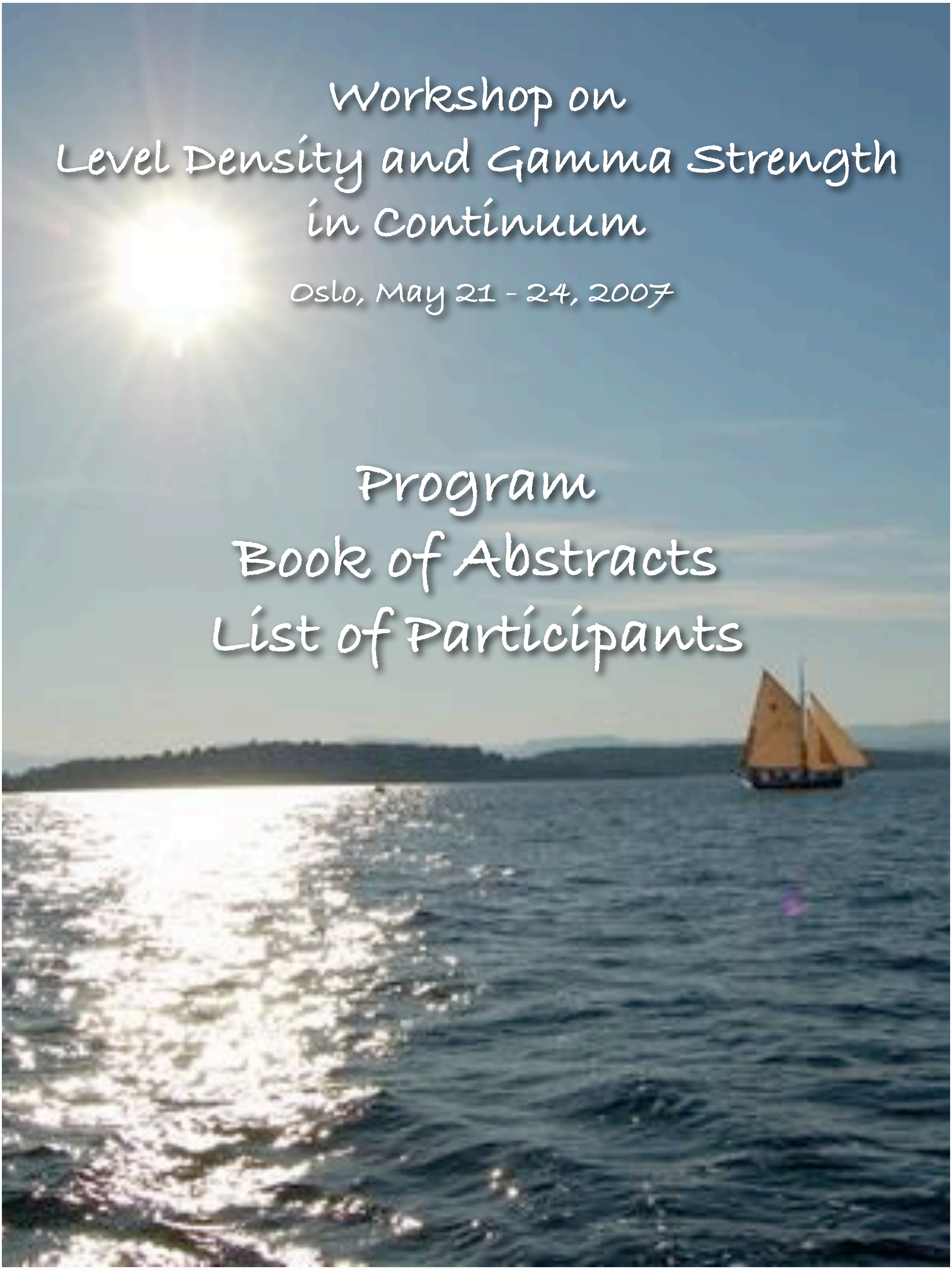
Workshop on Level Density and Gamma Strength in Continuum

Oslo, May 21 - 24, 2007



Program
Book of Abstracts
List of Participants

DEPARTMENT OF PHYSICS
UNIVERSITY OF OSLO

SAFE
Senter for Akseleratorbasert
Forskning og Energifysikk

NERLIENS
MESZANSKY

Program

Sunday May 20

19:00 – 21:00	*Registration and reception with wine and cheese* (*Location: Physics building, room FV139)*

Monday May 21

08:30 – 09:00	*Registration and coffee* (*Location: Physics building, outside room FV232, Lille Fy)*
09:00	**Welcome and opening of workshop** Sunniva Siem (chairman) and Pro-rector Haakon Breien Benestad
First session	*Chair: Eivind Osnes*
09:40	**Nuclear physics aspects of p-process nucleosynthesis** Sotirios Harrisopulos
10:20	**Continuous spectroscopy for nuclear structure and astrophysics: from stable to exotic nuclei** Andreas Schiller
11:00	*Coffee break*
Second session	*Chair: Lee Bernstein*
11:30	**Systematics of level density parameters** Till von Egidy
12:10	**Nuclear Level Densities** Steve Grimes
12:50	**Masses and fission barriers of atomic nuclei** Krzysztof Pomorski
13:30	*Lunch*
Third session	*Chair: Magne Guttormsen*
15:00	**Two-step cascade method** Frantisek Beckvar
15:40	**Neutron capture measurements with DANCE** Gary Mitchell
16:20	**Is there an enhancement of photon strength at low gamma-ray energies in Mo isotopes?** Milan Krticka
17:00	*End of day*
17:30	*Pizza and beer in Blindernkjelleren*

Tuesday May 22

08:30 – 09:00	*Coffee* (*Location: Physics building, outside room FV232, Lille Fy)*
First session	*Chair: Milan Krticka*
09:00	**Giant resonances, fine structure, wavelets and spin- and parity-resolved level densities** Achim Richter
09:40	**Properties of hot nuclei at extreme angular momenta** Adam Maj
10:20	**The giant dipole resonance, new measurements** Franco Camera
11:00	*Coffee break*
Second session	*Chair: Andreas Schiller*
11:30	**Superradiance effects, collectivity and chaos in the continuum** Vladimir Zelevinsky
12:10	**Particle-number conservation for pairing transition in finite systems** Kazunari Kaneko
12:50	**Theoretical predictions of effective GDR width at high spins from the thermal shape fluctuation model** Katarzyna Mazurek
13:30	*Lunch*
Third session	*Chair: Adam Maj*
15:00	**Strength distribution in the decay-out of SD bands** Araceli Lopez-Martens
15:40	**Landscapes and fluctuations of two-dimensional rotational spectra** Thomas Døssing
16:20	*Poster session*
17:00	*End of day*

Wednesday May 23

08:30 – 09:00	*Coffee* (*Location: Physics building, outside room FV232, Lille Fy)*
First session	*Chair: Thomas Døssing*
09:00	**Emergence of phase transitions with size** Stefan G. Frauendorf
09:40	**Phase transitions in nuclei and compact stars** Philippe Chomaz
10:20	**Quantum fluctuations of pairing in finite systems** Sven Åberg
11:00	*Coffee break*
Second session	*Chair: Sunniva Siem*
11:30	**Heat capacities of ^{56}Fe and ^{57}Fe** Emel Algin
12:10	**Level densities in closed shell nuclei** Naeem Ul Hasan Syed
12:50	**Experimental level densities and gamma-ray strength functions in the $f_{7/2}$ nuclei ^{44,45}Sc and ^{50,51}V** Ann-Cecilie Larsen
13:30	**The 3 MeV pygmy resonance in ^{163,164}Dy** Hilde Therese Nyhus
13:45	*Lunch*
Third session	*Chair: Gary Mitchell*
15:00	**Challenges on phase transitions and gamma strength functions** Magne Guttormsen
15:40	***Discussion on phase transitions*** ***Discussion on gamma strength functions***
17:00	*End of day*
20:00	*Workshop dinner at Holmenkollen Restaurant*

Thursday May 23

09:30 – 10:00	*Coffee* (*Location: Physics building, outside room FV232, Lille Fy)*
First session	*Chair: Sven Åberg*
10:00	**Shell model Monte Carlo approach to level densities: from medium-mass to heavy deformed nuclei** Yoram Alhassid
10:40	**Microscopic calculation of symmetry projected nuclear level densities** Kris Van Houcke
11:20	**Microcanonical level densities of non-magic nuclei** Robert Pezer
12:00	*Coffee break*
Second session	*Chair: Finn Ingebretsen*
12:30	**Nuclear physics in the continuum: surrogate reactions and nuclear physics using the national ignition facility** Lee Bernstein
13:10	**Structures in the continuum of light nuclei** Markus Norrby
13:50	*Concluding remarks by John Rekstad* *End of workshop*

All talks are to be held in the Physics building, room FV232 (Lille Fysiske Auditorium)

Abstracts

HEAT CAPACITIES OF ^{56}Fe AND ^{57}Fe

E. Algin[a], U. Agvaanluvsan[b,c,d], M. Guttormsen[e] G.E. Mitchell[b,c], J. Rekstad[e], A. Schiller[f], S. Siem[e], A. Voinov[g]

[a] *Dept. of Physics, Eskisehir Osmangazi University, Meselik, 26480, Eskisehir, Turkey*
[b] *North Carolina State University, Raleigh, NC-27695*
[c] *Triangle Universities Nuclear Laboratory, Durham, NC-27708*
[d] *Lawrence Livermore National Laboratory, L-414, Livermore, CA-94551*
[e] *Department of Physics, University of Oslo, N-0316 Oslo, Norway*
[f] *NSCL, Michigan State University, East Lansing, MI-48824*
[g] *Department of Physics and Astronomy, Ohio University, Athens, OH-45701*

Nuclear level densities for ^{56,57}Fe have been extracted from the primary γ-ray spectra using (^{3}He,^{3}He$'\gamma$) and (^{3}He,$\alpha\gamma$) reactions. From the experimental level densities, nuclear thermodynamic properties for ^{56}Fe and ^{57}Fe isotopes are extracted. These include entropy S, Helmholtz free energy F, caloric curves, i.e. $E-T$ relation, and heat capacity C_v. Experimental heat capacities are compared with Shell Model Monte Carlo calculations.

