Fifteenth International Workshop on Nuclear Theory

Rila Mountains,
Bulgaria
June 10-15, 1996

(Abstracts)

The Workshop was organized by the Nuclear Theory Group of the Department of Theoretical Physics in the Institute of Nuclear Research and Nuclear Energy (the Bulgarian Academy of Sciences), the Faculty of Physics of the University of Sofia "St. Kliment Ohridsky" and the Union of the Scientists in Bulgaria. It was partly supported by the Bulgarian National Science Foundation under contracts $\Phi - 406$, $\Phi - 415$, $\Phi - 527$ and $\Phi - 547$, the Bulgarian Committee for Peaceful Use of the Atomic Energy and the Foundation "St. St. Cyril and Methodius".

Fifteenth International Workshop on Nuclear Theory
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From 10^{th} to 15^{th} June, 1996, the 15^{th} International Workshop on Nuclear Theory was held at the Scientific House of the Sofia University "St.Kliment Ohridsky" in the Rila Mountains for about 40 participants. The Workshop takes place every year and is organized by the Nuclear Theory Group of the Department of Theoretical Physics in the Institute of Nuclear Research and Nuclear Energy of the Bulgarian Academy of Sciences, the Faculty of Physics of the University of Sofia "St. Kliment Ohridsky" and the Union of the Scientists in Bulgaria. The sponsors of the 15^{th} Workshop were the Bulgarian National Science Foundation, the Bulgarian Committee for Peaceful Use of the Atomic Energy and the Foundation "St.St. Cyril and Methodius".

This year the Workshop was dedicated to the memory of Professor Ivan Zhelyazkov Petkov who had been the initiator of the Workshop on Nuclear Theory and the President of the Organizing Committee from 1980 till 1995.

Lecturers and participants from Bulgaria, Greece, Italy, Japan, Romania, U.S.A. and Yugoslavia took part in the Workshop. A wide range of topics in the field of nuclear physics has been treated in the lectures and contributions.

Prof. M. Di Toro gave three lectures devoted to the hot giant dipole resonance problem, to the role of the dynamical fluctuations in medium energy heavy ion collisions and to the nuclear dynamics in the phase space.

The ground state correlations beyond RPA in finite Fermi systems were discussed by Prof. F. Catara. The short-range nucleon-nucleon correlation effects were considered on the examples of: i) various applications of semiclassical models (Prof. A.N. Antonov), ii) magnetic formfactors (D.N. Kadrev), iii) nucleon momentum distributions in exotic nuclei (M.K. Gaidarov), iv) charge densities (Dr. S. Massen).

The semiclassical distorted wave model for multistep direct processes in $(p, p'x)$ and (p, nx) reactions at intermediate energies was presented by Prof. M. Kawai.

In the lecture of Dr. M. Avrigeanu nuclear surface localization of preequilibrium reactions at low energies was discussed by means of the obtained radial dependences of the nucleon's mean free path, of the probability for the first NN collision and the considered average Fermi energy and average strength of the effective NN interaction.

The global properties of low and high energy magnetic excitations in deformed nuclei were the topic of the lecture of Prof. N. Lo Iudice.

The particle decay of high-lying states in odd nuclei and the electric dipole transitions in the even-even N=84 isotones have been investigated by Prof. Ch. Stoyanov and N. Tsoneva.

A prospect of the recent results on the baryon mapping of quark systems was presented by Prof. S. Pittel. The study of the proton-neutron pairing in a solvable $O(8)$ model of nuclei was discussed by Dr. M.V. Stoitsov.

The anomalous anisotropies of the fission fragments at near-barrier energies in heavy-ion induced reactions were treated by Dr. D. Vorcapic.

The experimental results on $p + p \rightarrow \pi^+ + d$ reaction at excess energies between 0.275 MeV and 3.86 MeV from COSY (Jülich) were presented by Dr. T. Kutsarova.

The applications of the collective vector-boson model to studies of the broken SU(3) symmetry in deformed even-even nuclei were given in the contribution of N.Minkov. Symmetries in nuclei and molecules were the subject of Dr. D. Bonatsos's lecture. P. Terziev presented the results obtained in the simplified boson realization of the $so_q(3)$ subalgebra of $u_q(3)$ and concerning also the matrix elements of $so_q(3)$ quadrupole operators.

The applications and the representation theory of the deformed U(su(2)) and U(osp(1,2)) algebras and the parafermionic oscillators were reviewed in the lecture of Dr. C. Daskaloyannis.

The Strutinsky's shell-correction procedure has been applied within the Hartree-Fock-Roothaan method to atoms and ions in the work presented by A. Kuleff.

The high-mountain lakes and tourist houses in Rila attracted again the participants during the rest hours after the lectures and discussions.

