ABSTRACTS

of the XXIV International Workshop on Nuclear Theory

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PROGRAMME

Monday, June 20

Morning session

09:30 – 10:00 Opening of the Workshop and Talk of *Prof. Yordan Stamenov*

10:00 – 10:20 *Coffee*

10:20 – 11:05 *Anthony Cowley*: The (p,2p) Knockout Reaction to Discrete Final States and Implications for Rescattering Processes

11:15 – 12:00 *Anton Antonov*: Nucleon Momentum Distributions in Nuclei from the Superscaling in Inclusive Electron Scattering

12:10 – 12:55 *Emil Běták*: Complex Particle Emission - Statistical Picture of Direct Reaction

16:30 – 17:00 *Coffee*

Afternoon session

17:00 – 17:45 *Sergio Scopetta*: ^{3}He Structure and Generalized Parton Distributions

17:55 – 18:40 *Frans Arickx*: A Three-Cluster Microscopic Model for the ^{5}H Nucleus

18:50 – 19:35 *Victor Vasilevsky*: A Microscopic Model for Cluster Polarization, Applied to the Resonances of ^{7}Be and the Reaction ^{6}Li(p,^{3}He)^{4}He

Tuesday, June 21

Morning session

09:30 – 10:15 *Heinz V. von Geramb*: The Surface Between QCD and Baryon Nuclear Physics

10:15 – 10:35 *Coffee*

10:35 – 11:20 *Francesco Cerutti*: Intermediate Mass Fragment Production in Light Ion Reactions

11:30 – 12:15 *Stelios Massen*: Information Entropy and Nucleon Correlations in Nuclei

12:25 – 13:10 *Dennis Bonatsos*: Analytic Description of Critical Point actinides and Rare Earths in a Transition from Octupole Deformation to Octupole Vibrations

15:30 – 16:00 *Coffee*

Afternoon session

16:00 – 16:20 *Dimitris Lenis*: Z(4): γ-rigid Solution of the Bohr Hamiltonian for $\gamma = 30^{\circ}$ Compared to the E(5) Critical Point Symmetry

16:20 – 16:40 *Dimitris Petrellis*: Critical Point Symmetries Derived from Davidson Potentials through a Variational Procedure

16:50 – 17:10 *Nikolay Minkov*: Nuclear Shape Dynamics in an Angular Momentum Dependent Potential of Quadrupole and Octupole Deformation Variables

17:10 – 17:30 *Ana Georgieva*: Transitional Nuclear Spectra within the Framework of IVBM with 6-Dimensional Davidson Potential

17:40 – 18:00 *Huben Ganev*: Electromagnetic Transitions in the Symplectic Extension of Rotational Limit of the Interacting Vector Boson Model

18:00 – 18:20 *Vladimir Garistov*: Analysis of New Experimental Data on ^{160}Dy Spectrum with Interacting Vector Boson Model

18:30 – 19:00 *Galya Deyanova*: Study of Exited States in ^{154}Gd with AFRODITE Spectrometer

Wednesday, June 22

Morning session

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10:15 – 10:35 *Coffee*

10:35 – 11:20 *Vladimir Kukulin*: Dibaryonic Deegrees of Freedom in Hadronic and Nuclear Physics

11:30 – 12:15 *Eduardo Lanza*: Multiphonon Excitations in Heavy Ion Collisions

12:25 – 13:10 *Evgeny Balbutsev*: The Nuclear Scissors Mode within Two Approaches (Wigner Function Moments Versus RPA)

15:30 – 16:00 *Coffee*

Afternoon session

16:00 – 16:40 *Lorenzo Fortunato*: Exact Solutions of the Bohr Hamiltonian and Symmetries of the Collective Model

16:50 – 17:10 *Alexander Andreev*: Cluster Aspects of Binary and Ternary Fission

17:10 – 17:30 *Andrea Mairani*: Emission of intermediate-mass fragments in the Interaction of Carbon and Oxygen with Heavy Ions

17:40 – 18:00 *Massimiliano Alvioli*: A Realistic Calculation of the Effects of Nucleon-Nucleon Correlations in High-Energy Scattering Processes Off Nuclei

18:00 – 18:20 *Dimitre Kadrev*: Charge and Matter Distributions and Form Factors of Light, Medium and Heavy Neutron-Rich Nuclei

18:30 – 19:00 *Liliya Atanasova*: High-Spin States in ^{185}Ir

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E X C U R S I O N

Friday, June 24

Morning session

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10:35 – 11:20 *Lubomir Penchev*: Two-Photon Exchange Effects in the Proton Form Factors Measurements at Jefferson Lab

11:30 – 12:15 *Vina Punjabi*: Jefferson Lab Experiments Shed New Light on the Proton

12:25 – 13:10 *Isabelle Deloncle*: New Clues for the B(E2: $0_1^+ \rightarrow 2_1^+$) Behavior around ^{68}Ni: Seniority and p-n Interaction

13:10 – 13:30 *Sevdalina Dimitrova*: Isoscalar and Isovector Pairing within the SO(5) Richardson-Gaudin Exactly Solvable Model

The (p,2p) Knockout Reaction to Discrete Final States and Implications for Rescattering Processes

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At incident energies below approximately 400 MeV our understanding of the mechanism by means of which the (p,2p) reaction to discrete final states proceeds is mainly based on a distorted-wave impulse-approximation (DWIA) theory. The success of the DWIA in reproducing experimental observables over a relatively large range of incident energies for various target nuclei will be presented. It will also be demonstrated that the formalism successfully describes the knockout process over a large range of kinematic conditions. Approximations that need to be introduced for practical implementation of the theory could in principle affect the results adversely, but it will be shown that there is not any reason for undue concern in this regard.

It is known that at these moderate incident energies knockout to discrete final states constitutes only a small part of the reaction cross section for two coincident protons emerging from the reaction. Therefore it is tempting to speculate that a large fraction of the observed inclusive yield of coincident protons would originate from a process in which one or both partners in an initial intranuclear collision undergo further rescattering with energy transfer to the spectator part of the target nucleus. Consequently, instead of observing the reaction with a clear (p,2p) signature, the reaction will lead to a distribution of emerging protons that only vaguely retain features of the driving knockout process. Furthermore, to indicate this rescattering, it is more appropriate to indicate the reaction as (p,$p'p''$). Evidence for the validity of such an interpretation of the reaction process will be reviewed.