Shell model Monte Carlo approach to level densities: from medium-mass nuclei to heavy deformed nuclei

Yoram Alhassid

Center for Theoretical Physics, Sloane Physics Laboratory, Yale University, New Haven, Connecticut 06520, U.S.A.

We use shell model Monte Carlo (SMMC) methods in the framework of the interacting nuclear shell model to calculate level densities. 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. We used the SMMC approach to calculate level densities of medium-mass nuclei $A \sim 50 - 70$ [1,2]. Our microscopic calculations are in remarkably good agreement with experimental level densities without any adjustable parameters and are an improvement over empirical formulas.

In recent years there have been several major developments:

(i) We have extended the shell model theory of level statistics (including continuum) to higher temperatures [3]. In particular, we have found that the backshifted Bethe formula for level density is valid up to higher excitation energies than previously thought.

(ii) We have introduced spin projection methods in SMMC to calculate the energy dependence of the spin distribution of level densities [4,5].

(iii) Applications to heavy nuclei has been a major challenge. On the conceptual level, a crucial question is whether a truncated spherical shell model Hamiltonian can describe the rotational properties of deformed nuclei. On the technical level, the low excitation energies make it necessary to perform calculations down to much lower temperatures. We have recently calculated the SMMC level density and the moment of inertia of the ground-state rotational band for a well-deformed nucleus ^{162}Dy [6]. Both level density and moment of inertia are found to be in very good agreement with the experiments.

[1] H. Nakada and Y. Alhassid, Phys. Rev. Lett. **79**, 2939 (1997).
[2] Y. Alhassid, S. Liu and H. Nakada, Phys. Rev. Lett. **83**, 4265 (1999).
[3] Y. Alhassid, G.F. Bertsch, and L. Fang, Phys. Rev. C **68**, 044322 (2003).
[4] Y. Alhassid, G.F. Bertsch, L. Fang, and S. Liu, Phys. Rev. C **72**, 064326 (2005).
[5] Y. Alhassid, S. Liu and H. Nakada, arXiv: nucl-th/0607062.
[6] Y. Alhassid, L. Fang and H. Nakada, in preparation (2007).

The method of two-step γ cascades as a tool for studying photon strength functions of intermediate-weight and heavy nuclei

F. Bečvář,[1] M. Krtička,[1] J. Honzátko,[2] I. Tomandl,[2] and G. Rusev[3]

[1] *Charles University, V Holešovičkách 2, 180 00 Prague 8, Czech Republic*

[2] *Nuclear Physics Institute, 250 68 Řež, Prague, Czech Republic*

[3] *Forschungszentrum Dresden, Bautzner Landstrasse 128, Dresden D-01328, Germany*

Abstract

In 1958 A. M. Hoogenboom proposed the idea of sum-coincidence measurements. More than two decades ago a group at Dubna implemented this idea in experiments with coincidence setups incorporating HPGe detectors. Thanks to a high-enough HPGe resolution power this method could be successfully used in numerous measurements of spectra of two-step γ cascades (TSCs) following the capture of thermal neutrons. Later, the TSC method turned out to be an efficient tool for studying the γ decay of highly excited levels in medium-weight and heavy nuclei, in particular the decay of the levels with energies above 3 MeV. The data on TSCs feeding selected low-lying levels in deformed nuclei made it possible to establish that $M1$ resonances, embodying the scissors-like $M1$ isovector vibrational mode, are built not only on the ground states of these nuclei, but also on all excited levels, including the levels in the quasicontinuum. In addition, the TSC data have indicated that the $M1$ scissors mode as such displays, indeed, distinct and consistent resonance behaviour. In this contribution we summarize the results achieved with the TSC method. In view of the importance of TSC data for better understanding of the behaviour of the photon strength functions – the entities responsible for the γ decay – we undertook benchmark test measurements of spectra of TSCs following the thermal neutron capture in ^{56}Fe. The data obtained made it possible to determine the response functions of our sum-coincidence detector system to a set of well-pronounced γ cascades. These response functions are compared with detailed predictions following from GEANT simulations. The results of this comparison are reported and conclusions regarding the accuracy and reliability of the TSC method are drawn. Further perspectives of this method are outlined.

Nuclear Physics in the continuum: Surrogate reactions and Nuclear Physics using the National Ignition Facility

Lee A. Bernstein
Lawrence Livermore National Laboratory, 7000 East Ave., Livermore, CA 94551

The Experimental Nuclear Physics Group at LLNL has pioneered an effort at determining neutron-induced reactions on radioactive nuclei using the surrogate ratio method [1-3]. The success of this technique provides strong, yet indirect evidence indicating that the continuum states populated by a "surrogate" direct reaction damp into compound nuclear states prior to particle emission. In this talk I will present a brief overview of the recent results using the surrogate reaction technique and discuss the implications of these results for understanding the properties of continuum nuclear states above S_n.

In addition, I will present plans to carry out nuclear physics experiments using the National Ignition Facility (NIF) at LLNL. NIF uses 10 MJ+ of laser energy to implode a capsule from an initial radius of approximately 1 mm down to 30 μm producing temperatures up to $k_BT=5\text{-}50$ keV and densities up to several kg/cm^3. NIF "ignition" shots using D+T fuel will also produce up to 10^{19} neutrons in 20 ps resulting in a neutron flux in excess of 10^{34} neutrons/s/cm^2. These conditions offer an unprecedented opportunity to measure nuclear reactions in quasi-stellar conditions and to study neutron-induced reactions on both the ground and quasi-continuum excited states of radioactive nuclei. In this talk I will review the capabilities of NIF and outline some possible programs in nuclear structure, reactions and astrophysics.

This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

The giant dipole resonance, new measurements

F. Camera [a], A.Bracco [a], F.C.L.Crespi [a], S. Leoni [a], B. Million [a] ,D. Montanari [a], M. Pignanelli [a], O. Wieland [a], A. Maj [b], P. Bednarczyk [b,c], J. Grebosz[b], M. Kmiecik [b], W. Meczynski [b], J. Styczen [b], T. Aumann [c] , A. Banu [c], T. Beck [c], F. Becker [c], L. Caceres [c], P. Doornenbal [c], H. Emling [c], J. Gerl [c], H. Geissel [c], M. Gorska [c], O. Kavatsyuk [c], M. Kavatsyuk [c],I. Kojouharov [c], N. Kurz [c], R. Lozeva [c], N. Saito [c], T. Saito [c], H. Shaffner c, H.J. Wollersheim [c], J. Jolie [d], P. Reiter [d], N. Warr [d], G. de Angelis [e], A. Gadea [e],D. Napoli [e], S. Lenzi [f], S. Lunardi [f], D. Balabanski [g], G. Lo Bianco [g], C. Petrache [g], A. Saltarelli [g], M. Castoldi [h], A. Zucchiatti [h], J. Walker [I] and A .Burger[l], F.Gramegna[m], S.Barlini[m], V.L. Kravchuck[m]

[a] University of Milan, and INFN Section of Milan, Italy
[b] Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland
[c] GSI, Planckstrasse 1, D-64291, Darmstadt, Germany
[d] University of Koeln, Germany
[e] National Laboratory of Legnaro, INFN, Italy
[f] University of Padova and INFN Section of Padova, Italy
[g] University of Camerino, and INFN Section of Perugia, Italy
[h] INFN Section of Genova, Italy
[i] University of Surrey, United Kingdom
[l] HISKP, Univ. Bonn, Nussallee 14-16, D-53115 Bonn,
[m] Laboratori Nazionali INFN di Legnaro

The latest results of the experimental studies of the gamma decay of the GDR in hot and ground states nuclei will be presented. In particular the γ decay following the Coulomb excitation of ^{68}Ni at 600 A MeV has been measured using the RISING array at GSI. The ^{68}Ni beam has been produced from the fragmentation of ^{86}Kr at 900 A MeV from the UNILAC-SIS on a ^{9}Be target and selected using the Fragment Separator. A peak centred at approximately 10.8 MeV has been observed when ^{68}Ni isotopes has been selected. Because of the reaction mechanism the measured peak is interpreted to have a dipole nature and to come from the Pygmy Dipole Resonance. The measured data are consistent with the predictions of the Relativistic Mean Field and the Random Phase Approximation approaches. This is the first measurement with radioactive beams of the γ decay of the Pygmy Resonance for nuclei in this mass region. In the case of hot nuclei, the temperature dependence of the GDR width has been measured in mass region A ~ 130. The measured Giant Dipole Resonance width shows an almost linear increase with the effective temperature and this is well described by the thermal fuctuations model including also the lifetime of the compound nucleus.

