ABSTRACTS

of the XXV International Workshop on Nuclear Theory

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PROGRAMME

Monday, June 26

Morning session

09:30 – 10:05 Opening of the workshop and talk of *Jordan Stamenov*, Director of INRNE-Sofia

10:05 – 10:40 *Rupert Machleidt*: The nuclear force problem: Is the never-ending story coming to an end?

10:40 – 11:00 *Coffee*

11:00 – 11:35 *Dorin Poenaru*: Proca equations of a massive vector boson field

11:35 – 12:10 *Francesca Sammarruca*: The nuclear equation of state: a tool to constrain hadronic interaction

12:10 – 12:45 *Aldo Covello*: Shell-model calculations with modern nucleon-nucleon potentials

16:30 – 17:00 *Coffee*

Afternoon session

17:00 – 17:35 *Jerry Draayer*: Light nuclei in the framework of the symplectic no-core shell model

17:35 – 18:10 *Radu Gherghescu*: Three center shell model

18:10 – 18:25 *Break*

18:25 – 18:45 *Raquel Alvarez-Rodriguez*: Isospin mixing and Fermi transitions within a mean field approach

18:45 – 19:20 *Dimitri Van Neck*: Quasiparticle properties in a density functional framework

19:20 – 19:40 *Cesar Fernandez-Ramirez*: Nucleon resonances: study of their properties through photo pion production

Tuesday, June 27

Morning session

09:30 – 10:05 *Anton Antonov*: Superscaling analyses of inclusive electron scattering and their extension to charge-changing neutrino cross sections in nuclei

10:05 – 10:40 *Maria B. Barbaro*: Superscaling in lepton-nucleus scattering

10:40 – 11:00 *Coffee*

11:00 – 11:35 *Carlotta Giusti*: Neutrino-Nucleus Quasielastic Scattering in a relativistic model

11:35 – 12:10 *Hiko Morita*: A Study of final state interaction in the ^{4}He(e,e'p)^{3}H reaction

12:10 – 12:45 *Daniela Rohe*: First measurement of the spectral function at high energy and momentum in medium-heavy nuclei

15:30 – 16:00 *Coffee*

Afternoon session

16:00 – 16:35 *Anthony Cowley*: Multistep direct mechanism in the ($\vec{p}$,^{3}He) inclusive reaction on ^{59}Co and ^{93}Nb at incident energies between 100 and 160 MeV

16:35 – 17:10 *Elena Zemlyanaya*: Calculations of nucleus-nucleus microscopic optical potentials and the respective elastic differential and total reaction cross sections

17:10 – 17:45 *Armando Relaño*: Chaos and 1/f noise in quantum many-body system

17:45 – 18:00 *Break*

18:00 – 18:35 *Hendrik Geyer*: Recent developments in non-hermitian quantum mechanics

18:35 – 19:10 *Nicola Lo Iudice*: Collective modes in nuclei: an exact microscopic multiphonon approach

19:10 – 19:30 *Stoyan Mishev*: Description of low-lying states in odd open-shell nuclei in the framework of the quasiparticle-phonon model

Wednesday, June 28

Morning session

09:30 – 10:05 *Werner Scheid*: Rotation modes in the dinuclear model

10:05 – 10:25 *Plamen Yotov*: High order angular momentum dependence of a nuclear rotation Hamiltonian

10:25 – 10:45 *Nikolay Minkov*: Description of parity-doublet splitting in odd-A nuclei

10:45 – 11:05 *Coffee*

11:05 – 11:40 *Eric Voutier*: Nucleon structure and generalized parton distributions

11:40 – 12:15 *Kristina Sviratcheva*: Dynamical symmetries reflected in realistic interactions

12:15 – 12:35 *Beatriz Errea*: Generalization of Richardson-Gaudin models to rank 2 algebras

12:35 – 12:55 *Huben Ganev*: Description of the odd mass nuclei within the framework of the Interacting Vector Boson Model

15:30 – 16:00 *Coffee*

Afternoon session

16:00 – 16:35 *Maria M. Garzelli*: Correlations in the interaction of ion beams with matter

16:35 – 17:10 *Dimiter Balabanski*: Evidence for X (5) critical point symmetry in ^{128}Ce

17:10 – 17:45 *Dennis Bonatsos*: The X(3) model and its connection to the shape/phase transition

17:45 – 18:00 *Break*

18:00 – 18:35 *Chavdar Stoyanov*: Nuclear structure calculation in large domain of excitation

18:35 – 18:55 *Dimitar Tarpanov*: Pygmy resonances in tin isotopic chain

Thursday, June 29

E X C U R S I O N

Friday, June 30

Morning session

09:30 – 10:05 *Heinigerd Rebel*: The highest energies in the universe

10:05 – 10:40 *Iliana Brancus*: Flux and charge ratio of atmospheric muons

10:40 – 11:00 *Coffee*

11:00 – 11:35 *Pavel Zarubin*: Clustering in fragmentation of relativistivistic nuclei

11:35 – 11:55 *Ralitsa Stanoeva*: Interactions of relativistic ^{8}B nuclei with photoemulsion nuclei

The Nuclear Force Problem: Is the Never-Ending Story Coming to an End?

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The attempts to find the right (underlying) theory for the nuclear force have a long and stimulating history. Already in 1953, Hans Bethe stated that "more man-hours have been given to this problem than to any other scientific question in the history of mankind". In search for the nature of the nuclear force, the idea of sub-nuclear particles was created which, eventually, generated the field of particle physics. I will review this productive history of hope, error, and desperation. Finally, I will discuss recent ideas [1, 2, 3] which apply the concept of an effective field theory to low-energy QCD. There are indications that this concept may provide the right framework to properly understand the nuclear force [4, 5].

