γ strength function from the low-energy region across the GDR. Such data would be important to understand the nature of resonance-like structures of the E1 strength distribution at energies below the GDR. First results from an experiment on ^{208}Pb are reported.

Sotirios V. Harissopulos

(pdf, ppt, wmv, mp4)

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Capture reactions relevant to p-process nucleosynthesis

The origin in the cosmos of the so-called p nuclei is one of the most puzzling problems to be solved by any model of heavy-element nucleosynthesis. The class of p nuclei consists of 35 proton-rich stable nuclei that are heavier than iron and cannot be synthesized by the two neutron-capture processes referred to as s and r process. To date, these nuclei have been observed only in the solar system. The reproduction of p-nuclei abundances on the basis of astrophysical processes occurring outside the solar system such as exploding supernovae (SNII) or He-accreting white dwarves with sub-Chandrasekhar mass, will enable us not only to understand the nuclidic composition of the solar system but also to further elucidate our fundamental picture of its creation.

So far, all the models of p-process nucleosynthesis are able to reproduce most of the p-nuclei abundances within a factor of 3, but they fail completely in the case of the light p nuclei. Due to the huge number of reactions involved in abundance calculations, the latter have to rely almost completely on the reaction cross-section predictions of the Hauser-Feshbach (HF) theory. It is therefore of key importance, on top of any astrophysical model improvements, to investigate the uncertainties in the nuclear data, and in particular in the nuclear level densities (NLD), nucleon-nucleus optical model potentials (OMP), and γ-ray strength functions entering the HF calculations.

In view of these problems, we have performed several in-beam cross sections measurements of proton- as well as α-capture reactions in the Ni-Sb region at energies well below the Coulomb barrier. Our aim is to contribute to a cross-section database relevant to the modeling of the p process and to obtain global input parameters for HF calculations. This contribution reports on 25 (p,γ) and 10 (α, γ) reactions. Our results, as well as all other existing data, are compared with HF calculations using various microscopic and phenomenological models of the nuclear input (NLD, OMP). Several aspects of all the experiments performed so far, as well as plans for additional measurements, also in inverse kinematics, are presented. Finally, the question of whether there is sufficient experimental information to put constraints on the theory and draw final conclusions is discussed.

Artemisia Spyrou

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Measuring reaction cross sections to understand the p-process

The production of the so-called p nuclei is still one of the puzzles of stellar nucleosynthesis. The existing astrophysical models can reproduce the abundances of the heavy p-nuclei fairly well. For the light ones, however, the discrepancies can be even higher than one order of magnitude. Such abundance calculations include, together with the description of the astrophysical environment, a nuclear reaction network that consists of more than 20000 nuclear reactions. Since the cross sections of all these reactions are not known experimentally, one has to rely on theoretical calculations, using the Hauser- Feshbach (HF) theory. The input parameters used in these calculations (such as the Nuclear Level Densities and the Optical Model Potential) need to be optimized using experimental results. In this direction, we have performed cross section measurements of proton and α particle capture reactions using three different techniques: the activation technique, γ-ray angular distributions and the 4π γ-summing method. In this contribution, results form our systematic work will be presented. Our results, as well as other existing data are compared with HF calculations using various models to describe the nuclear input parameters.

Magne Guttormsen

(pdf, ppt, wmv, mp4)

SAFE, Department of Physics, University of Oslo, Norway

Nuclear level density and its thermodynamical interpretation

The Oslo nuclear physics group has developed a method to extract nuclear level density from particle-γ coincidences. The experiments are performed with light-particle inelastic or transfer reactions. The charged ejectile enable tagging the γ-ray spectra with excitation energies from the ground state up to the neutron (or proton) binding energy.

The method will be explained to some detail, and the entropies as function of excitation energy will be presented for nuclei in various mass regions. The thermal motion of single particles represents the largest contribution to nuclear entropy and is essential for the description. It will be shown that the entropy is approximately extensive (additive) for mid-shell nuclei. Various applications of thermodynamics in warm nuclei will be discussed.

Ann-Cecilie Larsen

(pdf, ppt, wmv, mp4)

SAFE, Department of Physics, University of Oslo, Norway

Gamma-ray strength functions measured at OCL

Through the last decade, the Oslo method has proven its robustness and reliability for extracting nuclear level densities and γ-ray strength functions below the neutron separation energy. In this presentation, I will give a brief overview of the results on the γ-ray strength functions. The main part of the talk will be devoted to the most recent findings of the Oslo group, in particular the low-energy enhancement observed in medium-mass nuclei, and the pygmy resonance seen in tin isotopes.

