Adiabatic and Diabatic Dynamics of Fusion in Heavy Ion Collisions

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The content of this talk is a review on the different models for the description of fusion of heavy ions to superheavy nuclei. There exist in literature models using adiabatic potentials (e.g. of $Abe, Swiatecki, Zagrebaev$) and models using diabatic potentials (e.g. of $Volkov, Adamian, Antonenko$). The fusion is described by two main degrees of freedom, namely by the relative motion of the fusing nuclei with the coordinate R and by the mass and charge transfer between the nuclei expressed by the mass (charge) asymmetry coordinate $\eta = (A_1 - A_2)/(A_1 + A_2)$ ($\eta_Z = (Z_1 - Z_2)/(Z_1 + Z_2)$).

Adiabatic potentials represent the minimum energy of the system for a given set of collective coordinates and a given internuclear distance and have smaller barriers for similar projectile and target nuclei ($\eta \approx 0$). In this case the nuclei melt together reducing the internuclear distance. Adiabatic models usually yield larger fusion cross sections for collisions of equal projectile and target nuclei than those observed in experiments and often can not explain the isotopic trends. Diabatic potentials are strongly repulsive for smaller internuclear distances due to the structural forbiddenness and let develop the fusion process as a nucleon transfer in a touching configuration of the two nuclei what is named the dinuclear system. The cross section decreases with increasing symmetry between projectile and target nuclei which agrees with experimental data. So the dynamics of fusion is basically different in the two descriptions of fusion: In the adiabatic models the nuclei melt together, whereas in the diabatic models the nuclei transfer nucleons between each other up to the instant when the compound nucleus is formed.

As final result we summarize that diabatic potentials seem more appropriate for the description of the fusion of heavy nuclei than adiabatic potentials which are quite useful for treating fission processes.

Algebraic Approach to Non-central Potentials in the n-dimensional Schrödinger Equation

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Central potentials whose three-dimensional Schrödinger Hamiltonian has an underlying Lie-algebraic symmetry admit non-central extensions that can be described by symmetries in larger dimensions, $n > 3$, compact for bound states and non-compact for scattering states, and lend themselves to fully analytic solutions. The scattering matrix, in particular, can be worked out as an intertwining operator between Weyl-equivalent unitary irreducible representations of the corresponding potential algebra [1].

A simple example of bound state calculation is provided by a non-central extension of the three-dimensional harmonic oscillator with $u(4)$ symmetry [2], while an example of scattering is given by a non-central extension of the null potential with $e(4)$ symmetry [3].

In the present work we study in particular non-central extensions of the n-dimensional Coulomb potential, with underlying $so(n+4)$ symmetry in the bound state problem and $so(n+3, 1)$ symmetry in the scattering problem, with $n > 2$.

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Valence Shell Excitations in Even-even Spherical Nuclei within Microscopic Model

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A microscopic multiphonon approach is adopted to investigate the structure of some low-lying states observed experimentally in the $N = 80$ and $N = 84$ isotones. The calculation yields levels and electromagnetic transition strengths in good agreement with experiments and relates the observed selection rules to the neutron-proton symmetry and phonon content of the observed states. Moreover, it ascribes the splitting of the $M1$ strength in ^{138}Ce to the proton subshell closure which magnifies the role of pairing in the excitation mechanism [1]. In ^{144}Nd and ^{142}Ce the splitting of M1 strength is due to the interplay of collective and slightly collective quadrupole components [2].

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Antiproton-Nucleus Electromagnetic Annihilation as a Way to Access the Proton Timelike Form Factors

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Contrary to the reaction $\bar{p} + p \to e^+e^-$ with a high momentum incident antiproton on a free target proton at rest, in which the invariant mass $M_{e^+e^-}$ of the e^+e^- pair is necessarily much larger than the $\bar{p}p$ mass, in the reaction $\bar{p} + d \to ne^+e^-$ the value of $M_{e^+e^-}$ can be near or below the $\bar{p}p$ mass. In the antiproton-deuteron electromagnetic annihilation, this allows to access the proton electromagnetic form factors in the time-like region of q^2 near the $\bar{p}p$ threshold. We estimate the cross section $d\sigma(\bar{p} + d \to e^+e^-n)/dM_{e^+e^-}$ for an antiproton beam momentum of 1.5 GeV/c. We find that for values of $M_{e^+e^-}$ near the $\bar{p}p$ threshold this cross section is about 1 pb/MeV [1]. The case of heavy nuclei target is also estimated. These latter calculations were carried out for the ^{12}C, ^{56}Fe and ^{197}Au nuclei with the nuclear momentum distributions found in the papers [2]. Elements of experimental feasibility are presented in the context of the PANDA project. We conclude that this process has a chance to be measurable at PANDA.