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Proca Equations of a Massive Vector Boson Field

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We commemorate 50 years from A. Proca's death (see biographical details in a book edited by his son [1] and the web site [7] with many links). Proca equation [4, 5, 6] is a relativistic wave equation for a massive spin-1 particle. The weak interaction is transmitted by such kind of vector bosons. Also vector fields are used to describe spin-1 mesons (*e.g.* ρ and ω mesons). In his Nobel lecture [2] and in a review paper [3] Wolfgang Pauli mentioned Proca's theory and its importance for "a field consisting of a four-vector and an antysimmetric tensor like the potentials and field strengths in Maxwell's theory" as well as for understanding the nuclear forces. After a short biography, the present work presents an introduction into relativistic field theory, including Klein-Gordon, Dirac, and Maxwell fields, allowing to understand the Proca equations and some consequences for the theory of strong interactions as well as for Maxwell-Proca and Einstein-Proca theories. The modern approach of the nonzero photon mass and the superluminal radiation field are briefly outlined.

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The Nuclear Equation of State: A Tool to Constrain Hadronic Interactions

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Recently we have been concerned with the properties of the nuclear equation of state (EOS), a relation between thermodynamic variables characterizing a medium. At zero temperature, such relation can be expressed as energy (or pressure) as a function of density.

At this time, it is fair to say that the model dependence of the isospin asymmetric EOS is rather large. This is especially the case for the density dependence of the symmetry energy at high density. Furthermore, other mechanisms, such as spin-asymmetry and/or temperature, can have a dramatic impact on the equation of state and possibly alter its stability conditions.

We will review some of our recent work and its relevance towards a better understanding of the nuclear force in exotic matter. Work in progress will also be briefly discussed. Our study is broad-scoped in that it can reach out to neutron-rich systems on the nuclear chart *and*, on a dramatically different scale, astrophysical systems such as compact stars.

The approach we take is microscopic and relativistic. The calculated nuclear matter properties are derived self-consistently from realistic nucleon-nucleon interactions. This makes it possible to understand the predicted EOS properties in terms of specific features of the nuclear force model.

Shell-Model Calculations with Modern Nucleon-Nucleon Potentials

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In the past few years, shell-model calculations employing effective interactions derived from modern nucleon-nucleon (NN) potentials have produced results in remarkable agreement with experimental data for a number of nuclei in various mass regions. In shell-model calculations of this kind the difficulty posed by the short-range repulsion contained in all modern NN potentials is usually overcome by resorting to the Brueckner G-matrix method. Recently, a new method to renormalize the bare NN interaction has been proposed [1], which consists in constructing a low-momentum effective NN potential, $V_{\rm low-k}$, that preserves the physics of the original V_{NN} interaction up to a certain cutoff momentum Λ. The $V_{\rm low-k}$ potential is a smooth potential which can be used directly in nuclear structure calculations.

We have carried out several shell-model calculations [2,3] for nuclei around closed shells using the $V_{\rm low-k}$ approach. Attention has been focused on exotic nuclei around doubly magic ^{132}Sn, which offer the opportunity to investigate the effects of the effective interaction when approaching the neutron drip line. The experimental data are very well reproduced by the theory, showing that our effective interaction is well suited to describe these nuclei. Based on these results, we may conclude that to explain the presently available data on exotic nuclei in the ^{132}Sn region there is no need to invoke shell-structure modifications.

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Light Nuclei in the Framework of the Symplectic No-Core Shell Model

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A symplectic no-core shell model (Sym/NCSM) is constructed with the goal of extending the *ab-initio* NCSM to include strongly deformed higher-oscillator-shell configurations and to reach heavier nuclei that cannot be studied currently because the spaces encountered are too large to handle, even with the best of modern-day computers. This goal is achieved by integrating two powerful concepts: the *ab-initio* NCSM with that of the $Sp(3, R) \supset SU(3)$ group-theoretical approach. The NCSM uses modern realistic nuclear interactions in model spaces that consists of many-body configurations up to a given number of $\hbar\omega$ excitations together with modern high-performance parallel computing techniques. The symplectic theory extends this picture by recognizing that when deformed configurations dominate, which they often do, the model space can be better selected so less relevant low-lying $\hbar\omega$ configurations yield to more relevant high-lying $\hbar\omega$ configurations, ones that respect a near symplectic symmetry found in the Hamiltonian. Results from an application of the Sym/NCSM to light nuclei are compared with those for the NCSM and with experiment.

Three Center Shell Model

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The three center shell model has developed to account for the microscopic transition of a compound system into three fragments by ternary fission process. The core of the potential is based on three overlapping oscillators evolving towards three separated fragment nuclei. The level scheme submit to the transition from the initial parent spectrum, converging to independent fission fragment schemes as the distance between centers increases. The spin-orbit terms are constructed as potential dependent, thus the operators originate in the center of every of the three emitted nuclei. The interacting three level schemes are input data for the Strutinsky method in order to compute the shell corrections. Calculations are presented for different parent masses and different isospin values within isobaric systems.