Alexander V. Voinov

(pdf, ppt, wmv, mp4)

S.M. Grimes, C.R. Brune, T.N. Massey, B.M. Oginni, and A. Schiller

Ohio University, Athens, OH-45701, USA

Experimental study of level density and γ-strength functions at Edwards Accelerator Laboratory

An overview of an experimental technique used at Edwards Accelerator Laboratory and latest results on nuclear level density and γ-strength functions will be presented. The level density is obtained from particle spectra of compound nuclear reactions. The excitation energy dependence of level density for nuclear in the mass range $A \sim 50$–60 has been obtained and compared to model calculations. The problem of the constant temperature versus Fermi-gas models has been studied as well. The γ-strength function of ^{60}Ni below the particle separation threshold has been investigated from the $^{60}\mathrm{Co}(\mathrm{p}, 2\gamma)^{60}\mathrm{Ni}$ reaction. Results will be presented.

Sunniva Siem

(pdf, ppt, wmv, mp4)

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A. Schiller and A. Voinov

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Experimental level densities and radiative strength functions in rare earth nuclei

The level density and radiative strength function (RSF) are fundamental nuclear properties and provide information on the nuclear structural properties of the nucleus. The Oslo group has developed a technique to extract simultaneously the level density and radiative strength function from the primary γ-spectra from different initial excitation energies. I will present results from experiments carried out at the Oslo Cyclotron Laboratory, focusing the Sm and Dy isotopes. As one approaches the closed N=82 neutron shell, the structures in the level density become more pronounced due to shell effects. A pygmy resonance at around 3 MeV has been observed in several deformed rare earth nuclei and vanishes for the spherical Sm nuclei when approaching the N=82 closed shell. This is as expected for a scissors mode (M1 multipolarity) pygmy resonance. The width of the pygmy resonance observed for Dy isotopes in the Oslo experiments are about twice as wide as the width found by the Prague group when analyzing two-step cascades from neutron capture experiments. Further investigations into the possible spin dependence of the width of the pygmy resonance are in progress. Another unexpected result is that the strength function of 163Dy and ^{164}Dy are best fitted by using two pygmy resonances. The origin of the second resonance is not yet understood.

Ronald C. Johnson

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Transfer reactions with deuterons

Deuteron stripping and pick-up reactions are one of the most important sources of information of the way single particle strength and angular momentum quantum number are distributed among states of a given nucleus and over the periodic table. Modern studies seek to obtain this information for exotic nuclei near the drip lines. This may involve experiments in inverse kinematics. Credible reaction theories must be developed if reliable nuclear structure information is to result. I will discuss a theory that goes beyond the traditional DWBA and give an improved account of transfer experiments but involves fewer optical model parameters than DWBA and hence give less ambiguous nuclear structure information. I will emphasize theoretical methods which lead to analyses which can be carried out with only small modification of existing codes. Some challenges to theory will also be discussed.

Robert Charity

(pdf, ppt, wmv, mp4)

Washington University, St. Louis, MO, USA

Learning about correlations with the dispersive optical model and their relevance to the level density in neutron-rich systems

Information on correlations in nuclei is contained in the nucleon self energy. This self energy can be approximated by the optical-model potential if the dispersion relationships between the real and imaginary potentials are enforced. A recent dispersive-optical-model analysis of proton elastic-scattering and bound-state data for Ca isotopes indicates that proton long-range correlations (associated with coupling to collective modes) increase with neutron richness. The dependence of the neutron correlations is not clear at present. These correlations give rise to a compression of the energies of the single-particle levels near the Fermi surface and thus are important in determining the level- density parameter. The possible proton-neutron asymmetry dependences of the level-density parameter due to this effect are discussed.

Dorel Bucurescu

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T. von Egidy

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Nuclear level densities and spin distributions

The exponential increase of the nuclear level density $\rho(E, J)$ can be described by the Back-Shifted Fermi Gas formula (BSFG) with the two free parameters a and E_1, or by the Constant Temperature formula (CT) with the parameters T and E_0. A formula for the spin distribution $f(J)$ has to be also included: $\rho(E, J) = f(J)\rho(E)$.
We have empirically determined the two level density parameters for 310 nuclei between ^{19}F and ^{251}Cf, by fitting them to the known individual levels in a given energy and spin range at low excitation energies and the neutron resonance density at the neutron binding energy. We present briefly these results (Ref. [1]) for the empirical parameters, which were described by formulas that can be calculated by using only ground state mass tables. Thus one can calculate level densities up to the neutron binding energy in nuclei where experimental values are not available.
Experimental information for the spin distribution are rather scarce; we have used the data set of the low-energy level schemes of 310 nuclei (more than 8000 levels with their spin) to study the spin distribution

$$f(J) = e^{-\frac{J}{2\sigma^2}} - e^{-\frac{(J+1)}{2\sigma^2}}.$$

The spin cut-off parameter σ is predicted to depend on the moment of inertia, mass A, nuclear temperature T, but its dependencies on these quantities are not well known. Since we investigated only low-energy level schemes (complete data were available only below 2–3 MeV), no energy dependence was assumed for σ^2. The result of the fits is that σ^2 depends only weakly on A, and is practically independent of a, T, and nuclear deformation:

$$\sigma^2 = 2.61(21)\, A^{0.29(3)},$$

the two parameters varying weakly if one fits separately even-even, odd, and odd-odd nuclei. There is also a strong even-odd spin staggering in the **even-even** nuclei, which was managed in the following *ad-hoc* way:

$$f_{ee}(J) = \left(e^{-\frac{J^2}{2\sigma^2}} - e^{-\frac{(J+1)^2}{2\sigma^2}}\right)(1 + x)$$

$$x = \begin{cases} +0.227(14) & \text{for even spin levels} \\ -0.227(14) & \text{for odd spin levels} \\ +1.02(9) & \text{for spin 0 levels} \end{cases} .$$