It is supposed the next 16^{th} Workshop on Nuclear Theory to be held in June 1997.

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Professor Ivan Zhelyazkov Petkov

On 24 November 1995 Professor Ivan Zhelyazkov Petkov, D. Sc., the Head of the Nuclear Theory Group in the Institute of Nuclear Research and Nuclear Energy (INRNE, Sofia, Bulgaria) passed away. He had given the idea the International Workshop on Nuclear Theory (Giolechitsa, the Rila Mountains, Bulgaria) to be organized and held every year and had been the President of the Organizing Committee since 1980 up to 1995.

We lost our teacher and wonderful friend.

Professor I.Zh. Petkov was born in 1932 in Sliven (Bulgaria) and had graduated from the University of Sofia "St. Kliment Ohridsky" in 1956. After three years of work for the Institute of Physics of the Bulgarian Academy of Sciences in Sofia, he had been a Ph.D. student of the Moscow State University "M. Lomonosov". Later, from 1962 till 1970 he had worked as research fellow and senior research fellow for the Laboratory of Theoretical Physics of the Joint Institute for Nuclear Research in Dubna (Russia). In 1966 he acquired his Ph.D. degree in the same institute.

Since 1970 Prof. Petkov had started his work in the INRNE in Sofia and in the next years he created the Nuclear Theory Group. In 1976 he defended his D.Sc. thesis in Sofia and from 1983 he had been Professor in INRNE.

Professor Ivan Zh. Petkov published more than 150 scientific papers, the most of them in the important international journals on nuclear physics and many-body theory, such as Nuclear Physics, Annals of Physics, Zeitschrift für Physik, Soviet Journal of Nuclear Physics and others. He was a coauthor of three monographs in nuclear physics, two of them published in the Oxford University Press: "Nucleon Density and Momentum Distributions in Nuclei" (1988), "Nucleon Density Functional Theory" (1991) and one published by Springer-Verlag in Berlin "Nucleon Correlation in Nuclei" (1993).

The achievements of Prof. I.Zh. Petkov are in various fields. We will mention among them the results on the electron elastic and inelastic scattering on nuclei, the heavy ion physics (and especially some pioneer works on nuclear fusion studies), the optical potential theory, the studies of short-range correlation effects in nuclei, the density functional theory and its applications to nuclear, atomic and molecular systems.

Prof. I. Zh. Petkov was a supervisor of eight Ph.D. students who defended successfully their thesises. He took an important part in the work on substantial subjects developed in two D.Sc. thesises defended by his collaborators.

Prof. I.Zh. Petkov reported on important international conferences and meetings in Russia, Denmark, England, France, Germany, Japan and Bulgaria.

Prof. I.Zh. Petkov worked also as Head of the Physics Department of the University of Shoumen "Konstantin Preslavski" (1973-1976) giving lectures in Theoretical Physics, Atomic and Nuclear Physics. He was also a lecturer on Nuclear Reaction Theory in the University of Sofia "St. Kl. Ohridsky".

Prof. I.Zh. Petkov had been Vice-Director of the Centre of Physics of the Bulgarian Academy of Sciences and a scientific secretary of the INRNE in Sofia for several years.

The Bulgarian science lost one of the distinguished and recognized Bulgarian scientists abroad, as well as one of the initiators of the studies in nuclear structure and reaction theory in our country. He helped many young scientists to find their own way in the nuclear physics and left the Nuclear Theory Group founded by him in INRNE whose works have been accepted and recognized by the physical community abroad.

The memory of Prof. Ivan Zh. Petkov and his contributions will remain.

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References of Talks

V. Baran, M. Colonna, M. Di Toro, A. Guarnera, T.I. Mikhailova and A. Smerzi: "Giant Resonances at High Excitation Energy: A Test-ground for Nuclear Structure and Dynamics"

M. Bassi, M. Colonna, M. Di Toro, A. Guarnera, V. Kondratyev and S. Maccarone: "Reaction Mechanisms in Medium Energy Collisions: Influence of Dynamical Fluctuations"

F. Catara: "Ground State-Correlations Beyond RPA in Finite Fermi Systems"

Nguyen Van Giai, Ch. Stoyanov and V.V. Voronov: "Particle Decay of High-lying States in Odd Nuclei"

N. Tsoneva, M. Grinberg and Ch. Stoyanov: "Electric Dipole Transitions Between Low-lying States in Even-even N=84 Isotones"

M. Kawai, Y. Watanabe, M. Higashi and M. Kohno: "A Semi-classical Distorted Wave Model for Multistep Direct Processes in $(p, p'x)$ and (p, nx) Reactions at Intermediate Energies"

