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СЕМІНАР ІЗ СУЧАСНИХ ПРОБЛЕМ ФІЗИКИ
(Львів, 26–27 жовтня 2023 року)

WORKSHOP ON CURRENT PROBLEMS IN PHYSICS
(Lviv, 26–27 October 2023)

On 26–27 October 2023, the Physics Faculty of the Ivan Franko National University of Lviv hosted the Workshop on Current Problems in Physics. Representatives from scientific institutions of Ukraine and Poland participated in the Workshop, which was the thirteenth meeting of this series. The talks covered quantum mechanics, condensed matter physics, statistical physics, astrophysics, and some other subjects. The abstracts of the presentations are given below.

QUANTUM GRAPHS: COULOMB-TYPE POTENTIALS AND EXACTLY SOLVABLE MODELS

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We construct exactly solvable models for some non-relativistic quantum processes in ramified structures. The main object of the study is Schrödinger operators on non-compact star graphs with the Coulomb-type potentials having singularities at vertices (see Figure). The convergence of regularized Hamiltonians H_ε with cut-off Coulomb potentials coupled with $(\alpha\delta + \beta\delta')$-like ones is investigated. The 1D Coulomb potential [2] and the δ'-potential [3] are very sensitive to their regularization method. Our analysis of the Coulomb Hamiltonian can be viewed as a continuation of [2], where we have found conditions of the norm resolvent convergence of H_ε on the line and have constructed the solvable models for the one-dimensional hydrogen atom. The conditions of the norm resolvent convergence of H_ε on star graphs depending on the regularization are established. The limit Hamiltonians give the Schrödinger operators with the Coulomb-type potentials a mathematically precise meaning, ensuring the physically motivated choice of vertex conditions. We also describe all self-adjoint realizations of the formal Coulomb Hamiltonians on the star graph.

Our results remain valid for general quantum graphs. In this model, there is no interaction between vertices, and only the behavior of the Coulomb-type potential in the vicinity of a vertex is significant. Since we are interested in vertex couplings caused by the Coulomb singularity, we study the case of a star-shaped quantum graph.

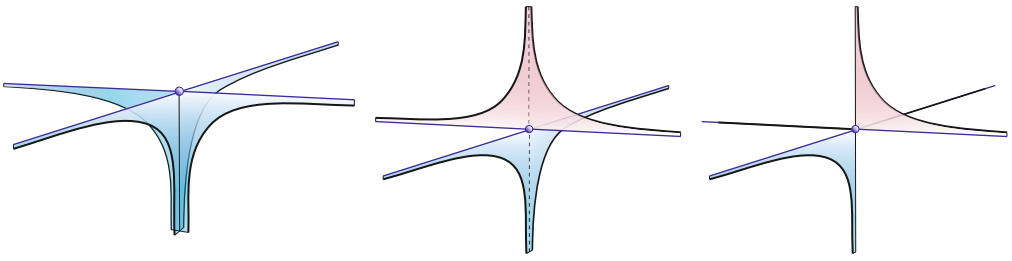

Figure. The "classic" and exotic Coulomb potentials

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MOTION IN A GRAVITATIONAL FIELD IN NONCOMMUTATIVE PHASE SPACE WITH PRESERVED ROTATIONAL AND TIME-REVERSAL SYMMETRIES

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The idea of deformation of commutation relations for operators of coordinates and operators of momenta for description of the features of space structure at the Planck scale is considered. Noncommutative algebra with canonical noncommutativity of coordinates and canonical noncommutativity of momenta which does not lead to violation of the time-reversal and rotational symmetries is examined. The algebra was proposed in [1]. In noncommutative phase space with preserved rotational and time-reversal symmetries, the motion of a particle is examined in the gravitational field. We have found the expression for the period of the circular motion in the space up to the second order in the parameters of noncommutativity. Also, on the basis of studies of the perihelion shift of the Mercury planet, the upper bound for the minimal length has been obtained. In addition, the weak equivalence principle has been studied and the way to solve the problem of violation of the principle has been proposed.

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CONTINUOUS AND DISCONTINUOUS WAVES IN AN ASEP WITH POCKETS

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One-dimensional transport phenomena are ubiquitous in nature. We encounter them among processes in narrow channels
[1], traffic flows
[2], biological systems
[3], etc.
They are usually described by stochastic models.

One of such models is the asymmetric simple exclusion process (ASEP), which has been considered fundamental in non-equilibrium statistical mechanics. It is defined by dynamic rules, rather than a Hamiltonian. Particles preferentially hop along the chain to neighbouring sites interacting only through the hard-core repulsion. Each site of the chain can accommodate one particle at most.

