South Africa - JINR Workshop on Theoretical and Computational Physics

Monday 23 June 2025 - Friday 27 June 2025

BLTP

Book of Abstracts

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Monday / 2

Giant resonances in nuclei and their wavelet analysis

Author: Valentin Nesterenko[1]

[1] *BLTP, Joint Institute for Nuclear Research*

Corresponding Author: nester@theor.jinr.ru

I present a brief review on multipole giant resonances (GR) n atomic nuclei. The origin, basic properties and present status of GR exploration are outlined. As an example, the wavelet analysis of GR fine structure, performed by collaboration of the experimentalists from iThemba Lab and theorists from BLTP JINR [1-5] is briefly described.

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[4] P. Adsley, V.O. Nesterenko, M. Kimura, L.M. Donaldson, R. Neveling et al "Isoscalar monopole and dipole transitions in ^{24}Mg, ^{26}Mg and ^{28}Si", Phys. Rev. C **103**, 044315 (2021).

[5] A. Bahini, V.O. Nesterenko, I.T. Usman, P. von Neumann-Cosel, R. Neveling et al, "Isoscalar giant monopole resonance in ^{24}Mg and ^{28}Si: effect of coupling between the isoscalar monopole and quadrupole strength", Phys. Rev. C **105**,024311 (2022).

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On quantum trapping of cold neutrons in nano-scaled Fabry-Perot resonating cavities & neutron lifetime considerations

Author: Malik Maaza[1]

[1] *iThemba LABS/National Research Foundation of South Africa (ITLABS/NRF) & University of South Africa (UNISA)*

Corresponding Author: maaza@tlabs.ac.za

Abstract:
Relatively to the atomic constituents'counterparts, the neutron is singular as it is sensitive to the four fundamental interactions: strong, weak, electromagnetic, and gravitational. This multi-sensitivity makes neutron wave-matter optics a particularly versatile tool for testing quantum mechanics specifically and fundamental physics concepts in general.
The lifetime of a free neutron defined via its beta-decay ⟨τn⟩ is of a pivotal importance within the standard model & cosmology.
Indeed, the precision on the neutron lifetime is paramount as it regulates the precision of the 1st element of the Cabibbo–Kobayashi–Maskawa matrix, central to the standard
model. The two major methods used to measure ⟨τn⟩ while trapping free neutrons, namely, the beam and the bottle methods give different neutron lifetime values; ⟨τn⟩Beam ~ 888.0 ± 2.0 s , that obtained by the bottle technique is smaller; of about ⟨τn⟩Bottle ~ 879.4 ± 0.6 s. In
addition of the persistent difference of ~10 s persists for years, even if the two methods have been modified to enhance the experimental accuracy. This latter was shown to be enhanced if one could trap cold neutrons in nanostructured Fabry-Perot resonators.
The de Broglie wave-particle duality coupled to the Fermi total reflection phenomenon in addition

to the tunneling & trapping of cold neutrons in such nano-resonating cavities,
allow trapping times with a precision governed by the Heisenberg uncertainty of 10-12 s [1-2].
[1]. M. Maaza, Journal of Neutron Research -1 (2023) 1–16 1 DOI 10.3233/JNR-220015,
[2]Nano-structured Fabry-Pérot resonators in neutron optics & tunneling of neutron wave-particles,
Maaza, M., Hamidi, D., Physics Reports 2012, 514(5), pp. 177–198

Monday / **4**

R-matrix and Jost function analysis of experimental nuclear scattering data.

Author: Paul Vaandrager[1]

Co-authors: Mantile Lekala [2]; Sergei Rakitianski [3]

[1] *University of South Africa (UNISA)*

[2] *University of South Africa*

[3] *University of Pretoria*

Corresponding Authors: vaandrager.pv@gmail.com, lekalml@unisa.ac.za, sergei.rakitianski@up.ac.za

In the analysis of nuclear scattering data to determine resonance parameters (among other scattering variables), both the well-known R-matrix and Jost function methods of analysis can be used. Each method has benefits and disadvantages. A new method for fitting non-relativistic binary-scattering data and for extracting the parameters of possible quantum resonances in the compound system that is formed during the collision, is proposed. This method combines the R-matrix approach with the analysis based on the semi-analytic representation of the Jost functions. In this presentation, the R-matrix method, Jost method and new method will be discussed, with reference to the benefits and disadvantages of each method. Furthermore, results from testing the efficiency and accuracy of the proposed new method are presented.

Thursday / **5**

Approximating the Jost function using artificial neural networks

Author: Tshegofatso Tshipi[1]

[1] *Sol Plaatje University*

Corresponding Author: t.tshipi@gmail.com

The theory of the Jost function provides an elegant and unified framework for determining resonance and bound states. These states are determined by 1)Solving a system of differential equations, which are equivalent to the Schrödinger equation, to obtain the Jost functions.
2)Searching for the zeros of the Jost function in the complex energy plane.

This approach has been successfully employed to determine these states with high accuracy using classical numerical methods techniques such as the Runge-Kutta-Fehlberg (RK45) method and the Newton-Raphson method. In this presentation, I will provide a brief introduction to the theory of Jost functions and discuss the potential of using Physics-Informed Neural Networks (PINNs) as an alternative approach for determining both the Jost function and the associated states

Wednesday / **6**

Spectrum of frustrated magnets

Author: Pavel Maksimov[1]

[1] *Joint Institute for Nuclear Research*

Corresponding Author: maksimov@theor.jinr.ru

Magnetic frustration, a situation where all interactions in the magnetic Hamiltonian can be realized either from geometry of the lattice , or from
anisotropic interactions. In some cases frustration can be strong enough to destroy magnetic long-range order in favor of a quantum disordered "spin liquid" regime. Such a state is highly sough after due to its entanglement and topological excitations. However, in the systems with magnetic order anisotropic interactions may strongly affect its ground state and spectral properties. We are going to show, using several examples, how anisotropic exchanges affect spectrum of magnetic excitations, and how, in turn, inelastic neutron scattering measurements can be used to identify the strength of anisotropic interactions.