M. Avrigeanu, A. Harangozo, V. Avrigeanu and A.N. Antonov: "Nuclear Surface Localization of Preequilibrium Reactions at Low Energies"

S.E. Massen, V.P. Garistov and M.E. Grypeos: "The Dependence of the Nuclear Charge Form Factor on Short–range Correlations and Surface Fluctuation Effects"

G.A. Lalazissis and S.E. Massen: "The Influence of Short– and Long–Range Correlations on the Charge Densities and Radii of Ca Nuclei"

K.A. Pavlova, M. Avrigeanu and A.N. Antonov: "Short-Range Nucleon Correlations in The Semiclassical Nuclear Models"

S.E. Massen, M.K. Gaidarov, A.N. Antonov and G.S. Anagnostatos: "Nucleon Momentum Distribution in Exotic Nuclei"

S. Pittel, M.V. Stoitsov and J. Dukelsky: "Proton–neutron Pairing in a Solvable Model of Nuclei"

D.N. Kadrev, A.N. Antonov, M.V. Stoitsov and S.S. Dimitrova: "Magnetic Form Factors and Natural Orbitals in Nuclei"

S. Pittel: "Baryon Mapping of Quark Systems: A Progress Report"

N. Lo Iudice: "Global Properties of Low and High Energy Magnetic Excitations in Deformed Nuclei"

D. Vorkapic and B. Ivanisevic: "Anomalous Anisotropies of Fission Fragments at Near-barrier Energies"

T. Kutsarova: "Study of the $p + p \rightarrow \pi^+ + d$ Reaction Close to Threshold"

N. Minkov, S. Drenska, P. Raychev, R. Roussev and D. Bonatsos: "Investigations of the Broken SU(3) Symmetry in Deformed Even–even Nuclei"

D. Bonatsos, C. Daskaloyannis, S.B. Drenska, P. Kolokotronis, G.A. Lalazissis, D. Lenis, N. Minkov, P.P. Raychev and R.P. Roussev: "Symmetries in Nuclei and Molecules"

D. Bonatsos and C. Daskaloyannis: "Applications and Representation Theory of the Deformed U(su(2)) and U(osp(1,2)) Algebras and the Parafermionic Oscillators"

D. Bonatsos, N. Lo Iudice, P.P. Raychev, R.P. Roussev and P.A. Terziev: "Simplified Boson Realization of the $so_q(3)$ Subalgebra of $u_q(3)$ and Matrix Elements of $so_q(3)$ Quadrupole Operators"

A.I. Kuleff, Ya.I. Delchev, F.E. Zahariev, R.L. Pavlov: "Formulation of the Strutinsky's Averaging Method in Hartree-Fock-Roothaan Framework: Open Shell Systems"

Giant Resonances at High Excitation Energy: A Test-ground for Nuclear Structure and Dynamics

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Properties of collective motions in highly excited nuclei are discussed from various points of view, with particular reference to the hot Giant Dipole Resonance (GDR) problem. The analysis will roughly focus on two main topics:

1) **End of collectivity.** The temperature dependence of one- and two- body dissipation in the collective dynamics is studied solving a linearized Landau equation for the phase space density. A clear interplay between the two sources of dissipation is revealed, quite important also at zero temperature. An increasing role of the collisional dissipation at larger excitation energy could lead to a *universal* spreading width of heated GDR's, not depending on the mass number, for temperature around $T = 2MeV$. The need of a larger systematics in this E^* region is stressed.

At higher excitation energies the contribution of all emission channels to the total width should be also taken into account, with an expected rapid disappearing of collective motions. However we also see a fast increasing diffusion term in the Landau equation joint to a larger single particle damping. We can predict the stimulating possibility of a transition from zero- to first- sound modes at relatively low excitation energies ($T = 2 \div 3MeV$). A related decrease of the spreading width should allow the observation of giant modes, of different microscopic nature, up to the maximum temperature an equilibrated nucleus can sustain.

2) **Fusion Dynamics.** Pre-equilibrium effects are thoroughly abasedly as important cooling mechanisms. Moreover the role of a entrance channel charge asymmetry is noticed as a source of dynamical dipole emissions before equilibration. A shift of the GDR strength to lower frequencies and a critical dependence on the E^*- behaviour of the GDR spreading width is expected. Some hints towards a direct observation of these pre-equilibrium collective photons are suggested, based on an angular distribution trigger. Finally the fusion hindrance due to an increasing role of dynamical instabilities in medium energy collisions is discussed. A careful analysis of the various evaporation sources is essential in order to extract correct excitation energies.