Nucleon Momentum Distributions in Nuclei from the Superscaling in Inclusive Electron Scattering

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The scaling functions $f(\psi')$ and $F(y)$ from the ψ'- and y-scaling analyses of inclusive electron scattering from nuclei are constructed within the Coherent Density Fluctuation Model (CDFM) [1, 2] which is related to the delta-function limit of the Generator Coordinate Method. The CDFM is used in two equivalent formulations based on either the local density distribution or the nucleon momentum distribution (NMD). Both functions $f(\psi')$ and $F(y)$ are calculated [2] using different NMDs and are compared with the experimental data for a wide range of nuclei. The calculations show that the high-momentum components of NMD in the CDFM and their similarity for different nuclei lead to quantitative description of the superscaling in nuclei. The good description of the data for $y < 0$ and $\psi' < 0$ (including $\psi' < -1$ in contrast to the Relativistic Fermi-gas Model results) makes it possible to show the sensitivity of the calculated scaling functions to the peculiarities of the NMDs in different regions of momenta. It is concluded that the available data on ψ'- and y-scaling are informative for NMDs at momenta not larger than 2.0–2.5 fm^{-1} [2]. The CDFM allows us to study simultaneously and on the same footing the role of both basic quantities, the momentum and density distributions, for the description of scaling and superscaling in nuclei.

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Complex Particle Emission — Statistical Picture of Direct Reactions

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Whereas the emission of nucleons in low-energy nuclear reactions (say, below the pion threshold) can be nicely described using statistical models (compound nucleus plus pre-equilibrium), that of the complex particles, *i.e.* light clusters up to α's, is far from satisfactory state. The main reason is – apart of very specific properties of the clusters themselves – that different types of direct reactions, like pickup, knockout and others, play an essential role. In the absence of more justified approaches, phenomenological ones are frequently applied, with very little (or no) physics in their background. We suggest a statistical description which is capable to incorporate the main features of direct reactions leading to the cluster emission, but – obviously, as any other statistical approach – pays for that generality by loosing details of nuclear structure and their manifestation in individual reactions.

^{3}He Structure and Generalized Parton Distributions

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The knowledge of Generalized Parton Distributions (GPDs) of nuclei would represent a unique tool to investigate the interplay of nucleon and parton degrees of freedom in the nuclear wave function [1]. A relevant experimental effort aimed at the measurement of GPDs is likely to take place. The study of GPDs of ^{3}He, for which conventional nuclear effects can be safely calculated, is particularly relevant. For this nucleus, strong deviations from the predicted behaviour could be ascribed to effects not included in its standard description. Besides, ^3He could be used as an effective neutron target, especially in the polarized case, to obtain information on the GPDs of the free neutron. In this talk, a realistic calculation of the unpolarized quark GPD H_q^3 of the ^{3}He nucleus is presented [2]. In Impulse Approximation, H_q^3 is obtained as a convolution between the GPD of the internal nucleon and the non-diagonal spectral function, describing properly Fermi motion and binding. The obtained formula has the correct forward limit, corresponding to the usual nuclear parton distributions, and first moment, giving the charge form factor of ^{3}He.

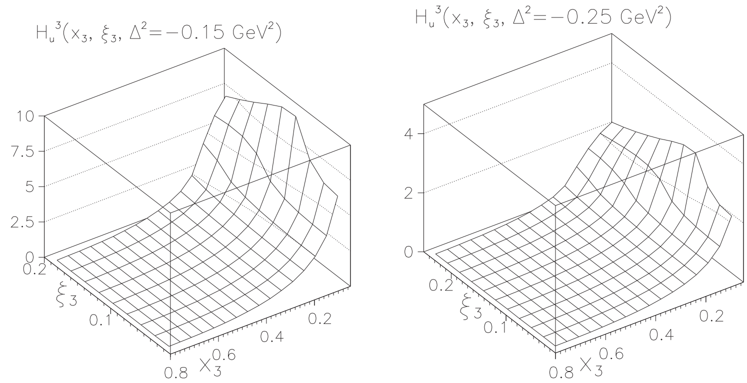

Figure 1: As an ilustration, the GPD $H_u^3(x, \xi, \Delta^2)$ of ^{3}He, for the flavour u, is shown, in the $\xi_3 = 3\xi$ range allowed at $\Delta^2 = -0.15$ GeV^2 (left) and at $\Delta^2 = -0.25$ GeV^2 (right).

Nuclear effects, evaluated by the AV18 interaction, are found to be larger than in the forward case; they increase with increasing Δ^2 at fixed asymmetry ξ, and with ξ at fixed Δ^2. Another relevant feature of the obtained results is that the nuclear GPD cannot be factorized into a Δ^2-dependent and a Δ^2-independent term. Prescriptions proposed for finite nuclei are found to give results at variance with the present approach. The relevance of the obtained results to study the feasibility of DVCS experiments is discussed.

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A Three-Cluster Microscopic Model for the ^{5}H Nucleus

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The study of the states, and their properties, of nuclei with large proton or neutron excess is a challenge in experimental and theoretical nuclear physics. Usually these states manifest themselves as resonances in multi-cluster continua. The theoretical investigation of in multi-cluster resonances requires the formulation of a model that takes the proper boundary conditions for the decay of the nucleus on three and more fragments into account.

In [1] we formulated a fully microscopic approach to study resonances embedded in a three-cluster continuum, and reactions with three clusters in exit channels. It was shown in [2, 3] that this approach is very suitable for the description of bound states of the Borromian nucleus ^{6}He and the three-cluster continuum of ^{6}He and ^{6}Be.

Our current aim is to study the resonance states in ^{5}H, and possible ways for their experimental identification. We want to do this within the microscopic model, formulated in [1]. In this model the wave function has the form

$$\Psi_{JM} = \widehat{A}\left\{\left[\Phi\left(^3\mathrm{H}\right)\chi_1\left(n\right)\chi_2\left(n\right)\right]_S f_{LJ}\left(\mathbf{q}_1,\mathbf{q}_2\right)\right\}_{JM}, \tag{1}$$

where $\Phi\left(^3\mathrm{H}\right)$ is an antisymmetric shell-model wave function describing the internal motion of the ^{3}H nucleus and $\chi_i\left(n\right)$ is a spin-isospin wave function of i-th neutron ($i = 1, 2$). The Jacobi vectors $\mathbf{q}_1$ and $\mathbf{q}_2$ define the distances between clusters.