We consider a geometric modification of the ASEP in which each site of a one-dimensional chain is attached to a lateral dead-end site (called pocket). Although this model has an uncorrelated steady state on a ring, it shows rich density-profile dynamics on large space and time scales.

We analyze various density waves emerging from initial step-wise profiles. The most interesting feature is that even without additional interaction and steady-state correlations this model demonstrates traveling rarefaction and contraction waves with a discontinuity at the leading edge.

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STABILITY OF COSMIC WEBS IN TERMS OF BETTI CURVES

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In our work, we explore Betti curves of the Cosmic webs of several simulations. In particular, we consider the halo catalogs of Bolshoi, Multidark and HOWLs simulations. Their mass (and spacial) resolutions differ a lot, being the lowest for the HOWLs and the highest for the Bolshoi simulation. All of them have almost the same ΛCDM cosmologies. We study the snapshots of the universes starting from redshifts $z = 2.5$ to $z = 0$. In each snapshot, we build an alpha-complex of the pointcloud of halos and study its Betti curve. We have discovered that Betti curves of the Cosmic web do not evolve with cosmological time

if the subpopulations of the narrow mass range are considered. We propose a log-normal-like function to approximate the Betti curves of both 1- and 2-dimensional homology features. These features can be associated with filament loops and voids, correspondingly. We find the evolution of the parameters of approximation functions, which show almost no evolution. The Betti curves do not depend either on the mass resolution of the simulation, nor on the redshift of the snapshot, nor on cosmic variance. There is a slight dependence of the parameters on the mass range of subpopulations. It can be explained by a different halo mass function inside even a narrow mass range. With our research, we confirm the effect earlier dubbed a "topological bias which can be formulated as follows: populations of heavier halos form larger structures. We also note that the Betti curves of a higher dimension have larger characteristic scales and lager dispersion.

Our study opens a possibility to use Betti curves and other topological data analysis tools as cosmological tests in the future.

STRONG ADSORPTION OF METHYLENE BLUE CATIONS IN ACIDIC SOLUTION BY A HYBRID MATERIAL BASED ON SILICA GEL AND IRON OXIDE NANOPARTICLES

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We present a way to increase the adsorption capacity of silica in acidic solutions by decorating its mesoporous structure with nanoparticles of a material with a much higher zero charge point value than in the case of pure silica. Because inside the silica pores, as the Debye length becomes comparable to the average pore size, the positive ionic layers formed around the iron oxide nanoparticles merge and fill the entire interior of the pore entrances, thus acting as anchored centers of positive electric charge. As a result, the silanol groups surrounding the pores on the outer surface of silica are deprotonated by electrostatic interactions up to the Debye length. It leads to a radical change in the Zeta potential of mesoporous silica gel in the pH range from 3.5 to 6.5 and a significant increase in its adsorption properties, as evidenced by the adsorption of methylene blue cations.

SEMI-EMPIRICAL ANALYSIS OF THE Co I STRUCTURE IN THE CONTEXT OF BOSE–EINSTEIN CONDENSATION

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Cobalt is an element belonging to the iron group with an open $3d$-shell. Its structure is interesting in various fields, astrophysics in particular. Determining its abundance is crucial for testing stellar atmosphere models, exploring galactic chemical evolution and examining the cobalt nucleosynthesis process. Co I was chosen for this study due to a plethora of highly reliable experimental measurements published by research groups. While cobalt has long held significance in astrophysical research, we have reasons to believe it may also prove to be a compelling candidate for the Bose–Einstein condensate creation.

The Bose–Einstein condensate (BEC) is among the most notable quantum materials. This remarkable state of matter holds promise for an array of applications, from the creation of ultra-precise time standards and the measurement of very weak magnetic fields to its potential role in quantum computing. As a macroscopic material that uncovers the profound quantum nature of matter, it can serve as an invaluable testing platform for the principles of quantum mechanics and electrodynamics, thanks to the relatively straightforward manipulation of its quantum state. Hence, understanding how to achieve BECs in various elements is crucial for advancing quantum technologies. To achieve this goal, it is necessary to advance our knowledge of the energy structure and radiative transition parameters within atoms of elements that have yet to experience the cooling necessary for condensate formation.