Isospin Mixing and Fermi Transitions within a Mean Field Approach

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We study Fermi transitions and isospin mixing in an isotopic chain ($^{70-78}$Kr) considering various approximations that use a Skyrme-Hartree-Fock single particle basis as a starting point. We study Coulomb effects as well as the effect of BCS and quasiparticle random phase approximation (QRPA) correlations. A measure of isospin mixing in the approximate ground state is defined by means of the expectation value of the isospin operator squared in $N = Z$ nuclei (which is generalized to $N \neq Z$ nuclei). In analogy with the quantity $\langle J_\perp^2 \rangle$, which measures the amount of angular momentum mixing, we introduce the quantity $\langle T_\perp^2 \rangle_0$ as a measure of the isospin mixing in the ground state,

$$\langle T_\perp^2 \rangle_0 = \langle T_\perp^2 \rangle - \left| \frac{N-Z}{2} \right| , \tag{1}$$

with

$$\langle T_\perp^2 \rangle = \langle T^2 \rangle - \left(\frac{N-Z}{2} \right)^2 . \tag{2}$$

Taking as a reference the case of a selfconsistent mean field calculation, we have seen that in the absence of Coulomb interactions (and in the limit of small pairing correlations) the isospin-forbidden transitions (β^- in $N \leq Z$ and β^+ in $N \geq Z$) are negligible. When the isospin breaking Coulomb interaction is switched on, there is an increase of isospin-forbidden Fermi transitions. Although this increase is small, it is a signature of isospin breaking. Pairing correlations increase by orders of magnitude the isospin-forbidden Fermi transitions, a fact that is related to the isospin breaking nature of the quasiparticle mean field, which increases with increasing pairing gaps. On the other hand, the isospin breaking effects and forbidden Fermi transitions are reduced when RPA correlations are taken into account. The enhancement produced by BCS correlations is compensated to a large extent by QRPA correlations induced by isospin conserving residual interactions that tend to restore isospin symmetry.

It is also shown that the total $\beta^{\pm}$ Fermi strengths can be separated into a one-body term counting basically the number of nucleons of a given type, and a two-body term that depends on the two-body correlations (BCS and RPA). The two-body term is identical in both β^{+} and β^{-} summed strengths and the Ikeda sum rule is fulfilled as a result of their cancellation. The isospin mixing $\langle T_{\perp}^{2}\rangle_{0}$ is purely due to the net effect of the correlation terms.

Quasiparticle Properties in a Density Functional Framework

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We propose a framework to construct the ground-state energy and density matrix of an N-electron system by solving selfconsistently a set of single-particle equations. The method can be viewed as a nontrivial extension of the Kohn-Sham scheme (which is embedded as a special case). It is based on separating the Green's function into a quasiparticle part and a background part, and expressing only the background part as a functional of the density matrix. The calculated single-particle energies and wave functions have a clear physical interpretation as quasiparticle energies and orbitals.

Nucleon Resonances: Study of Their Properties Through Photo Pion Production

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In the last years a great experimental and theoretical effort has been paid to meson production from the nucleon in order to study the properties of the low-lying nucleon resonances and to assess their parameters. This research is achieved through the excitation of the resonances by means of photonic or electronic probes and the study of their decays into mesons (mainly pions). These parameters are predicted by several theoretical models of the nucleon and their resonances – lattice QCD, skyrme, bag models, constituent quark models,. . . – and have to be extracted from experiments through reaction models. The comparison of theoretical predictions from nucleonic models to the results from reaction models provide a guide to improve hadron models and to discriminate among them. In this seminar I present an effective Lagrangian model of the pion photoproduction reaction that we have recently constructed. I also present a reliable technique to assess the parameters of the nucleon resonances.

Superscaling Analyses of Inclusive Electron Scattering and Their Extension to Charge-Changing Neutrino Cross Sections in Nuclei

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Superscaling analyses of inclusive electron scattering from nuclei are extended from the quasielastic processes to the delta-excitation region. The calculations of both quasielastic and delta longitudinal and transverse response functions, as well as of (e, e') cross sections for ^{12}C at various incident electron energies are performed in approaches going beyond the mean-field approximation, such as the coherent density fluctuation model and that one based on the light-front dynamics method. The obtained scaling functions are used to predict charge-changing neutrino-nucleus cross sections. The analysis makes it possible to gain information about the nucleon correlation effects on both basic quantities of the nuclear ground state, the local density and the nucleon momentum distributions.

Superscaling in Lepton-Nucleus Scattering

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Superscaling analyses of few-GeV inclusive electron scattering from nuclei, both in the quasielastic peak and in the region where Δ-excitation dominates, allow to make reliable predictions for charge-changing neutrino reactions at energies of a few GeV, relevant for neutrino oscillation experiments. The method will be illustrated and its relation with microscopic nuclear calculations will be discussed.

Neutrino-Nucleus Quasielastic Scattering in a Relativistic Model

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A relativistic distorted-wave impulse-approximation model is applied to quasi-elastic neutrino (antineutrino)-nucleus scattering. Neutral-current and charge-current processes are considered. For the inclusive reaction a Green's function approach is presented and applied to the charge-current scattering. For the neutral-current cross sections the sensitivity to the strange content of the nucleon is investigated and the possibility to determine the strange contribution to the nucleon form factors from ratios of different cross sections is discussed.

A Study of Finale State Interaction in the ^{4}He(e,e'p)^{3}H Reaction

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The $A(e,e'p)(A-1)$ process is a promising tool to investigate the Nuleon-Nuleon(NN) correlation inside nuclei. However in order to derive an information of the NN correlation, one must inevitably consider the final state interaction(FSI). Recently we developed the treatment of the FSI on the basis of the Glauber approach and applied it to the ^{4}He$(e,e'p)$X reaction, where a possibility of deriving the NN correlation information was discussed [1]. We also include the Finite Formation Time (FFT) effects, which describe the virtuality of the hit proton, and study its influence on the ^{4}He$(e,e'p)^3$H process [2]. A review of such analysis will be given in my talk. And also the same approach (Glauber-type FSI + FFT) will be applied to the Jlab97111-kiematics of ^{4}He$(e,e'p)^3$H process and the comparison between our results and the experimental data will be discussed.