In order to implement the proper boundary conditions for the three-cluster continuous spectrum states, and define the S matrix to describe processes in the three-cluster continuum, we make use of hyperspherical harmonics (see details in [1–3]):

$$f_{LJ}\left(\mathbf{q}_1,\mathbf{q}_2\right) = \sum_{n_\rho}\sum_{K:l_1,l_2} C_{n_\rho;K:l_1,l_2} R_{n_\rho;K}\left(\rho\right) U_{K;l_1,l_2;L}\left(\theta,\widehat{\mathbf{q}}_1,\widehat{\mathbf{q}}_2\right)$$

where $\theta, \widehat{\mathbf{q}}_1, \widehat{\mathbf{q}}_2$ are the hyperspherical angles and ρ is the hyperspherical radius.

We used different NN forces to determine the interaction between the clusters ^{3}H+n and $n+n$, and to study the effects of the form of NN potential on the position and decay time of resonances in ^{5}H. We also consider the impact of the spin-orbital components of the NN force on the properties of the resonances states. To obtain stable and converged results for the energy and width of a sufficient number of resonances, a distributed computational approach is developed to allow for high K-values to be considered.

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A Microscopic Model for Cluster Polarization, Applied to the Resonances of ^{7}Be and the Reaction ^{6}Li(p,^{3}He)^{4}He

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As many of the light nuclei are weakly bound, they can change their size and shape when interacting with other nuclei. We refer to this phenomenon as cluster polarization. One expects cluster polarization to play an important role in reactions which involve light nuclei with small separation energy such as the deuteron, ^{6}Li, ^{7}Li, and so on. It may be more pronounced for small energies of the colliding nuclei.

To take into account cluster polarization we have formulated a three-cluster model in which the wave function is constructed in the form

$$\Psi=\widehat{A}\{\Phi_1(A_1)\,\Phi_2(A_2)\,\Phi_3(A_3)\,[f_1(\mathbf{x}_1,\mathbf{y}_1)+f_2(\mathbf{x}_2,\mathbf{y}_2)+f_3(\mathbf{x}_3,\mathbf{y}_3)]\}\,, \qquad (2)$$

where $\Phi_i\left(A_i\right)$ are shell-model wave functions describing the internal motion of cluster i ($i=1,2,3$), and $f_i\left(\mathbf{x}_i,\mathbf{y}_i\right)$ are Faddeev components. The Jacobi vectors $\mathbf{x}_i$ and $\mathbf{y}_i$ define the distance between the j and k clusters, and the distance between cluster i and the center of mass of the j and k clusters; the indexes i,j,k form cyclic permutations of 1, 2, 3. Each Faddeev component $f_i\left(\mathbf{x}_i,\mathbf{y}_i\right)$ is expanded on combined Gaussian and oscillator bases

$$f_i\left(\mathbf{x}_i,\mathbf{y}_i\right)=\sum_{\sigma=1}^{N_G}\sum_{\nu=1}^{N_G}\sum_{n=0}^{\infty}C_\nu^{(\sigma;G)}\phi\left(\mathbf{x}_i,b_\nu\right)\Phi_n\left(\mathbf{y}_i,b\right),$$

where

$$\phi\left(\mathbf{x}_i,b_\nu\right)=\sqrt{\frac{2}{\Gamma(\lambda_i+3/2)}}\left(\frac{1}{b_\nu}\right)^{3/2}\left(\frac{x_i}{b_\nu}\right)^{\lambda_i}\exp\left\{-\frac{1}{2}\frac{\mathbf{x}_i^2}{b_\nu^2}\right\}\cdot Y_{\lambda_i\mu_i}\left(\widehat{\mathbf{x}}_i\right)$$

is a Gaussian function, and

$$\Phi_n\left(\mathbf{y}_i,b\right)=(-1)^n\sqrt{\frac{2\,(n!)}{\Gamma(n+l_i+3/2)}}\frac{1}{b^{3/2}}\,\rho^{l_i}\exp(-\frac{1}{2}\rho^2)\times$$
$$\times\,L_n^{l_i+\frac{1}{2}}(\rho^2)\cdot Y_{l_im_i}\left(\widehat{\mathbf{y}}_i\right),\quad (\rho=\frac{y_i}{b})$$

is an oscillator function. The $\left\{C_\nu^{(\sigma;G)}\right\}$ are eigenfunctions of the two-cluster hamiltonian, obtained with N_G Gaussian functions, and describe the bound and pseudo-bound states of the two-cluster subsystem. The oscillator functions allow to implement the proper boundary conditions for two-cluster bound and continuum spectrum states (see details in [1–3]).

This microscopic model is applied to investigate the resonance states of ^{7}Be and the reaction ^{6}Li$(p,^3$He$)^4$He in an energy range of astrophysical interest. To this aim we consider the three-cluster configuration ^{4}He $+\, d + p$, which allows us to study the cluster polarization of ^{6}Li as ^{4}He$\,+\,d$, ^{5}Li as ^{4}He$\,+\,p$ and ^{3}He as $d + p$.

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The Surface between QCD and Hadron Physics

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The relativistic potential concept is fostered for the description of nucleon-nucleon (NN) interaction and scattering for energies $0 < T_{Lab} \leq 3$ GeV. We use a formalism, developed by Crater and Van Alstine, for two coupled spin 1/2 particles in terms of coupled Dirac equations with constraint instant form dynamics. Sets of coupled Dirac equations are used and reduced into partial wave Schrödinger type equations. We study np and pp scattering phase shifts for energies 0 to 3 GeV and the deuteron bound state. The interactions are inspired and parameterized in terms of π, η, ρ, ω and σ meson exchanges for which we adjust coupling constants. This yields, in the first instant, high quality fits to the Arndt phase shifts 0 to 300 MeV. Second, the potentials show a universal, independent from angular momentum, core potential which is generated with the relativistic meson exchange dynamics. Extrapolations towards higher energies, up to T_{Lab} equal 3 GeV, allow to separate a QCD dominated short range zone as well as inelastic nucleon excitation mechanism contributing to meson production. A local short range optical model, replacing the short range meson exchange Dirac potential, produces exact agreement between theoretical and phase shifts data. The optical model potentials reflect short lived complex multi hadronic intermediate structure formation of which the optical model parameters give a consistent picture. This phenomenological approach shows the need to describe the short range NN interaction zone $r < 0.8$ fm with a microscopic model. It implies using the quark content of the nucleons and gluon exchange as well as the need for a microscopic description of intermediate Δ and hadron pair excitations. The conventional soft or hard core NN potentials remain valid for an effective short range low energy description.