Thus, σ^2 is found to vary surprisingly little from light to heavy nuclei, only from about 7 to 12, with an average value around 9.

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Olof Henrik Uhrenholt

(pdf, ppt, wmv, mp4)

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Microscopic collective enhancements in the combinatorial nuclear level density model

The combinatorial level density model is a way to go beyond the statistical models of Fermi-gas type and include nuclear structure effects into the level density.

We suggest a fully microscopic method to take into account collective enhancements within the combinatorial nuclear level density model starting from a deformed mean field potential. The collective effects include pairing interaction, rotational and vibrational states which are all treated microscopically and counted combinatorially while keeping track of the parity and angular momentum quantum numbers. The tracking of these quantum numbers lead to microscopic parity and angular momentum distributions. The model is compared to available experimental data and the role of asymmetric parity distribution in astrophysical application is discussed.

With no adjustable parameters the model gives satisfactory results when compared to experimental data from neutron resonances in the RIPL-2 database and rare-earth nuclei measured by the Oslo method.

Oliver Wieland

(pdf, ppt, wmv, mp4)

INFN Section of Milan, Italy

The γ decay of nuclei under extreme conditions

The measurements of the γ decay from the giant dipole resonance (GDR) at high temperature and far from stability is used to obtain information on the properties of the nucleus.

At first the study of the temperature dependence of the GDR width with exclusive measurements of γ-decay following fusion reactions will be presented. Results concerning the mass region A=130 obtained in experiments at the INFN laboratory LNL (Italy) will be discussed. An increase of the GDR-width mainly due to thermal fluctuations has been obtained up to approximately T=4 MeV. Entrance channel effects will be discussed.

In the second part collective modes far from stability will be shortly discussed. The subject is the search for the pygmy resonance in ^{68}Ni using Coulomb excitation at 600 A MeV with the RISING array at GSI (Germany). A ^{68}Ni beam was produced from the fragmentation of ^{86}Kr at 900 A MeV from the UNILAC-SIS on a ^{9}Be target and selected with the Fragment Separator (FRS). The decay of Coulomb excited ^{68}Ni isotopes were measured in BaF_2 and HPGe detectors under forward and backward angles. A peak at approximately 11-MeV was observed. This is the first measurement with radioactive beams of the γ decay of the Pygmy Resonance for nuclei in this mass region.

Ronald Schwengner

(pdf, ppt, wmv, mp4)

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Gamma-ray strength function measurements at ELBE

Dipole-strength functions up to the neutron-separation energies S_n of the N=50 isotones ^{88}Sr, ^{89}Y, ^{90}Zr and the even-mass Mo isotopes from ^{92}Mo to ^{100}Mo have been studied in photon-scattering experiments using the bremsstrahlung facility at the superconducting electron accelerator ELBE of the Forschungszentrum Dresden-Rossendorf.

To estimate the distribution of inelastic transitions from high-lying levels at high level density to low-lying levels, simulations of γ-ray cascades were performed. On the basis of these simulations intensities of inelastic transitions were subtracted from the experimental intensity distributions, including the resolved peaks as well as a continuous part formed by unresolved transitions, and the intensities of elastic transitions to the ground state were corrected for their branching ratios.

The photoabsorption cross sections obtained in this way connect smoothly to (γ, n) data. The combination of our (γ, γ') data with (γ, n) data gives novel information about the dipole-strength functions in the whole energy range from about 4 MeV up to the giant dipole resonance (GDR).

They show that

1. there is extra strength in the energy range from about 6 to about 12 MeV with respect to simple Lorentzian-like approximations of the tail of the GDR,

2. the accumulated dipole-strength in the energy range from about 6 to 12 MeV grows with increasing neutron number in the chain of Mo isotopes.

Calculations in the framework of a quasiparticle-random-phase approximation (QRPA) in a deformed Woods-Saxon basis describe the increase of strength towards the heavier Mo isotopes as a consequence of growing nuclear deformation.

Milan Krticka

(pdf, ppt, wmv, mp4)

Charles University, Prague, Czech Republic, and North Carolina State University, Raleigh, NC

The two-step γ cascade method as a tool for studying γ-ray strength functions

The method of two step γ cascades following the thermal neutron capture together with the interpretation of experimental data in medium-weight and heavy nuclei using the DICEBOX algorithm will be described.