Tuesday / **7**

Basis invariants in two-higgs-doublet model: Hilbert series, syzygies, and renormalization-group equation

Author: Alexander Bednyakov[1]

[1] *Joint Institute for Nuclear Research*

Corresponding Author: alexander.bednyakov@jinr.ru

Physical questions can be obscured by basis redundancies. We discuss reparametrization invariants in the scalar sector of the general Two-Higgs-Doublet Model (2HDM). These invariants form a polynomial ring, with variables corresponding to a finite generating set. We derive six-loop renormalization group equations (RGEs) for all invariants in this set. Notably, our approach does not involve computing individual Feynman diagrams; instead, we rely on general RGE results for scalar theories. Our methods combine linear algebra with techniques from invariant theory. The latter not only helps determine the number of linearly independent invariants appearing in beta functions at a given loop order (via Hilbert series) but also provides a systematic way to handle polynomial relations (syzygies) among the variables of the ring.

Based on https://arxiv.org/pdf/2501.14087

Monday / **9**

New variational method in quantum few-body theory

Author: Sergei Rakityansky[1]

[1] *BLTP, JINR, Dubna*

Corresponding Author: rakitsa@theor.jinr.ru

A new variation method for solving the bound-state problem for a system of few particles is proposed. Unlike the traditional variational approach,
where the expectation value of the Hamiltonian is minimized, i.e. just a single quantity, in the proposed method the approximate solution is constructed by fitting a continuum of quantities, namely, the entire function that describes

the interaction potential in one of the two-body subsystems. Another advantage of the new method is that the resulting approximate wave function of the few-body system satisfies the corresponding Schroedinger equation with a given (experimental) binding energy. As an example, an approximate analytic expression of the ground-state wave function of ^{9}Be nucleus is obtained. This nucleus is treated as a bound system of two α-particles and one neutron. Within the new variational method the problem is solved by postulating a trial wave function, using which in the three-body Schroedinger equation with experimental value of the energy, the corresponding $\alpha\alpha$-potential is recovered. The parameters of the trial function are varied in order to minimize the difference between the exact and recovered $\alpha\alpha$-potentials.

Monday / 10

At the dawn of research in artificial intelligence and structured programming in physics institute

Author: Alexander Zakharov[1]

[1] *ITEP; JINR*

Corresponding Author: alex_f_zakharov5@mail.ru

In the mathematical department of Institute of Theoretical and Experimental Physics (Moscow) in 1960s it was decided to choose a some intellectual game to compare skills of programmers working in different countries or in other words, it was necessary to select criteria to compare AI teams. In 1960s Alexander Kronrod coined slogan "Chess is drosophila of Artificial Intelligence"and ITEP programmers started to develop chess programs. After conversations of ITEP mathematicians with US programmers they started to develop also their own chess programs in 1960s (it was done in times when "the iron curtain"was rather high). In 1967 it was organized a chess tournament between Adelson-Velskij (ITEP) and Kotok–McCarthy (Stanford, USA) programs and the Soviet program beat the American one with score 3–1. Soviet newspapers wrote about a sound success of Soviet programmers and mathematicians. It is clear that it is much more pleasant to remember your successes, but if you do not remember your defeats and do not draw conclusions from them, then victories may not come. The failure of US computer program in the chess tournament was so disappointed for American AI experts that they often remembered results of the tournament and the American failure in the competition in their books and articles. I recall also the Kronrod's contribution in a development of structural programming and mathematical education in the Soviet Union.

Thursday / 11

Extended Dual QCD and its mass spectrum

Author: Garima Punetha[1]

[1] *LSM Campus, Soban Singh Jeena University Almora Uttarakhand, India*

Corresponding Author: garimapunetha@gmail.com

We investigate the framework of extended dual Quantum Chromodynamics (QCD), wherein confinement and mass generation are described through a dual superconducting model of the QCD vacuum. By extending the conventional dual QCD approach—typically centered on the Abelian projection and monopole condensation—we incorporate additional dual gauge degrees of freedom and scalar fields associated with an enriched dual symmetry structure. This allows for a more comprehensive treatment of color confinement and hadronization mechanisms. We compute the mass eigenvalues

of both gauge and scalar sectors, revealing a non-trivial structure that includes glueball-like excitations and potential bound states. Our results provide insight into the dual Meissner effect, the role of topological solitons, and the phenomenological implications for glueball masses and confinement scales. These findings contribute to a deeper understanding of non-perturbative QCD dynamics and offer testable predictions for lattice simulations and future experiments.

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Influence of Resonances on Breakup Dynamics in 6,7Li + 209Bi Systems

Authors: Lucas Vusi Ndala[1]; Mantile Leslie Lekala[1]

[1] *University of South Africa*

Corresponding Authors: ndalal@unisa.ac.za, lekalml@unisa.ac.za

The study of exotic nuclei, particularly those that are weakly bound, continues to attract significant interest due to their unique structural and reaction properties. In this work, we investigate the influence of resonant states on the breakup process and its interplay with other reaction channels such as elastic scattering and fusion cross sections. Specifically, we examine the 6Li and 7Li systems on a heavy target nucleus 209Bi, at energies above the Coulomb barrier. The theoretical framework employed is the Continuum Discretized Coupled Channels (CDCC) method, which accounts for the coupling between bound and continuum states of the projectile. Our results highlight the significant role of resonances in enhancing breakup, elastic scattering angular distributions, and suppressing complete fusion through increased flux loss to nonelastic channels. These findings provide further insight into the reaction dynamics of weakly bound systems and the impact of cluster resonances on nuclear reaction observables.