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Reaction Mechanisms in Medium Energy Collisions: Influence of Dynamical Fluctuations

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We discuss the role of dynamical fluctuations in heavy ion collisions at beam energies between 20 and 200 MeV/u. The analysis will be roughly focussed on three main topics:

1. **Fragment formation from dynamical instabilities.** We start from a general procedure to identify instability regions of the nuclear dynamics which lead to fragment production. A detailed study of the interplay between the fragment formation time and the freeze-out time is performed: various physical scenari for different theoretical models are proposed. We can go from the observation of critical transitions in multifragmentation events to the possibility of detecting memory effects, of collective dynamics type.

2. **Neck fragmentation and variances.** For more peripheral collisions in the same energy range a novel reaction mechanism is revealed, due to the onset of new neck instabilities coupled to an increasing amount of dynamical fluctuations. Expected consequences: possibility of intermediate mass fragment emission from the neck region and larger variances in projectile-like and target-like observables. A great variety of sources for dynamically emitted particles is predicted. Due to the short time scale of the process. we expect to see also important isospin effects, with the possibility of producing highly exotic nuclear systems from neck ruptures. Instabilities seem to be present also in lower energy deep inelastic collisions: this can be very useful to study shape instabilities, quite important for the fission dynamics.

3. **Dynamics of fluctuations.** A fully consistent treatment of the dynamics of the fluctuations is presented, including short range (Langevin type) and long range (mean field) correlations. This allows the possibility of including fluctuations also in low energy dynamics, where hard two-body collisions are Pauli suppressed. A stochastic transport model is constructed with the presence of a random force related to consistent density fluctuations. Moreover the Boltzmann-Nordheim-Vlasov equation for a mean phase space trajectory is modified by a correlation term with the structure of a diffusion in momentum space. Effects are discussed for collective motions (transition from zero- to first-sound modes) and in regions of mean field instabilities. Finally relevant contributions from fluctuations are predicted for the production of high energy photons with a coherent mechanism. In particular a soft component in the bremsstrahlung γ−spectrum is strongly enhanced, with important consequences on the properties of hot giant resonances that can be extracted from experiments.

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Ground State Correlations Beyond RPA in Finite Fermi Systems

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Random Phase Approximation is the simplest theory of excited states of a quantum system including correlations in the ground state. In this theory one introduces a set of operators Q_ν: the vacuum of these operators defines the ground state of the system, while the action of $Q_\nu^\dagger$ on this vacuum gives the excited states. Having a Hartree-Fock (HF) basis as a reference, the $Q_\nu^\dagger$ operators are defined as linear superpositions of creation and annihilation particle-hole (*ph*) pair operators. The formal equations for the coefficients can be derived by using the equation of motion method. With a hamiltonian made of one- and two-body terms, the solution of these equations implies the evaluation of one- and two-body density matrices. In standard RPA, this difficulty is overcome by replacing the correlated ground state with the uncorrelated HF one. This introduces a clear inconsistency, especially when the two differ appreciably from each other.

In the first part, previous attempts to eliminate as far as possible the above inconstintency are shortly reviewed and some results are presented. In the second part, a new approach is proposed to go further towards a self-consistent RPA. Finally, some results on metallic clusters are presented. The latters have been obtained by using a simplified version of the approach which requires less computational effort. It represents, however. a significant improvement over the methods used so far.

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Particle Decay of High-lying States in Odd Nuclei

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A method for calculating non-statistical particle decay of excited states in odd nuclei is presented. Using the quasiparticle-phonon model partial cross sections and branching ratios for the neutron decay of the high angular momentum states in ^{209}Pb and ^{91}Zr excited by means of the (α,^{3}He) reaction have been evaluated. The calculated branching ratios are compared with existing experimental data.

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Electric Dipole Transitions Between Low-Lying States in Even-Even N=84 Isotones

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The low-lying excited states in N=84 isotones have been investigated in the framework of the quasiparticle-phonon model. The level energies and the transition relevant to the members of quadrupole-octupole two-phonon multiplet are calculated and compared to the experiment in the case of ^{142}Ce and^{144}Nd. The two-phononon character of the first 1^- state is confirmed on the basis of calculations in large space including one-, two- and three -phonon states. A B(E1;$1^-_1 \rightarrow g.s.$) value of the order of 10^{-3}W.u. is obtained taking into account the influence of the giant dipole resonance. Several E1, E2, E3 transitions are calculated which give additional information on the properties of the two-phonon states in the N=84 region.

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A Semi-classical Distorted Wave Model for Multistep Direct Processes in $(p,p'x)$ and (p,nx) Reactions at Intermediate Energies

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A distorted wave model for inclusive cross sections of $(p,p'x)$ and (p,nx) at intermediate energies is described. The model is based on the DWBA series of the T-matrix, a local semiclassical approximation of distorted waves, Eikonal approximation to the Green functions of propagation of the intermediate nucleons, and the local density Fermi gas model of the nucleus. The model does not contain adjustable parameters, so that the absolute magnitude of the cross sections is significant. Some results of calculations of cross sections including up to 3 steps direct processes are presented. Contribution of the higher-order steps, medium effects on nucleon-nucleon interactions, effects of the non-locality of distorting potentials are discussed.