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Novel Techniques and Recent Measurements of Nuclear Moments

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An important aspect to understand collective excitations in atomic nuclei is through measurements of their magnetic dipole and electric quadrupole moments. While nuclear magnetic moments are sensitive to the orbits occupied by the valence particles, the electric quadrupole moments prove the deformation and the collective behavior of nuclei at both low and high excitation energy. Both, the nuclear gyromagnetic factor and the electric quadrupole moment can be compared to theory and thus play important role to establish changes in nuclear shell structure far away from stability. Recent results from experiments aiming at measurements of electromagnetic moments of exotic nuclei will be reported. The following experiments will be discussed:

- Transient field measurement of the g factor of the first 2^+ state in ^{72}Zn [1], which were measured at GANIL at intermediate energies, will be presented, and the experimental technique will be discussed;
- First rmeasurement of a isomeric electric quadrupole moment in ^{66}Cu in transfer reaction [2] will be presented and the perspectives to utilize this technique with post-accelerated ISOL beams in inverse kinematics will be discussed;
- A method for polarizing of post-accelerated ISOL beams [3], which is under development at ISOLDE, will be presented.

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g-factor Measurements for $^{127-128}$Sn and Shell Model Calculations for $^{124-130}$Sn Nuclei

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g-factor measurements for the $19/2^+$ $T_{1/2} = 4.5(3)\mu s$ isomer in ^{127}Sn [1, 2] and 10^+ $T_{1/2} = 2.69(23)\mu s$ isomer in ^{128}Sn were carried out at GSI within the g-RISING campaign [3], utilizing the TDPAD technique. The obtained results $g(19/2^+) = -0.17(2)$ and $g(10^+) = -0.20(4)$ are compared with the results from calculations, which were done with two different shell model calculations. The first model (SM I) uses ^{132}Sn as a closed core and the second one (SM II), the ^{88}Sr closed core. Both models describe well the experimental results. Systematic calculations were performed for the $^{124-130}$Sn nuclei. The different components of the wave function of the isomers and the differences between the two calculations will be discussed.

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Investigating the Structure of ^{128}I Nucleus

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A series of nuclear spectroscopy experiments for studying the $^{127-129}$I isotopes following the fusion-evaporation reaction of ^{7}Li projectile at 23, 26 and 27 MeV with a ^{124}Sn (3,4 mg/cm^2 thick on Au 13 mg/cm^2) target were made, using either continuous and pulsed beam. The composite gamma array dedicated for nuclear spectroscopy measurements recently developed at the Tandem Laboratory from Bucharest consisting of eight large volume HPGe and five $LaBr_3$ scintillator detectors was used, combined with neutron and charged particles detectors. A preliminary level scheme for ^{127,128}I nuclei were obtained, with new information regarding high spin levels. The observed level scheme for ^{128}I is compared in a systematic of its odd-A neighbors. TRS calculations were made for ^{128}I and his odd-A neighbors in order to have a clear view regarding the structure of this nucleus.

Quasiparticle Random Phase Approximation – Application Towards the $N = 80$ and $N = 84$ Isotonic Chains

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This work is devoted to the systematic investigation on the M1 strength between the low lying 2^+ states and the first 2^+, along the N=80 and N=84 isotonic chains. We have analyzed the influence of the single particle structure on the transitions. All calculations have been done within the Quasiparticle Random Phase Approximation [1], where the mean field has been treated in the framework of Skyrme-Hartree-Fock model [2] similarly to the work done in [3, 4]. For consistency we adopt the following relation between the radial part of the residual interaction and the derivative of the mean field potential $f(r) = dV/dr$.

We have investigated the behavior of the M1 strength, to the first 2^+ state in the N=80 and N=84 chains. It is shown that in the whole region the M1 strength is considerable. Also we have shown that a splitting of the $M1$ strength is observed for ^{138}Ce. In addition we have made a prediction for the M1 strength for nuclei with proton number 54-70 for both N=80 and N=84 isotonic chains. This results gives very positive message for application of $QRPA$ in the domains of exotic nuclei.

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The Stability of High Spin Isomers

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High-spin isomers have half-lives ranging from nanoseconds to years [1]. Although the role of angular momentum is clearly manifest in the decay rates, quantitative analysis reveals many unexplained features related to the nuclear shape, level density and pairing correlations. The present work addresses some of the most important degrees of freedom, with a focus on the way that isomers can be longer lived than their respective ground states. This stabilising effect of high-spin isomers becomes especially significant at the limits to nuclear binding, where ground-state half-lives become very short. It is then necessary to consider proton decay, fission and α decay [2], as well as β and γ decay.

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Thermal Effects on Nucleus-Neutrino Inelastic Scattering in Stellar Environment

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Neutral-current inelastic neutrino scattering on nuclei plays an important role in the evolution of the core collapse of a massive star [1]. This process together with inelastic neutrino-electron scattering rapidly leads to an equilibrium between neutrinos and matter, helping to maintain a larger lepton fraction inside the core and, hence, to attain a stronger shock wave responsible for the supernova explosion. Analyzing the corresponding cross sections one should keep in mind that during the collapse neutrino-induced reactions occur at finite temperature when the thermal population of nuclear excited states is expected to be important. Transitions from these states to low-lying final states can enhance neutrino-nucleus cross sections (see, e.g., [2]).