The aim of our research is to determine the energy structure, the values of radiative lifetimes and oscillator strengths for Co I, based on the most recent experimental data, using a semi-empirical approach. The method of parameterization of the atomic structure and the appropriate program package have been developed for many years by Dembczyński, Elantkowska and Ruczkowski [1]. The software for semi-empirical calculations is a set of programs enabling a complete description of all attributes of the atomic structure and can be used for any atom or ion occurring in nature, with any chosen arrangement of electronic configurations. Its effectiveness has been confirmed over several years of studies. The semi-empirical method embraces three pivotal phases in unraveling the energy structure of an atom: calculation of eigenvectors pertaining to the atom's fine structure, determination of the hyperfine splittings, and parameterization of radiative transitions. All these steps collectively deepen the understanding of the

electron shell structure within the atom, laying the groundwork for the potential realization of Bose–Einstein condensation in the chosen element. The presentation highlights very promising results achieved to date in the process.

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PREDICTING UNIVERSAL SIZE RATIOS FOR COMPLEX POLYMERS

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Dilute polymer solutions, rare in practical applications, play an important role in studying polymer architecture due to large distances between macromolecules and, thus, neglectably small interactions. Experimental measurements in static light scattering provide the values for the gyration radius of the molecules in question among other parameters.

Since the early days of polymer physics, there have been numerous attempts and methods to predict the size of the macromolecule in a solution. In practice, for such predictions the ratio between a branched architecture and its linear counterpart is considered, as such a ratio is universal and does not depend on chemical details of the macromolecule.

One of the more successful models for the gyration radius calculations is a continuous chain model. However, for a quantitative comparison with experiments it requires at least two orders of perturbation expansions, which is often unreachable for complex architectures. In 1984, Douglas and Freed proposed an approximation that allows to get a good quantitative prediction from just the first order calculations.

In resent decades, new synthesis methods allowed us to receive well controlled synthesis of complex architectures for a wide range of applications. Thus, this chain of studies was dedicated to predictions of the size ratios using the Douglas Freed approximation and molecular dynamics simulations. It was shown that for a range of architectures the approximation provides good results while failing at some others.

QUANTUM SYSTEMS WITH RESONANCES INDUCED BY SYMMETRY DISRUPTION

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We consider a non-relativistic quantum system with and asymptotically straight, so called "soft", waveguide. We show that the local deformation of the symmetric waveguide can lead to the emerging of the embedded eigenvalues living in the continuous spectrum. The main focus of the talk is on the analysis of the weak perturbation of the symmetric system. We show that the original embedded eigenvalues constitute resonances under a weak symmetry disruption. We describe the asymptotics lifetime of the resonance states in terms of deformation parameters.

QUASIORDERING OF SINGLE-FILE WATER MOLECULES CONFINED IN SINGLE-WALL CARBON NANOTUBE

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In this study, we investigate the behavior of water molecules confined within narrow single-wall carbon nanotubes (SWCNTs) arranged in a single-file chain. Our approach involves molecular dynamics simulations, where we use quantum chemistry-derived charges for the water oxygen, ammonia nitrogen, and hydrogen atoms, along with lattice-model calculations. Our results reveal a temperature-driven phenomenon: the water dipoles exhibit orientational quasiorder, aligning parallel to the tube axis at temperatures around 150 K, and a similar reorientation occurs for ammonia dipoles at temperatures below 100 K.

We delve deeper into this temperature-induced quasiphase transition by conducting additional quantum chemical calculations to determine the optimal geometry and charges within the water molecules and the

SWCNT system. Utilizing these findings, we propose a simplified lattice model that effectively replicates the characteristics of one-dimensional confined arrays of water molecules. This lattice model takes into consideration both short-range and long-range interactions, as well as the constraints imposed by the narrow tube, offering an explanation for the temperature-dependent orientational ordering. This ordering persists across a substantial temperature range.

Our theoretical investigations were prompted by experiments conducted by X. Ma and colleagues, specifically their work on the temperature dependence of photoluminescence spectra in water-filled (6,5) SWCNTs [1].

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THE INDUCED GRAVITY BASED ON THE μ-THERMODYNAMICS AND SOLUTIONS OF THE μ-DEFORMED EINSTEIN EQUATION

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We propose a μ-deformed generalization of Einstein's equation as a new version of the induced gravity based on μ-thermodynamics. In this version, the system's temperature, entropy and mass depend on the parameter μ and, thus, induce a μ-gravitational field. The derived μ-deformed gravitational field equation describes some dynamical or field nonlinearities that have an effect on gravity. In the limit of $\mu \to 0$, the standard General Relativity gravitational field equation is recovered, which confirms consistency of the μ-deformed induced approach.

We analyze solutions of the μ-deformed Einstein equation in the Schwarzschild metric and compare them with the nondeformed case. The deformed Schwarzschild radius is deduced and a possible connection between deformation and gravitational waves is considered, which could suggest physical meaning of the μ parameter. Possible implications of this kind of deformations for astrophysics are briefly discussed.