Paul Koehler

(pdf, ppt, wmv, mp4)

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Two new techniques for determining spins and parities of neutron resonances, and the search for non-statistical effects in neutron capture

We have developed two new techniques for determining J^π values for neutron resonances, especially for odd-A samples. Resonance J^π values for these nuclides typically have been sketchy, although they can be vital for the full evaluation of reported non-statistical effects. Both methods make use of information contained in the γ-ray cascade following neutron capture. First, using the 4π BaF_2 detector DANCE at LANSCE, we developed a new technique which employed two different linear combinations of γ-ray multiplicities to determine which of the two possible s-wave spins could be assigned to each resonance. Our first measurements [1], with a ^{147}Sm sample, allowed us to determine spins of almost all known resonances below 1 keV. Furthermore, analysis of these data revealed that the reduced-neutron-width (Γ_n^0) distribution was in good agreement with the expected Porter-Thomas (PT) distribution for resonances below 350 eV, but in sharp disagreement with PT for resonances between 350 and 700 eV. Our previous (n,α) measurements [2] had revealed that the α strength function also changes abruptly at this energy. There currently is no known explanation for these two non-statistical effects as well as other reports of deviations from a PT distribution for other odd-A nuclides [3]. Second, very recently we have developed another new method for determining the spins of neutron resonances. To implement this technique required a small change to a much simpler apparatus: A pair of C_6D_6 γ-ray detectors which we have employed for many years to measure neutron-capture cross sections at ORELA. First measurements with a ^{95}Mo sample revealed that not only does the method work very well for determining spins, but it also makes possible parity assignments. Furthermore, part of the new technique does not require a change in our apparatus and, therefore, can be applied retroactively to our previous data taken on many other nuclides. Taken together, the new techniques at LANSCE and ORELA should make possible J^π assignments for many more neutron resonances, especially for odd-A nuclides. New measurements using these methods could be very useful for further elucidation of non-statistical effects. This work was supported in part by the U.S. Department of Energy under Contract No. DEAC05-00OR22725 with UT-Battelle, LLC.

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Rebecca Surman

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Aspects of the astrophysics and nuclear physics of r-process nucleosynthesis

While many aspects of r-process nucleosynthesis are well understood, considerable uncertainties remain, both in the astrophysical site and in the nuclear physics of the thousands of unstable nuclei that participate. The most favored astrophysical site is within a core collapse supernova, though difficulties with this environment persist; here we discuss an alternate or additional site – hot accretion disk outflows from a black hole-neutron star merger. On the nuclear physics side, the importance of experimental data for and reliable theoretical estimates of nuclear masses and β-decay rates has long been recognized, while neutron capture rates have so far received less attention. Here we discuss how individual neutron capture rates of nuclei near the A=130 peak can impact the r-process abundance pattern.

Babatunde Moses Oginni

(pdf, ppt, wmv, mp4)

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Test of level density models from reactions of ^{6}Li on ^{58}Fe and ^{7}Li on ^{57}Fe

The reactions ^{6}Li on ^{58}Fe and ^{7}Li on ^{57}Fe have been studied; these two reactions give the same compound nucleus, ^{64}Cu. The charged particle spectra were measured at the backward angles, and the level densities of the residual nuclei have been obtained. The breakup mechanism of the Lithium beam has been studied. The data obtained have been compared with Hauser Feshbach model calculations performed with the HF and Empire codes. We also give insight into how level densities change as we move away from the nuclear stability line. Three reactions have been studied to look at this. These are: ^{18}O on ^{64}Ni reaction, this gives ^{82}Kr as compound nucleus which is on the stability line; ^{24}Mg on ^{58}Fe, this gives ^{82}Sr as compound nucleus, and ^{24}Mg on 58Ni which gives ^{82}Zr as compound nucleus; these are two and four steps away from the stability line respectively. Some results are presented.

Yoram Alhassid

(pdf, ppt, wmv, mp4)

Center for Theoretical Physics, Sloane Physics Laboratory, Yale University, New Haven, CT 06520, USA

Statistical properties of nuclei: beyond the mean field

Correlations beyond the mean field are important in the microscopic calculations of nuclear statistical properties. Such correlations can be accounted for by considering fluctuations around the mean field. The static path approximation (SPA) takes into account static fluctuations only while the auxiliary field Monte Carlo (AFMC) method includes all fluctuations. We use SPA and AFMC methods in the framework of the interacting nuclear shell model [the latter is also known as shell model Monte Carlo (SMMC)], to calculate the statistical properties of nuclei at finite temperature and/or excitation energies [1-7]. With this approach we can carry out realistic calculations in model spaces that are many orders of magnitude larger than spaces that can be treated with conventional diagonalization methods. A major application of the methods has been the microscopic calculation of partition functions, level densities and thermodynamic properties. The SMMC method has been applied successfully to medium-mass nuclei ($A \sim 50 - 70$) [1-5] and, more recently, to heavy deformed nuclei [6]. The results are in good agreement with experiments. The shell model theory of level statistics was extended to higher temperatures (including continuum effects) [4], and the dependence on good quantum numbers such as parity [1,3] and angular momentum [5] is determined by exact projection methods. Simple statistical models based on the SPA and number-parity projection have been introduced to explain the microscopic results for the angular momentum [7] and parity [8] distributions.