We study thermal effects on inelastic neutral-current neutrino scattering on even-even nuclei in the iron region. It is assumed that allowed GT_0 transitions in the neutral channel dominate the inelastic cross section. To obtain the GT_0 strength distribution at finite temperature we employ the quasiparticle random phase approximation extended to finite temperatures within the thermo field dynamics [3]. It is found that a temperature growth increases the fraction of low- and negative-energy transitions in the GT_0 strength distribution. The latter corresponds to transitions from thermally excited nuclear states to low-lying states. It is shown that at neutrino energy $E_\nu < 10$ MeV the inelastic scattering cross section essentially depends on temperature.

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Microscopic Description of Nuclear Structure with Skyrme and Gogny Interactions

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In this contribution, we will present illustrative examples of the microscopic description of the nuclear many-body problem based on modern nuclear Energy Density Functionals (EDFs) of Skyrme and Gogny types. Together with the standard EDFs Skyrme-SLy4 and Gogny-D1S, novel results obtained with the most recent incarnation of the Gogny interaction (called Gogny-D1M) will also be discussed. The complexity of the nuclear many-body problem will be considered both with a mean field and beyond mean field perspective (i.e., symmetry projected configuration mixing). Several regions of the nuclear chart will be considered in a search for signatures concerning the role of shape coexistence, shape transitions, island of triaxiality and octupole degress of freedom. Results for odd nuclei in the framework of the so called Equal Filling approximation (EFA) will also be discussed.

Scaling in Electroweak Reactions: What is it useful for?

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Scaling clearly emerges from the analysis of world (e,e') data, hence it constitutes a strong constrain for any theoretical model trying to describe lepton-nucleus scattering. In past years we have investigated extensively this phenomenon showing how a model based on the Relativistic Impulse Approximation (RIA) is capable of reproducing not only scaling but also the specific shape of the experimental scaling function. However, a basic question still remains: why scaling is so important and what is it useful for? In this talk I discuss how scaling can be used to make predictions on some basic properties in Nuclear Physics, such as nucleon momentum distributions, spectral functions and Coulomb Sum Rule. Furthermore, the real impact of scaling shows up when applying this phenomenon to neutrino scattering processes. Thus, the scaling function, as a "universal" property, can provide a powerful tool to get insight into neutrino-nucleus dynamics and its impact on neutrino oscillation experiments.

Scaling Function, Spectral Function and Nucleon Momentum Distribution in Nuclei

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The aim of the study is to find a good simultaneous description of the spectral function and the momentum distribution in relation to the realistic scaling function obtained from inclusive electron-nuclei scattering experiments. We start with a modified Hartree-Fock spectral function in which the energy-dependent part (δ-function) is replaced by the Gaussian distributions with hole-state widths as free parameters. Following Ref. [1] we calculate the scaling function and the nucleon momentum distribution on the basis of the spectral function constructed in this way, trying to find a good description of the experimental data. The obtained scaling function has a weak asymmetry and the momentum distribution has not got a high-momentum tail in the case when harmonic-oscillator single-particle wave functions are used. So, to improve the behavior of the momentum distribution we used the basis of natural orbitals (NO) in which short-range correlations are partly incorporated. The results for the scaling function show again a weak asymmetry, but in this case the momentum distribution has a high-momentum tail. As a next step we are trying to include final-state interactions (FSI) in the calculations to reproduce the experimentally observed asymmetry of the scaling function. The first way to incorporate FSI in the calculations is proposed

in Ref. [2], where two types of FSI effects have been considered: the Pauli blocking and reinteractions of the struck nucleon with the spectator system described by means of the time-independent optical potential. Another way is proposed by J.M. Udias using the 'distorted' momentum distributions that are constructed on the basis of the Relativistic Mean Field model. The work is in progress.

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Momentum Distributions in Medium and Heavy Exotic Nuclei

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Nucleon momentum distributions of even-even isotopes of Ni, Kr, and Sn [1] are studied in the framework of deformed self-consistent mean-field Skyrme HF+BCS method [2, 3], the theoretical approach [4–6] based on the light-front dynamics [7] and the theoretical method based on the local density approximation [8]. The isotopic sensitivities of the calculated neutron and proton momentum distributions are investigated together with the effects of pairing and nucleon-nucleon correlations. The role of deformation on the momentum distributions in even-even Kr isotopes is discussed. For comparison, the results for the momentum distribution in nuclear matter are also given.

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Study of ^{6}He+^{12}C Elastic Scattering Using a Microscopic Optical Potential

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The ^{6}He+^{12}C elastic scattering data at beam energies of 3, 38.3 and 41.6 MeV/nucleon are studied utilizing the microscopic optical potentials obtained by a double-folding procedure and also by using those inherent in the high-energy approximation. The calculated optical potentials are based on the unfolded neutron and proton density distributions of colliding nuclei established in an appropriate model for ^{6}He and obtained from the electron scattering form factors for ^{12}C. The depths of the real and imaginary parts of the microscopic optical potentials are considered as fitting parameters. At low energy the volume optical potentials reproduce sufficiently well the experimental data. At higher energies, generally, additional surface terms having form of a derivative of the imaginary part of the microscopic optical potential are needed. The problem of ambiguity of adjusted optical potentials is resolved requiring the respective volume integrals to obey the determined dependence on the collision energy. Conclusions on the role of the aforesaid effects and on the mechanism of the considered processes are made.