Phase transitions in nuclei and compact stars

Philippe Chomaz
Ganil, France

Landscapes and Fluctuations of two-dimensional Rotational γ-ray spectra

T. Døssing, *The Niels Bohr Institute, University of Copenhagen*

Rotational spectra of deformed nuclei provide evidence of the most collective mode of motion in nuclei. With the addition of temperature to the nucleus, this collective mode of motion is still present with its full strength, but this strength is spread out over an interval in energy, *the rotational damping width* Γ_{rot}.

An overview is given of damping of the rotational motion, with special emphasis of the scaling laws as function of temperature and rotational frequency. With increasing temperature, the two-dimensional spectrum of consecutive γ-rays display characteristic patterns of hills and ridges whose width in energy carry information about the statistics of levels contributing to the level density and the rotational strength. In theoretical calculations, one mostly finds power laws of angular momentum and temperature, associated with thermal fluctuations and with densities of levels obeying selection rules, but some quantities depend on the total level density at given angular momentum and heat energy.

Experimental spectra sample a whole cascade of γ-rays, and one cannot separate consecutive spectra from other coincidences. Still, the spectra display a characteristic behaviour, with a valley running diagonal through the spectrum, flanked by ridges. An analysis of the landscape of the spectrum, namely the width of the valley and the ridges provide information about the rotational damping width Γ_{rot}, and the compound spreading width Γ_{comp}. An analysis of fluctuations of these spectra carry information about the number of transitions, and thereby about the level density.

These techniques are discussed and illustrated, and a rather consistent picture emerges of the strength functions and level densities, although the information on the compound spreading width Γ_{comp} is not so convincing.

Finally, a recent analysis of superdeformed rotational bands of the nucleus ^{194}Hg is presented and discussed. For this case, only the ridges occur, and one finds unusually many rotational bands contributing to the ridge. It is argued that this gives a hint of the existence of ergodic bands for which the rotational motion is ordered and the intrinsic degrees of freedom are mixed in a chaotic way, as first speculated by Ben Mottelson and Sven Åberg.

Systematics of Level Density Parameters

T. von Egidy, H.-F. Wirth
Physik-Department, Technische Universität München, Germany
D. Bucurescu
National Institute of Physics and Nuclear Engineering, Bucharest, Romania

Nuclear level densities contain the essential information on nuclei at higher excitation energies, especially when individual levels cannot be resolved anymore. In addition to this fundamental property they are needed for the calculation of reaction rates, in astrophysics and for reactor design. Although the simple relation between mass and energy is well known, it is not obvious that the level density at higher excitation energies depends mainly on the ground state masses as will be shown in this contribution.

The exponential increase of the level density can be described by the Back-Shifted Fermi Gas formula (BSFG) with the two free parameters **a** and $\mathbf{E_1}$ or by the Constant Temperature formula (CT) with the parameters **T** and $\mathbf{E_0}$. These two free parameters can be determined for each nucleus by a fit to the known individual levels in a given energy and spin range at low excitation energies and by the neutron resonance density at the neutron binding energy. Additionally a formula for the spin distribution has to be assumed. We have done this for 310 nuclei between ^{19}F and ^{251}Cf. For most of them the neutron resonance density was known.

In the next step we made a careful search for correlations of these level density parameters with well known observables such as mass number A, ground-state mass, pairing energy or shell effect. We found that the pairing correction is best reproduced by the deuteron pairing energy: Pa = ½ $(-1)^Z$ [-M(A+2,Z+1) + 2 M(A,Z) – M(A-2,Z-1)], where M is the experimental mass or mass excess value. For the shell correction S we used the liquid-drop mass formula of Pearson (Hyperfine Interact.132(2001)59): S = M – M_{ld} and S' = S – Δ, Δ = +0.5 Pa, 0, -0.5 Pa for even-even, odd-A and odd-odd nuclei, respectively. Our result is that the level density parameters of the 310 nuclei can be well reproduced using very simple formulas containing only A, Pa, S' and dS/dA:

$a/A^{0.90} = 0.1848 + 0.00828\ S'$, $\qquad E_1 = p_1 +/- 0.5\ Pa + p_2\ dS/dA$,

$1/(T\ A^{2/3}) = 0.0571 + 0.00193\ S'$, $\qquad E_0 = q_1 +/- 0.5\ Pa + q_2\ dS/dA$,

(values in MeV or MeV^{-1}) .

The fitted values p_i and q_i are different for even-even, even-odd, odd-even and odd-odd nuclei.

These new simple formulas can be applied to calculate level density parameters of nuclei where experimental values are not available.

Furthermore we investigated the correlations between the level density parameters of the BSFG and CT formulas and found the simple relation for the back shifts: $E_0 = E_1 + \Delta E$, with ΔE = - 821 keV. The parameters a and T are related as $T = C\ a^c$ with C = 5.53 and c = - 0.773. Since the experimental results show that T varies with $A^{-2/3}$, we conclude that on the average a does not vary with A, as usually assumed, but with $A^{0.90}$.

Details of our studies can be found in:

T. von Egidy, D. Bucurescu, Phys.Rev.C**72**,044311(2005); Phys.Rev.C**72,**067304(2005); Phys.Rev.C**73**,049901(E)(2006).

Emergence of phases with size

S. Frauendorf

University of Notre Dame, USA

Emergence is a central concept of complex systems, which denotes the appearance of simple patterns on a higher structural level than the interacting constituents. In Physics, mesoscopic systems allow us studying how such phenomena emerge with increasing particle number. Since emergent phenomena are not sensitive to the details of the interactions between the constituent particles, they may appear in non-nuclear mesoscopic systems quite analogous to nuclei. Phases are an important emergent phenomenon, which involve some long-range correlation between the constituents. When the size of mesoscopic systems becomes comparable with the correlation length the properties of the phase are substantially modified. The modifications concern typical properties of the phase, as e.g. the flow pattern of a superfluid. As examples, I compare superconductivity and superfluidity in nano-grains, He droplets, and nuclei with their macroscopic limit in bulk matter. The small number of particles, which is typically fixed, and the restricted energy exchange with the environment determine the thermodynamic behavior of mesosopic systems, in particular around a phase transition. One may have to resort to the canonical or microcanonical ensembles. As examples, I discuss the transition from the paired to the unpaired state in He-droplets and nuclei, which corresponds to a second order phase transition in bulk matter, and the melting of Na clusters, which corresponds to a first order phase transition of bulk Na.

Nuclear Level Densities

S.M. Grimes
Ohio University
Athens, OH 45701
USA

ABSTRACT

A pair of recent papers have proposed a dependence of the level density parameter a on N and Z as well as A. The dependence on these parameters was such as to cause a to drop for given A as the nucleus becomes proton or neutron rich.

A model which reflects this behavior has been developed. Results using this model will be presented. Although the model predicts some reduction in a for N and Z near the stable values for a given A compared to the N and Z values for the stable nucleus, the effects become large enough to be interesting only when the nucleus is three or more positions from stability. Predicted effects on the spin cutoff parameter and parity ratio will also be discussed.

Challenges on phase transitions and gamma-strength functions

Magne Guttormsen

Department of Physics, University of Oslo, Box 1048, Blindern, 0316-Oslo, Norway

The thermodynamic description of small, isolated systems like the atomic nucleus is usually performed within the micro-canonical or canonical ensemble. Both pictures exhibit some advantages and weaknesses. The quest for a new thermodynamic theory is stressed.

The gamma-strength functions measured in various nuclear reactions often differ in strength and shape. This concerns e.g. the scissor mode pygmy width and strength, the tail of the GEDR and the behavior at low gamma energy, the so-called upbend. The upbend phenomenon seems to be a real physical property in the Oslo type of experiments.

Blind-tests of the Oslo method are shown. Other challenges coming up during the workshop will also be addressed.

Nuclear physics aspects of p-process nucleosynthesis

S. Harissopulos

Tandem Accelerator Laboratory, Institute of Nuclear Physics,
NCSR "Demokritos", 15310 Aghia Paraskevi, Athens, Greece.

Abstract

The synthesis of the so-called *p nuclei*, i.e. a certain class of proton rich nuclei that are heavier than iron, requires a special mechanism known as *p process*. This process consists of various nucleosynthetic scenaria. In some of them proton and alpha-capture reactions are strongly involved. p-process nucleosynthesis is assumed to occur in the Oxygen/Neon rich layers of type II supernovae during their explosion. p nuclei are typically 10-100 times less abundant than the corresponding more neutron-rich isotopes. The prediction of their abundances is one of the major puzzles of all models of p-process nucleosynthesis. Until now all these models are capable of reproducing these abundances within a factor of 3. However, they all fail in the case of the light p nuclei with $A \leq 100$. The observed discrepancies could be attributed to uncertainties in the pure "astrophysical" part of the p-process modelling. However, they could also be the result of uncertainties in the nuclear physics data entering the corresponding abundance calculations. In order to perform these calculations the cross sections of typically 20000 nuclear reactions of an extended reaction network involving almost 2000 nuclei from A=12 to 210 are used as input data. Such a huge amount of experimental cross section data are not available. Hence, all extended network calculations rely almost completely on cross sections predicted by the Hauser-Feshbach (HF) theory. It is therefore of paramount importance, on top of any astrophysical model improvements, to test also the reliability of the HF calculations, i.e. to investigate the uncertainties associated with the evaluation of the nuclear properties, like nuclear level densities, γ-ray strength functions and nucleon-nucleus potentials, entering the calculations. Until now, this check has been hindered significantly by the fact that there has been scarce experimental information on cross sections at astrophysically relevant energies.