Wednesday / 13

Neural Operators and Neural Networks for Physics Applications

Author: Heinrich van Deventer[1]

[1] *University of Pretoria*

Corresponding Author: hpdeventer@gmail.com

Neural networks serve as universal continuous function approximators in finite-dimensional spaces and can offer an alternative to finite element methods for solving partial differential equations (PDEs). Extending neural networks to neural operators, which can approximate continuous (and potentially non-linear) mappings between function spaces, is non-trivial. Neural operators are designed to be independent of discretization or resolution, making them highly effective tools for physics and engineering applications. They can act as surrogate models for solving PDEs. Additionally, neural operators have potential applications in operator or functional approximation using experimental data, especially when the underlying mapping is complicated or lacks an analytical solution.

Tuesday / 14

CFD: A powerful virtual laboratory for fluid dynamics

Author: Pedro Mafa[1]

[1] *University of KwaZulu-Natal*

Corresponding Author: mafat@ukzn.ac.za

Computational Fluid Dynamics (CFD) serves as a powerful virtual laboratory for simulating and analysing complex fluid flow phenomena. By discretising the equations of fluid motion, CFD enables researchers, physicists, and engineers to model fluid behaviour in various areas such as astrophysics, nuclear physics, plasma physics, atmospheric physics and more. The talk will give an overview of this tool, which provides deep insights into fluid dynamics, allowing for virtual experiments and design optimisations without the costs of physical experiments. CFD is essential for understanding, predicting, and controlling fluid flows through flow field visualisation and data extraction.

Thursday / 15

New minimal set of the spherical bipolar harmonics

Author: Сергей Ершов[1]

[1] *JINR*

Corresponding Author: ershov@theor.jinr.ru

In many applications one has to deal with functions that depend on two directions. In this case a convenient basis for function expansion is provided by bipolar harmonics that are given by irreducible
tensor product of the spherical functions with different arguments. The basis of biharmonic functions is
overcomplete for a fixed total angular momentum and for arbitrary internal angular momenta. Very often bipolar harmonics with a small rank of total momentum enter the final results while the ranks
of the internal tensors can run over a wide (or infinite) range. But it is possible to decompose the bipolar harmonic using the smallest set of internal orbital momenta for a fixed total momentum. Here we apply the new method for calculations of decomposition coefficients at low values
of total angular momenta and arbitrary values of internal momenta, which is not related with the special choice of a coordinate system. Then the basis functions from the minimal set are modified in two respects. 1) All dependence on angle between two directions in bipolar harmonica will be contained
only in expansion coefficients and basis functions are independent of this angle. 2) The new basis will
be orthogonal and have the same normalization. We can call these tensors as the normalized orthogonal
bases from the minimal set of bipolar harmonics. The new basis and expansion coefficients for the low
values of total orbital momentum are presented explicitly.

Tuesday / 16

Phase diagram of nuclear natter. Collective effects and phase transitions in nuclear systems.

Author: Dmitry Voskresensky[1]

[1] *BLTP, JINR Dubna*

Corresponding Author: dvoskre@theor.jinr.ru

In this talk I will review phase diagram of nuclear matter. Different temperature–density regimes will be discussed: low temperature–law density, low temperature–high density, high temperature—low density, and high temperature– high density. Focus will be made on role of collective medium effects and possibilities of various phase transitions. Information from experiments and theoretical models used for description of heavy-ion collisions, neutron stars, hypothetical hybrid and quark stars, etc. will be discussed.

Tuesday / **17**

METHOD OF OPTIMIZATION OF EMPIRICAL INTERATOMIC POTENTIALS

Author: M.Y. Shatalov[None]

Co-authors: F.E. Olayiwola ; S. Surulere ; T. T. Malange

The problem of optimizing interatomic potentials is addressed by generalizing various potential models, such as Morse, Rydberg, Kaxiras-Pandey, and Lennard-Jones. These models are considered as solutions to second-order ordinary differential equations, which are classified and analyzed. An optimal analytical forms for these models are proposed based on a one-dimensional search for an optimal characteristic parameter. These optimal models are analyzed for several metals, including gold, copper, aluminum, titanium, and silver-copper alloys. The least squares method is used to estimate the model parameters. Classical Rydberg, Morse, and Kaxiras-Pandey models are also studied, as well as new models based on combinations of these. An objective function is used to determine the optimal values of the characteristic parameters, leading to the introduction of new optimized interatomic models.

Tuesday / **18**

A NOVEL APPROACH TO PARAMETRIC EVALUATION OF THE BUCKINGHAM INTERATOMIC POTENTIAL

Author: M.Y. Shatalov[None]

Co-authors: M.C. Kekana ; P. Sehlabelo-Makhabane ; T. Malange

The Modified Buckingham Potential is an empirical phenomenological model that describes interatomic interaction. It offers an alternative to commonly used potentials, such as the Lennard-Jones and Morse potentials. This potential uses a real exponential function to approximate repulsive forces and a negative integer exponential function for attractive forces. In the report, we propose an original method for estimating the parameters of the Buckingham potential. This method is based on representing the potential as a general solution to an equivalent ordinary differential equation, allowing us to estimate a new set of parameters from a linear differential model. The advantage of this approach is that it allows us to find the new unknown parameters by solving a linear algebraic system with constraints, depending on the original parameters.

Tuesday / **19**

SELF-ORGANIZATION OF CHARGED PARTICLES IN LATERAL POTENTAILS WITH HIGH SYMMETRY

Author: Rashid Nazmitdinov[1]