References

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First measurement of the spectral function at high energy and momentum in medium-heavy nuclei

D. Rohe for the E97-006 collaboration

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The experiment E97-006 was performed at Jefferson Lab to measure the momentum and energy distribution of protons in the nucleus far from the region of the (approximate) validity of the mean field description, *i.e.* at high momentum and energy. The occurrence of this strength attributed to short-range and tensor correlations (SRC) is long known from occupation numbers that experimentally one found to be significantly smaller than one. In the experiment reported here this strength was directly measured for the first time [1]. In a microscopic approach the contribution from secondary reactions of protons in the nucleus (rescattering) were calculated [2] and found to be small in parallel kinematics, *i.e.* initial momentum of the proton parallel to the momentum transfer. The results are compared to modern many-body theories like the Correlated Basis Function theory (CBF) [3] and the Selfconsistent Green's Function approach (SCGF) [4].

Further the transparency factor of ^{12}C was determined in the Q^2-region of 0.6 to 1.8 $(\mathrm{GeV/c})^2$. For its extraction from the data the spectral function from CBF was used for the first time instead of the spectral function from mean field theory modified by a factor to account for SRC. Even at small Q^2 the data are well described by the Correlated Glauber theory which takes into account Pauli Blocking, dispersion effects and dynamical correlations [5].

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Multistep Direct Mechanism in the ($\vec{p}$,^{3}He) Inclusive Reaction on ^{59}Co and ^{93}Nb at Incident Energies between 100 and 160 MeV

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An understanding of the mechanism of proton-induced inclusive reactions that lead to emission of complex particles is of fundamental importance. Until fairly recently most studies in the incident energy region around 100 to 200 MeV have been based on investigations of differential cross section distributions, which are rather featureless. However, analysing power proves to be a much more sensitive observable which reveals details, such as the multistep character of the reaction process. Of course, within the framework of a pre-equilibrium model, one expects a large value of the analysing power if few successive intranuclear collisions occur before the emission of a complex ejectile. Conversely, a small value of the analysing power is obtained if the number of successive collisions is large. This expectation was demonstrated to be correct in studies of the reaction ($\vec{p}$,^{3}He) by Spasova *et al.* [1] and Cowley *et al.* [2] at incident energies of 72 and 100 MeV, respectively. Although the theoretical treatment is rather basic, the intrinsic formulation in terms of statistical multistep two-nucleon pickup appears to be sound. Results will be presented for the ($\vec{p}$,^{3}He) reaction on ^{59}Co and ^{93}Nb at higher incident energies, namely 130 and 160 MeV. It will be shown that, not only are the experimental analysing power distributions still reproduced well by the theory, but that we also understand the evolution of the characteristic features of the experimental distributions as a function of incident energy.

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Calculations of Nucleus-Nucleus Microscopic Optical Potentials and the Respective Elastic Differential and Total Reaction Cross Sections

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Basing on the double-folding model and using the high-energy microscopic theory of scattering, the nucleus-nucleus optical potential is constructed [1]. Such potentials are applied in calculations of differential elastic and total reaction cross sections, and the corresponding comparisons with the experimental data are made [2]. The role of relativization, effects of the nuclear medium and the trajectory distortion of colliding nuclei on cross sections are estimated at intermediate collision energies [3]. For the best fit to experimental data the so-called semi-microscopic potentials are introduced which use two free parameters to adjust only strengths of the microscopically calculated real and imaginary parts of optical potentials. Also, comparison with the experimental total reaction cross section of exotic nuclei ^{6,8}He and ^{6,7}Li on ^{28}Si is demonstrated and discussed [4, 5].

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Chaos and $1/f$ Noise in Quantum Many-Body Systems

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Many complex systems in nature exhibit time fluctuations characterized by a power spectrum $S(f)$ which is a power function of the frequency f; dynamical systems, electronic devices, network traffic, financial data, heartbeat and DNA sequences are a few paradigmatic examples of this behaviour. In this work, it is shown that the energy spectrum of quantum systems can be formally considered as a discrete time series, with energy playing the role of time. Because of this analogy, the fluctuations of quantum energy levels can be studied using traditional methods of time series analysis, *i.e.* calculating the Fourier transform and studying the power spectrum. We have studied paradigmatic quantum systems like atomic nuclei (by means of large scale shell-model calculations) and quantum billiards, and some theoretical models, like the k-body random ensembles and the classical random matrix ensembles. We have found a general property of quantum systems: the energy spectra of chaotic quantum systems are characterized by $1/f$ noise, while regular quantum systems are characterized by $1/f^2$ noise.

The same tools of analysis can be applied to study the regularity to chaos transition. It has been found that some systems, like a class of quantum billiards, exhibit a $1/f^\alpha$ noise with the exponent α changing smoothly from $\alpha = 2$ in regular systems to $\alpha = 1$ in chaotic ones. Nevertheless, other paradigmatic systems, like the (1+2)-body random ensemble, a very useful model to study many-body quantum systems, do not follow this simple law. In this last case, the transition is not characterized by a scale-free $1/f^\alpha$ noise, but we can find instead a privileged scale in which correlations abruptly change from $1/f^2$ to $1/f$.

Finally, a similar correlation pattern has been found studying the ground-state of some many-body quantum systems. In this case, we can establish an analogy between time and a model parameter, like the number of particles in quantum many-body systems, and then we can calculate the power spectrum of the ground-state energy in terms of this parameter. The results show than it could be also a relationship between the exponent α of the power spectrum and the chaotic or regular character of the system.