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Nuclear Surface Localization of Preequilibrium Reactions at Low Energies

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Average quantities related to the characteristics of the nucleon-nucleon (NN) interaction along the trajectory of the projectile in preequilibrium reactions are calculated by using the semiclassical method to follow the incoming particle's path in the nuclear target. The radial dependences of the nucleon's mean free path and the probability for the first NN collision have pointed out the surface character of the first NN interaction in multistep reactions even at low energies. In the local density approximation an average Fermi energy and an average strength of the effective NN interaction $\overline{V}_0$ along the trajectory of the incident nucleon are obtained with respect to both the nuclear density and the first NN-collision probability. A good agreement is found between the average strengths obtained with the Hartree-Fock potential plus the dispersive component and by using the parametrization based on the Brueckner-Hartree-Fock nuclear matter calculations. It is also shown that the nuclear-density dependence of the effective NN interaction may account for the low-energy phenomenological V_0-values which are much more increased in comparison with any predictions.

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The Dependence of the Nuclear Charge Form Factor on Short Range Correlations and Surface Fluctuation Effects

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We investigate the effects of fluctuations of the nuclear surface on the harmonic oscillator elastic charge form factor of light nuclei, while simultaneously approximating the short-range correlations through a Jastrow correlation factor. Inclusion of surface-fluctuation effects within this description, by truncating the cluster expansion at the two-body part, is found to improve somewhat the fit to the elastic charge form-factor of ^{16}O and ^{40}Ca. However, the convergence of the cluster expansion is expected to deteriorate. An additional finding is that the surface-fluctuation correlations produce a drastic change in the asymptotic behavior of the point-proton form factor, which now falls off quite slowly (i.e. as $const. \cdot q^{-4}$) at large values of the momentum transfer q.

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The Influence of Short and Long Range Correlations on the Charge Densities and Radii of Ca Nuclei

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The available experimental data for the charge(proton) density differences of Ca nuclei of the $1f_{7/2}$ neutron shell is analyzed on the basis of a simple phenomenological model, where the effect of short and long range correlations is taken into account.

Short range correlations (SRC) are introduced through the Jastrow ansatz, while as long range correlations the flactuations of the nuclear surface (SFC) due to zero point motion of collective surface vibrations are considered.

The role of the correlations is examined and it turns out that the inclusion of both types of correlations is important. It is the interplay between the SFC and SRC which leads to a better description of the empirical data.

The calculated charge radii show the well known anomalous A-dependence and reproduce the observed parabolic behavior. The isotopic changes of the charge radii agree well with laser spectroscopy measurements of the isotope shifts of Ca nuclei.

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Short-Range Nucleon Correlations in the Semiclassical Nuclear Models

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The applicability of the local density approximation (LDA) is studied along with the problems of short-range nucleon correlation effects on nuclear structure and reactions. The calculations for correlated nuclear matter enable us to introduce an equivalent local Fermi momentum and local Fermi energy which can be used within the LDA to various studies of quantities such as level densities, reaction cross sections, effective mean field potentials and others. The equivalent Fermi energy averaged over the density and the radial distribution of the first N-N collision probability is calculated as a function of the correlation parameter within the Jastrow correlation method. A quantitative criterion for the applicability of the semiclassical models is studied in more details.

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Nucleon Momentum Distribution in Exotic Nuclei

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Nucleon momentum distributions of light neutron-rich nuclei are calculated by a model using the natural orbital representation and the experimental data for the momentum distribution of the ^4He nucleus. The model allows realistic momentum distributions to be obtained using only hole-state natural orbitals or mean-field single-particle wave functions as a good approximation to them. Harmonic-oscillator wave functions were employed in order to predict the nucleon momentum distributions of exotic nuclei whose properties are studied intensively nowadays.

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Pairing Correlations in a Solvable O(8) Model

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Generalized pairing theory is applied for studying proton–neutron pairing within a solvable $O(8)$ model. Solution of the pairing problem is found in close analytical form. It takes into account all possible modes of proton–neutron pairing in nuclei. A comparison is made with the exact ground–state energies for a number of even–even and odd–odd nuclei. The importance of proton–neutron pairing in nuclei is demonstrated. The resulting analytical solution is suitable for further investigation of QRPA description of nuclear double β-decay.