[1] *BLTP, JINR;*

Corresponding Author: rashid@theor.jinr.ru

A question of the optimal configuration of a finite number of particles in a plane has been a difficult problem of both physics and mathematics for many centuries. Back in 1611, Kepler posed already the question of why a snowflake has perfect hexagonal symmetry [1]. At present, increased interest in the problem of the optimal configuration in a plane is also due to the development of nanotechnologies which make it possible to form systems of similarly charged particles confined by external potentials with a high symmetry. In particular, one of the important achievements of modern technology consists in the creation of «artificial atoms» or quantum dots, where a finite number of electrons is confined electrostatically in a nanometer-sized region [2].
In this communication we discuss the basic principles of self-organization of one-component charged particles, confined in disk and circular parabolic potentials. A system of equations is derived, that allows to determine equilibrium configurations for arbitrary, but finite, number of charged particles that are distributed over several rings [3,4]. The results of our approach demonstrate a remarkable agreement with the values provided by molecular dynamics calculations. With the increase of particle number n>180, we find a steady formation of a centered hexagonal lattice. At the same time, the energetic preferences for nonuniform local density then favor ground states where this locally hexagonal structure is isotropic dilated and contracted throughout the structure. In fact, the equilibrium configuration is determined by the need to achieve equilibrium through the formation of a hexagonal lattice on one side and a ring-like structure on the other. This competition leads to the formation of internal defects in such systems, in contrast to the case of unlimited regions, where the ground state of the system has no defects. Finally, this structure smoothly transforms to valence circular rings in the ground state configurations for both potentials. We briefly discuss the precursor of the phase transition of the type “hexagonal lattice - hexatic phase” with the increase of a particle number in the system at zero temperature [5].

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3.M. Cerkaski, R. G. Nazmitdinov, A. Puente, Phys. Rev. E 91, 032312 (2015).
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Tuesday / 20

Acceleration and twisting of neutral atoms by laser fields

Author: Vladimir Melezhik[1]

[1] *BLTP JINR Dubna*

Corresponding Author: melezhik@theor.jinr.ru

The spatial inhomogeneity **kr** in the electromagnetic wave and the magnetic component in it lead to non-separability of the variables of the electron and the center-of-mass in the hydrogen atom interacting with the laser pulse, and, as a consequence, to the acceleration of the atom [1,2]. We have shown that the influence of the laser polarization on the excitation, ionization and acceleration of the hydrogen atom is insignificant in IR, optical and UV region. However, the transition from linear to circular laser polarization leads to the twisting of the atom. We have also established a mechanism for n-photon resonant twisting of an atom with the transfer of helicity of photons of a circularly polarized laser field to it [3]. This alternative way for twisting of neutral atoms may be of interest for a number of promising applications.

[1] V.S. Melezhik, J. Phys A 56, 154003 (2023).
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[3] V.S. Melezhik and S. Shadmehri, J. Chem. Phys. 162, 174304 (2025).

Monday / **21**

From Dinuclear System to Close Binary Cosmic Objects

Author: Nikolai Antonenko[1]

[1] *BLTP, JINR*

Corresponding Author: antonenk@theor.jinr.ru

Applying the ideas from microscopic objects to macroscopic stellar and galactic systems, the evolution of compact di-stars and di-galaxies is studied in the mass asymmetry coordinate. The formation of stable binary systems is analyzed. The role of symmetrization of an initially asymmetric binary system is revealed in the transformation of gravitational energy into internal energy of stars or galaxies accompanied by the release of a huge amount of energy. For the contact binary stars, the change of the orbital period is explained by evolution to symmetry in mass asymmetry coordinates.

Monday / **22**

Polarization, vorticity and shear in hadronic and heavy-ion collisions

Author: Oleg Teryaev[1]

[1] *JINR*

Corresponding Author: teryaev@theor.jinr.ru

The common and specific features of particle polarization in hadronic and heavy-ion collisions are discussed. The analogs of characteristics of hadronic and quark gluon media in hadronic structures are suggested.
The special attention is paid to shear viscosity and physical reasons of its smallness.

Tuesday / **23**

Study of spatial structures in α-cluster nuclei by the Feynman Path Integral method

Author: Viacheslav Samarin[1]

[1] *Joint Institute for Nuclear Research, Flerov Laboratory of Nuclear Reactions*

Corresponding Author: samarin@jinr.ru

Calculations of the probability densities and energies of the ground states for α-cluster nuclei ^{12}C (3α), ^{16}O (4α), ^{20}Ne (5α), ^{24}Mg (6α), ^{28}Si (7α) and for nuclear
molecules ^{9}Be (2α + n), ^{10}Be (2α + 2 n), ^{10}B (2α + n + p), ^{10}C(2α + 2 p), ^{11}B(2α + 2 n + p), ^{11}C(2α + n + 2 p) were performed by the Feynman Path Integral (FPI) method [1] using parallel computing based on NVIDIA CUDA technology. The FPI method is used because it is not limited by the number of the particles. The reason why FPI is a natural choice for studying spatial structures is because the asymptotic form of the FPI kernel contains density distributions explicitly (Fig. 1).

Fig. 1. The probability density for the ground state of the ^{16}O nucleus as a 4α-system calculated by the FPI method along with the potential landscape (curves) (a-c) with the 3D models of some configurations (d) and Jacobi coordinates with $x = y$ (e). The tetrahedron configuration 1 is the most

probable; the square configuration 2 is of considerably lower probability; the dinuclear configurations 3, 4 (α + ^{12}C) are even less probable.

1. V. V. Samarin, Eur. Phys. J. A, **58**:117 (2022).

Thursday / 24

Time-dependent description of nucleon-transfer in nuclear reactions

Author: Viacheslav Samarin[1]

[1] *Joint Institute for Nuclear Research, Flerov Laboratory of Nuclear Reactions*

Corresponding Author: samarin@jinr.ru

The numerical solution of the time-dependent Schrodinger equation (TDSE) [1] for outer neutrons and protons of colliding nuclei are used for description of nucleon-transfer reactions. The calculated cross sections show satisfactory agreement with the experimental data for representative set of reactions. The cross sections for the production of the isotopes ^{196,198}Au in ^{4,6,8}He+^{197}Au reactions were calculated in work [2]. The evolution of wave functions for all nucleons was used to describe multineutron- and multiproton-transfer reactions in ^{40}Ca+^{124}Sn [3] ^{17,18}O+^{27}Al, ^{18}O+^{58}Ni [4], ^{40}Ca+^{96}Zr [1] collisions. The example of evolution of probability density for outer proton of the ^{197}Au nucleus in collision with ^{48}Ca is shown in Fig. 1. The evolution of the alpha-cluster probability density was calculated for the complete and incomplete fusion as well as transfer channels in works [3, 5].