Estimation of the ^{6}He Breakup Cross Sections in ^{6}He+^{12}C Reaction Using the High-energy Approximation and Microscopic Optical Potential

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The ^{6}He breakup cross sections in the ^{6}He+^{12}C reaction are calculated at energy about 40 MeV/nucleon using the high-energy approximation (HEA) and the corresponding microscopic optical potentials (OP) between the ^{4}He and 2n fragments of ^{6}He interacted with the target nucleus ^{12}C. The ^{4}He+2n wave function was estimated using the correlated pair of neutrons as a single particle bounded in the potential with parameters fitted to the separation energy 0.975 MeV and the rms radius of ^{6}He [1]. Also, the other density distribution of this pair was taken in correspondence with the LSSM model calculations of the ^{6}He structure [2]. Doing so, in the frame of HEA, the stripping and absorbtion cross sections were estimated and their sum was obtained in a good agreement with the total reaction cross section calculated with a help of the one-particle microscopic OP [3] which explains the ^{6}He+^{12}C elastic scattering differential cross section at the same energy [4]. It was concluded that breakup channels give the main contribution to the imaginary part of the elastic scattering OP.

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Phase Structure of the Interacting Vector Boson Model

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The two-fluid Interacting Vector Boson Model (IVBM) with the $U(6)$ as a dynamical group possesses a rich algebraic structure of physical interesting subgroups that define its distinct exactly solvable dynamical limits. The classical images corresponding to different dynamical symmetries are obtained by means of the coherent state method. The phase structure of the IVBM is investigated and the following basic phase shapes, connected to a specific geometric configurations of the ground state, are determined: spherical, $U(3) \otimes U(3)$, $\gamma-$unstable, $SO(6)$, axially symmetric deformed, $SU_+(3)$, and deformed triaxial, $SU_-(3)$. The obtained phase diagram of the IVBM resembles that of IBM-2 and reveals the common physical content that relates the two algebraic models.

Core-particle Interaction in Odd-A Nuclei beyond the Random Phase Approximation

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We first review the Extended Random Phase Approximation [1] as a suitable tool to study the properties of the lowest-lying states in even-even nuclei and discuss its area of applicability. Then we proceed with the topic of the core-particle coupling in odd-A nuclei derived using the Extended Boxon Approximation in terms of quasiparticles and phonons [2, 3]. The main focus of the talk will be on the effects of the presented theory on a number of measurable quantities in odd-even nuclei such as the energy spectrum, transition probabilities and spectroscopic factors.

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Approximate Symmetries in Nuclear Structure

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Dynamical symmetries have played a central role for many years in the study of nuclear structure. Recently, the concepts of Partial Dynamical Symmetry (PDS) and Quasi-Dynamical Symmetry (QDS) have been introduced. We shall discuss examples of PDS appearing in the framework of geometrical collective models [1, 2], as well as examples of PDS and QDS appearing in the large boson number limit of the Interacting Boson Model [3, 4].

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Multiple Reflection–asymmetric Type Band Structures in Actinides

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The properties of rotational and quasirotational negative parity bands with different values of K in actinides are investigated in the frame of dinuclear system model [1]. The model is based on the assumption that cluster degrees of freedom play the main role in the formation of these bands. To describe the reflection–asymmetric collective modes characterized by the nonzero values of K, the relative angular motion together with the intrinsic excitations of the clusters are taken into account. There are two physically different cases which can be distinguished. If the heavy fragment of the system is strongly deformed, the light fragment tends to stay in the pole-to-pole configuration performing small angular oscillations around this position. This case holds for the heavy isotopes of actinides. If the heavy fragment is nearly spherical, the angular dependence of the interaction potential is small to prevent the light cluster from rolling along the surface of the heavy one. Such case realizes in the light isotopes of actinides, for example in ^{220}Th [2]. In the frame of the proposed model we described the properties of the negative parity bands in even-even isotopes of Ra, Th, U and Pu.

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Pygmy Resonances in Exotic Nuclei

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The existence of enhanced, resonance-like, low-energy, dipole strength is observed as a common feature of stable and unstable nuclei with neutron excess. This clustering of strong dipole transitions has been named Pygmy Dipole Resonance (PDR).

Further, it was suggested that an oscillation of a small portion of neutron-rich nuclear matter relative to the rest of the nucleus is responsible for the generation of pygmy resonances.
Here, we present systematic, theoretical studies, based on method incorporating HFB and QPM theory, of dipole and other multipole excitations over isotonic and isotopic chains of nuclei with predominantly neutron excess [1, 2]. Our calculations indicate a correlation between the observed total pygmy resonance strength and the neutron-to-proton ratio N/Z [1]. From the analysis of transition densities, the unique behavior of the pygmy resonance mode is revealed, making it distinct from giant resonances. In addition, it has been suggested that the pygmy resonances are independent of the type of nucleon excess (neutron or proton) [1, 2].