QUANTUM WAVE IMPEDANCE APPROACH FOR FINDING EIGENENERGIES OF A SYSTEM WITH AN ARBITRARY PIECEWISE CONSTANT POTENTIAL

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It was shown how to get an analytical expression of the characteristic equation for finding energies of bound states of a system with an arbitrary piecewise constant potential. For this purpose, the approach of quantum wave impedance was applied. In a general case, the obtained characteristic equation cannot be solved analytically, and thus the numerical methods are needed to achieve this goal. But having the analytical expression for the characteristic equation, one is able to simplify significantly the complexity of the task of finding eigenenergies of the quantum mechanical system, compared to the direct numeric calculations. As an illustration, it was demonstrated how the approach works for a few samples of a piecewise constant potential.

PROTOCOL FOR DETECTING THE PURELY IMAGINARY FISHER ZEROS ON A QUANTUM COMPUTER

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We propose a protocol for the study of the purely imaginary Fisher zeros of the Ising model on a quantum computer. The protocol is based on the direct relation between the partition function for purely imaginary temperature and the evolution operator of the Ising model. In this case, the inverse temperature is equal to the time of evolution. We test this protocol on the IBM quantum computer in the cases of a 3-spin chain and triangle cluster in the purely imaginary magnetic field, and a 7-spin cluster (the interaction between spins reproduces the architecture of the quantum computer).

STUDIES OF TWO-QUBIT QUANTUM STATES CONCURRENCE ON IBM'S QUANTUM COMPUTER

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The focus of the talk is on the concurrence of two-qubit quantum state [1]. We present quantum protocols for measuring mean values of the spin on a quantum device and detection of the concurrence. We investigate the dependence of the concurrence on parameters of three particular states, namely $(|00\rangle + \exp(i\alpha_1)\,|01\rangle + \exp(i\alpha_2)\,|10\rangle + \exp(i\alpha_3)\,|11\rangle)/2$, $\cos(\theta/2)\,|01\rangle + \sin(\theta/2)\,|10\rangle$, $\cos(\theta/2)\,|00\rangle + \sin(\theta/2)\,|11\rangle$. All computations are made on the quantum computer IBM Lima [2]. The results of the quantum calculations are in agreement with the theoretical ones.

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MUTUAL EXCLUSION OF THE FIRST- AND SECOND-ORDER CORRELATIONS IN A MULTI-MODE SYSTEM

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We investigate the first- and second-order correlation functions in a multi-mode system and find several interesting relations between the correlations. Firstly, the perfect coherence is accompanied by a vanishing anticoherence and vice versa, the vanishing coherence is accompanied by a nonvanishing anticoherence. The modes can be perfectly mutually coherent regardless of the distribution of the population between them, the phenomenon known as induced coherence without induced emission [1,2]. Secondly, the nonvanishing anticoherence corresponds to a situation in which the modes could be entangled [3]. Thus, interference effects between the modes signal the complete separability of the modes, while entanglement signals that he modes are mutually incoherent [4]. Thirdly, a linear superposition of two modes interacting with thermal reservoirs of different temperatures can be perfectly coherent with the other orthogonal superposition of the modes.

The investigations are illustrated on the example of the modes of a tripartite optomechanical system composed of two cavity modes and a mechanical mode, Figure. We assume that the modes are coupled to external reservoirs, which are in thermal states of unequal mean photon numbers.

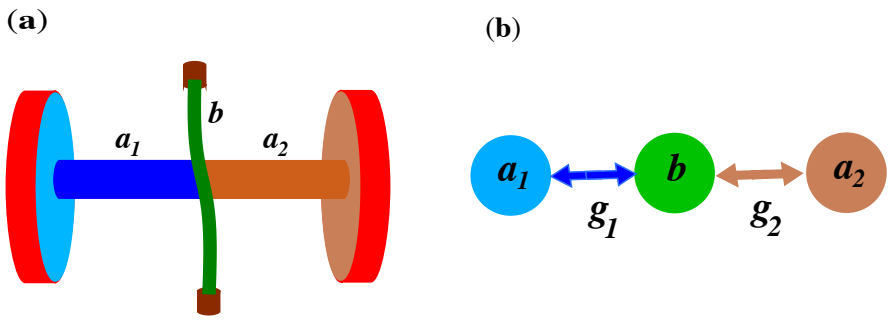

Figure. Schematic diagram of a three mode optomechanical system composed of two cavity modes, a_1 and a_2 and the membrane mode b.