Fig. 1. Evolution of the probability density for the outer proton $1h_{11/2}$ of the ^{197}Au nucleus calculated by the TDSE method along with the potential landscape (curves) for ^{40}Ca+^{197}Au reaction. The c.m. collision energy is 322 MeV, and the impact parameter is b = 9 fm. The order of panels (a, b, c, d) corresponds to the course of time.

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Thursday / 25

Study of the structure of nuclei in the alpha-cluster model by hyperspherical functions method

Author: Anton Bazhin[1]

[1] *Joint Institute for Nuclear Research*

Corresponding Author: vichshizik@gmail.com

The light nuclei 18O, 12C, 9Be and 6Li used as target and projectile nuclei in the many experimental studies of the nuclear reactions, including Flerov Laboratory of Nuclear Reaction (JINR). The study

of the structure of these nuclei is necessary for theoretical description of such reactions. Wave functions of the ground state of the 18O, 12C, 9Be and 6Li nuclei in the alpha-cluster model are calculated using hyperspherical functions. Cubic spline interpolation is applied for solving hyperradial equations. The alpha-alpha interaction in nucleus is changed in comparison with well-known Ali-Bodmer potential. As a result, the energy of separation to alpha-particles and the charge distributions were calculated and agreement with experimental data was obtained.

Thursday / 26

Confluence of Strong correlation, Quantum materials, and Topology

Author: Каушаль Кешарпу[1]

Co-author: Evgenii Kochetov [2]

[1] *BLTP, JINR*

[2] *JINR*

Corresponding Authors: kesharpu@theor.jinr.ru, kochetov@theor.jinr.ru

In last two decades identification of topological properties in low dimensional quantum materials (specifically one and two-dimensional) has been one of the principal area of investigation condensed matter research. It resulted in several impressive discoveries, e.g., topological insulators, topological superconductors, topological Hall effect etc. The related underlying theory had been built in the free electron
approximations, i.e. the Coulomb interactions between electrons have been neglected [4, 1]. However, there remains a large class of quantum materials where the electron correlation can not be neglected [3]. One needs a completely different approach to analyze the topological properties of these materials [2]. We will discuss a possible approach to treat the materials with strong electron-electron correlation. We will
also show some examples how the model can be applied to one-dimensional and two-dimensional quantum matters .

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Tuesday / 27

Quantum Algorithms for the Quantum Simulation of Closed and Open Quantum Systems

Author: Ian Joel David[1]

Co-author: Ilya Sinayskiy [2]

[1] *University of KwaZulu-Natal*

[2] *University of KwaZulu-Natal, Durban, South Africa*

Corresponding Authors: ilsinay@gmail.com, ianjoeldavid290614@gmail.com

Quantum Simulation, the emulation of quantum system dynamics with quantum computers, is an application of quantum computing which showcases a clear advantage over classical computing. This
advantage arises from the inherent difficulty in simulating quantum dynamics on classical systems, a
challenge that originally inspired Feynman and others to propose quantum computing.
The efficient simulation of quantum dynamics on quantum computers promises profound insights into
various physical systems including many-body physics, quantum chemistry and quantum field theory.
Quantum Simulation has also been pivotal in developing new quantum algorithms for state preparation and
for solving both ordinary and partial differential equations on quantum computers.
The goal of quantum simulation is to construct a quantum channel that approximates the evolution operator
of a quantum system within some specified precision. This channel should be constructed such that it can
be efficiently implemented on a quantum computer. We focus on two primary types of quantum systems:
closed quantum systems, which evolve via unitary evolution, and open quantum systems, which interact
with their environment and experience dissipation and decoherence.

This talk will convey the essential concepts and principles underlying the quantum simulation of both closed and open quantum systems. It will also cover some novel results in our recent work.

Wednesday / **28**

An Introduction to Solving Differential Equations with Physics-Informed Neural Networks

Author: Shivani Mahashakti Pillay[1]

Co-author: Ilya Sinayskiy [2]

[1] *University of KwaZulu-Natal*

[2] *University of KwaZulu-Natal, Durban, South Africa*

Corresponding Authors: ilsinay@gmail.com, pillay.shivani6@gmail.com

Artificial Intelligence is revolutionising the way we solve complex problems in science. One example is the Physics-Informed Neural Network (PINN)—a machine learning approach that offers an effective framework for solving differential equations by embedding physical laws directly into the neural network's training process. Unlike traditional numerical methods for solving differential equations, such as finite difference and finite element schemes, PINNs do not rely on expensive computations on fine grids. They also offer the flexibility to incorporate experimental or noisy data, making them particularly useful in settings where data and models must be combined. In this talk, I will provide a gentle introduction to neural networks and explain how PINNs extend these ideas to solve differential equations. I will also present a PyTorch-based Python package I have developed for implementing PINNs and demonstrate its use through a selection of results obtained from my own research.

Wednesday / **29**

Thermal enhancement of nuclear (anti)neutrino emission during pre-supernova stage

Authors: Alan Dzhioev[1]; Andrey Vdovin[2]; Andrey Yudin[3]; Natalya Dunina-Barkovskaya[3]

[1] *Joint Institute for Nuclear Research, Bogoliubov Laboratory of Theoretical Physics*

[2] *BLTP JINR*

[3] *NRC "Kurchatov Institute"*

Corresponding Authors: vdovin@theor.jinr.ru, dunina@itep.ru, dzhioev@theor.jinr.ru, yudin@itep.ru

Accurate estimates of (anti)neutrino spectra and luminosities are essential for assessing the possibility of detecting neutrinos from pre-supernova stars. Using the thermal quasiparticle random-phase approximation (TQRPA) method, we studied the effects of nuclear temperature on pre-supernova (anti)neutrino emission. Comparing the ν_e and $\bar{\nu}_e$ spectra produced in neutral- and charged-current weak reactions involving cold and thermally excited (hot) nuclei, we conclude that energy transfer from hot nuclei not only enhances (anti)neutrino emission but also hardens the spectrum.