Recent Developments in Non-Hermitian Quantum Mechanics

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Non-hermitian Hamiltonians are of course not unfamiliar to the nuclear physics community, both in the obvious context of absorptive processes as described *e.g.* by the optical model, and in the less obvious context of non-hermitian Hamiltonians which retain a real spectrum. The latter category had been investigated in connection with microscopic underpinnings of the Interacting Boson Model (IBM) via so-called generalized Dyson mappings.

More recently much work has been done in the context of PT-symmetric quantum mechanics with the identification of a class of non-hermitian Hamiltonians where reality of the spectrum may be linked to invariance under simultaneous parity and time reversals. It turns out that a consistent quantum mechanical framework may be retained for such Hamiltonians by adopting a modified inner product based on a non-trivial metric.

In the context of boson mappings this was already analysed in depth by Scholtz, Geyer and Hahne in a 1992 paper, *Ann. Phys.* (NY) **213** (1992) 74. We will discuss the role and construction of a metric in so-called quasi-hermitian quantum mechanics, how this links to developments in PT-symmetric quantum mechanics, and if this allows new avenues in *e.g.* IBM type phenomenology to be explored.

Collective Modes in Nuclei: an Exact Microscopic Multiphonon Approach

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We propose a method for solving the nuclear eigenvalue problem using a Hamiltonian of general form in a space spanned by multiphonon states built out of particle-hole Tamm-Dancoff phonons. The method consists in deriving for a given n-phonon subspace a set of equations of motion of simple structure, where all quantities are expressed in terms of energies and one-body density matrices determined in the $(n-1)$-phonon subspace. Their solution, therefore, yields states built out of particle-hole operators applied on top of the $(n-1)$-phonons basis states. Because of this peculiar structure, the states so generated form an overcomplete set. The redundancy, however, is removed completely and efficiently by a procedure based on the Choleski decomposition. The phonon composition of the basis states allows to remove naturally and maximally the spurious admixtures induced by the center of mass motion. The iteration of the equations from $n = 0$ up to an arbitrary number N of phonons generates an orthogonal basis spanning a space which is the direct sum of $0 + 1 + .. + N$ phonon subspaces. This basis decomposes the full Hamiltonian into N diagonal blocks plus off-diagonal terms coupling the n-phonons with the ($n \pm 1$)- and ($n \pm 2$)-phonon subspaces. These off-diagonal terms are computed by recursive relations. The Hamiltonian can, therefore, be diagonalized by resorting to importance sampling techniques [1,2], which allow to truncate the multiphonon space while monitoring the accuracy of the solutions.

The method can be easily upgraded so as to generate a particle-hole or quasiparticle RPA multiphonon basis. It is suitable for describing with high accuracy low-lying multiphonon spectra, whose experimental evidence is rapidly growing, as well as high-energy resonances like the recently discovered double dipole giant resonance. It can account with great accuracy for the anharmonicities associated with all collective modes. Last, but not least, it yields a highly correlated ground state which contains explicitly up to N particle - N hole configurations and, therefore, applies to the cases where the quasiboson approximation breaks down.

For illustrative purposes, we apply the method to ^{16}O, whose low-lying states are dominated by complex configurations containing up to 4 particle – 4 hole states. Such a calculation probes the accuracy of the method, on the one hand, and, on the other hand, provides a detailed information on the microscopic structure of low and high energy states in ^{16}O.

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Ground State Correlations and Structure of Odd Spherical Nuclei

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The quasiparticle-phonon nuclear model (QPM) is widely used for the description of the energies and fragmentation of nuclear excitations at intermediate and high energies. The QPM equations for odd spherical nuclei accounting for the interaction between quasiparticles and phonons, enable one to describe the structure of the low lying states with a reasonable accuracy. It is well known, however, that the Pauli principle plays a substantial role at low energies because the phonon operators are not ideal bosons. Taking the exact commutators between the quasiparticle and phonon operators one can consider the Pauli principle corrections. Besides the ground state correlations due to the quasiparticle interaction in the ground state influence the single particle fragmentation as well. In this paper, we generalize the basic QPM equations to account for both effects mentioned. As an illustration of our approach, calculations on the structure of the low lying states in ^{131}Ba have been performed.

Rotation Modes in the Dinuclear Model

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The dinuclear system concept assumes two touching nuclei (clusters) which keep their individuality and can exchange nucleons [1]. The system has the collective degrees of freedom of the relative motion between the nuclei, the mass asymmetry motion by exchanging nucleons, the rotation-oscillations of the deformed nuclei with respect to the internuclear axis and $\beta-$ and $\gamma-$vibrations of the individual nuclei. Until now the mass asymmetry degree was successfully applied to the description of the properties of alternating parity bands in rare-earth and actinide nuclei [2] and to normal and superdeformed bands of ^{60}Zn [3], ^{190,192,194}Hg and ^{192,194,196}Pb [4].

Here we present a new treatment which includes both the mass asymmetry degree of freedom and the rotation-oscillations of deformed clusters (bending modes). The basis states used for diagonalizing the Hamiltonian are characterized by the quantum numbers of the total angular momentum, of the angular momenta of the rotation of the individual clusters and of the molecular states in the mass asymmetry motion. As first applications we plan to calculate the spectra of lighter nuclei as ^{60}Zn and those of certain actinides.

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High Order Angular Momentum Dependence of a Nuclear Rotation Hamiltonian

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A nuclear Hamiltonian with high order terms in collective angular momentum operators is constructed by applying the method of contact transformations to a Hamiltonian including intrinsic particle motion and Coriolis interaction. The properties of the Hamiltonian with respect to the time reversal transformation are examined. It is shown that the coefficients in the different collective angular momentum powers are related to matrix elements depending on the intrinsic angular momentum operators. The coefficients have strictly determined symmetry properties with respect to the time reversal operation. The developed formalism gives an insight into the intrinsic origin of the high order effects in rotation motion of nuclei with complex shape deformations.