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ON THE ROTATION OF CONDUCTIVE AND DIELECTRIC SPHERES IN A STATIC UNIFORM ELECTRIC FIELD

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The focus is on the free rotation of neutral spherical particles levitating in a static uniform electric field $\boldsymbol{\mathcal{E}}$. The external field $\boldsymbol{\mathcal{E}}$ induces in the particles the electric dipole moment $\boldsymbol{d}$, which is inclined towards this field due to the particle rotation. In turn, the interaction of the particle dipole moment $\boldsymbol{d}$ with the external field $\boldsymbol{\mathcal{E}}$ causes the torque $\boldsymbol{M} \equiv \boldsymbol{d} \times \boldsymbol{\mathcal{E}}$ braking the particle rotation. Details of this rotary motion depend on electric properties of the particles. Three basic examples have been considered: the Ohm conductor, the Debye model of polar dielectric, and the Lorentz model of non-polar dielectric. We assume that the distribution of free and bound charges resulting in a dipole moment follow adiabatically the change of the particle rotation with the characteristic relaxation time τ. The corresponding Euler equations of the particle rotary motion are reduced to quadratures and integrated out. In all cases, the solutions reveal common features.

The component of angular velocity parallel to the external field $\boldsymbol{\mathcal{E}}$ is unchanged, $\Omega_3 = \text{const}$, while the orthogonal component $\boldsymbol{\Omega}_\perp$ decreases asymptotically (at $t \to \infty$) according to the exponential law $\boldsymbol{\Omega}_\perp \sim \exp(-t/T)$. The same happens with the dipole moment: $d_3 = \text{const}$ while $\boldsymbol{d}_\perp \sim \exp(-t/T)$.

The value of the relaxation time τ varies in a wide range, from $\tau \sim 6 \cdot 10^{-19}\,\text{s}$ for good conducting golden particles to $\tau \sim 5 \cdot 10^{-5}\,\text{s}$ for ice, the polar dielectric. The same is true for the maximal inclination angle at $\Omega_{\max} = 2\pi\,\text{GHz}$: from $\psi_{\max} \sim 4 \cdot 10^{-9}$ to $\psi_{\max} \sim \pi/2$. The minimal braking time T is inversely proportional to the relaxation time τ; thus it varies in a wide range too: from $T \sim 10^6\,\text{s}$ for golden particles to $T \sim 2 \cdot 10^{-8}\,\text{s}$ for ice. Despite such a large difference in numbers, the solutions for Ohm conductors and Debye polar dielectrics are similar: up to a replacement of parameters, they coincide and can be represented in an explicit form via the Lambert W function. In particular, they describe the clockwise precession.

In contrast, the simplest Lorentz model of a non-polar dielectric characterized by the single resonance frequency Ω_0 leads to a more complicated solution which describes the counterclockwise precession in the infrared region $\Omega < \Omega_0$.

The results have potential applications for designing electromagnetic traps for neutral particles.

OPTICAL SPECTROSCOPY AND LOCAL STRUCTURE OF LEAD-CONTAINING GLASSES WITH DIFFERENT COMPOSITIONS

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Lead-containing glasses with basic compositions PbO–GeO_2, PbO–SiO_2, PbO–B_2O_3, PbO–B_2O_3–GeO_2, PbO–GeO_2–AlF_3, PbO–SiO_2–AlF_3, and PbO–SiO_2–ZnO–K_2O–BaO–CuO were studied using X-ray diffraction (XRD), electron paramagnetic resonance (EPR), infrared (IR) transmission, UV–Vis optical absorption, photoluminescence and decay kinetics [1–3]. The obtained glassy-like XRD patterns for the studied glasses were analyzed in order to obtain the radial distribution functions and to define the Ge–O, Si–O, B–O, Pb–O, O–O, and Pb–Pb average interatomic distances and coordination numbers of Ge, Si, and B atoms in the first coordination sphere and Pb atoms in the first and second coordination spheres in the glass network. A characteristic EPR spectrum of the Cu^{2+} ions was observed in the PbO–SiO_2–ZnO–K_2O–BaO–CuO glass, which was described using the spin Hamiltonian formalism.

The registered UV–Vis optical absorption spectra show that the fundamental absorption edge of the studied glasses is located in the UV–blue spectral region, which shows a tendency to shift towards longer wavelengths with a increase in the PbO content. The registered IR transmission spectra show that the transmittance of the studied glasses is relatively high (close to 80%) up to a wavelength of 2.7 μm. The transmittance decreases to zero at 4–6 μm due to stretching vibrations of hydroxyl groups and glass forming units. The addition of AlF_3 to the PbO–GeO_2 and PbO–SiO_2 glasses significantly reduces the absorption of the free and bound hydroxyl groups and increases their transmission cut-off wavelength.