Intermediate Mass Fragment Production in Light Ion Reactions

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A reaction between two heavy ions, being an interaction between two many body systems, offers a complex variety of processes. In addition to the development of detailed analyses deeply investigating a specific process, covering just a fraction of the reaction cross-section, it is important to be able to give a comprehensive description including the leading reaction mechanisms and accounting for different observables. Such requirement is essential for the increasing number of nuclear physics application fields, like for instance hadrontherapy and space radiation protection, in which the role of heavy ions is crucial. In these fields, Monte Carlo codes, simulating the propagation of radiation into any complex geometry consisting of any materials, may represent a very helpful tool on condition that they are supplied with reliable interaction models. Our collaboration is in charge of the improvement of the nucleus–nucleus reaction treatment at low and intermediate energies (below 5 GeV/n) in the FLUKA code, which is increasingly used inside the community of scientists.

Along last years, we could satisfactorily reproduce various sets of data at bombarding energies below 50 MeV/n within a semiclassical approach based on the Boltzmann Master Equation theory and a binary fragmentation model. Recently, we wanted apply our calculations to lighter systems, which are of particular interest for the mentioned application fields.

Besides the description of theoretical ingredients employed in our analysis, results concerning the C+Al system at 13 MeV/n, studied both in direct and inverse kinematics so allowing to fix the calculation parameters, will be shown. Furthermore, the approach used at higher energies (above 100 MeV/n) will be briefly discussed together with some examples of its predictive capabilities.

Information Entropy and Nucleon Correlations in Nuclei

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The information entropies in coordinate and momentum spaces and their sum (S_r, S_k, S) are evaluated for many nuclei using "experimental" densities or/and momentum distributions. The results are compared with the harmonic oscillator model and with the short-range correlated distributions. It is found that S_r depends strongly on $\ln A$ and does not depend very much on the model. The behaviour of S_k is opposite. The various cases we consider can be classified according to either the quantity of the experimental data we use or by the values of S, *i.e.*, the increase of the quality of the density and of the momentum distributions leads to an increase of the values of S. In all cases, apart from the linear relation $S = a + b \ln A$, the linear relation $S = a_V + b_V \ln V$ also holds. V is the mean volume of the nucleus. If S is considered as an ensemble entropy, a relation between A or V and the ensemble volume can be found. Finally, comparing different electron scattering experiments for the same nucleus, it is found that the larger the momentum transfer ranges, the larger the information entropy is. It is concluded that S could be used to compare different experiments for the same nucleus and to choose the most reliable one.

Analytic Description of Critical Point Actinides and Rare Earths in a Transition from Octupole Deformation to Octupole Vibrations

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An analytic collective model in which the relative presence of the quadrupole and octupole deformations is determined by a parameter (ϕ_0), while axial symmetry is obeyed, is developed [1]. The model [to be called the Analytic Quadrupole Octupole Axially symmetric model (AQOA)] involves an infinite well potential, provides predictions for energy and $B(EL)$ ratios which depend only on ϕ_0, draws the border between the regions of octupole deformation and octupole vibrations in an essentially parameter-independent way, and in the actinide region describes well ^{226}Th and ^{226}Ra, for which experimental energy data are shown to suggest that they lie close to this border. The similarity of the AQOA results with $\phi_0 = 45^o$ for ground state band spectra and $B(E2)$ transition rates to the predictions of the X(5) model is pointed out. Analytic solutions are also obtained for Davidson potentials of the form $\beta^2 + \beta_0^4/\beta^2$, leading to the AQOA spectrum through a variational procedure. In the rare earth region it is proved that the N=90 isotones ^{150}Nd, ^{152}Sm, ^{154}Gd, and ^{156}Dy, which are known to provide the best examples of the X(5) critical point symmetry between quadrupole vibrations [U(5)] and axial quadrupole deformation [SU(3)], also lie on the border between the regions of stable axial octupole deformation and octupole vibrations, thus exhibiting a doubly critical character. Spectra and B(EL) transition rates are described in terms of the AQOA model including tunneling effects.

References

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Z(4): γ-rigid Solution of the Bohr Hamiltonian for $\gamma = 30^{\rm o}$ Compared to the E(5) Critical Point Symmetry

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A γ-rigid solution of the Bohr Hamiltonian for $\gamma = 30^{\rm o}$ is derived, its β-part being related to the second order Casimir operator of the Euclidean algebra E(4). The solution is called Z(4), since it corresponds to the Z(5) model [1] with the γ variable "frozen". Parameter-free (up to overall scale factors) predictions for spectra and B(E2) transition rates are in close agreement to the E(5) critical point symmetry, as well as to experimental data in the Xe region around $A = 130$.

References

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Critical Point Symmetries Derived from Davidson Potentials through a Variational Procedure

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Davidson potentials of the form $\beta^2 + \beta_0^4/\beta^2$ are known [1,2] to bridge the U(5) and SO(6) [axial prolate SU(3)] symmetries, leading to the E(5) [X(5)] critical point symmmetries, through a variational procedure in which the rate of change of various physical quantities ($R_4 = E(4)/E(2)$ ratios, for example) is maximized. It is shown that the method also works in the Z(5) [3] and Z(4) frameworks, bridging the limits of vibrator and rigid triaxial rotator, as well as in the framework of the Analytic Quadrupole Octupole Axially symmetric (AQOA) model [4], bridging the limits of vibrator and rigid axial rotator. Several monoparametric curves (curves on which the parameter value is changing along the curve, but are otherwise parameter independent) correlating various physical quantities (the 0_2^+ bandhead to the R_4 ratio [5], for example) are derived and compared to experimental data.

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Nuclear Shape Dynamics in an Angular Momentum Dependent Potential of Quadrupole and Octupole Deformation Variables

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We propose a collective Hamiltonian for the rotation–vibration motion of nuclei in which the axial quadrupole and octupole degrees of freedom are coupled through the centrifugal interaction. The potential of the system depends on the two deformation variables β_2 and β_3. Its shape shows the contributions of both degrees of freedom which determine the softness of the system with respect to the quadrupole and octupole oscillations. The contribution of the octupole deformation is considered to be smaller compared to that of the quadrupole deformation. In the limit of a frozen β_2 the system oscillates between positive and negative octupole deformations by tunnelling through the barrier of the double-well potential in β_3. When β_2 is let to vary, the system oscillates between the positive and negative β_3-values by rounding the barrier in the $(\beta_2, \beta_3)-$ plane, instead of tunnelling. The effects of "rounding" in the two-dimensional space and the tunnelling in the one dimensional space are the respective physical manifestations of the octupole degrees of freedom in dependence on the quadrupole deformation properties of the system. We examine the consequence of the "rounding" in the cases when i) the potential possesses fixed β_2 and β_3 minima, and ii) the minima increase with the angular momentum. In the first case the spectrum of the system is characterized by a constant parity shift effect, while in the second one, the parity shift decreases with the increase of the angular momentum. This result demonstrates the evolution of quadrupole–octupole shapes in nuclear regions where octupole vibrations and octupole deformations are observed.