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Shell model Monte Carlo approach to level densities of heavy deformed nuclei

The microscopic calculation of nuclear level densities requires the inclusion of both shell effects and collective two-body correlations. The shell model Monte Carlo (SMMC) method [1,2] has

been applied successfully to carry out such calculations in medium-mass nuclei [3-5].
We have recently extended the SMMC approach to calculate level densities of heavy deformed nuclei [6]. In this talk I shall present results for the well-deformed even-even rare-earth nucleus ^{162}Dy. The spherical single-particle basis is chosen to include the 50–82 shell plus $1f_{7/2}$ for protons, and the 82–126 shell plus $0h_{11/2}$, $1g_{9/2}$ for neutrons. This is the largest SMMC calculation to date. The effective two-body interaction consists of the monopole pairing and the quadrupole, octupole, and hexadecupole multipole- multipole interaction terms. This effective interaction has a good Monte Carlo sign, yet is sufficiently realistic for level density calculations. The application of SMMC to heavy nuclei has required several technical developments: (i) extension of the SMMC approach to the proton-neutron formalism, (ii) implementation of a stabilization method at low temperatures [7] in the framework of the canonical ensemble, (iii) accounting for discretization corrections in the imaginary time step.
We have calculated the state density of ^{162}Dy in the saddle-point approximation [3], and found it to be in excellent agreement with the experimental level density. The latter was extracted using level counting (below excitation energy of ~ 2 MeV), neutron resonance point and the Oslo data [8-13]. We also find the SMMC state density to be strongly enhanced in comparison with the state density calculated in the finite-temperature Hartree-Fock-Bogolyubov approximation, because of the collective rotational motion. We confirm that the rotational character of ^{162}Dy and that its ground-state moment of inertia are well reproduced within the above model space.

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Level densities in the shell model Monte Carlo method: parity dependence and rare-earth nuclei

We study parity distribution of shell-model Monte Carlo level densities in medium-mass region and in particular investigate the interplay of shell effects and two-body correlations in the equilibration of level densities of opposite parities [1,2].
Recently shell-model Monte Carlo method formulated in a new proton-neutron formalism was applied to the study of even-even rare-earth nucleus, ^{162}Dy [3]. We extend the application of the method in this region to calculate the total level densities of odd-even ^{161}Dy and odd-odd ^{160}Tb nuclei. The computational challenge in such nuclei is a sign problem that originates in the projection on an odd number of particles. The results are then compared with experimental level densities extracted from available data [4].

[1] C. Özen, K. Langanke, G. Martinez-Pinedo and D. J. Dean, Phys. Rev. C **75**, 064307 (2007).
[2] Y. Kalmykov, C. Özen, K. Langanke, G. Martinez-Pinedo, P. von Neumann-Cosel and A. Richter, Phys. Rev. Lett. **99**, 202502 (2007). [3] Y. Alhassid, L. Fang and H. Nakada, arXiv:0710.1656.
[4] C. Özen, Y. Alhassid and H. Nakada, *in preparation.*

Jürgen Gerl

(pdf, ppt, wmv, mp4)
Gesellschaft für Schwerionenforschung, Darmstadt, Germany

Nuclear structure studies using fast radioactive beams

Nuclear spectroscopy using radioactive isotope beams requires dedicated set-ups. State-of-the-art Ge arrays recently started to provide valuable γ

spectroscopic data. At the SIS/FRS facility at GSI exotic beams at relativistic energies (100 – 400 A MeV) were employed for Coulomb excitation and secondary fragmentation experiments with the fast beam RISING set-up. Beams of radioactive isotopes were produced by fragmentation or fission of heavy stable nuclei on a production target. Isotopes of interest were selected and identified ion by ion in mass and charge. In addition position and direction tracking was performed. After the secondary target the scattering angle, charge and total energy of projectile-like fragments was determined. Euroball Cluster detectors forming a forward wall were employed to measure γ rays emitted in secondary reactions.
Coulomb excitation at relativistic energies provides a unique possibility to excite collective nuclear levels from the first excited state up to giant resonances. Selected examples from ^{68}Ni to ^{136}Nd investigated in the fast RISING experimental campaign will be presented to demonstrate the power, the limitations and the perspectives of this new method.