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Magnetic Form Factors and Natural Orbitals in Nuclei

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Natural orbitals containing nucleon correlation effects accounted in the coherent density fluctuation model (CDFM) are used to calculate characteristics of the A–nucleon system, such as the electron elastic magnetic scattering form factors. The calculations are performed for nuclei with a doubly–closed core and a valence nucleon in a stretched configuration ($j = l + 1/2$), such as the ^{17}O and ^{41}Ca nuclei. It is shown that the calculations of the transverse form factors using natural orbitals improve the agreement with the experimental data in comparison with the case when shell–model single–particle wave functions are used.

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Baryon Mapping of Quark Systems: A Progress Report*

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In this talk, I will review progress that we have made over the last several years in the development of baryon mappings as a practical tool for achieving a microscopic quark description of nuclei.

I will begin with a brief discussion of a new and consistent baryon mapping that we developed a couple of years ago and then discuss a test of this mapping in the context of a three-color extension of the familiar Lipkin Model. The test confirms that the mapping is able to fully reproduce within its physical subspace all the exact states of the model. Equally important, it produces unphysical states fairly high in energy. This is essential for practical applications of the method, in which variational approximations after the mapping invariably mix physical and unphysical states.

The test on the three-color Lipkin Model was unable, however, to address two key issues: (1) Will baryon mappings continue to be useful in the presence of strong spatial three-quark correlations? (2) Will they remain useful in the presence of variational approximations? To address these issues, we have studied a series of models due to Koltun and collaborators. In these models, quarks with color move in one dimension subject to an attractive delta-function interaction. The model is exactly solvable in the infinite-matter limit, both for two and three colors. Furthermore, in both cases, the exact solutions indeed exhibit spatial clustering at low densities.

I will first present the results obtained in a boson mapping of the two-color delta model combined with a Hartree Bose variational analysis. Then I will present analogous results for the three-color model, involving a baryon mapping followed by a Hartree Fock treatment. Both analyses are unable to treat correctly effects of the cluster-cluster interactions, even at the lowest order at which they contribute.

*Work carried out in collaboration with J.M. Arias, J. Dukelsky, A. Franc, A.I. Georgieva, R.P. Roussev, P.P. Raychev and M.V. Stoitsov.

I will then discuss an improved analysis of the two-color model, in which short-range correlations between bosons (quark pairs) are treated in Brueckner theory. This analysis gives perfect agreement with the exact results, through the lowest order in which the cluster-cluster interaction contributes.

Finally, I will discuss the implications of these results for subsequent application of baryon mapping methods to realistic quark systems.

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Global Properties of Low and High Energy Magnetic Excitations in Deformed Nuclei

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Low- and high-energy magnetic dipole excitations, known as scissors modes [1-3], are studied in schematic proton-neutron quasi-particle random-phase approximation using a Hartree mean field obtained self-consistently from a separable quadrupole-quadrupole interaction.

It is shown that the Hartree mean field enables us to separate exactly the redundant rotational mode from the physical intrinsic states. The separation remains exact even if pairing correlations are accounted for.

The formalism can be exploited to deduce unweighted sum-rules which connect the $M1$ to the $E2$ transition strengths of each $M1$ mode. The relevance of these new $M1 - E2$ relations to the study of the mode in deformed as well as in super-deformed nuclei is stressed.

An energy weighted $M1$ sum-rule of general validity is finally deduced and computed using the Hartree mean field. It is shown that restoring the spherical symmetry of the Hamiltonian is crucial for a correct computation of such a sum-rule.

This sum enables us to relate the $M1$ transition strengths to the quadrupole collectivity of the deformed ground state in agreement with the observed deformation properties of the low-energy mode.

Unweighted and weighted sum-rules are used to give largely model independent estimates of the summed $M1$ strengths of both low and high energy $M1$ excitations.

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Anomalous Anisotropies of Fission Fragments at Near-barrier Energies

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Anomalous anisotropies in the angular distribution of fission fragments have been observed in several heavy-ion induced nuclear reactions at near- and sub-barrier energies[1]. The fission fragment anisotropy is found to be larger than that predicted theoretically by standard statistical saddle-point model [SSPM] for the fission of the compound nucleus formed by the fusion of the projectile and target nuclei. The same compound nucleus (^{248}Cf) has been formed at similar excitation energies in three different reactions: $\alpha + ^{244}Cm$, $^{16}O + ^{232}Th$ and $^{12}C + ^{236}U$. The first reaction can be explained by standard theory [SSPM]. The experimental angular distribution for the $^{16}O + ^{232}Th$ and $^{12}C + ^{236}U$ reactions at near- and sub- barrier energies exhibits much larger anisotropy than predicted by SSPM. It has been shown that the fission fragment angular distribution are anomalous, when the entrance channel mass asymmetry is less than the critical Businaro-Gallone mass asymmetry[2].