Under UV photoexcitation the studied glasses exhibit an intense broad emission band in the blue-yellow spectral region with a lifetime in the nanosecond range. This emission is caused by band-to-band electron-hole recombination. The Ge-containing glasses show also the shoulder near 610 nm with a lifetime in the microsecond range. This emission is related to the recombination of electrons with O^- hole centers located in the sites of non-bridging oxygen of the GeO_4 glass-forming tetrahedra. Besides, photoluminescence spectra and decay kinetics of Cu^+ ions in the $PbO–SiO_2–ZnO–K_2O–BaO–CuO$ glass were registered and interpreted. The CIE chromaticity diagram shows a variation in the emission colour of the studied glasses with a change in their composition.

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MODELING OF q-DEFORMED HARMONIC OSCILLATOR ON QUANTUM COMPUTER

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We demonstrate a quantum simulation of a q-deformed quantum harmonic oscillator on an IBM quantum computer. Using the method of detection of energy levels of a spin system on a quantum computer by probe spin evolution, proposed in [Eur. Phys. J. Plus **137**, 522 (2022)], we obtain the energy levels of both the q-deformed quantum harmonic oscillator and an unharmonic oscillator.

LOCAL STRUCTURE AND SPECTROSCOPIC PROPERTIES OF THE $Li_2B_4O_7$:Cu,Eu AND $Li_2B_4O_7$:Cu,Sm GLASSES

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The $Li_2B_4O_7$:Cu,Eu and $Li_2B_4O_7$:Cu,Sm glasses containing 1.0 mol.% CuO, Eu_2O_3, and Sm_2O_3 impurities were obtained and studied in detail using X-ray diffraction (XRD), electron paramagnetic resonance (EPR), optical absorption, and photoluminescence (excitation, emission, decay kinetics) techniques [1,2]. The obtained XRD patterns confirm the disordered (vitreous) structure of the studied $Li_2B_4O_7$:Cu,Eu and $Li_2B_4O_7$:Cu,Sm samples. Parameters of the local structure (average interatomic distances and coordination numbers) for $Li_2B_4O_7$:Cu,Eu and $Li_2B_4O_7$:Cu,Sm glasses were derived from radial distribution functions (RDF), calculated from experimental XRD data. The EPR and optical spectroscopy (absorption, photoluminescence excitation, emission, and decay kinetics) show that the Cu impurity is incorporated into the $Li_2B_4O_7$ glass as Cu^{2+} ($3d^9$, $^2D_{5/2}$) and Cu^+ ($3d^{10}$, $^1S_0$) ions. The EPR spectra of the $Li_2B_4O_7$:Cu,Eu and $Li_2B_4O_7$:Cu,Sm glasses reveal an anisotropic axially-symmetric signal with a characteristic hyperfine structure belonging to the Cu^{2+} paramagnetic ions. Spin Hamiltonian parameters of the observed axial EPR spectra ($g_\parallel$, $g_\perp$, $A_\parallel$, $A_\perp$) and peak-to-peak derivative linewidths ($\Delta H_{pp}^{\parallel}$, ($\Delta H_{pp}^{\perp}$) for Cu^{2+} ions were determined in the $Li_2B_4O_7$:Cu,Eu and $Li_2B_4O_7$:Cu,Sm glasses, which were compared with corresponding parameters for $Li_2B_4O_7$:Cu glass.

Optical absorption spectra of the $Li_2B_4O_7$:Cu,Eu and $Li_2B_4O_7$:Cu,Sm glasses were analyzed and interpreted. Optical band gap and Urbach energy for $Li_2B_4O_7$:Cu,Eu and $Li_2B_4O_7$:Cu,Sm glasses have been evaluated. Optical absorption spectrum of the $Li_2B_4O_7$:Cu,Eu glass shows a very broad intense band attributed to Cu^{2+} ions (superposition of the $^2B_{1g} \rightarrow ^2A_{1g}$, $^2B_{1g} \rightarrow ^2B_{2g}$, and $^2B_{1g} \rightarrow ^2E_g$ transitions) and several weaker narrow bands attributed to characteristic $f-f$ transitions of the Eu^{3+} ($4f^6$, $^7F_0$) ions. Optical absorption spectrum of the $Li_2B_4O_7$:Cu,Sm glass also shows a very broad intense band attributed to Cu^{2+} ions and several weaker narrow bands attributed to characteristic $f-f$ transitions of the Sm^{3+} ($4f^5$, $^6H_{5/2}$) ions.