Furthermore, recent calculations of low-energy E1 and spin-flip M1 excitations in N=82 nuclei are presented in comparison with experimental data [3]. These investigations allow to decompose the dipole strength below the GDR to elastic E1 component, related to skin oscillations and PDR, and background component composed of elastic and inelastic E1 and M1 transitions, respectively. The obtained information reveals new aspects in the isospin dynamics of the nucleus.

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On the Nature of the Pygmy Dipole Resonance

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Among the different effects of the neutron skin on the collective properties of neutron rich nuclei the so called pygmy dipole resonances (PDR) have been the ones that have aroused more interest. Early calculations, done by our group, of strength distribution in neutron rich nuclei have shown that as far as the neutrons number increases the strength is moving towards the low energy region. Whether or not such strength at low energy corresponds to a collective mode is still under discussion. Information on this point can be achieved by looking at the details of the transition densities and by comparing the microscopic densities with the macroscopic ones dictated by the pigmy resonance model. Further information can be obtained by the excitation probabilities measured in reactions with different probes (pure Coulomb excitation, nuclear inelastic with isoscalar or isovector projectiles). To this end cross section calculations have been performed for these reactions by constructing nuclear formfactors from the corresponding transition densities.

Order Amidst Chaos: The Alhassid–Whelan Arc of Regularity

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Dynamical symmetries are the dominant feature of the Interacting Boson Model of nuclear structure. Regular behavior of spectra and B(E2) transition probabilities appears when they are present, while chaotic behavior appears when they are broken. However, a peculiar region, the Alhassid-Whelan arc of regularity, has been known for twenty years to occur in cases in which the dynamical symmetries are known to be severely broken. It has been recently realized [1] that a Quasi-Dynamical SU(3) symmetry, appearing at the lower part of the spectrum, is responsible for its existence. Extending the study to the whole spectrum in the large boson number limit of the Interacting Boson Model reveals interesting changes in regularity with increasing energy.

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New Description of Long Yrast and Octupole Bands in Even-Even Heavy Nuclei

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We obtain a very accurate description of the long yrast lines in even-even heavy nuclei, based on the proposition that they are formed by parts of crossing 0^+ bands. For each of these bands we employ and compare the simple rigid rotor and generalized rotor model comming from the Interacting Vector Bosons Model /IVBM/. In both cases the moments of inertia for each of these bands directly depend on the collective structure of the corresponding 0^+ band head, defined and classified by the number of phonon excitations that build them. The analysis of the long octupole bands shows that in many nuclei their behavior is similar to that of the yrast band and is reproduced by the same set of parameters.

SUSYQM in Nuclear Structure: Bohr Hamiltonian with Deformation-dependent Mass Term

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A long standing problem in nuclear structure is the increase of the moment of inertia predicted by the Bohr Hamiltonian as a quadratic function of the deformation, while experiment suggests a much more moderate increase. We show [1] how this problem can be avoided by allowing the nuclear mass to depend on the deformation. Exact analytical expressions are derived for spectra and wave functions using techniques of SUSYQM. Spectra and B(E2) transition probabilities are compared to experiment.

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Non-yrast Alternating Parity Bands in the Model of Coherent Quadrupole-octupole Motion

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The model of coherent quadrupole-octupole vibrations and rotations [1] is applied to describe non-yrast energy sequences with alternating parity in even-even rare-earth and actinide nuclei. Within the model scheme the yrast alternating parity band is constructed by the members of the ground-state band and the lowest negative parity levels with odd angular momenta. The non-yrast alternating parity sequences unite the levels of the β- bands with the respective higher negative parity levels. It is shown that the analytic model expression successfully reproduces the yrast and the first non-yrast alternating parity bands in several rare-earth nuclei ^{150}Nd, ^{152}Sm, ^{154}Gd and ^{156}Dy and the actinides ^{232,236}U. In some nuclei like ^{168}Er and ^{234,238}U the model provides a good description of the yrast band together with the first and the second alternating parity sequences for which experimental data are available. The approach allows one to study the formation and the changes in the alternating parity spectra in the different regions of heavy deformed nuclei.

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Extended Microscopic Theory for Medium-mass Nuclei - Basics, First Results, Future

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An extended SU(3) shell model that for the first time explicitly includes unique-parity levels is introduced. Its relevance is established by calculations with a realistic interaction performed for a group of upper fp-shell nuclei where valence nucleons beyond the N=28=Z core occupy levels of the normal parity upper-fp shell $(f_{5/2}, p_{3/2}, p_{1/2})$ and the unique parity $g_{9/2}$ intruder configuration. The levels of the upper fp-shell are handled within the framework of an m-scheme basis as well as its pseudo-SU(3) counterpart, and respectively, the $g_{9/2}$ as a single level and as a member for the complete gds shell. More detailed analyses are done for the waiting-point nuclei of ^{64}Ge and ^{68}Se which demonstrate that the extended SU(3) approach allows one to better probe the effects of deformation and to account for many key properties of the system by using a highly-truncated model space. The model holds promise to be extremely useful for the rare-earth domain as well where many previous results can and will be complemented, revised and improved.