It has been shown that preequilibrium fission can give rise to a large anisotropy at sub-barrier energies for $^{16}O + ^{232}Th$ and $^{12}C + ^{236}U$ reactions[3]. We assume that sub-barrier fusion takes place preferentially along the symmetry axis of the deformed target and that in these reactions the emission of fission fragments not only came from the compound nucleus, but also had a component from a system, where the K degree of freedom "was not fully equilibrated" (preequilibrium fission). We have used K distribution around the most probable projection on the symmetry axis. The K distribution is represented by a narrow Gaussian with a time dependence σ_k variance, given by $\sigma_k = ICt_m$, where t_m is the mean of some time interval, and C is a constant which represents the speed of equilibration. In the sub-barrier region for deformed nuclei transmission coefficients are many times larger for target orientation angles around 180° and 0° in comparison with angles around 90°. Therefore these target angles around 180° (0°) contribute significantly to the fission fragment angular distribution, and preequilibrium fission can give rise to a large anisotropy at sub-barrier energies. We have calculated fission fragment angular distributions for $^{16}O + ^{232}Th$ and $^{12}C + ^{236}U$, using the value $C = 0.75 \cdot 10^{-21} s$. Good agreement has been found between the experimental and calculated results.

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2.V.S. Ramamurthy et al., Phys. Rev. Lett. 65 (1990) 25
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Nuclear Surface Oscillation model in Heavy Nuclei Fission

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The fission of many heavy nuclei shows a bimodal character, with both low and high – energy components in the kinetic energy distribution. These two components are thought to arise because the nucleus can choose two different paths to scission from the ground state, either a path leading to elongated scission shapes and low fission fragment kinetic energies or a path leading to the compact scission configuration of two touching spheres and high fission fragment kinetic energies. We consider the second path. The vibration of the fragment surfaces leads to more realistic density distributions of the fragments. We consider that the neck density is responsible for the asymmetry and odd-even effects. Our results are compared with a large amount of experimental data in the cases of spontaneous fission of U, Pu and Cf isotopes.

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Study of the $p + p \rightarrow \pi^+ + d$ Reaction Close to Threshold[†]

The GEM Collaboration

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The $p + p \rightarrow \pi^+ + d$ reaction has been studied at excess energies between 0.275 MeV and 3.86 MeV. The experiments were performed with the external proton beam of the *CO*oler *SY*nchrotron (COSY) in Jülich. Differential and total cross sections were measured employing a high resolution magnetic spectrometer with nearly 4π acceptance in the center of mass system. The values of the total cross sections are – when corrected for the Coulomb effects – in agreement with results obtained from the time reversed reactions as well as from the isospin related reactions. The measured anisotropies between 0.008 and 0.29 indicate that the p-wave is not negligible even so close to threshold. The s-wave and p-wave contributions at threshold are deduced.

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Investigations of the Broken SU(3) Symmetry in Deformed Even–Even Nuclei

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A collective vector–boson model is applied to study the broken SU(3) symmetry in deformed even–even nuclei. In the cases of ^{164}Dy, $^{164-168}$Er, ^{168,172}Yb, ^{176,178}Hf and ^{238}U, the model description of the ground and γ bands together with the corresponding B(E2) transition probabilities is evaluated within a broad range of SU(3) irreducible representations (irreps) (λ,μ). The calculations show that the (λ,μ) characteristics of rotational nuclei depend to a great extent on the magnitude of SU(3) splitting. It is found that for the weakly splitted spectra (as in ^{164}Dy, $^{164-168}$Er, ^{168}Yb), the ground–γ band coupling scheme is realized relevantly within narrow regions of "favored" (λ,μ) irreps, while in the cases of strong splitting (as in ^{172}Yb, ^{176}Hf, ^{238}U) the scheme is principally restricted with respect to the consistent description of nuclear collective properties. The obtained results are analyzed in terms of the bandmixing interactions. It is established that the increasing number of vector bosons N_{VB} corresponds to the increase in the splitting of the SU(3) multiplet and leads to the decrease in the bandmixing interaction within the framework of SU(3) symmetry. Hence the large λ limit corresponds to $N_{VB} \rightarrow \infty$ and is equivalent to the group contraction SU(3)$\rightarrow$T$_5\Lambda$SO(3). In this limit the SU(3) symmetry is completely destroyed and the bands can not be united anymore in one SU(3) multiplet. We have, therefore, suggested that the strongly splitted spectra should be considered as special cases in which the ground and the γ–bands are weakly coupled. Furthermore we have indicated the possibility for a transition from the ground–γ band coupling scheme (in the nuclei with small splitting) to an alternative collective scheme (in the cases of large splitting), in which the ground band is situated in a separate irrep. It is proposed that the collective dynamical mechanisms causing such a transition could be sought in the framework of more general dynamical symmetry group.