Photoluminescence spectra of the $Li_2B_4O_7$:Cu,Eu glass reveal a broad blue emission band of the Cu^+ ions ($3d^94s^1 \rightarrow 3d^{10}$ transition) and 5 narrow emission bands in the orange-red range belonging to the $^5D_0 \rightarrow ^7F_J$ ($J = 0-4$) transitions of the Eu^{3+} ions with characteristic lifetime values [1]. Photoluminescence spectra of the $Li_2B_4O_7$:Cu,Sm also show a very broad blue emission band assigned to the

$3d^9 4s^1 \rightarrow 3d^{10}$ transition of the Cu^+ ions and 4 narrow emission bands in the yellow-red range assigned to the ${}^4G_{5/2} \rightarrow {}^6H_J$ ($J = 5/2, 7/2, 9/2, 11/2$) transitions of the Sm^{3+} ions. A detailed comparison of the results obtained for the $Li_2B_4O_7$:Cu,Sm, $Li_2B_4O_7$:Sm, and $Li_2B_4O_7$:Cu glasses allows us to notice a slight quenching of the Sm3+ photoluminescence, a shortening of the Sm^{3+} lifetime, and an elongation of the Cu^+ lifetime in $Li_2B_4O_7$:Cu,Sm glass. The observed effects are explained by the excitation energy transfer from Sm^{3+} to Cu^+ and Cu^{2+} ions [2].

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AXIONLIKE DARK MATTER MODEL INVOLVING TWO-PHASE STRUCTURE AND PARTICLE COMPOSITES

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Focusing on the self-gravitating Bose–Einstein condensate (BEC) model of dark matter (DM), we show that the axionlike self-interaction of ultralight bosons ensures the existence of both rarefied and dense phases in the DM halo core of dwarf galaxies [1]. In fact, this stems from two independent solutions of the Gross–Pitaevskii equation corresponding to the same model parameters. The existence of two-phase structure was also established in previously studied models with polynomial self-interactions, which actually involve the truncated expansion series of the axionlike self-interaction [2,3,4]. For a small number of particles, this structure disappears along with the gravitational interaction, and the Gross–Pitaevskii equation reduces to stationary sine-Gordon equation, the one-dimensional anti-kink solution of which mimics a single-phase DM radial distribution in the halo core. Quantum mechanically, this solution corresponds to a zero-energy bound state of two particles in a closed scattering channel formed by the domain-wall potential with a finite asymptotics. To produce a two-particle composite with low positive energy and a finite lifetime, we appeal to the resonant transition of one asymptotically free particle of a pair from an open channel (with a model scattering potential) to the closed channel. Using the Feshbach resonance concept [5], the problem of two-channel quantum mechanics is solved in the presence of a small external impact which couples the two channels, and an analytical solution is obtained in the first approximation. Analyzing the dependence of scattering data on interaction parameters, we reveal a long-lived two-particle composite (dimer) state possessing a lifetime of millions of years. This result is rather surprising and supposes important implications of dimers' being involved in forming large DM structures. It is shown that the dimers' appearance is related with the regime of infinite scattering length due to resonance [6]. The revealed dependence of the DM scattering length a on the parameters of interactions can theoretically justify variation of a in the DM dominated galaxies and its role for large DM structures.

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PRELIMINARY INVESTIGATIONS OF SPECTRAL DEPENDENCE OF ODMR SIGNAL IN NV^- COLOR CENTERS IN DIAMONDS

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Nitrogen vacancies (NV^-) in diamonds are among the most studied color centers with non-zero spin, showing the ground state splitting, in wide-bandgap semiconductors. They usually coexist with NV^0 color centers, which possess no spin. Because NV^- defects are well isolated from the rest of the crystal lattice,

their electron states have relatively long quantum coherence times and can be easily controlled, they have many applications in quantum technologies [1]. The transition between the ground state sublevels can be induced by microwave radiation; the resonance can be detected by the change in intensity of laser-excited fluorescence, which is the essence of the ODMR (*optically detected magnetic resonance*) method. Excitation is usually achieved with green light (diode or DPSS lasers); however, in this region the probability of exciting NV^0 fluorescence (which increases the global fluorescence intensity and lowers ODMR signal contrast) is still substantial. There were also reports about excitation of NV^- color centers with yellow light, which highly reduces fluorescence from NV^0 vacancies, but no comparison with green light excitation was made. The fluorescence dependence on the excitation light wavelength (up to 520 nm) was already studied [2], but no papers reported any systematic studies of this aspect for ODMR signal.