Dependence of Perturbed Nuclear Rotation on Quadrupole and Octupole Deformations

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A particle-plus-rotor Hamiltonian with Coriolis interaction is treated by the contact transformation method [1]. The transformed Hamiltonian is diagonal in the space of the collective rotation functions and is obtained as a series of high order angular momentum terms whose coefficients depend on the motion of the single particle (s.p.) [2]. The coefficients are operators which act in the s.p. space and reflect the interplay between collective and single particle degrees of freedom. In this framework the Coriolis interaction is incorporated into the high-order rotation terms and expectation values of their coefficients in the s.p. space. The numerical behavior of the expansion coefficients is examined with respect to the quadrupole and octupole deformations. By minimizing the energy expression for a given state with respect to the third projection of the angular momentum K, one finds the physically reasonable K value for a given angular momentum. The procedure is similar to the one performed in the quadrupole - octupole rotation model (QORM) [3] but here the s.p. degree of motion is taken into account.

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Projectile Coulomb Excitation of ^{154}Sm

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A projectile Coulomb excitation experiment has been performed with a beam of ^{154}Sm. The projectile ions have been accelerated to 570 MeV by the ATLAS accelerator of the Argonne National Laboratory and then hit a thin natural carbon target. Gamma rays following Coulomb excitation have been detected using the Gammasphere array. Absolute $E2$ transition strengths were deduced from the experimentally observed Coulex yields of the observed states, using the result from a DSAM measurement [1] for the lifetime of the 2_4^+ state as a normalization. Previously known experimental values show good agreement with predictions from the CBS-Rotor-Model [2], but are incomplete for the β-band. The results of this experiment show good agreement with the predictions also for the 2_2^+ state from the β-band.

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Improvements of the Differential Decay Curve Method for the Analysis of Doppler Shift Lifetime Measurements

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The standard way of determine lifetimes of excited states in $\gamma\gamma$ coincidence Recoil Distance Doppler Shift (RDDS) experiments is the Differential Decay Curve (DDC) Method [1]. Some modifications have been developed to improve the quality of the results:

Peak intensities were fitted in two dimensions in the $\gamma\gamma$ coincidence matrix to avoid the the loss of information from the application of small gates in the case of overlapping peaks. Instead of splines a better suited set of functions was used in the analysis of the resulting decay curves. Additionally the detailed simulated velocity distribution of the γ emitting recoils was taken into account.

These modifications have been applied on data taken in a RDDS measurement for the ground state band of ^{168}Yb. The ^{18}O(^{154}Sm, 4n)^{168}Yb fusion evaporation reaction was induced by an 80 MeV ion beam of the tandem accelerator facility in Cologne. The target was mounted in the Cologne coincidence plunger device.

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Clusters and Molecules in Extreme Light

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The progress in laser technology over the last decades has opened up new avenues for the exploration of properties of clusters and molecules. A laser pulse is characterized by its frequency but also by the laser intensity as well as the laser time profile. While for years the variations of these parameters were heavily constrained by technology, the last two decades and even more so the last years have seen tremendous increases in the range of attainable parameters. This is true for intensity, which since the 1990's can reach huge values which can lead to very large energy deposits and possibly violent disintegration of the irradiated species. But this is also true for the tunnig of the time profile which can now be tailored up to time scales of the order of magnitude of electronic motion and even below. This allows the follow up of the detail of electronic dynamics at its own "natural" time. The latest breaktroughs were attained in terms of laser frequency with the ongoing possibility of reaching very large frequencies up the X domain. This opens up new possibilities of imaging which are progressively being explored.

We shall discuss these various directions of investigation, taking examples in cluster and molecular physics. We shall especially discuss the case of high intensity and short time pulses for which a sizable amount of results have already been attained. We shall also briefly discuss the case of very short times (attoseconds) and very large frequencies (several hundreds of eV) which are becoming more and more studied.

Nuclear Effects in Incoherent DVCS Processes in Light Nuclei

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Incoherent Deeply Virtual Compton Scattering (DVCS) on light nuclei is receiving considerable attention, both from the theoretical and experimental points of view, as a mean to obtain information on the Generalized Parton Distributions of quasi-free (neutron) and bound nucleons. An accurate extraction of the latter requires a reliable description of nuclear effects, not only for the actual DVCS process, but also for the interfering Bethe-Heitler (BH) contribution to the measured observables. While at the free nucleon level DVCS has been extensively studied, and the BH contributions are exactly known, at the nuclear level only a few studies exist, and the correpsonding nuclear model uncertainties have not been estimated.

In my talk, after introducing shortly the general DVCS + BH processes on nuclei, I will develop a formalism for incoherent BH, in analogy with the Plane Wave Impulse Approximation approach to $(e, e'N)$ reactions. I will then apply this formalism to calculate incoherent BH cross sections on Deuterium and ^4He targets, at kinematics relevant for the current experimental program at the Jefferson Laboratory. Finally I will briefly discuss possible extensions of these calculations in order to include final state interaction effects.