Using the MESA stellar evolution code, we generated density, temperature, and chemical composition profiles for a $14.0\,M_\odot$ pre-supernova model. From these results, we calculated the time evolution of luminosities and spectra for (anti)neutrinos emitted via thermal and nuclear processes. We find that the luminosity of ν_e from electron capture on hot nuclei exceeds that from e^+e^--pair annihilation by an order of magnitude even one day before collapse. Moreover, we show that for $\bar{\nu}_e$ production, neutrino-antineutrino pair emission via nuclear de-excitation (ND) is at least as significant as pair annihilation. We also demonstrate that flavor oscillations amplify the high-energy component of the ND process in the $\bar{\nu}_e$ flux. This effect could be crucial for the detection of pre-supernova $\bar{\nu}_e$ by terrestrial detectors.

Monday / **30**

Openning words

Thursday / **32**

KINETICS OF CHROMIUM SILICIDE LAYER GROWTH IN SILICON –CHROME BINARY PLATES

Author: Pavel Selyshchev[1]

[1] *University of Pretoria*

Corresponding Author: selyshchev@gmail.com

The presentation discusses the experimentally observed formation and growth of a chromium silicide layer in a silicon wafer with a deposited chromium layer. The chromium silicide layer forms and grows at the boundary between silicon and chromium. The time dependence of the layer thickness is first described by linear functions with different growth rates: rapid growth is replaced by slow growth, the dependence has a kink; and then it becomes parabolic. At the same time, a layer of its oxide appears on the outer boundary of the chromium layer with some delay, which grows parabolically with time.
The conditions and results of the experiment are analysed.
A theoretical model of the formation and growth of silicide and oxide layers is proposed, which explains this growth as a result of chemical reactions, diffusion and structural transformations.

Thursday / **33**

Regularized Integrodifferential Equations Approach

Author: Gaotsiwe Rampho[1]

[1] *University of South Africa*

Corresponding Author: ramphjg@unisa.ac.za

The traditional two-variable few-body integrodifferential equations approach is modified by introducing boundary conditions in both the hyperradial and hyperangular variables. In addition, the inclusion of the effects of higher partial waves of the interaction potential is also modified. The new approach reproduces results obtained by an exact method for boson systems. These results confirm that many-body correlations in large systems are very small in systems with short-range interactions and that effect of higher partial waves are adequately accounted for by the revised hypercentral potential.

Wednesday / **34**

JINR-UNISA COLLABORATION ON NONLINEAR AND CHAOTIC PHENOMENA OCCURING IN SUPERCONDUCTING ELECTRONIC AND SPINTRONIC JOSEPHSON STRUCTURES

Authors: A. E. Botha[1]; Yu. M. Shukrinov[2]

[1] *UNISA, South Africa*

[2] *BLTP, JINR, Dubna*

An overview of the results obtained in the framework of JINR-UNISA collaboration in the field of theoretical research on superconducting electronics, spintronics and chaos is presented [1-7]. The important role played by nonlinear and chaotic phenomena in different types of Josephson structures will be discussed within the context of our present studies and future plans.

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Closing

Monday / **36**

Spectrum of frustrated magnets

Author: Pavel Maksimov[1]

[1] *Joint Institute for Nuclear Research*

Corresponding Author: maksimov@theor.jinr.ru

Magnetic frustration, a situation where all interactions in the magnetic Hamiltonian can be realized either from geometry of the lattice , or from
anisotropic interactions. In some cases frustration can be strong enough to destroy magnetic long-range order in favor of a quantum disordered “spin liquid” regime. Such a state is highly sough after due to its entanglement and topological excitations. However, in the systems with magnetic order anisotropic interactions may strongly affect its ground state and spectral properties. We are going to show, using several examples, how anisotropic exchanges affect spectrum of magnetic excitations, and how, in turn, inelastic neutron scattering measurements can be used to identify the strength of anisotropic interactions.

Wednesday / **37**

Spectrum of frustrated magnets

Author: Pavel Maksimov[1]

[1] *Joint Institute for Nuclear Research*

Corresponding Author: maksimov@theor.jinr.ru

Thursday / **38**

First-Principles Investigation of the Properties of VSnPt, NbSnPt and TaSnPt Half-Heusler Compounds for High-temperature Structural Applications

Author: Malebo Tibane[1]

Co-author: Bhila Oliver Mnisi [1]

[1] *University of South Africa*

Corresponding Authors: tibanmm@unisa.ac.za, mnisibo@unisa.ac.za

This study investigates the structural, electronic and mechanical properties of the half-Heusler compounds: VSnPt, NbSnPt and NbSnPt employing density functional theory (DFT) within the generalized gradient approximation (GGA). The equilibrium lattice constants, bulk moduli and their pressure derivatives were computed and compared with the related theoretical data. The results indicate that all computed elastic constants satisfy the mechanical stability criteria for cubic crystals,

confirming structural robustness of the compounds, reinforcing their potential suitability for experimental synthesis and practical application. Electronic structure analysis reveals that VSnPt possesses a half-metallic character, while NbSnPt and TaSnPt exhibit metallic behaviour. Dynamic stability was assessed using phonon dispersion calculations, with CASTEP calculations suggesting dynamic instability. However, VASP results confirm stable behaviour for both VSnPt and NbSnPt. Overall, the results contribute valuable insight into the fundamental pro perties of the studied half-Heusler alloys and support their potential in solid-state applications and advanced materials design.