Description of Parity-Doublet Splitting in Odd-A Nuclei

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A collective axial quadrupole–octupole Hamiltonian is used to describe the rotation–vibration motion of odd nuclei with a Coriolis coupling between the even-even core and the unpaired nucleon state. It is considered that the core oscillates coherently with respect to the quadrupole and octupole axial–deformation variables. The coupling between the core and the unpaired nucleon provides a split parity-doublet structure of the spectrum. The model formalism successfully reproduces the parity-doublet splitting in odd-A isotopes of the nuclei Pm, Fr, Ac, Ra, Th, U, Pu, Am, Cm and Bk. The calculations provide a detailed analysis of the band structures with estimations of the third angular momentum projection K, indications of the change in the intrinsic parity, as well as predictions of energy levels that can be observed in future experiments.

Nucleon Structure and Generalized Parton Distributions

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After fifty years of intensive theoretical and experimental studies, the structure of the nucleon still keeps a lot of secrets. Historically, elastic electron scattering off proton has first revealed the non-point-like nature of the nucleon. In these experiments, the proton structure is parametrized in terms of electromagnetic form factors corresponding to the Fourier transforms of the charge and the current densities inside a volume which size is comparable to the wave lenght of the probing virtual photon. In parallel to the advent of Quantum Chromo-Dynamics, deep inelastic scattering of unpolarized and polarized electrons has revealed the composite nature of the nucleon. It appears as an assembly of quarks and anti-quarks interacting via gluon exchange and confined in the nucleon. This structure is described by parton and helicity distribution functions essentially depending on the momentum fraction carried by partons. These experiments have shown that the nucleon momentum is roughly equally spread between quarks and gluons and led to the surprising result that quarks carry only 20-25% of the nucleon spin.

Though these observables are characteristic of the same physics content, there is no explicit link between electromagnetic form factors and parton distributions. It is only recently that the unified description of the nucleon structure in terms of Generalized Parton Distributions (GPDs) has provided a conceptual link. GPDs represent the interference between amplitudes describing different quantum states and describe the correlations between quarks. They carry spatial and momentum information, therefore providing an access to the total angular momentum of the quarks. This talk will review the GPDs framework and its benefit for the study of the nucleon structure. Particular emphasis will be put on the present and future experimental program investigating GPDs in deep exclusive scattering of polarized leptons.

Dynamical Symmetries Reflected in Realistic Interactions

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Realistic nucleon-nucleon (NN) interactions, derived within the framework of meson theory or more recently in terms of chiral effective field theory, yield new possibilities for achieving a unified microscopic description of atomic nuclei. Based on spectral distribution methods, a comparison of these interactions to a most general $\mathrm{Sp}(4)$ dynamically symmetric interaction, which previously we found to reproduce well that part of the interaction that is responsible for shaping pairing-governed isobaric analog 0^+ states, can determine the extent to which this significantly simpler model Hamiltonian can be used to obtain an approximate, yet very good description of low-lying nuclear structure. And furthermore, one can apply this model in situations that would otherwise be prohibitive because of the size of the model space. In addition, we introduce a $\mathrm{Sp}(4)$ symmetry breaking term by including the quadrupole-quadrupole interaction in the analysis and examining the capacity of this extended model interaction to imitate realistic interactions. This provides a further step towards gaining a better understanding of the underlying foundation of realistic interactions and their ability to reproduce striking features of nuclei such as strong pairing correlations or collective rotational motion.

Generalization of Richardson-Gaudin Models to Rank 2 Algebras

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We generalize the Richardson-Gaudin (RG) exactly solvable models based on SU(2) and SU(1,1) rank 1 algebras to rank 2 algebras. We will present the complete set of integrals of motion for the SU(3), SO(5) and SO(3,2) algebras, from which large classes of integrable hamiltonians can be derived. In particular, we study the SO(5) and SO(3,2) integrable models giving rise to the isovector proton-neutron pairing model and to the proton-neutron Interacting Boson Model 2 (IBM2) respectively.

The exact solution of the rank 2 RG models involves expressions for the common set of eigenvectors of the integrals of motion and the corresponding eigenvalues in terms of a set of parameters (pair energies) which satisfy a system of nonlinear coupled equations (Richardson equations). The general exact solution includes the seniority quantum number and the reduced isospin of the unpaired particles, as well as symmetry breaking isospin or F-spin terms.

These exactly solvable models allow the treatment of systems whose dimensions largely exceed the limits of a Lanczos diagonalization. Making use of this advantage, we include high spin bosons in the IBM2 calculations. In particular, g-bosons has been proposed to explain some intruder states, such as the first three 4^+ state in ^{192}Os. We will show the spectra of a chain of isotopes in which mixed symmetry states have been experimentally found, with and without the addition of a g-boson.

Finally, we will discuss how the isospin breaking term in the case of SO(5) or the F-spin breaking term in the case of SO(3,2) affects the pair energies and the occupation numbers.

Description of the Odd Mass Nuclei within the Framework of the Interacting Vector Boson Model

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A supersymmetric extension of the dynamical symmetry group $Sp^B(12, R)$ of the symplectic Interacting Vector Boson Model to the orthosymplectic group $OSp(4/12, R)$ is presented in order to incorporate fermion degrees of freedom into nuclear dynamics and encompasses the treatment of odd mass nuclei. The bosonic sector of the supergroup is used to describe the complex collective spectra of the neighboring even-even nuclei and is considered as a core structure of the odd nucleus, while through its fermionic sector the fermion spin group $SU^F(2) \subset O(4)$ is involved into the algebraic considerations. One of the new exactly solvable limiting cases which arise is applied for the examination of the nuclear collective spectra of odd mass nuclei. The theoretical predictions for different collective bands in odd mass nuclei from the actinide region are compared with the experiment. The obtained results reveal the applicability of the model.