This contribution reports on a systematic investigation of 30 proton and α-particle capture reactions at energies relevant to p-process nucleosynthesis. Our results as well as all other existing data are compared with HF calculations using various microscopic and phenomenological models of the nuclear input data. Several aspects of all the experiments performed so far as well as plans for additional measurements, will be presented. Finally, the question of whether there is sufficient experimental information to put constraints on the theory and draw final conclusions will be discussed.

Particle-number conservation for pairing transition in finite systems

Kazunari Kaneko

Department of Physics, Kyushu Sangyo University, Fukuoka 813-8503, Japan

Abstract

By applying the particle-number projection to the static path approximation (SPA), heat capacity and pairing correlations are investigated in thermal superfluid systems. Phase transitions have often been discussed in connection with symmetry breaking, leading to violation of conservation laws. Since the particle number is broken in the superfluid phase yet preserved in the normal phase, particle-number projection becomes important in the superfluid-to-normal phase transition in finite systems. Exact number projection is essential for an accurate description of heat capacity and pairing correlations in small superfluid systems.

Throughout this discussion, I will present the exact number projection in the SPA, and report on the implications of the numerical results.

Is there an enhancement of photon strength at low γ-ray energies in Mo isotopes?

M. Krtička

Charles University, Prague, Czech Republic

Abstract

A strong enhancement of photon strength function of Mo isotopes has been recently reported from (^{3}He,^{3}He$'\gamma$) and (^{3}He,$\alpha\gamma$) reactions [1,2]. In order to verify this interesting phenomenon a dedicated sum-coincidence measurement of spectra of two-step γ cascades following the neutron capture in ^{95}Mo was undertaken at the thermal neutron beam of the LWR-15 research reactor at Řež. The analysis of these spectra shows that the enhancement has to be much weaker compared to that reported in Ref. [2]. This conclusion is corroborated by a preliminary analysis of data from the ^{95}Mo(n,γ)^{96}Mo and ^{94}Mo(n,γ)^{95}Mo reactions at isolated *s*- and *p*-wave neutron resonances. These data have been accumulated from the measurements on the DANCE 4π detector system installed at the Los Alamos pulsed spallation neutron source facility.

[1] A. Voinov *at al.*, Phys. Rev. Lett. **93**, 142504 (2004)

[2] M. Guttormsen *et al.*, Phys. Rev. C **71**, 044307 (2005)

Experimental level densities and gamma-ray strength functions in the $f_{7/2}$ nuclei ^{44,45}Sc and ^{50,51}V

A. C. Larsen[1], R. Chankova[1], M. Guttormsen[1], F. Ingebretsen[1], T. Lönnroth[2], S. Messelt[1], A. Schiller[3], S. Siem[1], N. U. H. Syed[1], A. Voinov[4] and S. W. Ødegård[1]

[1]Department of Physics, University of Oslo, Norway
[2]Department of Physics, Åbo Akademi, Turku, Finland
[3]NSCL, Michigan State University, Michigan, USA
[4]Department of Physics and Astronomy, Ohio University, Ohio, USA

We report on experiments carried out at the Oslo Cyclotron Laboratory on the nuclei ^{44,45}Sc and ^{50,51}V. The Oslo Cyclotron group has developed a method to extract first-generation (primary) γ-ray spectra at various initial excitation energies. From such a set of primary spectra, the nuclear level density and the γ-ray strength function can be found simultaneously [1,2]. Besides their fundamental importance in nuclear structure, level densities and γ-ray strength functions are the basic input parameters in nuclear reaction models.

The extracted level densities and γ-ray strength functions of ^{44,45}Sc and ^{50,51}V will be presented. The level densities display fine structures that cannot be obtained from standard statistical level-density models. At γ energies below ~3 MeV, an unexpected enhancement of the strength functions is observed in all nuclei presented here. The physics behind this very interesting behaviour is not yet understood, as none of the common models can account for it [3].

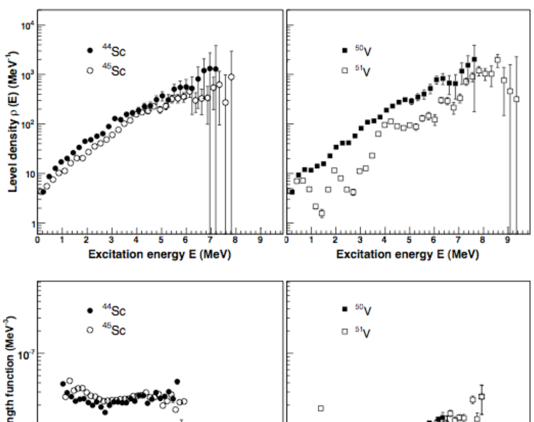


Figure 1. Level densities (top) and γ-ray strength functions (bottom) of ^{44,45}Sc and ^{50,51}V

[1] L. Henden *et al.*, Nucl. Phys. **A589**, 249 (1995).
[2] A. Schiller *et al.*, Nucl. Instr. Methods Phys. Res. A **447**, 498 (2000).
[3] A. Voinov *et al.*, Phys. Rev. Lett. **93**, 142504 (2004).

This work was supported by the Norwegian Research Council (NFR)

Strength distribution in the decay out of superdeformed bands

A. Lopez-Martens[1], T. Dossing[2], T.L. Khoo[3], B. Herskind[2] and T. Lauritsen[3]

[1]CSNSM, IN2P3-CNRS,UMR8609, F-91405, France
[2]Niels Bohr Iinstitute, Copenhagen, Denmark
[3]Argonne National Laboratory, USA

The decay from superdeformed (SD) states occurs over 2-3 transitions. In the process, the nucleus gains a certain deformation energy, which it evacuates by emitting a series of gamma-rays to reach its normally deformed (ND) ground state. In the cases where a large amount of excitation energy is gained, the nucleus may undergo a transition from ordered to chaotic motion. The degree of chaoticity of the ND spectrum can reveal itself through the strength distribution of the transitions deexciting the SD state. Three different techniques have been applied to study the primary strength distribution of the decay out of SD ^{194}Hg. First, the strongest experimental strengths are analyzed in terms of the most likely chi squared distribution. Then two different schematic models are applied to describe the order to chaos properties of the spectrum of ND states to which the SD state is coupled at decay out: (i) Gaussian Orthogonal Ensemble (GOE) matrices with off-diagonal matrix elements scaled down and (ii) sparse GOE matrices. The results seem to indicate that the ND states in ^{194}Hg are chaotic in the excitation energy range of decay-out. Furthermore, it is found that the strongest decay-out transitions yield as much information on the chaoticity of the ND spectrum as the more conventionally applied Δ_3 statistics, which, in this case, is completely inaccessible.

Properties of hot nuclei at extreme angular momenta

Adam Maj
The Henryk Niewodniczanski Institute of Nuclear Physics,
Polish Academy of Sciences
Krakow, Poland

The gamma-decay of the GDR has been proven to be a basic probe for the shapes of hot and rotating nuclei, especially to study the shape evolution as a function of angular momentum. In this context an interesting question arises – what is the nuclear shape at extreme values of spin – close to the limit impose by the fission process.

In the talk I will presented results from the experiments aimed to answer this question in the case of two nuclei from very different mass regions, namely for ^{46}Ti (EUROBALL+HECTOR and ICARE experiments at IReS Strasbourg) and ^{216}Rn (HECTOR experiment at LNL Legnaro). In the case of ^{46}Ti large deformations at highest spins were observed both in the GDR and alpha-particle spectra, and were ascribed to the Jacobi shape transition taking place at high angular momenta. Contrary, almost no spin evolution up to the fission limit was observed in the case of ^{216}Rn. The results are compared to the predictions based on the liquid drop model.

Possible perspectives of these type of studies by using the soon available radioactive beams and new instrumentation will be discussed.

Theoretical prediction of effective GDR width at high spins from the thermal shape fluctuation model[1]

K. Mazurek[a], M. Kmiecik[a], A. Maj[a], M. Matejska[a,b], and J. Dudek[c]

[a] The Niewodniczański Institute of Nuclear Physics, PAN, 31-342 Kraków, Poland

[b] Cracow University of Technology,31-155 Kraków, Poland

[c] IPHC IN_2P_3-CNRS/Université Louis Pasteur, Strasbourg, France

The thermal shape fluctuation method with the Lublin-Strasbourg Drop (LSD) model, which reproduces quite satisfactorily the nuclear fission barriers, has been used in order to compute effective GDR shapes of hot nuclei in particular at the regime of Jacobi shape transitions. In particular, the effective GDR width of ^{98,120}Cd, ^{106}Sn,^{176}W, ^{194}Hg and its evolution as a function of angular momentum and temperature was calculated and compared to the existing experimental results.

[1]This work was partially sponsored by the IN2P3 - Polish Laboratories Convention, Project No. 99-95, and by the Polish Ministry of Science and Higher Education (Grant 1 P03B 030 30).

Neutron Capture Reactions with DANCE

G. E. Mitchell*

North Carolina State University, Raleigh, NC
and Triangle Universities Nuclear Laboratory, Durham, NC

Our research efforts involve the measurement of cross sections of neutron-capture reactions and the determination of neutron level densities and γ-ray strength functions. The measurements are performed with the γ-ray array DANCE (Detector for Advanced Neutron Capture Experiments) at LANSCE/LANL. DANCE is an array of 160 Barium Fluoride Detectors that form a nearly 4π calorimeter that is designed for the study of very small and/or radioactive samples.