Transitional Nuclear Spectra within the Framework of IVBM with 6-Dimensional Davidson Potential

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A new dynamical symmetry of the Interacting Vector Bosons Model (**IVBM**), that starts with the $Sp(12, R) \supset SU(1,1) \times SO(6)$ reduction corresponds to the consideration of a model Hamiltonian wich contains 6-dimensional Davidson potential. Exact analitic solutions for its eigenstates are obtained in the basis defined by the subgroup chain of $SO(6) \supset SU(3) \otimes O(2) \supset SO(3)$. This algebraic approach leads to simple and direct applications of the theory to nuclear spectra transitional between the rotational and vibrational cases. Something more, energy spectra of nuclei at the critical point of phase/shape transition are also well reproduced, which is illustrated on the example of ^{152}Sm with proved $X(5)$ symetry.

Electromagnetic Transitions in the Symplectic Extension of Rotational Limit of the Interacting Vector Boson Model

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The tensor properties of all the generators of Sp(12,R) – the group of dynamical symmetry of the Interacting Vector Boson Model (IVBM), are given with respect to the reduction chain Sp(12,R) $\supset$ U(6) $\supset$ U(3) $\times$ U(2) $\supset$ O(3) $\times$ (U(1) $\times$ U(1)). Matrix elements of the basic building blocks of the model are evaluated in symmetry adapted basis along the considered chain. As a result of this, the analytic form of the matrix elements of any operator in the enveloping algebra of the Sp(12,R) can be calculated. The structure of E2 transition operator between collective states of the ground and first excited negative parity band is determined and comparision of its matrix elements with the experimental data for nuclei in the actinide region is presented.

Analysis of New Experimental Data on ^{160}Dy Spectrum with Interacting Vector Boson Model

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The experimental information on a large sequences of states with $J^\pi = 0^+, 2^+, 4^+, 6^+...$, in a given nucleus is quite a lot. Many such well studied nuclei can be listed. The theoretical approaches that are able to explain and correctly describe all the data in this respect are seemingly in debt to the experiment. Analysis of the recently obtained experimental data for collective states of ^{160}Dy is presented. The Interacting Vector Boson Model (IVBM) was applied for the classification of low lying states with positive parity $0^+, 2^+, 4^+, 6^+$ and for description of rotational ground , first β with $K^\pi = 0^+$, γ with $K^\pi = 2^+$ and two negative parity bands with $K^\pi = 1^-$ and $K^\pi = 2^-$. The energies of the bands are reproduced with high accuracy using only one set of the model parameters for all bands and average energy deviation $\langle|E_{\rm expt} - E_{\rm calc}|\rangle$ for all bands under consideration is less than 9 KeV per point. Also, the comparison between experiment and calculations for fifth order staggering function is presented.

Study of Exited States in ^{154}Gd with AFRODITE Spectrometer

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Exited states in ^{154}Gd has been studied in $^{152}\mathrm{Sm} + \alpha \rightarrow^{154} \mathrm{Sm} + 4\mathrm{n}$ reactions. Gamma rays has been detected with AFRODITE spectrometer. The yrast band is observed up to $20\hbar$. The four negative parity bands are confirmed up to $18\hbar$. The two side bands, based on 2622 and 3155 keV levels respectively are also observed.

The decay of β band levels is analyzed in framework of X(5) symmetry.

Description of the Nuclear Octupole and Quadrupole Deformation

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The collective octupole and quadrupole excitations are investigated in the frame of Bohr hydrodynamical model, using an intrinsic reference frame defined by the principal axes of the overall tensor of inertia. A parametrization suitable to describe situations close to the axial symmetry is discussed, and elementary excitations carrying one, two or three units of angular momentum along the approximate symmetry axis are identified [1].

This theoretical frame provides the basis for specific models describing particular situations of the collective nuclear motion, as the critical point of phase transition in the octupole mode.

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Dibaryonic Degrees of Freedom in Hadronic and Nuclear Physics

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The basic aim of the talk is to show that the dibaryons (independently upon the fact of existence or nonexistence of narrow dibaryons) may become one of the main ingredients and degrees of freedom in hadronic and nuclear physics. It follows straightforwardly from the new model for nuclear force [1,2], in which the intermediate-state dibaryons play the role of main carriers of strong interaction of nucleons at intermediate and short ranges in $2N$, $3N$ and other nuclear systems. These intermediate-state dibaryons, or dressed six-quark bags in NN-scattering are strongly coupled to the initial and final NN-channels and thus they have large widths which prevent their direct experimental evidence. However the new model predicts a lot of new effects of dibaryons, which should be seen experimentally in hadronic and nuclear processes. Some of these new predictions have been already confirmed in numerous calculations made jointly in Moscow and Tuebingen university groups. We enumerate shortly here only the most interesting effects of dibaryons in hadronic and nuclear physics:

(i) partial restoration of chiral symmetry in multiquark (*i.e.* $6q$, $9q$ *etc.*) systems with the respective reduction of the scalar sigma-meson mass;

(ii) enhancement of the near-threshold π^0 and $\pi^+\pi^-$, $\pi^0\pi^0$ – production in pp, pd *etc.* collisions; explanation of the long-term ABC-puzzle;

(iii) enhancement of the vector-meson and (e^+e^-) production in the GeV region in pp, pd *etc.* collisions;

(iv) large yield of cumulative mesons and other hadrons (studied experimentally by Baldin with coworkers) in p-A, d-A *etc.* high-energy collisions;

(v) new electro-magnetic currents related intimately to the dibaryon degrees of freedom, which contribute to the all deuteron e.-m. observables, like deuteron magnetic and quadrupole moments, cross sections of photo-disintegration *etc.*;

(vi) some novel contribution to the Coulomb energies of all nuclei ($\sim 15\%$), which is able to explain the long-standing Nollen–Schiffer paradox;

(vii) large effects in many electromagnetic and weak precesses accompanied with high-momentum transfer.

In the talk we plan to discuss some of the above effects in full detail and present numerous results of recent calculations which confirm our above claims.