Monday / **39**

Bounds on variation of eigenvectors and spectral subspaces under a perturbation

Author: Alexander Motovilov[1]

[1] *Joint Institute for Nuclear Research*

Corresponding Author: motovilv@gmail.com

We are reviewing known bounds on the variation of a spectral subspace (and, in particular, of an eigenvector) of a self-adjoint operator under an additive Hermitian perturbation. To this end we first recall the concept of operator angle between two subspaces of a Hilbert space. Then we recollect the spectral dispositions for which sharp norm bounds on the variation of the spectral subspace associated with an isolated spectral set have already been established. Starting from the celebrated Davis-Kahan trigonometric theorems in the subspace perturbation theory, all of these bounds have the form of an estimate of a norm of some trigonometric function of the operator angle Θ between the unperturbed and perturbed spectral subspaces through the same norm of the perturbation operator. The latest known sharp norm estimate called the a priori $\tan\Theta$ theorem serves for the case where the unperturbed spectral set lies in a finite gap of the remainder of the spectrum. We conclude the presentation by mentioning those questions of the subspace perturbation theory that still remain open.

Thursday / **40**

Three-dimensional configuration space Faddeev equations: Theory and Applications

Author: Mantile Lekala[1]

[1] *University of South Africa*

Corresponding Author: lekalml@unisa.ac.za

One of the common approaches toward solving the Faddeev and Faddeev-Yakubovsky equations is the use of partial-wave expansion of the solution sought, resulting in the reduction of the Faddeev equations to a set of two-dimensional coupled equations, which are amenable to numerical solution. For systems interacting via a force strong repulsive core lots of partial waves are necessary to achieve convergence. However, with the inclusion of lots of partial waves the result is an intractable numerical problem, that may only be solved with the use of high-performance computing facilities. The total-angular momentum approach proposed in [1] provides an efficient alternative to solving the Faddeev equations. In this work we use the total-angular momentum approach to solve configuration space Faddeev equations. In applications, we consider realistic nonrelativistic nuclear systems, weakly bound systems and large systems such as the 16O8. The results obtained are in good agreement with the experimental values (where they exist) and the literature ones. An attempt to present the three-dimensional version for Faddeev-Yakubovsky equations is given.

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Wednesday / 41

Computational study of materials in the department of Physics (University of Limpopo)

Author: Mulatedzi Gandamipfa[1]

[1] *University of Limpopo*

Corresponding Author: mulatedzi.gandamipfa@ul.ac.za

The research team operates within the Department of Physics at the University of Limpopo. Their computational studies focus on a range of materials, including gold, silver, and copper nanoparticles, as well as the field of physics education. These nanoparticles are explored as potential candidates for chemical sensing and energy storage through theoretical and computational approaches. Specifically, the team examines their electronic, structural, optical, and thermodynamic properties to improve semiconductor capabilities. These findings are then compared with experimental results to assess their viability in gas sensing and energy applications. The DL_POLY software supports in examining structural, dynamical, and thermodynamic properties, while the exciting code sheds light on electronic, excited state, and transport characteristics of these materials. Through the CHPC, Materials Studio is employed to elucidate interactions involving these noble metals.

Thursday / 42

The Langevin description of deep-inelastic heavy-ion collisions

Author: Гурген Адамян[1]

[1] *BLTP, JINR*

Corresponding Author: adamian@theor.jinr.ru

A specific feature of the deep-inelastic collisions is the high loss of kinetic energy of the collision heavy ions. This means that the latter become highly excited during the collision. The mechanism of the energy loss of the colliding nuclei is described within the theory of Brownian motion as classical friction due to the coupling of the relative motion of heavy ions to the internal nucleonic degrees of freedom, which are represented by a “heat bath” of harmonic oscillators.

Wednesday / 43

Neutron stars as a nuclear physics laboratory

Author: Evgeni Kolomeitsev[1]

[1] *BLTP, JINR, Dubna*

Corresponding Author: kolomei@theor.jinr.ru

Compact astronomical objects, historically called neutron stars, are remnants of dying stars that survived supernova explosions. They can be viewed as giant nuclei held together by gravitational forces acting against the pressure of degenerated nuclear matter.
We discuss astronomical constraints on the neutron star properties: mass, radius, temperature, age. Then we review the nuclear physics inputs needed for the description of neutron star properties.

Thursday / **44**

Chaotic structures in collision of solitons

Author: Yakov Shnir[1]

[1] *BLTP, JINR*

Corresponding Author: shnir@theor.jinr.ru

We investigate soliton collisions in scalar field theories in 1+1 dimensions and a model, which interpolates between the sine-Gordon theory, phi4 theory and a model with sextic potential. Various resonant structures emerging in this model because of energy transfer between the modes of excitation. We also emphasise the role of radiation and oscillon formation in the collision process.

Monday / **45**

Leigh-Strassler theories and their Hopf algebra structure

Author: Hector Dlamini[1]

[1] *University of Witwatersrand*

Corresponding Author: sickmech@gmail.com

We discuss the underlying mathematical structure that suitably describes the symmetries of the Leigh-Strassler [LS] theories as marginal deformations of the 4D $\mathcal{N}$ = 4 super Yang-Mills [SYM]. We present Hopf algebras as a mathematical language suited to describe how to obtain LS theories from the SYM. The hope is obtain a bridge through which to port all the knowledge/lessons/techniques we have learnt from SYM in order to understand more realistic theories.

Wednesday / **46**

The entrance channel effect in the reactions of heavy-ion collisions

Author: Avazbek Nasirov[1]

Co-author: Elzod Khusanov [2]