We have measured neutron capture on ^{94,95}Mo.[1] For s-wave resonances on ^{95}Mo (ground state $J^{\pi} = 5/2^{+}$), the compound nuclear states have J = 2 or 3. The average multiplicity $< m >$ is different for the two different spin states. In addition the energy spectra for s-wave resonances with spin 2 or 3 are quite different. The combination of the average multiplicity and the m = 2 and 3 spectra give a very clear signature for the resonance spin.

We have also performed neutron capture measurements on ^{151,153}Eu.[2] Resonances in ^{152}Eu and ^{154}Eu are well resolved up to neutron energy 130 eV. The cascade multiplicity distributions of ^{151,153}Eu are quite different from the multiplicity distribution arising from neutron scattered from the Beryllium backing and captured in the detector. This difference is utilized to perform background subtraction and obtain the cross section for the ^{151}Eu(n,γ) and ^{153}Eu(n,γ) reactions from E_n = 0.2 eV to 10 keV.

We have also studied ^{152,154,157,160}Gd.[3] The gadolinium analysis is at an early stage.

* For the DANCE Collaboration.

[1] S. A. Sheets, Ph.D. dissertation, North Carolina State University (2007).

[2] U. Agvaanluvsan *et al.*, Lawrence Livermore Technical Report (2007).

[3] W. Parker *et al.*, International Conference on Nuclear Data (2007).

Structures in the Continuum of Light Nuclei

Markus Norrby
Department of Physics, Åbo Akademi University, Finland (e-mail: mnorrby@abo.fi)
Abstract for *Workshop on Level Density and Gamma Strength in Continuum, Oslo, May 21 - 24, 2007*

1. Alpha-cluster states: what are they and how can they be examined?

This presentation looks at some aspects of nuclear properties at relatively high excitation, at about 5–25 MeV, for "light" nuclei (mass ∼20–40). The *Turku Alpha Clusters at High Excitation* (TACHE) project works with these issues mainly from an experimental point of view [1].

In this region Alpha cluster states reveal themselves in elastic scattering as structures in the excitation function. To examine these states high resolution experiments have to be done over many angles and in a very big energy interval. With the traditional thin-target stepping methods for elastic scattering experiments, gathering this type of data would require thousands of energy steps and simply would not be practical. Therefor novel experimental methods have been developed and used successfully [2].

The method used for the latest experiments is the Reverse-Geometry Method, which uses a high-energy heavy ion beam on a helium gas target instead of the traditional alphas on a solid target. The main advantage of this method is gathering continuous energy and angle spectra in one single run, thus saving weeks and months of beam time (and PhD-student work).

2. Some experimental results

Elastic scattering experiments carried out at the Jyväskylä K-130 cyclotrone using the reverse geometry method are being analyzed for $\alpha + {}^{28}\mathrm{Si}, \alpha + {}^{30}\mathrm{Si}, \alpha + {}^{40}\mathrm{Ar}$ and $\alpha + {}^{36}\mathrm{Ar}$. The first of these to be analyzed is ^{28}Si, since it is the reaction best covered in earlier works, and therefor is a test of the reliability of the method.

So far the results show that the method is certainly reliable and the results are comparable with earlier works. The details in the continuous spectrum for the excitation function given by the reverse geometry method compensates for the slightly poorer resolution of the method. The center-of-mass energy range of 3–11.6 MeV (corresponding to 10–18 MeV excitation energy in ^{32}S) shows an excitation function with more than 100 peaks of which most can be assigned a definite spin value.

3. The connection to level densities

Excitation functions for alpha scattering also gives another view of level densities. We can see that there are narrow and well separated levels that persist up to very high excitation (up to 33 MeV in ^{32}S!). The density of these levels in different nuclei can be used as an estimate of how the over-all level density changes with mass number [3]. The alpha cluster levels also have a number of interesting and unexplained features, such as a more or less constant density over a very large energy interval, narrow widths (corresponding to ∼100 transit times) and very high spin values [4].

References

[1] K.-M. Källman et al., European Phys. J. A16, 159 (2003)
[2] K.-M. Källman et al., Nucl. Instr. Meth. Phys. Res. A338, 413 (1994)
[3] M. Guttormsen et al., J. Phys. G29, 263 (2003)
[4] T. Lönnroth et al. (in preparation)

The 3MeV Pygmy resconance in $^{164,163}Dy$

H.T. Nyhus[1], S. Siem[1], M. Guttormsen[1]
[1] Department of Physics, University of Oslo, P.O.Box 1048 Blindern, N-0316 Oslo, Norway

^{164}Dy and ^{163}Dy were analyzed using the Oslo method (ref.1,2) that enables us to extract both the level density and the gamma-ray strength function simultaneously. The experiment was performed at Oslo cyclotron laboratory, where the nuclei where excited through the reactions; $^{164}Dy(^3He,\alpha)^{163}Dy$ and $^{164}Dy(^3He,^3He)^{164}Dy$, using a 38 MeV beem of ^3He.

Both the Oslo group and the group from Prague have investigated various rare earth nuclei. The Oslo group has then measured a larger width of the pygmy resonance than has the group in Prague, but without measuring on the same isotop. The motivation for analyzing ^{163}Dy is that it is one of the nuclei earlier analyzed in Prague, then through the reaction $^{162}Dy(n,\gamma)^{163}Dy$. The aim is to investigate if the two different reactions influence the width of the pygmy resonance.

Preliminary result of the gamma-ray strength function will be presented.

[1] A Schiller et al., NIM A447 (2000) 494.
[2] E. Melby et al., Phys. Rev. Lett. 83 (1999) 3150.

Microcanonical level densities of non-magic nuclei

Robert Pezer[1] and Alberto Ventura[2,3]

[1] Physics Dept., Faculty of Science, University of Zagreb, Croatia
[2] Ente Nuove Tecnologie, Energia e Ambiente, Bologna, Italy
[3] Istituto Nazionale di Fisica Nucleare, Sezione di Bologna, Italy

The micro-canonical ensemble is particularly suited to the statistical description of nuclei at low excitation energy, since it permits a detailed analysis of fluctuations of level densities connected with the structure of the underlying Hamiltonian, which would be drastically smoothed out in a grand-canonical formalism, more convenient at high excitation energy, where the two approaches become equivalent.

The present model is based on a modified version of the SPINDIS combinatorial algorithm [1], very effective to compute excitations at mean field level by distributing all nucleons among the single-particle levels generated in a spherical Woods-Saxon potential.

Pairing interactions are treated exactly, too, by solving a set of non-linear Richardson equations for any microscopic configuration generated by the combinatorial algorithm. Other two-body interactions, particularly important in open-shell nuclei, are dealt with in an approximate way and include, in the present version of the model, an additional monopole interaction between like nucleons, a neutron-proton quadrupole interaction and a Gaussian shaped random interaction with density dependent width.

In this way a dynamical deformation is introduced, thus removing the need for a phenomenological enhacement factor, present in our combinatorial calculations of total level densities of magic and semi-magic nuclei [2], and permitting a quantitative reproduction of recent experimental data of open-shell nuclei in the A = 50 mass region [3].

[1] D. K. Sunko, Comput. Phys. Comm. 101 (1997) 171.
[2] R. Pezer, A. Ventura and D. Vretenar, Nucl. Phys. A 717 (2003) 21.
[3] A. Schiller et al., Phys. Rev. C 68 (2003) 054326.

NUCLEAR LEVEL DENSITY PARAMETER

Krzysztof Pomorski, Bożena Nerlo-Pomorska
Department of Theoretical Physics, Marie-Curie-Skłodowska University, 20-031 Lublin, Poland

The macroscopic microscopic calculations have been performed with the Yukawa folded mean field for 134 spherical even-even nuclei and 12 deformed ones at temperatures $0 \leq T \leq 4$ MeV [1,2] . Single-particle level densities for this sample of nuclei are determined for various temperatures. In Ref.[3] we have studied the mass-number and isospin dependence of the single-particle level density obtained in the relativistic mean-field theory (RMFT) with the NL3 parameter set and in Ref. [4] with Skyrme Skm* force. Using the traditional Strutinsky shell-correction method we have *removed* [3,4,5] the shell effects from the selfconsistent energies . Estimates of the macroscopic binding energies (free of shell and pairing effects) at zero temperature obtained in this way were then used as reference points to determine the variation of the total energies with temperature. Since at temperatures beyond $T \approx 2$ MeV shell effects practically vanish, we have evaluated at first the shell correction at finite temperatures by the phenomenological formula [3] and then the free energy shell correction by the Strutinsky method with energy folding in the nucleon number $\mathcal{N}$- space [6] at finite temperature. Similarly as in Ref. [3,4,7,8,9] , the variation of the macroscopic binding energies with temperature was approximated by a liquid-drop type expression, which leads to a simple form for the single-particle level-density parameter. The average dependence of the single-particle level density parameter on mass number A and isospin I for various elonations c was found [1,2] and compared with previous estimates obtained using RMFT [7,8,9] Skyrme [4] force and different semiclassical and experimental approaches [10,11,12].