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Symmetries in Nuclei and Molecules

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Recent progress in two different fronts is reported.

First, the concept of bisection of a harmonic oscillator or hydrogen atom, used in the past in establishing the connection between U(3) and O(4), is generalized into multisection (trisection, tetrasection, etc). It is then shown that all symmetries of the N-dimensional anisotropic harmonic oscillator with rational ratios of frequencies (RHO), some of which are underlying the structure of superdeformed and hyperdeformed nuclei, can be obtained from the U(N) symmetry of the corresponding isotropic oscillator with an appropriate combination of multisections. Furthermore, it is seen that bisections of the N-dimensional hydrogen atom, which possesses an O(N+1) symmetry, lead to the U(N) symmetry, so that further multisections of the hydrogen atom lead to the symmetries of the N-dim RHO. The opposite is in general not true, i.e. multisections of U(N) do not lead to O(N+1) symmetries, the only exception being the occurrence of O(4) after the bisection of U(3).

Second, it is shown that there is evidence that the recently observed in superdeformed nuclear bands $\Delta I = 4$ bifurcation is also occurring in normal deformed bands of actinides and rare earths, in hyperdeformed nuclear bands, as well as in rotational bands of diatomic molecules. In addition there is evidence that a $\Delta I = 8$ bifurcation, of the same order of magnitude as the $\Delta I = 4$ one, is observed in superdeformed nuclear bands and rotational bands of diatomic molecules.

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Simplified Boson Realization of the $so_q(3)$ Subalgebra of $u_q(3)$ and Matrix Elements of $so_q(3)$ Quadrupole Operators

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Quantum algebras (also called quantum groups) are nonlinear generalizations of the usual Lie algebras, to which they reduce in the limiting case when the deformation parameters are set equal to unity. From mathematical point of view they have the structure of Hopf algebras. The interest for applications of quantum algebras in physics was triggered in 1989 by the introduction of the q-deformed harmonic oscillator. In this connection the quantum algebra $su_q(2)$ has been used for description of superdeformed bands of even-even nuclei and rotational nuclear and molecular spectra.

The construction of chains of subalgebras of a given q-algebra is a non-trivial problem, since the existence of a chain of subalgebras of the corresponding Lie algebra does not guarantee the existence of the q-analogue of this chain. In particular, the $so_q(3)$ subalgebra of $u_q(3)$ has attracted much attention, since its classical analogue is a basic ingredient of several nuclear models, as the Elliott model and the $su(3)$ limit of the Interacting Boson Model (IBM), the Fermion Dynamical Symmetry Model (FDSM), the Interacting Vector Boson Model (IVBM), the nuclear vibron model for clustering, as well as of the $su(3)$ limit of the vibron model for molecules.

In the present report we compute the reduced matrix elements of a special second-rank tensor operator (quadrupole operator) in the $u_q(3) \supset so_q(3)$ basis (for the most symmetric $u_q(3)$-representation) and investigate some of their properties. Also we construct a simplified boson realization of the $so_q(3)$ subalgebra of $u_q(3)$ and the corresponding $so_q(3)$ basis states.

It should be noted that the obtained results, are valid only for real values of the deformation parameter q. On the other hand the comparison of the experimental data with the predictions of a number of physical models, based on the q-deformed $su_q(2)$ algebra, shows that one can achieve a good agreement between theory and experiment only if q is a pure phase ($q = e^{i\tau}$). Nevertheless, we suppose that these quadrupole operators describe some q-deformed excitations (q-deformed phonons).

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Applications and Representation Theory of the Deformed U(su(2)) and U(osp(1,2)) Algebras and the Parafermionic Oscillators §

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A large number of algebras with three generators can be studied in a unified framework, using Verma modules, which are quotient modules of the algebra. The representation theory and the applications of associative algebras, which are usually referred to as nonlinear deformed extensions (or polynomial variations) of the U(su(2)), U(su(1,1)), U(osp(1,2)) or U(sl(2)) algebras are reviewed here. Realizations of these algebras can be obtained by using the deformed parafermionic oscillators. The applications of the parafermionic algebras to the discrete phase space problems and the spectra of the deformed nuclei will be discussed.

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Formulation of the Strutinsky's Averaging Method in Hartree-Fock-Roothaan Framework: Open Shell Systems

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Strutinsky's shell-correction method [1,2] is applied in the framework of an analytical version of the Hartree-Fock method developed by Roothaan (HFR) [3] in the atoms and ions with an open shell. Applying the Strutinsky energy averaging to the density matrix define a self-consistently averaged HFR system as a solution of the variational problem. We derive the explicit expressions for the shell-corrections.

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§Presented by Costas Daskaloyannis