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Multiphonon Excitations in Heavy Ion Collisions

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Recently heavy ion inelastic scattering experiments have clearly shown the existence of states in the high excitation energy region which can be described as a Giant Resonance (GR) built on top of another GR. The systematics on the energies and widths is in qualitative agreement with the harmonic approximation. However, the inelastic cross sections, when calculated within the harmonic picture, are almost always smaller than the measured ones. The discrepancy can range from 30% up to a factor 2.

In order to understand this discrepancy, corrections to the harmonic approximations have to be included, like anharmonicities in the internal hamiltonian and non-linearities in the external field. The effects of these new terms on the excitation probabilities of DGR have been studied both in schematic model [1] as well as in realistic cases [2].

Starting from a microscopic approach based on RPA, mixing of two-phonon states among themselves and with one-phonon states is considered within a boson expansion approach with Pauli corrections. The calculations are done by solving semiclassical coupled channel equations, the channels being superpositions of one- and two-phonon states. As first application of this approach, we have studied the relativistic Coulomb excitation for ^{208}Pb+^{208}Pb at $E/A = 641$ MeV. The increase of the cross section in the DGDR region is mainly due to the excitation of several states whose population is strongly suppressed by selection rules when anharmonicities and non-linearities are neglected. A good agreement with the experimental cross section has been found. A satisfactory agreement is also obtained when we extend the model by introducing both Coulomb and nuclear excitations [3] and perform calculations for the systems ^{40}Ca+^{40}Ca at 50 MeV/u.

Motivated by these results and by the ones obtained by applying boson expansion methods to an extended, exactly solvable, two level Lipkin-Menshkov-Glick (LMG) model, we have extented the microscopic calculations to the study of three-phonon states [4] also because an experiment to excite such states has been performed at GANIL. By diagonalizing a quartic microscopic Hamiltonian in the space of two- and three-phonon states one realizes that a correct description of a two-phonon state requires the inclusion of one and three-phonon components. The anharmonicity in most of the cases is of the order of 1 MeV. A very important role is played by the monopole mode. We show that large amplitude motion induce a strong coupling to giant monopole and quadrupole vibrations. Calculations of the inelastic cross section for the excitation of one- two- and three-phonons states has been performed in the framework of the model described above. The importance of the anharmonicity and non-linearity has once again manifested giving a good description of the experimental results.

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The Nuclear Scissors Mode within Two Approaches (Wigner Function Moments Versus RPA)

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Two complementary methods to describe the collective motion, RPA and Wigner Function Moments (WFM) method, are compared on an example of a simple model – harmonic oscillator with quadrupole–quadrupole residual interaction. It is shown that they give identical formulae for eigenfrequencies and transition probabilities of all collective excitations of the model including the scissors mode, which here is the subject of our special attention. The exact relation between the variables of the two methods and the respective dynamical equations is established. The transformation of the RPA spectrum into the WFM one is explained.

In spite of 25 years of research and many valuable contributions to the subject the subtleties of the scissors mode are still under debate [1]. The WFM allows one to establish the optimum set of collective variables: quadrupole moment, angular momentum, pressure tensor, *etc.* These variables are, in the scheme of our formalism, absolutely unambiguous and, together with the analytic solution, they allow for a maximum of physical insight. First of all, the inevitable coupling of the scissors mode with the IsoVector Giant Quadrupole Resonance (IVGQR) becomes obvious already at the stage of formulation of the model. Furthermore, the Fermi surface deformation, whose decisive role in the physics of the scissors mode is difficult to predict employing naive phenomenological models, appears in our approach quite naturally. The equations of motion for collective variables are written in the laboratory coordinate system, that allows one to get rid of any troubles connected with spurious rotation, because the total angular momentum is conserved. The orthogonality of the spurious state to all physical states is proved rigorously. Analytical expressions for energies, B(M1)- and B(E2)-values, sum rules and flow-patterns of the scissors mode and IVGQR are found for arbitrary values of the deformation parameter δ. Both modes are quite distinct: the low lying mode has essentially a rotational flow pattern, whereas the high lying mode has essentially irrotational character. Accordingly, the flow lines of the scissors mode are closed ellipses leading to a compression of the long axis, while the ones of the high lying mode are open hyperbolas leading to an elongation of the long axis. The analytical form of our results is very convenient to study the deformation dependence of the position of resonances and the transitions probabilities. In the small δ limit we mostly reproduce results already obtained by other authors with different methods. However, for large δ we obtain predictions for superdeformed nuclei. This area is practically new land still to be explored. Our results are in good agreement with that of the only existing microscopic calculation [5]. The normalization factor of the "synthetic" scissors state and its overlap with physical states are calculated analytically for a first time.

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Exact Solutions of the Bohr Hamiltonian and Symmetries of the Collective Model

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We review some recent developments of the Bohr-Mottelson Collective Model. Namely we illustrate new analytic solutions of the Bohr hamiltonian with solvable potentials, $V(\beta,\gamma)$, for a few cases of interest. In particular, after a brief review of the most important mathematical solutions of the problem [1], we concentrate on the potential of the Kratzer type that can be specialized to $\gamma-$unstable, axial rotor and triaxial cases [2-4]. A characteristic of many of these new solutions is to account for $\gamma-$soft potentials (in contrast with rigid models, like the Davydov model). An exact solution for triaxial rotors around $\gamma = 30°$ is analyzed and its generalization to the sector $0 \leq \gamma \leq 60°$ is sketched. The symmetries and the group structure SU(1,1), associated with some of the solutions mentioned above are briefly discussed. The connection with the issue of shape phase transitions and critical point symmetries is discussed and an extension, for the celebrated E(5) symmetry, to two-fluid systems in interaction is proposed [5]. We discuss in detail an application to the spectrum of ^{128}Xe.

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Cluster Aspects of Binary and Ternary Fission

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Within the scission-point model the binary and ternary fissions of actinides are considered. For binary fission, the explanation of bimodality effect is proposed. The scission configurations are considered as dinuclear systems (DNS). Analyzing potential energy of DNS with particular mass and charge asymmetries as function of fragment deformations, the most probable deformations of the fragments are obtained. It is found that elongated and compact shapes correspond to scission configurations with the same mass asymmetry and different charge asymmetries. This demonstrates that bimodality in fission of actinides at fixed mass splitting is related to different charge splittings. The main features of mass distributions for both modes are also well described.

For ternary fission of actinides, the scission-point-type model is used. The scission configuration is considered as two heavy fragments with light charged particle between them. The potential energy of different scission configurations as function of deformations of two heavy fragments is analyzed for ternary fission of ^{252}Cf with ^{4}He, ^{10}Be and ^{14}C.