Takashi Nakamura

(pdf, ppt, wmv, mp4)

Tokyo Institute of Technology, Japan

E1 strength distribution of halo nuclei observed via the Coulomb breakup

One of the unique features of halo nuclei is the large E1 strength which appears at low excitation energies (soft E1 excitation). In this talk, we present experimental results of Coulomb breakup of halo nuclei, and discuss the observed B(E1) distributions. Here I would like to focus on ^{11}Li, which is composed of ^{9}Li surrounded by two halo neutrons. By using the analysis to disentangle two neutrons emitted at very forward angles, we could precisely determine the E1 strength distribution of ^{11}Li down to very low relative energies for the first time. The B(E1) spectrum showed a strong peak at the excitation energy of about 600 keV with the integrated strengths of 4.5(6) W.u. below the relative energy of 3 MeV. The extracted large E1 strength has been interpreted as a manifestation of two-neutron spatial correlation in ^{11}Li. We also discuss the possible other two-body correlation in ^{11}Li by applying further detailed analysis of three-body breakup.

[1] T. Nakamura *et al.*, Phys. Rev. Lett. **96**, 252502 (2006).

Gary E. Mitchell

(pdf, ppt, wmv, mp4)

North Carolina State University, Raleigh, NC 27695, USA and
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Purity and completeness – issues for nuclear resonances

The most common way to determine nuclear level densities is by direct counting of nuclear resonances. Difficulties arise because the resonance data are impure (quantum numbers are not assigned for some resonances) and/or incomplete (some levels are missed). We report new approaches to these issues. For neutrons on targets with spin, we utilize the high segmentation of the DANCE array to determine spins and parities. For the missing level issue, the standard method assumes the Porter-Thomas distribution and analyzes the strength distribution to determine the missing fraction. Although generally successful, this method is sensitive to non-statistical effects. We have developed a new method to determine the missing level fraction that analyzes the spacing distributions and is insensitive to non-statistical effects.

Robert C. Haight

(pdf, ppt, wmv, mp4)

Los Alamos Neutron Science Center, Los Alamos National Laboratory, Los Alamos, NM 87544, USA

Statistical neutron-induced reactions studied by neutron, proton, and α-particle emission

At the LANSCE spallation neutron source, we are measuring (n,xn), (n,xp), (n,xα) and (n,fission + xn) emission cross sections, angular distributions and spectra. Because the neutron source is continuous in energy, excitation functions can be measured in one experiment from threshold to tens of MeV to test statistical reaction models. The present capabilities will be described briefly. Examples of data for each of these reactions will be presented to illustrate the capabilities of the approaches and the complementarities of the data obtained. Reactions on targets near A$\sim$56 will be discussed in more detail.

Roberto Capote Noy

(pdf, ppt, wmv, mp4)

International Atomic Energy Agency, Vienna, Austria

IAEA nuclear data: the Reference Input Parameter Library (RIPL) for nuclear reaction calculations

Extensive efforts have been instigated to develop a library of validated nuclear-model input parameters, referred to as the Reference Input Parameter Library (RIPL). A consistent library of recommended nuclear input parameters is now available (http://www-nds.iaea.org/RIPL-2/) that includes a large amount of theoretical information suitable for nuclear reaction calculations, along with a number of computer codes for parameter retrieval and related calculations. A third phase of this project designed to update and extend the current database is close to be finished. Several nuclear data needs have been addressed: emerging nuclear technologies that require model parameters for the calculation of nuclear reactions; energy and non-energy applications such as advanced reactors, accelerator-driven waste incineration, production of radioisotopes for therapy and diagnostics, charged-particle beam therapy, and materials analysis. There is also a worldwide interest in nuclear astrophysics, which is constrained to rely on theoretical calculations of nuclear reaction cross-sections to model the distribution of isotopes in the universe.

A review of latest developments for the RIPL-3 database will be presented. New optical model potentials (OMP) developed for nucleon-induced reactions on deformed nuclei using a coupled-channel approach and for deuteron- and α-induced reactions have been added to the database. The discrete level database was updated using latest ENSDF release (Sept. 2007). The RIPL-2 resonance data was reviewed and updated to consider latest evaluations. Phenomenological level density (LD) parameterizations and semi-microscopic HFB LDs were refitted to the recommended resonance data and discrete level schemes. There has been an active work on the fission parameters – HFB LDs at saddles and HFB fission barriers have been derived for all potentially fissile nuclei; actinide fission cross-section calculations (using calculated HFB barriers and LDs) were implemented in EMPIRE and TALYS nuclear reaction codes. Finally, uncertainties of OMP, LD and fission parameters were assessed.