Neutron-rich N=126 Nuclei: Structure and Fragmentation Reaction Mechanism Studies

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A series of experiments devoted to the study of the neutron-rich N=126 region have been performed at GSI, Darmstadt, within the Rare Isotopes Investigations at GSI (RISING) project. Exotic nuclei were synthesised using relativistic projectile fragmentation of ^{208}Pb.

The highlights of the experimental results from these highly successful experiments include the first observation of excited states in three neutron-rich N=126 closed shell nuclei: ^{205}Au [1], ^{204}Pt [2] and ^{203}Ir.

Shell model calculations have been performed in order to get a deeper understanding of the structure of these nuclei. It was found that in order to get a good description for all available information on the N=126 isotones below lead, both on excitation energies and transition strengths, small modifications of the standard two-body matrix elements [3] were required. The possible consequences of these modifications on the structure of the more exotic N=126 nuclei as approaching the r-process waiting points is investigated.

I addition, the isomeric ratios of two metastable states in the two neutron-hole nucleus ^{206}Hg were determined experimentaly. These are compared with the predictions of two neutron-removal theories. Although the high density of final states complicates the prediction of isomeric ratios for those states fed by unobserved prompt γ-ray cascades, a fair agreement between theory and experiment was found [4].

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The Nucleon Electromagnetic Structure in the Relativistic Model of Constituent Quarks

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The talk is devoted to description of the nucleon electromagnetic structure in the relativistic three-quark model. The method in the relativistic theory of composite systems which is used here is based on the direct realization of the Poincaré algebra on the set of dynamics observables of systems. This approach is called the relativistic Hamiltonian dynamics (RHD) or the relativistic quantum mechanics with fixed number of particles.

The main problem in construction of these models is known to be the problem of construction of operators of transition currents. The approach to describing the electromagnetic structure of three-particle systems presented in this talk has the following features [1]: the matrix element of the electromagnetic current of the composite system automatically satisfies the relativistic covariance conditions and the conservation law, in addition, the relativistic impulse approximation is formulated in a relativistically invariant way with account of the conservation law.

Three-particle wave functions of the nucleons in sense of RHD are calculated as eigenfunctions of the complete set of commuting operators by variational method [2]. In the instant form of RHD, which is used in this work, the complete set is following.

$$\hat{M}_N\ ,\ \hat{J}^2\ ,\ \hat{J}_3\ ,\ \hat{\vec{P}}\ .$$

$\hat{M}_N$ is the mass operator of three-quark system with interaction, $\hat{J}^2$ is the total angular momentum square, $\hat{J}_3$ is the third component total angular momentum and $\hat{\vec{P}}$ is the total momentum of the three-quark system.

The dependence of the electromagnetic nucleon form factor on the parameters of the constituent quark model is studied. It is shown that our relativistic calculations give the good description of the experiment data for the nucleon form factors.

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Challenges in Modeling Nuclear Structure and Reactions

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The high precision, derived within the QCD-based EFT, nucleon interaction that describes the NN-scatering phase shifts, the deuteron, and the light s- and p-shell nuclei points to the necessity of NNN-interaction terms [1, 2]. Small discrepancy in the NNN contact interaction parameters for He^3 and H^3 suggest the need for fully consistent NN and NNN interaction terms at the N3LO EFT level and probably the need for actual proton and neutron masses in future precision calculations. Higher many-body interaction terms (e.g. NNNN-interaction terms) are also part of the interaction as derived from QCD via Chiral perturbation theory [3]. The Okubo-Lee-Suzuki effective interaction method, employed in solving the nuclear many-body problem, also introduces interaction terms beyond the common 2-body interaction [4, 5]. In many-body systems, collective phenomena quickly become as important modes of excitation as single and few particle excitations. In order to solve the nuclear many-body problem one can utilize oblique basis states build on exactly solvable models [6, 7]. For example, the breaking of the SU(3) symmetry in the pf-shell nuclei is clearly due to spin-orbit interaction that lifts the single-particle energy degeneracy [8]. Other possible applications are related to the three exactly solvable limits of the IBM or the interplay between Pairing and the SU(3) symmetry in heavy nuclei. The exactly solvable Extended Pairing model is a relevant model for studying the applicability of the A-body interactions to very heavy nuclei [9, 10]. For strongly deformed nuclei, particle transfer reaction calculations with non-ortogonal Sturmian Basis are the natural counterpart of the oblique basis for nuclear structure calculations [11].

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Fast-timing Measurements in ^{103,105,107}Cd

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The talk will be focused on fast-timing experiments recently performed at NIPNE-Magurele. The aim of the experiments was to measure picoseconds lifetimes in ^{103,105,107}Cd by using five $LaBr_3$:Ce detectors in coincidence with eight HPGe detectors. The coincidences between the HPGe and $LaBr_3$:Ce detectors were used to select gamma-ray cascades that feed the levels of interest. The lifetimes of those particular excited states were extracted from the decay time spectra, obtained from the time-difference between the feeding and de-exciting transitions detected by $LaBr_3$:Ce detectors. In order to fully use the efficiency of the five-detector $LaBr_3$:Ce array, a special procedure for processing the collected time information was developed. Lifetimes of the excited $7/2^+$ and $11/2^-$ were obtained for the ^{103,105,107}Cd, which allows to track the single particle properties of the state in those nuclei.