[1] K. Pomorski, B. Nerlo Pomorska, J. Bartel, Phys. Rev. **C74**, 034327 (2006).
[2] K. Pomorski, B. Nerlo-Pomorska, J. Bartel, Int. Journ. of Mod. Phys. **E16**, 368 (2007).
[3] B. Nerlo-Pomorska, K. Pomorski, J. Bartel, K. Dietrich, Phys. Rev. C **66**, 051302(R) (2002).
[4] J. Bartel, K. Pomorski, B. Nerlo-Pomorska, Int. Journ. of Mod. Phys. **E15**, 478 (2006).
[5] B. Nerlo-Pomorska, J. Sykut , Int. Journ. Mod. Phys. **E13**, 75 (2004).
[6] K. Pomorski, Phys. Rev. **C70**, 044306 (2004).
[7] B. Nerlo-Pomorska, J. Sykut , Int. Journ. Mod. Phys. **E13**, 1147 (2004).
[8] B. Nerlo-Pomorska, K. Pomorski, J. Sykut, J. Bartel, Int. Journ. Mod. Phys. **E14**, 505 (2005).
[9] B. Nerlo-Pomorska,J.Sykut,J.Bartel, Acta.Phys.Polon.**B36**,1377(2005).
[10] J. Töke, W. J. Świątecki, Nucl. Phys. **A372**, 141 (1981).
[11] N. Dilg, W, Chantl, H. Vonach, M. Uhl, Nucl. Phys. **A217**, 269 (1973).
[12] T. v. Egidy, H. H. Schmidt, A. N. Behkami, Nucl. Phys. **A481**, 189 (1988).

MASSES AND FISSION BARRIERS OF ATOMIC NUCLEI

K. Pomorski

Theoretical Physics Department Maria Curie Skłodowska University, PL-20-031 Lublin

Theoretical estimates of the masses of nuclei which are not far from stability agree well with the measured data. Nevertheless the progress made in experimental nuclear physics over the last years, like discovery of superheavy nuclei or isotopes close to the proton or neutron drip-lines, demands for a more careful checking of the theoretical model predictions and may lead to some revision of its parameters.

The recently developed Lublin-Strasbourg Drop (LSD) [1] model together with the Moeller microscopic corrections [2] is very successful in describing many features of nuclei. In addition to the classical liquid drop model the LSD contains the curvature term proportional to the $A^{1/3}$. Its parameters were adjusted to the bindings energies of presently known 2766 [3] with proton and neutron numbers larger or equal to 8. The r.m.s. deviation of the experimental binding energies versus those predicted by the LSD model, equal to 0.698 MeV, is smaller than the ones given by other more elaborated theories like the finite-range droplet [2] or the Thomas-Fermi model of Myers and Świątecki [4].

It turns out that the liquid drop model which in addition to the volume, surface and Coulomb energies contains just the first order curvature term gives not only a very good description of the masses but also a rather satisfactory prediction of the fission barrier heights. It is worth emphasizing that all the parameters of the LSD model were fitted to the nuclear masses only and thus the correct reproduction of the barrier heights can be seen as an additional sign of the intrinsic consistency of the model. The mean square deviation of the barrier heights from experiment is 3.56 MeV, but it decreases to only 0.88 MeV when the four lightest nuclei are disregarded i.e. when only the nuclei with $Z>70$ are considered. In addition it was found in Ref. [5] that taking into account the deformation dependence of the congruence energy proposed by Świątecki significantly approaches the theoretical LSD-model barrier-heights to the experimental data in the case of the light isotopes while the fission barriers for heavy nuclei remain nearly unchanged and agree well with experiment. It was shown in Ref. [6] that the saddle point masses of 18 even-even transactinides from ^{232}Th to ^{250}Cf evaluated using the LSD differ by less than 0.67 MeV from the experimental data.

Recently developed in Ref. [7] new shell correction method by averaging in the particle number space (not by smoothing the single energies as in the traditional Strutinsky prescription) predicts deeper minima for spherical nuclei what can change the estimates of the barrier height of fissioning superheavy isotopes [8].

1. K. Pomorski and J. Dudek, Phys. Rev. **C67**, 044316 (2003).
2. P. Moeller, J.R. Nix, W.D. Myers, and W.J. Świątecki, At. Data Nucl. Data Tab. **59**, 185 (1995).
3. M.S. Antony, Chart of Nuclides – Strasbourg 2002, IReS, France.
4. W.D. Myers and W.J. Świątecki, Nucl. Phys. **A601**, 141 (1996).
5. K. Pomorski and J. Dudek, Int. Journ. Mod. Phys. **E13**, 107 (2004).
6. A. Dobrowolski, K. Pomorski, and J. Bartel, Int. Journ. Mod. Phys. **E16**, No. 2, (2007).
7. K. Pomorski, Phys. Rev. **C70**, 044306 (2004).
8. A. Sobiczewski and K. Pomorski, Prog. Part. Nucl. Phys. **58**, 292 (2007).

Giant resonances, fine structure, wavelets and spin- and parity-resolved level densities *

A. Richter

Institut für Kernphysik, Technische Universität Darmstadt, Schlossgartenstr. 9, D-64289 Darmstadt, Germany

The decay of giant resonances in nuclei is a prime example of how a well-ordered collective excitation dissolves into disordered motion of internal degrees of freedom in fermionic quantum many-body systems (see, e.g., [1]). In heavy nuclei the dominant damping mechanism to result from a coupling hierarchy of the initially excited one-particle one-hole (1*p*1*h*) states to two-particle two-hole (2*p*2*h*) and finally to *npnh* states, leading to internal mixing. A recent high-resolution study of the isoscalar giant quadrupole resonance (ISGQR) over a wide mass range as well as the Gamow-Teller resonance (GTR) has provided a new experimental access to this problem [2,3]. The data systematically exhibits tremendous fine structure in the energy region of the resonances. This fine structure carries the relevant information on the damping of the resonances and is analyzed with a novel method based on wavelet analysis techniques.

With a continuous wavelet transform exploited for the first time in nuclear physics it has become possible to extract characteristic energy scales of the fine structure ("nuclear noise") and to study the coupling mechanism mentioned above. A comparison with microscopic model calculations including two-particle two-hole degrees of freedom identifies the coupling to surface vibrations as the main source of the observed scales [2]. A generic pattern is also found for the stochastic coupling to the background of the more complex states.

Another important information hidden in the fine structure is the level density. Indeed, high energy resolution along with excellent selectivity of the nuclear probes achieved by a proper choice of the kinematics give a possibility to extract spin- and parity-separated level densities by means of an autocorrelation analysis in the regime of not fully resolved individual states. A new method using the discrete wavelet transform provides a nearly model-independent determination of the non-resonant background which is crucial for the applicability of this technique [3]. Results for 1^+ states in ^{58}Cu and ^{90}Nb, 2^- and 2^+ states in ^{58}Ni and ^{90}Zr as well as 2^+ states in a broad range of nuclei are presented. Such data have an important application as a test of state-of--the-art models used, e.g., in nucleosynthesis network calculations. An emphasis is also placed on the possible parity dependence in nuclear level densities which is predicted by Monte-Carlo shell model [4] and deformed Skyrme–Hartree–Fock–Bogolyubov [5] calculations. Some signatures for shell effects in nuclear level densities are discussed.

[1] P. F. Bortignon, A. Bracco, and R. A. Broglia, *Giant Resonances: Nuclear Structure at Finite Temperature* (Harwood Academic, Amsterdam, 1998).
[2] A. Shevchenko *et al.*, Phys. Rev. Lett. **93**, 122501 (2004).
[3] Y. Kalmykov *et al.*, Phys. Rev. Lett. **96**, 012502 (2006).
[4] Y. Alhassid, G. F. Bertsch, S. Liu, and H. Nakada, Phys. Rev. Lett. **84**, 4313 (2000).
[5] S. Hilaire and S. Goriely, Nucl. Phys. **A779**, 63 (2006).

* Work supported by the SFB634 of the Deutsche Forschungsgemeinschaft.

Continuous spectroscopy for nuclear structure and astrophysics; from stable to exotic nuclei

A. Schiller

National Superconducting Cyclotron Laboratory,
Michigan State University, East Lansing, MI 48824, U.S.A.

Excitation-energy indexed continuous γ-ray spectra from excitations below the particle-separation energy have been used to measure radiative strength functions since almost forty years [1]. Such spectra are often analyzed in the framework of the generalized Brink-Axel hypothesis [2, 3], which assumes that any excitation built on the ground state can also be built on any excited state, and that the properties of the excitation does not depend on the temperature of the state on which it is built. Under this assumption, it is possible to not only extract the radiative strength function, but also the nuclear level density [4]. The level densities are in excellent agreement with results from particle-evaporation measurements [5] and show signs of a phase transition in a finite system, namely the pairing phase transition [6]. The radiative strength functions match the tail of photoneutron cross sections and are in excellent agreement with available literature data on hard, primary-γ transition intensities, and with total-cascade γ spectra after neutron capture [7]. A low-lying $M1$ mode in rare-earth nuclei and a low-energy enhancement of the radiative strength function for Fe nuclei have been confirmed by two $(n, 2\gamma)$ experiments [8, 9]. A connection to (γ, γ') experiments remains controversial [10].

In this talk, I will review the experimental evidence which led us to this almost unified picture and good understanding of level density and radiative strength below the particle separation energy, although some open questions still remain. Interesting aspects related to phase transitions in small systems [11], violations of the Brink-Axel hypothesis at high temperatures and corresponding hot giant-dipole-resonance width systematics [12], astrophysical applications of radiative strength functions, and the opportunity to measure radiative strength functions by Coulomb breakup of radioactive nuclei will be discussed as well [13].