Attempting to reproduce the experimental data on charge distribution of the fragments in these reactions, one can conclude on the mechanism of formation of ternary systems. It is shown that ternary system does not appears straightly from the initial nucleus, but as the second step after formation of the DNS. Light charged particle is extracting from one of the heavy fragments in the region of interaction or it can be constructed of several alpha-particles extracted from both fragments. In this way the charge distributions are well reproduced.

Emission of Intermediate-Mass Fragments in the Interaction of Carbon and Oxygen with Heavy Ions

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There is an ever-increasing demand for the creation of databases of experimental data and theoretical predictions concerning heavy ion reactions which could be used in interdisciplinary fields. The aim of our research is just acquiring data which could provide this comprehensive information and developing phenomenological theories able to reproduce all measured observables in reactions induced by light ions, such as ^{12}C and ^{16}O. These data include the spectra of many ejectiles and the yields of recoiling residues which are produced, and consist of the excitation functions for production of a large number of residues in the interaction of ^{12}C and ^{16}O with ^{103}Rh at energies ranging from the Coulomb barrier up to 400 MeV and of the emission spectra of light particles and intermediate mass fragments (IMFs) in the interaction of these ions with ^{59}Co, ^{93}Nb and ^{197}Au. A theoretical model able to afford a very reasonable reproduction of all these data considering both the fusion of ^{12}C and ^{16}O with the target nucleus and their fragmentation followed by the fusion of one fragment with the target nucleus is briefly outlined.

A Realistic Calculation of the Effects of Nucleon-Nucleon Correlations in High-Energy Scattering Processes Off Nuclei

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A new linked cluster expansion for the calculation of ground state observables of complex nuclei with realistic interactions has been developed [1–3]; using the V8' potential the ground state energy, density and momentum distribution of complex nuclei have been calculated and found to be in good agreement with the results of [4], obtained within the Fermi Hyper Netted Chain, and Variational Monte Carlo [5] approaches. Using the same cluster expansion, with wave function and correlations parameters fixed from the ground state calculation, the semi-inclusive reaction of type $A(e, e'p)X$ has been calculated taking final state interaction effects into account within a Glauber type calculation [6]; the comparison between the resulting distorted and undistorted momentum distributions provides an estimate of the transparency of the nuclear medium to the propagation of the hit proton. The effect of color transparency has also been considered within the approach of [7]; it is shown that at high values of Q^2 finite formation time effects strongly reduce the final state interaction, consistently with the idea of a reduced interaction of the hadron produced inside the nucleus. The total neutron-nucleus cross section at the energies has also been calculated [9] by considering the effects of nucleon-nucleon correlations, which are found to increase the total cross section by about 10% in disagreement with the experimental data. The inclusion of inelastic shadowing effects [10, 11] decreases the cross section, leading to a final good agreement between experimental data and theoretical calculations.

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Charge and Matter Distributions and Form Factors of Light, Medium and Heavy Neutron-Rich Nuclei

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Results from calculations on charge form factors of several unstable neutron-rich isotopes of light, medium and heavy nuclei (He, Li, Ni, Kr, Sn) are presented and compared to those of stable isotopes in the same isotopic chain. For the lighter isotopes (He and Li) the proton and neutron densities are obtained from microscopic large-scale shell-model calculations, while for heavier ones Ni, Kr and Sn the densities are calculated in deformed self-consistent mean-field Skyrme HF+BCS method. We also compare proton densities to matter densities together with their corresponding rms radii and diffuseness parameter values. Whenever possible comparison of matter densities and rms radii with available experimental data is also performed. Calculations of form factors are carried out both in Born approximation and by numerical solving the Dirac equation using the corresponding nuclear charge distribution. These form factors are suggested as predictions for the future experiments on the electron-radioactive beam colliders where the effect of the neutron halo or skin on the proton distributions in exotic nuclei is planned to study and thereby the various theoretical models of exotic nuclei will be tested.

High-Spin States in ^{185}Ir

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We investigated high-spin states in ^{185}Ir which were populated by in the $^{1}81$Ta(^{9}Be, 5n) reaction at 55 MeV. The nuclear gamma-decay has been measured with EUROBALL IV spectrometer. The level scheme of ^{185}Ir was extended considerably and DCO ratios were measured. $\pi h_{9/2}$ and $\pi d_{5/2}$ rotational bands have been obsered to high spin and an irregular structure of most probably single-particle origin was found to compete with the rotational bands above $I^{\pi} = 17/2^{-}S$. The backbanding in different bands was found to occur at different frequensies which is attributed to the rotational alignment of different pairs of nucleons.

Hadron Form Factors: Status and Perspectives

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Form factors, since decades, are an active field of experimental and theoretical studies, as they describe the internal, dynamical structure of the nucleon. Recently, the possibility to access very short distances, has given evidence of interesting and unexpected features. For example it appeared that the electric and magnetic distribution inside the proton are different and that the neutron electric form factor is small but can not considered as vanishing. The deuteron can be considered as composed by a proton and a neutron, even when one looks at distances where the two nucleons should be overlapping. In next future, nucleon form factors will be studied at larger momentum transfer, where the charge proton form factor could vanish and even become negative, if the present tendency is extrapolated. Moreover, great progress is expected in time-like region, accessible through annihilation reactions, at Frascati and at the FAIR facility, at GSI. Some of the theoretical models will be discussed in oder to stress the need for a global representation, in the full kinematical region. of the nucleon.

Two-Photon Exchange Effects in the Proton Form Factors Measurements at Jefferson Lab

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Recent Jefferson Lab measurements [1, 2] of the proton elastic form factor ratio G_E^p/G_M^p using polarization method showed significant linear decrease of the ratio with increasing Q^2 up to values of 5.6 GeV^2. The data surprisingly deviates from the view commonly accepted before and based on ep cross-section measurements using the Rosenbluth separation method, that the two form factors fall at similar rates with Q^2. The discrepancy between the two methods *"is a serious problem as it generates confusion and doubt about the whole methodology of lepton scattering experiments"* [3].

Two-photon exchange process is considered to be the most likely explanation. Recent GPD [4] and hadronic [5] model calculations as well as fits to the data, indicate that the two-photon corrections to the cross-section and to the polarization components are of the same order and relatively small, about several percents. These corrections, however, are enough to affect the Rosenbluth separation significantly, while the polarization results remain almost unchanged.