[1] *Joint Institute for Nuclear Research*

[2] *Institute of Nuclear Physics*

Corresponding Authors: nasirov@jinr.ru, xusanovelzod.99@gmail.com

An analysis of the energy, mass and angular distributions of the binary reaction products in the heavy ion collisions allows us to construct the mechanisms of their formation in dependence on the beam energy, orbital angular momentum and structure of the colliding nuclei.
The theoretical methods [1] based on the dinuclear system (DNS) concept [2] suggested by Prof. Vadim Volkov are used to calculate the collision dynamics leading to formation of a molecule-like system. The formation of the DNS is considered the doorway state and its characteristics play a crucial role at its evolution, which leads to complete fusion or to its alternative end—quasifission of the DNS into binary fragments without reaching compound nucleus state. The quasifission is a group of deep-inelastic collisions. The large number of the transferred nucleons and strong dissipation of the relative kinetic energy are inherent for the quasifission events.
Recently, in our paper [1] we have proved that the incomplete fusion occurs during multinucleon transfer from the light nucleus to the heavy one in collisions with the large orbital angular momentum. In this case, the centrifugal force increases due to small values of the moment of inertia of the DNS consisting of alpha particle and conjugate nucleus during its evolution. As a result, the centrifugal force causes a hindrance to complete fusion and at the same time breaks this very asymmetric system.
The multinucleon transfer in the opposite direction from heavy nucleus to light one leads to quasifission of the DNS. The possibility of overlap of the mass distributions of the fusion-fission and quasifission products depends on the mass asymmetry of the entrance channel and dynamics of the heavy ion collision.
The nature of the overlap of the mass distributions of the fusion-fission and quasifission products is discussed on the base of the theoretical results obtained at the analysis of the deviations of the mass distributions of the fusion-fission products observed in the experiments performed for collisions of nuclei different mass asymmetry in the entrance channel. The role of the orientation angles of the axial symmetry axis of the colliding nuclei, beam energy and orbital angular momentum on the mass distribution of the quasifission products is demonstrated by the analysis of the theoretical results obtained to interpret the experimental data.
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Tuesday / **47**

Low-energy spectra of nobelium isotopes: scissors mode in 254No

Authors: Valentin Nesterenko[1]; Мария Мардыбан[None]

[1] *BLTP, Joint Institute for Nuclear Research*

Corresponding Authors: nester@theor.jinr.ru, mmardyban@theor.jinr.ru

The description of low-energy multipole specta in isotopes 250-260No within fully self-consistent Quasiparticle-Random-Phase-Approximation (QRPA) method [1, 2] with Skyrme forces is briefly discussed [5]. The main attention is paid to nuclei 250,252,254No, where we have most of the experimental spectroscopic information [3, 4].
The QRPA description of the recent experimental data on low-energy M1 strength in 254No [6] is provided. The interplay of M1 spin-flip and orbital scissors excitations is discussed. The collectivity of the states is estimated. The interference of spin and orbital degrees of freedom is analyzed.

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Wednesday / **48**

Precision Physics for Fundamental Physics

Author: Vladimir Korobov[1]

[1] *BLTP, JINR, Dubna, Russia*

Corresponding Author: korobov@theor.jinr.ru

We give a review of the modern precision table-top experiments and precision physics. Status of theory: two-body and three-body calculations. We discuss impact of precision physics on the fundamental physical constants, search for space-time variations of fundamental constants, precision determination of masses, search for new exotic forces, CP violation and electron EDM.

We consider precision spectroscopy of exotic atoms (antiprotonic/pionic/kaonic helium, antihydrogen, μCF), CPT violation and determination of properties of exotic particles.

Monday / **49**

Small atomic He clusters at low energies

Author: Elena Kolganova[1]

[1] *BLTP, JINR, Dubna*

Corresponding Author: kea@theor.jinr.ru

Clusters of gas atoms form a broad class of molecules bound by van der Waals-type interactions. Some weakly bound clusters exhibit universal characteristics and scale invariance linked to the famous Efimov effect, which was first experimentally confirmed in an ultracold gas of Cs atoms. The helium trimer system has long been regarded as an ideal candidate for observing Efimov states. After extensive research, the Efimov state—corresponding to the excited state of 4He3 —was finally detected in 2016.

Numerous realistic He-He potential models have been developed, achieving increasingly accurate reproductions of two-body data. However, highly precise calculations are necessary to assess the influence
of these potential models on the properties of three-body systems. One of the most effective methods for studying triatomic clusters relies on solving the differential Faddeev equations which we use for calculation of helium trimer.

Wednesday / **50**

Role of the hard-core nucleon-nucleon interactions on the structure of three-body weakly bound systems

Author: Bahati Mukeru[1]

[1] *UNISA, South Africa*

Various nucleon-nucleon interactions are used to study the ground state structure of weakly bound three-body systems. It is found that when a hard-core nucleon-nucleon is used, a strongly attractive three-body force is required to keep the system bound in the case of a light system. However, the strength of the three-body force is substantially reduced as the atomic mass of the system increases.

Also, for a light system, as the two peripheral nucleons strongly repel at short distance, they carry the whole system toward the peripheral region. Consequently, in this case, the 6He system is found to have a large matter radius compared to the 22C. This work serves to emphasis that indeed in a three-body system, the halo nucleons only interact at rather short distance. This distance can be estimated to be around the radius of the of the interaction core.

Monday / **51**

Opening

Tuesday / **52**

1

Monday / **53**

Recent paradoxes of cosmology

Author: Anton Baushev[1]

[1] *BLTP, JINR, Dubna*

We present a brief overview of some recent observational results that challenge the validity of the standard LambdaCDM cosmology. These results still need further verification, but their confirmation could lead to revolutionary changes in our understanding of the construction of our Universe.

Tuesday / **54**

An Introduction to Quantum Computing and Quantum Machine Learning with Quantum Parametric Circuits

Author: Ilya Sinayskiy[1]

[1] *University of KwaZulu-Natal, Durban, South Africa*

Corresponding Author: ilsinay@gmail.com

Quantum Computing promises to solve specific classes of problems exponentially faster than any possible classical counterpart. However, testing this result in real life requires a large-scale universal error-correcting fault-tolerant quantum computer, which has not yet been built. We live in the age of noisy intermediate-scale quantum computers (NISQ) with several hundreds of noisy qubits. One of the most promising ways of using NISQ devices is Quantum Parametric Circuits (QPC) for various optimization problems (ground state energy estimation, MaxCut, QAOA, etc.). In this talk, I will introduce the basics of quantum computing with parametric circuits and show how to map various problems to QPCs. Afterwards, I will review some results achieved by some of my students.