Exposure of Nuclear Emulsion in the Beam of Relativistic Nuclei and Some Results

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The BECQUEREL Project at the JINR Nuclotron is devoted systematic exploration of clustering features of light stable and radioactive nuclei [1]. A nuclear track emulsion is used to explore the fragmentation of the relativistic nuclei down to the most peripheral interactions - nuclear "white" stars. The analysis of the relativistic fragmentation of neutron-deficient isotopes has special advantages owing to a larger fraction of observable nucleons.

A peripheral dissociation is revealed as a narrow jet of relativistic fragments the total charge of which is close to the charge of the primary nucleus. In spite of the relativistic velocity of fragments the relative velocities inside the jet are non-relativistic ones. In principle, information about the generation of such fragment ensembles can be used in nuclear astrophysics in development of nucleosynthesis scenarios on the basis of few-particle fusion. The challenging task for a detection technique is to provide the completeness in the observation of relativistic fragments.

The emulsion composition provides a special convenience to explore just peripheral interactions. It includes the Br, Ag and H nuclei in comparable concentrations and allows one to compare fragmentation patterns of various origins. Under the same conditions it is possible to observe the very peripheral break-up in the electromagnetic field on a heavy target nucleus (EM dissociation) as well as in collisions with target protons. Microphotographs and movies of typical events can be found http://becquerel.lhe.jinr.ru/movies/movies.html.

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Quantum Kinetic Approach for Spatio-temporal Carrier Dynamics in Femtosecond-laser Irradiated Materials

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A microscopic quantum-kinetic theory based on density matrix approach (using Wigner function representation) is formulated to describe the processes of short pulse laser interaction with materials such as semiconductors accounting for arbitrary spatial inhomogeneities in the excitation conditions and other spatial phenomena such as filamentation of tightly focused femtosecond laser pulses, structural modification and catastrophic optical damage. A system of Boltzmann-Bloch transport equations is established that includes both space and momentum dependence of the electron and hole distribution functions and the polarization. Microscopic electron-phonon and electron-electron scattering terms as well as scattering terms that lead to transitions between valence and conduction bands, i.e. impact ionization and recombination terms, are included explicitly in the equations. The formulated theory describes the spatio-temporal carrier dynamics in inhomogeneously excited materials including the coherent interactions of carriers and the laser light field as well as transport due to spatial gradients and electrostatic forces.

Effects Induced by Nuclear Deformations in Ground State Electron Energy and Electron Correlations of Multiply Charged Helium Like Ions in High-temperature Plasma

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Multiply charged isoelectronic Helium like ions in high-temperature astrophysical and laboratory plasma possess specific properties and characteristics caused by the non-compensated by electrons long-range Columb field of the nuclei.

This field determines the possibility one or two electrons to occupy highly excited quasidiscrete (autoionized) states, outside the ionization limit. There are two decomposition channels of the excited ion: autoionization and radiation. In that case one can observe several resonance processes, for example radiative recombination (RR) and the opposite process - photoionization.

The Columb field plays also the significant role in all interaction processes of multiply charged ions with electrons and photons in plasma.

In the case of electron capture the decomposition channels of double excited ion are two also: autoionization and radiation. In the case of electron "observer" the transition of ion's electron from unbound to bound state is accompanied by so called satellite lines in the spectrum. In the case of interaction with electron having the appropriate resonance energy, the radiative decomposition of double excited ion realizes by photon emission and electron transition into bound state. When the radiative transition realizes by the internal electron, the process is dielectronic recombination (DR).

The opposite effects of the influence of the specific electron processes on the nucleus, that is manifested as a deviation of the pure nuclear Coulomb potential and the nuclear excitation, denoted as nuclear excitation by electron capture $(NEEC)$.

Nuclear motion, nuclear mass and nuclear size exert an influence over the processes in the electron system also. Many theoretical investigations concern the effects of these nuclear characteristics on the electron system.

The proposed work concerns for the first time and studies the effects resulting from nuclear deformations on the formation of the electron energy quantities of multiply charged ions. In the current stage the investigations are performed on the base of obtained numerical results for the ground state energies, mass corrections and mass correlations of the electronic systems for multiply charged He like ions with charge Z from 2 to 118. The nuclides of all existing isotopes are included. A modified method is used based on explicitly correlated wave functions $(ECWF)$ approach. Staggering effects of the electron energy quantities with nuclear magic numbers by N (number of neutrons) and A (mass number) are investigated for each value of Z (number of protons). The effects of nuclear deformations on the electron energy quantities are also investigated through the formation of all nuclear deformation multiplets.

The extremely high accuracy of the obtained numerical results allows their application in precise approaches for plasma diagnostics.