Several forthcoming experiments at Jefferson Lab aim to investigate the discrepancy. In the one-photon exchange approximation the proton form factor ratio obtained from the polarization method at fixed Q^2, does not depend on the value of the virtual photon longitudinal polarization ε. Measurements [6] of the form factor ratio as a function of ε will test the validity of the polarization method and can identify deviations from one-photon exchange approximation.

I will review both the theoretical and the experimental efforts that aim to reconcile the discrepancy.

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Jefferson Lab Experiments Shed new Light on the Proton

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The electromagnetic form factors of the nucleon describe charge and current distributions inside the nucleon and thus are quite intimately related to its structure. In two experiments 93-027 (1998) and 99-007 (2000) at Jefferson Lab the ratio of the electromagnetic form factors of the proton was obtained by measuring P_t and P_ℓ, the transverse and longitudinal recoil proton polarization in $\vec{e}p \to e\vec{p}$; in one-photon approximation G_{Ep}/G_{Mp} is proportional to P_t/P_ℓ. Simultaneous measurement of P_t and P_ℓ provides good control of the systematic uncertainty.

An initial measurement of the G_{Ep}/G_{Mp} ratio was made in Hall A at JLab to $Q^2 = 3.5$ GeV^2 [1] with unprecedented accuracy. The results demonstrated unambiguously for the first time that the Q^2 dependencies of G_{Ep} and G_{Mp} are different from one another. The ratio $\mu G_{Ep}/G_{Mp}$ was found to decrease linearly with Q^2, down to 0.6 at $Q^2 = 3.5$ GeV^2. The results of a second measurement of this ratio with similar accuracy, show that the ratio decreases further to 0.28 at Q^2 of 5.6 GeV^2 [2]. In the non-relativistic limit, this indicates that the spatial distributions of charge and magnetization current densities in the proton are different.

Double spin experiments [3, 4] measure the product $G_{Ep}G_{Mp}$ as well as $(G_{Mp})^2$, and hence determine the relative sign of the form factors. The combined results of the two JLab experiments were surprising as they appeared to contradict the consensus based on Rosenbluth separation results for $(G_{Ep})^2$ and $(G_{Mp})^2$: the ratio $\mu_p G_{Ep}/G_{Mp}$ obtained with the Rosenbluth method appear to be near 1 up to 5 GeV^2 ([5]. This un-bridgeable difference between cross section and polarization experiments has been reinforced with two recent JLab Rosenbluth experiments [6, 7]; it appears increasingly difficult to explain it away by methodological or systematic errors [8].

These two experiments contribute to the characterization of the structure of the nucleon, which is of fundamental importance to nuclear and particle physics. In fact, precise knowledge of the elastic form factors of the nucleon is a prerequisite for the test of any theory of strong interaction based on QCD.

We are currently preparing a third experiment at JLab, this time in Hall C, to extend the Q^2-range to 9 GeV^2 [9]. This high priority experiment requires a new polarimeter to be installed in the focal plane of the high momentum spectrometer, and a new large acceptance calorimeter to detect the electron. Both instruments are now in an advanced stage of construction. The experiment will be ready to go on the Hall C floor in the later part of 2005.

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New Clues for the B(E2: $0_1^+ \rightarrow 2_1^+$) Behavior around ^{68}Ni: Seniority and p-n Interaction

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The B(E2: $0_1^+ \rightarrow 2_1^+$) (B(E2)↑) reduced transition probability of an even-even nucleus is correlated to the possibilities to perform, from the single-particle level spectrum of the ground state, excitations leading to the 2_1^+ state. Its value is then very sensitive to the (sub-)shell structure. The difference of B(E2)↑ behavior observed in ^{66,68}Ni and ^{68,70}Zn [1] is important to understand since concerning the still discussed N=40 sub-shell closure.

In recent theoretical papers [2,3] the ^{66,68}Ni B(E2)↑ decrease is discussed using different calculations performed on Ni isotopes only, in relation with the size of the N=40 sub-shell closure. In another paper [4] the $^{62-70}$Zn B(E2)↑ values are analysed on the basis of shell-model calculations performed only in $^{62-70}$Zn. Nevertheless, the Ni and Zn B(E2)↑ curves exhibit features, also observed in heavier nuclei wih N, Z≃40, that a N=40 gap does not allow to explain.

Taking into account these common features, we have analysed the experimental B(E2)↑ values as a function of N using curves obtained in an approximation of the generalized seniority which gives a very simple expression of the B(E2)↑.

Our analysis casts a new light not only on the Ni and Zn B(E2)↑ difference but on the whole B(E2)↑ evolution from the Ni up to the Se isotopes. The reproduction of this evolution requires a complex sub-shell structure in which the p-n interaction plays an important role [5]. It suggests a scenario locating the sub-shell closure at N=38, and a small spacing at N=40 which diminishes with Z as indicated by the excited spectra in the odd-Ni and Zn isotopes.

It is worth noting that the predictions ensuing our calculations have been very recently confirmed by results obtained recently at Ganil on the ^{70}Ni and ^{74}Zn B(E2)↑ [6], at Isolde on $^{74-78}$Zn (preliminary) [7,8]. The results obtained at Riken on the $^{78-80}$Ge [8] fit also pretty well with our scenario. All these new results will be discussed and compared with the predictions of other theoretical approaches.

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Isoscalar and Isovector Pairing within the SO(5) Richardson-Gaudin Exactly Solvable Model

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Recently is has been demonstrated that the properties of a system of nucleons interacting via isoscalar or like-particle pairing and isovector or proton-neutron pairing can be described by the generalized Richardson-Gaudin exactly solvable model within the SO(5) algebra [1]. We present the results for a system of 12 pairs occupying the *fpg* shell model space. For T=0 this is the ^{64}Ge nucleus considered as a ^{40}Ca core and 12 valent neutrons and 12 valent protons.

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Ground State Energies for the Neutral and 1s Core-Ionized Helium-Like Atoms from Lithium to Xenon

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The non-relativistic energy magnitudes for the ground state of 1s Helium isoelectronic series 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 that allows solving the two-particle Schr*ö*dinger equation for a practically unlimited number of parameters in a series of trial wave-functions along the positive degrees of Hylleraas coordinates. The contributions to the energy for the various parameters is investigated. The so-called mass-polarization correction to the non-relativistic energy is also studied. The results obtained are compared to available data from other authors. One should note that up to now such data have been computed only for atomic numbers Z from 2 to12.

In order to investigate the contribution of the nuclei motions of non-relativistic energies for 1s – Helium isoelectronic series we performed calculations for a number of nuclides of one and the same proton Z number and of various neutron number.

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