In this new application the algebras associated with the bosonic and fermionic components of the nuclear systems are unified in the superalgebra which might be further used to examine the correlations between the spectroscopic properties of neighboring even-even, odd-even, odd-odd nuclei and the underlying supersymmetry in nuclei.

Correlations in the Interaction of Ion Beams with Matter

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Heavy-ion collisions can be simulated through Monte Carlo approaches, to include the many different reaction mechanisms that can occur, which depend on the impact parameter, the bombarding ion incident energy and the reaction asimmetry. The relative occurrence and correlation among different mechanisms, such as deep-inelastic scattering, binary fragmentation, knock-on and pick-up reaction processes, follow in a natural way from Monte Carlo calculations. QMD models and their relativistic extensions are examples of such a kind of comprehensive approaches. They follow nuclear phase-space evolution during each ion-ion collision event, by correlating the coordinates of each nucleon to those of all other nucleons. Their fermionic versions are even more interesting from a theoretical point of view, since they fully describe the fermionic nature of nuclei through nuclear wave-function antisymmetrization. Unfortunately at present, due to their complexity, these approaches can not be conveniently applied in a practical and systematic way to simulate heavy-ion collisions occurring in application problems (e.g. shielding project, dose calculation), which have to be addressed by general purpose tools describing beam propagation and interaction in matter of whichever composition. In this talk results are shown obtained by coupling a new version of a QMD code, which describes the fast stage of ion-ion collisions, to the evaporation/fission/Fermi break-up routines present in the FLUKA multipurpose Monte Carlo transport and interaction code. In particular, we compare the predicted neutron and fragment production yields and cross-sections to available experimental data from thin and thick targets. In the calculation only a few QMD parameters, concerning nucleon-nucleon interaction potential and nucleon wave-packet gaussian width, are adjusted to reproduce the data. The role of these parameters is investigated and their relation with the nuclear matter equation of state is discussed.

Evidence for X(5) Critical Point Symmetry in ^{128}Ce

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We report a study of the electromagnetic properties of the ground-state (gs) band of ^{128}Ce which is considered as a candidate for X(5) critical point symmetry based on comparison of the ratios of the energies of the levels within the gs band to values predicted in the framework of X(5). Lifetimes of excited states in ^{128}Ce were measured using the recoil distance Doppler-shift (RDDS) and the Doppler-shift attenuation (DSAM) methods. The experiment was performed at the ESTU tandem accelerator at the Wright Nuclear Structure Laboratory of Yale University. Excited states in ^{128}Ce were populated in the ^{100}Mo(^{32}Si,4n) reaction at 120 MeV and the nuclear γ decay was measured with an array of eight Clover detectors positioned at forward and backward angles. The deduced transition strength within the gs band of ^{128}Ce follows the X(5) limit. Thus, we suggest ^{128}Ce as a benchmark X(5) nucleus in the mass $A \approx 130$ region. Systematic comparison of the properties of nuclei in this region will be presented, too.

The X(3) Model and Its Connection to the Shape/Phase Transition Region of the Interacting Boson Model

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A γ-rigid version (with $\gamma = 0$) of the X(5) critical point symmetry is constructed. The model, to be called X(3) [1] since it is proved to contain three degrees of freedom, utilizes an infinite well potential, is based on exact separation of variables, and leads to parameter free (up to overall scale factors) predictions for spectra and $B(E2)$ transition rates, which are in good agreement with existing experimental data for ^{172}Os and ^{186}Pt. The predictions of X(3) are furthermore compared to two-parameter calculations in the framework of the Interacting Boson Approximation (IBA) model. The results show [2] that X(3) coincides with IBA parameters consistent with the phase/shape transition region of the IBA. The same turns out to hold [2] also for the parameter independent (up to overall scale factors) predictions of the X(5)-β^2 and X(5)-β^4 models [3], which are variants of the X(5) critical point symmetry developed within the framework of the geometric collective model, manifested experimentally in ^{146}Ce, ^{174}Os, and ^{158}Er, ^{176}Os respectively.

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Nuclear Structure Calculation in Large Domain of Excitation Energy

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The microscopic quasiparticle-phonon model (QPM) is applied to study the properties of the excited states of atomic nuclei in large domain of excitation energy. The following topics are included:

1. The correlation entropy as a measure of the complexity of high- lying single-particle mode.
2. Microscopic description of mixed-symmetry states.
3. Dipole excitations – low-lying, Pygmy resonance *etc*.

Pygmy Resonances in Tin Isotopic Chain

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A finite rank approximation of Skyrme type force, was propoced several years ago [1, 2]. Within this method it is possible to avoid some complications connected with the diagonalization of large model Hamiltonian in a large configurational space. This approximation was used for calcultion of excited states of varios nuclei [2].

Recently, the dipole excitations in nuclei, having excitation energy near the neutron separation energy have been studied [3, 4]. These excited states, known as Pygmy resonances, are slightly collective (the contribution of the excitations in EWSR is around one percent) and the collectivity increases with enlargement of the neutron excess. The experimental information concerning Pygmy resonances is available for tin isotopes. The tin isotopic chain includes a lot of nuclei in the domain between neutron magic numbers 50 (^{100}Sn) and 82 (^{132}Sn). Because of that the tin isotopic chain gives the opportunity to study the dependence of the properties of Pygmy resonance on the neutron excess.