[1] G.A. Bartholomew *et al.*, Can. J. Phys. **48**, 687 (1970).
[2] D.M. Brink, Ph.D. thesis, Oxford University, 1955.
[3] P. Axel, Phys. Rev. **126**, 671 (1962).
[4] A. Schiller *et al.*, Nucl. Instrum. Methods Phys. Res. **A 447**, 498 (2000).
[5] A. Voinov *et al.*, Phys. Rev. C **74**, 014314 (2006).
[6] A. Schiller *et al.*, Phys. Rev. C **63**, 021306(R) (2001).
[7] A. Voinov *et al.*, Phys. Rev. C **63**, 044313 (2001).
[8] A. Schiller *et al.*, Phys. Lett. **B 633**, 225 (2006).
[9] A. Voinov *et al.*Phys. Rev. Lett. **93**, 142504 (2004).
[10] A. Schiller *et al.*, nucl-ex/0011018.
[11] A. Schiller *et al.*, Phys. Rev. C **66**, 024322 (2002).
[12] A. Schiller and M. Thoennessen, At. Data Nucl. Data Tables (accepted for publication).
[13] The MoNA collaboration whitepaper. Status report and future plans (2007).

Calculation of Level Densities for Nuclei around the Drip Lines

Shaleen Shukla
Ohio University, Athens, OH 45701, USA

Nuclear level densities provide crucial input in any statistical model calculation of compound nuclear decay, applied to the various processes like the study of fission hindrance in heavy nuclei, the yields of evaporation residues to populate certain exotic nuclei, production of heavy elements in stellar processes etc.
We calculate nuclear level densities for nuclei near the drip line. We use a single fermion model [1] with non interacting fermions and spectral distribution methods [2] which allow moments to be calculated in huge spaces using a fairly small sum. We shall present results for mass number in the range 40 - 60. Future efforts would include investigating the effect of two-body interactions [3].

Supported by grant # DE-FG02-88ER40387 of US-DOE

References:

1. C. Jacquemin and S. K. Kataria, Z. Phys. A **324**, 261 (1986).
2. J. B. French and K.F. Ratcliff, Phys. Rev. C **3**, 94 (1971).
3. D. A. Resler and S. M. Grimes, Comp in Phys **2** (3), 65 (1988)

Nuclear level densities and in closed shell lead nuclei

Syed Naeem Ul Hasan[1)], M. Guttormsen[1)], S. Siem[1)], A. C. Larsen[1)], J. Rekstad[1)], F. Ingebretsen[1)], T. Lønnroth[2)], A. Voinov[3)], A. Schiller[4)]

1) Department of Physics, University of Oslo, P.O.Box 1048 Blindern, N-0316 Oslo, Norway
2) Åbo Akademi University, FIN-20500 Åbo, Finland
3) Department of Physics and Astronomy, Ohio University, Athens, Ohio 45701, USA
4) National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, MI 48824, USA

The energy dependent nuclear level densities and γ-strength functions for closed shell $^{205\text{-}208}$Pb nuclei have been determined. The scattering and transfer reactions were used to observe the particle-γ coincidences, which are analyzed, unfolded and then primary-γ spectra are extracted from these. The primary-γ spectra are factorized according to the Brink-Axel hypothesis [1], into level density and γ-strength function as,

$$P(E_x, E_\gamma) = \mathrm{T}(E_\gamma)\rho(E_x, E_\gamma).$$

This method of extracting nuclear level density and γ-strength function simultaneously is called the Oslo method.

The method has previously been successfully tested on rare earth nuclei. The preliminary results of lead nuclei show that the method works well in closed shell nuclei, as well.

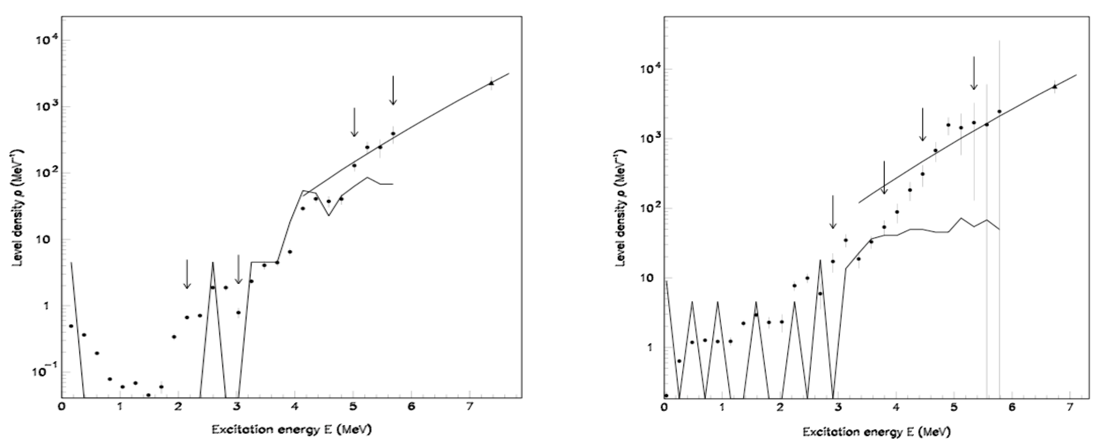


Fig. 1): Left panel: The Experimental nuclear level densities of ^{208}Pb using the Oslo method. **Right panel:** The normalized level density of ^{207}Pb. The filled circles are data points compared with BSFG model at higher excitation energies.

1) P. Axel, Phys. Rev. **126**, 671 (1962).

Microscopic calculation of symmetry projected nuclear level densities

K. Van Houcke[1], S.M.A. Rombouts[1], K. Heyde[1] and Y. Alhassid[2]

[1] Vakgroep Subatomaire en Stralingsfysica, Universiteit Gent - UGent, Proeftuinstraat 86, B-9000 Gent, Belgium
[2] Center for Theoretical Physics, Sloane Physics Laboratory, Yale University, New Haven, Connecticut 06520, U.S.A.

Contact e-mail: kris.vanhoucke@ugent.be

Nuclear level densities are critical for estimating nuclear reaction rates. The simplest approach to estimating the nuclear level density is to assume a free Fermi gas, leading to the well-known Bethe formula [1]. A simple phenomenological way of incorporating pairing correlations and shell effects is to back-shift the excitation energy E_x by an amount Δ, resulting in the back-shifted Bethe formula. The calculation of statistical nuclear reaction rates also requires knowledge of the angular momentum distribution of the nuclear level density. An empirical formula for the angular momentum distribution of the level density at a fixed excitation energy E_x assumes uncorrelated and randomly coupled single-particle spins, and is given by the spin-cutoff model [2, 3]. The main drawback of this approach is that it requires a fit for each individual nucleus. Getting information on the level density, and in particular the angular momentum dependence of this quantity beyond the free particle model, poses a complex problem.

We present a quantum Monte Carlo (QMC) method to solve a general isovector $J = 0$ pairing model and solve the angular momentum projection problem for seniority conserving models [4]. This method provides us with a microscopic test for the validity of the Fermi gas and spin-cutoff model for nuclei that exhibit strong pairing correlations. The pairing model serves as a benchmark to identify signatures of pairing correlations in the nuclear level density. In a finite nucleus, the number of paired particles is relatively small, and the identification of such signatures of the nuclear superfluid transition is difficult. For the pairing model, the projection on angular momentum in our QMC simulation is direct, and does not cause a sign problem for any component of J and odd particle number. In addition, our QMC method allows us to to treat the very large model spaces, which are needed for the calculation of level densities at higher excitation energies, and, particula rly, for the study of the parity and angular momentum dependence of level densities.

We present parity and angular momentum projected level densities for the even-even nucleus ^{56}Fe, and the adjacent odd-even isotopes ^{55}Fe and ^{57}Fe. Even projected on a specific angular momentum, we find that the nuclear level density has a strong dependence on parity. Signatures of the pairing phase transition are obtained in the angular momentum distribution of the nuclear level density.

1. H.A. Bethe, Phys. Rev. **50** (1936) 332; Rev. Mod. Phys. **9** (1937) 69.
2. C. Bloch, Phys. Rev. **93** (1954) 1094.
3. T. Ericson, Adv. Phys. **9** (1960) 425.
4. K. Van Houcke, S.M.A. Rombouts, K. Heyde and Y. Alhassid, nucl-th/0702041.

Superradiance effects, collectivity and chaos in the continuum

Vladimir Zelevinsky

National Superconducting Cyclotron Laboratory and
Department of Physics and Astronomy,
Michigan State University, East Lansing, MI 48824-1321 USA

New physics arises in open and marginally stable mesoscopic systems, including loosely bound nuclei. Coupling of intrinsic states with and through continuum at certain conditions leads to the phenomena analogous to super-radiance in quantum optics (sharp redistribution of the decay widths with formation of broad super-radiant and narrow trapped states). The appropriate theoretic description is based on the effective non-Hermitian and energy-dependent Hamiltonian. The discussion will include the construction of the continuum shell model, coexistence of the width collectivity with giant resonances, width and level spacing distributions, fluctuations of cross sections and examples of analogous solid state physics.

Quantum Fluctuations of Pairing in Finite Systems [1]

S. Åberg,[1], H. Olofsson,[1] and P. Leboeuf [2]
[1] *Mathematical Physics, LTH, Lund University, P.O. Box 118, S-221 00 Lund, Sweden*
[2] *Laboratoire de Physique Théorique et Modèles Statistiques, CNRS, Bât. 100, Université de Paris-Sud, 91405 Orsay Cedex, France*

Superfluidity and superconductivity are genuine many-body manifestations of quantum coherence. For finite-size systems like atomic nuclei the associated pairing gap fluctuates as a function of size or shape. Connected to this is a variation in the single-particle level density around the fermi surface. The variation in the level density has previously been described by periodic orbit theory. We now develop a periodic orbit theory for the pairing field (in the abstract gauge space), and can without any parameter describe the variation of the pairing gap in nuclei as well as in other finite fermi systems.