Toshihiko Kawano

(pdf, ppt, wmv, mp4)

Los Alamos National Laboratory, NM, USA

Statistical model calculations for neutron radiative capture process

Statistical nuclear reaction theories have been widely applied to calculate nuclear reaction rates for astrophysics, especially neutron capture rate for nucleo-synthesis, together with the direct/semidirect (DSD) process. Although the statistical Hauser-Feshbach theory with width fluctuation correction gives fairly good excitation functions of neutron capture cross sections in the energy range of astrophysical interests, the accuracy of predicted absolute values is not satisfactory, and the calculations are often adjusted to experimental data available. There are several possible reasons of this; the γ-ray transmission coefficient is obtained by assuming a detailed balance exploiting the inverse photo-absorption and a simple Brink-Axel hypothesis, the total neutron absorption cross sections (partial wave transmission coefficients) in the tens of keV region are strongly affected by a nuclear deformation, uncertainties in the model parameters such as the level density, optical model potential, and so on. In this talk we summarize our recent developments in the neutron capture modeling. We calculate the neutron radiative capture cross sections on deformed nuclei based on the coupled-channels Hauser-Feshbach method with the width fluctuation correction. Sensitivities of the model parameters are also discussed.

Anna Hayes

(pdf, ppt, wmv, mp4)

Los Alamos National Laboratory, NM, USA

Statistical spectroscopy for fundamental physics, applied science, and national security

Nuclear level densities provide crucial information for a number of processes ranging from fundamental physics to national security. In this talk I will review examples from several areas including parity violation, stockpile stewardship, nuclear energy, nuclear forensics, and the National Ignition Facility.

Marco Pigni

(pdf, ppt, wmv, mp4)

Brookhaven National Laboratory, Upton, NY, USA

Predicting cross section uncertainties for neutron-nucleus scattering

Distinct maxima and minima in the neutron total cross section uncertainties were observed in our large scale covariance calculations using spherical optical potentials. In this contribution we investigate physical origin of this oscillating structure. Specifically, we analyze the case of neutron reactions on ^{56}Fe, for which total cross section uncertainties are characterized by the presence of three distinct minima at 0.1, 1.1, and 5 MeV. To investigate their origin, we calculated total cross sections perturbing the real volume depth Vv by its expected uncertainty +/- DVv. Inspecting the effect of this perturbation on the partial wave cross sections we found that the first minimum (at 0.1 MeV) is exclusively due to the contribution of the s-wave. On the other hand, the same analysis at 1.1 MeV showed that the minimum is the result of the interplay between s-, p-, and d-waves; namely the change in the s-wave happens to be counterbalanced by changes in the p- and d-waves. The third minimum (at 5 MeV) can be explained in terms of the Ramsauer model. We discuss the potential importance of these minima for practical applications as well as the implications of this work for the uncertainties in nonelastic cross sections.

Calvin Johnson

(pdf, ppt, wmv, mp4)

San Diego State University, CA, USA

Moment methods for modeling nuclear level densities

Moments methods are a potentially efficient approach to extracting the level density from a microscopic nuclear Hamiltonian. I will discuss the advantages and disadvantages of such an approach and give some examples.

René Reifarth

(pdf, ppt, wmv, mp4)

Gesellschaft für Schwerionenforschung, Darmstadt, Germany

Recent neutron capture measurements at FZK

The main focus of recent neutron capture measurements at the Karlsruhe Van de Graaff accelerator were activation measurements on nuclei in the mass range between A=56 and A=90, which is most important for the weak component of the s process taking place in massive stars. I will present selected results, a comparison with other measurements as well as with model calculations, and a discussion of the astrophysical impact. Finally I will present the current status of FRANZ, the planned neutron facility at the Goethe University Frankfurt.

Richard Cyburt

(pdf, ppt, avi, wmv, mp4)

National Superconducting Cyclotron Laboratory Michigan State University, East Lansing, MI

Impact of nuclear input on X-ray bursts

The thermonuclear explosions on the surfaces of accreting neutron stars are some of the brightest stellar X-ray sources in the sky. These X-ray bursts display a wide range a variability, ranging from milliseconds to months and years. The bursts themselves are governed by the underlying nuclear physics input and the X-ray binary properties. I will discuss how changing the nuclear input affects these Type I X-ray bursts and where continued experimental and theoretical research is most beneficial. One goal of this research is to reduce nuclear uncertainties to the point that we can learn more about the physics of neutron stars and X-ray binaries.

Richard N. Boyd

(pdf, ppt, wmv, mp4)

Lawrence Livermore National Laboratory, CA, USA

Performing nuclear astrophysics experiments at the National Ignition Facility

The National Ignition Facility, when completed in 2009, will be the world's largest laser. As such it is expected to compress a pellet of ^{2}H and ^{3}H to a temperature and density that will produce ignition and energy gain. The temperature and density that NIF is expected to achieve are in excess of 100×10^6 K and $1000\,\mathrm{g\,cm^{-3}}$, both seven times their values at the core of the Sun. NIF also plans to encourage programs in basic research, with nuclear astrophysics being part of that program. This talk will describe the basic operation of NIF, then will discuss the motivation and some details of several nuclear astrophysics experiments that might be conducted at NIF.