We have calculated the properties of Pygmy resonance,using finit range approximation for the tin chain. The structure of the excited states was calculated using "quasiparticle random phase approximation". A Skyrme-type interaction has been used as residual particle-hole interaction. Several parameterizations of the Skyrme force were used.

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The Highest Energies in the Universe

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There are not many issues of fundamental importance which have induced so many problems for astrophysicists like the question of the origin of cosmic rays. This radiation from the outer space has an energy density comparable with that of the visible starlight or of the microwave background radiation. It is an important feature of our environment with many interesting aspects. A most conspicuous feature is that the energy spectrum of cosmic rays seems to have no natural end. In fact the highest particle energies ever observed on the Earth, stem from observations of ultrahigh energy cosmic rays. But the present observations, partly a matter of debate, are origin of a number of puzzling questions, where these particles are coming from, by which gigantic acceleration mechanism they could gain such tremendous energies and how they have been able to propagate to our Earth. These questions imply serious problems of the understanding of our Universe. There are several approaches to clarify the mysteries of the highest energies and to base the observations on larger statistical accuracy. The Pierre Auger Observatory, being in installation in the Pampa Amarilla in the Province Mendoza in Argentina, is a hybrid detector, combining a large array of water Cherenkov detectors (registering charged particles of giant extended air showers) with measurements of the fluorescence light produced during the air shower development.

The talk will illustrate the astrophysical motivation and sketch the current status of the experimental effort and of the ideas about the origin of these particles.

The Flux and the Charge Ratio of the Atmospheric Muons and Neutrinos

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The atmospheric muons are produced by interactions of primary cosmic rays particles with the Earth's atmosphere, mainly by the decay of pions and kaons generated in hadronic interactions. They decay further on in electrons and positrons accompanied by electronic and muonic neutrinos with a half-life of 2.2 μs. The flux and the muon charge ratio, the ratio of positive to negative atmospheric muons, carry information which controls calculations of the neutrino fluxes and the hadronic interactions of the parent particles. Thus, the muon charge ratio provides relevant information for the so called neutrino anomaly. In addition, the knowledge of local flux of atmospheric muons is crucial for various astrophysical, environmental and material research studies.

WILLI is a rotatable stack of scintillators detectors, which allows measurements of the charge ratio of low energy atmospheric muons, incident under different zenithal and azimuthal angles by observing the lifetime of the stopped positive and negative muons. The measured data of the energy and the angle dependence of the muon charge ratio, which displays a pronounced East–West effect due to the influence of the geomagnetic field control advanced Monte Carlo simulations of the flux of atmospheric muons and neutrinos. They can be used to scrutinize the high – energy hadronic interaction models which are currently en vogue as generators in the Extensive Air Shower Monte Carlo simulation program CORSIKA. We present results of extensive CORSIKA simulations, taking explicitly into account the solar modulation of the flux of primary cosmic rays, the geomagnetic field and its cut off, and we compare with recent measurements of atmospheric muon flux and charge ratio for various sites of different geomagnetic coordinates.

Additionally, the muon flux as predicted by CORSIKA simulations is compared with simple semi-analytical approximations, usually used to account for the atmospheric muon flux in different applications.

Clustering in Fragmentation of Relativistic Nuclei

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The degree of the dissociation of the relativistic nuclei in peripheral interactions can reach a total destruction into nucleons and singly and doubly charged fragments. In spite of the relativistic velocity of motion of the system of fragments as a whole, the relative motion of fragments is non-relativistic one. The invariant presentation makes it possible to extract qualitatively new information about few-cluster systems from fragmentation of relativistic nuclei in peripheral interactions. The emulsion technique allows one to observe these systems to the smallest details and gives the possibility of studying them experimentally [1].

References

[1] Web site of the BECQUEREL Project, `http://becquerel.jinr.ru`.

Interactions of Relativistic ^{8}B Nuclei with Photoemulsion Nuclei

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In the present paper, experimental observations of the multifragmentation processes of relativistic nuclei ^{8}B with the momentum 2.0 A GeV/c per nucleon carried out by means of emulsions are investigated. The main features of these interactions – mean range of free path ^{8}B nuclei, fragmentation channels and mean transverse momenta of projectile fragments are measured. The type of events called "white" stars in which the dissociation of relativistic nuclei is not accompanied by the production of mesons and the target-nucleus fragments are considered.

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Effects Induced by Nuclear Motion and by Nuclear Structure on the Ground State Energies of 1s-Helium Isoelectronic Series

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The non-relativistic energy magnitudes for the ground state of 1s-Helium isoelectronic series for the main nuclides, with atomic number Z from 2 to 54 are calculated. Calculations are performed using an explicitly correlated trial wave-function of the generalized Hylleraas type. We have developed a variational procedure which allows solving of two-particle Schrodinger equation for practically unlimited number of parameters in a series of trial wave-functions along the positive degrees of Hylleraas coordinates.

Taking into account of the nuclear motion in the two-electron Schrodinger equation leads on an introduction of both corrections: the mass correction, determined by nuclear mass and the mass polarization correction which is connected with the position of the electrons.

In order to investigate the contribution of the nuclear motion in forming the energies of the electron system, the mass correction and the so-called mass-polarization correction are calculated. Dependence upon the atomic number Z and the mass number A of the electron system energy, without and with this corrections, is studied..

In order to investigate the role of nuclear structure in forming the energies of electron system, we performed calculations of the energies together with the mass corrections for all existing isotopes of the elements with atomic number Z from 2 to 54. For each value of Z, the dependence of the energy upon the neutron number within nucleus, is investigated. For a number of fixed Z values, we set the staggering effects in respect to the mass numbers A (*i.e.* the staggering pattern). The observed staggering effects indicate correlations between the electron energies and several nuclear magic numbers.

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