The pairing gap is divided in a smooth part and a fluctuating part, $\Delta = \bar{\Delta} + \widetilde{\Delta}$, and expressions for $\widetilde{\Delta}$ are obtained. We find for the second moment of $\widetilde{\Delta}$ (normalized to the single–particle mean level spacing, δ), assuming regular dynamics,

$$\sigma^2_{\rm reg} = \frac{\pi}{4}\frac{\bar{\Delta}}{\delta} F_0\,(D) \ , \tag{1}$$

and assuming chaotic dynamics,

$$\sigma^2_{\rm ch} = \frac{1}{2\pi^2} F_1\,(D) \ , \tag{2}$$

where $F_n(D) = 1 - \int_0^D x^n K_0^2(x)dx / \int_0^\infty x^n K_0^2(x)dx$, where K_0 is the modified Bessel function of second kind. The argument $D = \frac{2\pi}{g}\frac{\bar{\Delta}}{\delta}$ is a system dependent quantity proportional to the quotient of the average pairing gap, $\bar{\Delta}$, and $g = \tau_H/\tau_{\rm min}$, where $\tau_H = h/\delta$ and $\tau_{\rm min}$ is the period of the shortest periodic orbit. g is an intrinsic characteristic of the system ("dimensionless conductance"), independent of pairing. In Fig. 1 we show fluctuations as a function of the average pairing gap for different values of g. Different physical systems are marked out: pairing gaps in nuclei (mainly regular system), and superconductivity of small metallic grains (chaotic). Also pairing in ultracold gases of fermionic atoms (regular or chaotic) can be described.

The experimentally best established case is pairing in nuclei. The connection between the pairing gap and the nuclear mass differences is best given by the three–point measure $\Delta_3(N)$=$B(N)$-$[B(N+1)$+$B(N-1)]/2$, where N is the odd neutron or proton number, and is shown in the inset of Fig. 2 for neutrons. The average dependence of the neutron and proton gaps is well approximated, from experimental data, by $\bar{\Delta} = \frac{2.7}{A^{1/4}}$ MeV. We notice a rather strong variation of the pairing gap around the average value. In Fig. 2 the A dependence of the RMS of the experimental pairing fluctuations are compared to the present theory, assuming regular or chaotic dynamics. The explicit variation of the pairing gap with number of particles is also provided by the theory.

[1] Submitted to PRL; arXiv:0704.2310

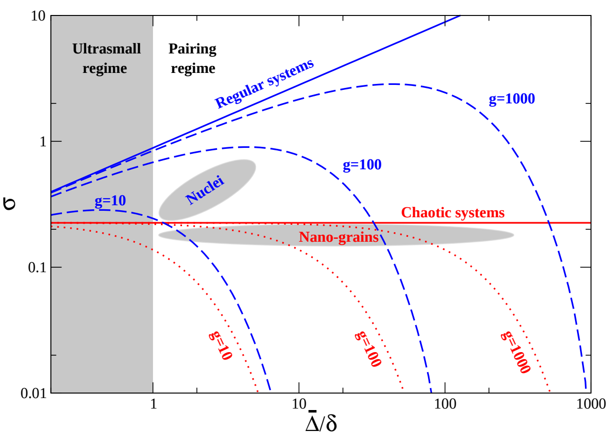


FIG. 1: Fluctuations of the pairing gap as a function of the mean value (log-log scale). Regular and chaotic dynamics are shown by blue and red lines, respectively. The dashed curves correspond to different values of g. Applications to Nuclei and Nano-grains are marked out.

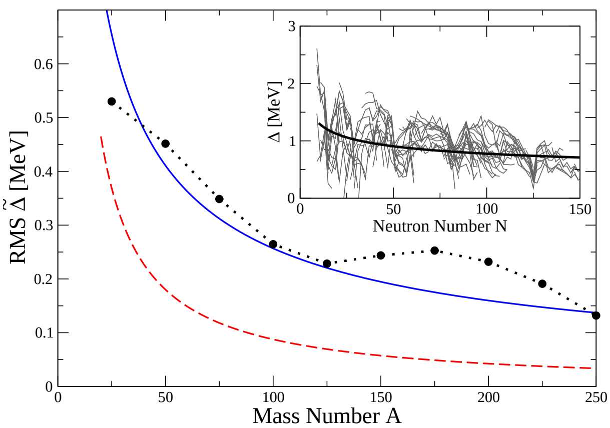


FIG. 2: Root-Mean-Square of the nuclear pairing gap fluctuations as a function of mass number A. The dots are experimental data for protons and neutrons (see inset). The solid and dashed lines are regular and chaotic predictions, respectively, given by Eqs. (1) and (2). Inset: Experimental nuclear odd-even mass-difference for neutrons (isotone sequences are connected). The black line shows the average pairing gap $\bar{\Delta}$.

List of participants

Emel Algin
Eskisehir Osmangazi University
Turkey

Yoram Alhassid
Yale University
USA

Frantisek Beckvar
Charles University
Prague
Czech Republic

Lee Bernstein
LLNL
USA

Franco Camera
INFN and University of Milano
Italy

Deepshikha Choudhury
George Washington University
USA

Philippe Chomaz
Ganil
France

Thomas Døssing
University of Copenhagen
Denmark

Till von Egidy
München University of Technology
Germany

Stefan G. Frauendorf
University of Notre Dame
USA

Steve Grimes
Ohio University
USA

Magne Guttormsen
University of Oslo
Norway

Sotirios Harrisopulos
Demokritos
Athens
Greece

Kris Van Houcke
Ghent University
Belgium

Finn Ingebretsen
University of Oslo
Norway

Kazunari Kaneko
Kyushu Sangyo University
Japan

Milan Krticka
Charles University
Prague
Czech Republic

Maria Kmiecik
IFJ PAN Kraków
Poland

Ann-Cecilie Larsen
University of Oslo
Norway

Araceli Lopez-Martens
CSNSM, IN2P3-CNRS
France

Adam Maj
IFJ PAN Kraków
Poland

Katarzyna Mazurek
IFJ PAN Kraków
Poland

Gary Mitchell
NCSU
USA

Markus Norrby
Åbo Akademi
Finland

Jon Petter Omtvedt
University of Oslo
Norway

Eivind Osnes
University of Oslo
Norway

Hilde Therese Nyhus
University of Oslo
Norway

Robert Pezer
University of Zagreb
Croatia

Bozena Nerlo-Pomorska
University M.C.S.
Lublin
Poland

Krzysztof Pomorski
University M.C.S.
Lublin
Poland

John Rekstad
University of Oslo
Norway

Achim Richter
Darmstadt University of Technology
Germany

Munib Sarwar
University of Oslo
Norway

Andreas Schiller
MSU
USA

Shaleen Shukla
Ohio University
USA

Sunniva Siem
University of Oslo
Norway

Naeem Ul Hasan Syed
University of Oslo
Norway

Vladimir Zelevinsky
MSU
USA

Sven Åberg
Lund Institute of Technology
Sweden

Detektorer for gammaspektroskopi

NERLIENS MESZANSKY
laborel

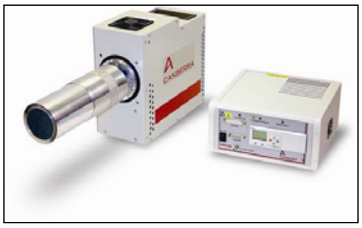
Cryo-Cycle

Cryo-Cycle

Er en unik kombinasjon av elektrisk kjøling for Germanium detektorer og flytende nitrogen. Nitrogenet blir regenerert i beholderen.

Alle fordelene ved flytende nitrogen er biholdt.

- Minimal støy
- Meget driftsikker
- Lavt energiforbruk
- Lite vedlikehold (Bytt LN2 en gang i året)
- Ingen merkbar degradering av oppløsning i forhold til ”vanlige” elektrisk kjølte detektorer
- Fem års garanti!
- Kjøler 2-3 uker selv om strømmen forsvinner



Cryo-Pulse 5

Cryo-Pulse 5

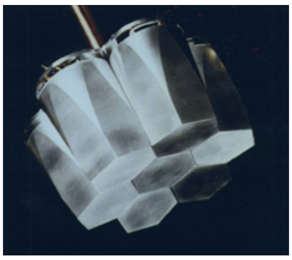
Cryo-Pulse 5 er resultatet av mange års utvikling av elektrisk kjølte detektorer. Meget driftsikker og lydløs.

- Meget driftsikker og lydløs
- Bruker ikke flytende nitrogen
- Utvikler lite varme/vibrasjon og bruker lite strøm
- Kan brukes i alle vinkler
- Ingen merkbar degradering av oppløsning i forhold til ”vanlige” elektrisk kjølte detektorer
- 5 års garanti!

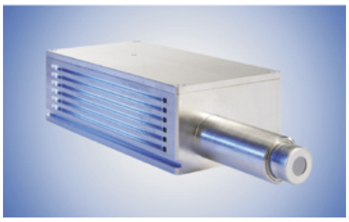
Lanthanum Bromide

Lanthanum Bromide (LaBr3(Ce))

En revolusjon innen gammaspektroskopi. Dobbelt så god oppløsning som standard NaI detektor.



Avansert cluster (Clover detektorer)



X-PIPS røntgen detektor

CANBERRA

Kontakt:
Eirik Gundersen, telefon 22 66 65 22 eller e-post eirik.gundersen@nmas.no