Micah Johnson

(pdf, ppt, wmv, mp4)

Lawrence Livermore National Laboratory, CA

Using nuclear resonance fluorescence to isotopically map containers

Nuclear Resonance Fluorescence (NRF) has been used to probe collective excitations in deformed rare-earth and actinide nuclei. Two collective modes have been established below 3 MeV, magnetic dipole excitations and octupole-quadrupole excitations. We will present research at LLNL to develop systems, based on NRF, to excite collective modes in materials to map their distribution in various containers. Recent measurements of NRF states below 2.5 MeV in ^{239}Pu will be discussed.

* Part of this work was done in collaboration with Passport Systems Inc.
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Boris Zhuravlev

(pdf, ppt, wmv, mp4)

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Nuclear level densities near Z=50 from neutron evaporation spectra in (p,n) reactions

Neutron spectra and angular distributions in the (p,n) reactions on the isotopes of ^{116}Sn, ^{118}Sn, ^{122}Sn, ^{124}Sn, have been measured in the proton energy range of (7-11) MeV. The measurements were performed by the time-of-flight fast neutron spectrometer on the pulsed tandem accelerator EGP-15 of IPPE. A high resolution (about 0.6 ns/m) and a stability of the time-of-flight spectrometer made it possible to identify reliably low- lying levels along with the continuum part of the neutron spectra. Analysis of the measured data have been carried out in the framework of statistical equilibrium and pre-equilibrium models of nuclear reactions. The calculations are done using the exact formalism of the statistical theory as given by Hauser- Feshbach. The nuclear level densities of ^{116}Sb, ^{118}Sb, ^{122}Sb, ^{124}Sb, their energy dependences and model parameters have been determined. In the excitation energy range of (0-2) MeV, the energy dependences of the nuclear level density exhibits a structure that is associated with the shell inhomogenities of a single-particle state spectrum for nuclei near filled shells. The isotopic dependence of the nuclear level density is found out. It is shown also that the obtained data differ essentially from the predictions of nuclear level density model systematics.

Shaleen Shukla

(pdf, ppt, wmv, mp4)

Ohio University, Athens, OH, USA

Calculation of nuclear level densities near the drip lines

Nuclear level densities are crucial inputs in the study of many physical processes spanning from astrophysics to nuclear medicine. The knowledge of nuclear level densities provides information about the internal structure of any nucleus, which determines the manner in which the nucleus participates in a physical process. This talk focuses on nuclear level densities for nuclei that exist away from the valley of stability.
The efforts to make these nuclei theoretically accessible involve a variety of theoretical and computational tools. Effective potentials and regular quantum mechanical methods have been used to compute the single particle excitation energies of a neutron or a proton inside a nucleus. These single particle energy levels are then used as inputs in rigorous many-body calculations that formulate the nucleus as a gas of Fermions.
The results reported in this talk show that nuclei near the drip lines can indeed be studied using the methods described here at least for $40 \leq A \leq 100$. Due to the lack of experimental data for such nuclei, a comparison of these results with experimental extractions was not possible at this time. In the near future, however, such comparisons will be made possible due to ongoing efforts at Ohio University and Yale University.

Vladimir Plujko

(pdf, ppt, wmv, mp4)

Taras Shevchenko National University, Kyiv, Ukraine

Closed-form E1 radiative strength functions for photoabsorption and γ-decay

The calculations of nuclear reaction ingredients within statistical approach are as a rule rather time consuming procedure and simple closed-form expressions are often used to estimate input parameters of the evaluations. In this contribution, different models of the dipole radiative strength functions (RSF) are discussed. Photoabsorption cross sections and isovector E1 γ-decay strength functions are calculated for the middle-weight and heavy atomic nuclei within the Lorentzian-type

models [1,2] with asymmetric and symmetric shapes. The theoretical calculations are compared with experimental data to test the RSF models.
A new ready-to-use table and systematic of the giant dipole resonance (GDR) parameters are obtained from fitting the theoretical calculations for photoabsorption cross sections to the experimental data. The errors of the GDR parameters are estimated too.
It is also shown that closed-form approaches with asymmetric shape of the RSF provide a unified and rather reliable simple method to estimate the dipole RSF both for γ-decay and for photoabsorption over a relatively wide energy interval ranging from zero to slightly above the GDR peak, at least, when GDR parameters are known or their systematics can be safely applied to. The modified Lorentzian approach, that is based on general relations between the RSF and the nuclear response function, can potentially lead to more reliable predictions among simple models. However, the energy dependence of the width is governed by complex mechanisms of nuclear dissipation and is still an open problem. Reliable experimental information is needed to better determine the temperature and energy dependence of the RSF, so that the contributions of the different mechanisms responsible for the damping of the collective states can be further investigated. This should help to discriminate between the various closed-form models describing the dipole RSF.

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[2] V. A. Plujko, I. M. Kadenko, E. V. Kulich, S. Goriely, O. I. Davidovskaya, O. M. Gorbachenko, in proceeding of Workshop on Photon Strength Functions and Related Topics, Prague, Czech Republic, June 17-20, 2007, Proceedings of Science, PSF07, 2008, and http://arxiv.org/abs/0802.2183 .