We conducted such investigations with an in-house developed experimental setup, including a self-made confocal microscope. So far, the ODMR signal was recorded for the excitation wavelength range of 490–540 nm, accessible with available tunable dye lasers. The upper limit was determined by spectrally selective optical elements, currently optimized for excitation with 520 nm wavelength. Fluorescence spectra were also recorded for the same excitation wavelength range. There was a clear, monotonic growth of both fluorescence (which was consistent with literature reports for up to 520 nm [2]) and ODMR signals with increasing excitation wavelength. The correlation between both relationships is currently under investigation. In the near future, extension of the excitation range towards longer wavelengths is planned. This might help to determine the possible optimal excitation wavelength for the ODMR signal detection for the color centers under study.

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GLOBAL SIGNAL IN THE REDSHIFTED 21-cm LINE FROM DARK AGES: THEORETICAL PREDICTIONS AND DETECTION POSSIBILITIES

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The report presents the results of the analysis of signal formation in the line of the hyperfine structure of 21 cm of hydrogen in the Dark Ages ($30 \leq z \leq 300$) in various cosmological models and the possibility of its detection by radio telescopes of the decameter range UTR-2 and GURT of the National Academy of Sciences of Ukraine.

To study the dependence of the intensity and profile of the line on the values of cosmological parameters and physical conditions in the intergalactic medium, the evolution of the global (averaged over the sky) differential brightness temperature in the redshifted 21 cm line was estimated in the standard and non-standard cosmological models with different parameters. The standard ΛCDM model with post-Planck parameters predicts the value of the differential brightness temperature in the center of the absorption line $\delta T_{br} \approx -35$ mK at $z \approx 87$. The line frequency at the absorption maximum is 16 MHz, the effective line width is ≈ 25 MHz. The line depth is moderately sensitive to Ω_b and H_0, and weakly sensitive to Ω_{dm}, and insensitive to other parameters of the standard ΛCDM model. But the line is very sensitive to additional mechanisms of heating or cooling of baryonic matter during the Dark Ages; so it can be an effective test of non-standard cosmological models. In the models with decaying and self-annihilating dark matter, as well as with primordial global stochastic magnetic fields, the temperature of baryonic matter in this period is higher, the greater the density of these dark matter components and the strength of the magnetic field. The absorption line becomes shallower, vanishes and turns into emission at values of the component parameters lower than the upper limits on them, which result from the observational data.

The 21 cm line of neutral hydrogen is informative, but too weak to be detected using traditional methods even for the world's largest radio telescope of the decameter wavelength range UTR-2, since the signal level of the galaxy's synchrotron radiation, which is the foreground background, is 20,000–40,000 K at these frequencies. The report highlights the peculiarities of spectroscopy on decameter waves, interfering factors of natural and hardware origin and ways to eliminate them in order to reliably detect a signal in the 21 cm line. It is concluded that the detection of such a signal using the largest radio telescopes in the decameter wavelength range is quite possible and can be implemented in the postwar years in Ukraine.

PERSPECTIVES ON 2D PRINTING TECHNOLOGY FOR FLEXIBLE MAGNETOELECTRONICS SYSTEMS USING MAGNETIC NANOPARTICLES

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The presentation focused on the main trends in magnetoelectronics on thin flexible films. In this context, the possibility of 2D printing of multi-ring structures of magnetic nanoparticles on such films was shown. In this case, the mechanism of drying magnetic liquid droplets on a suitably prepared polyethylene thin film was used [1]. Using the theoretical model [2], the mechanism for controlling the elastic deformation of such thin film with magnetic nanoparticles was shown. Additionally, the prospects of obtaining submicron conductive paths of various shapes on these films, controlled by magnetic nanoparticles, were discussed.

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ПАМ'ЯТІ ПРОФЕСОРА ЙОСИПА МИХАЙЛОВИЧА СТАХІРИ (1934–2023)

IN MEMORY OF PROFESSOR YOSYP STAKHIRA (1934–2023)

4 грудня 2023 року пішов із життя відомий учений, лауреат Державної премії України в галузі науки і техніки, професор Стахіра Йосип Михайлович.

Йосип Михайлович Стахіра народився в с. Ниркові тепер Заліщицького р-ну Тернопільської області. Закінчив фізико-математичний факультет Чернівецького університету 1958 року та аспірантуру 1963 року. У 1964–68 роках був завідувачем кафедри фізики Чернівецького медичного інституту. У 1968–70 роках працював доцентом кафедри теорії твердого тіла, у 1970–78 роках — доцентом кафедри загальної фізики, у 1978–80 роках — старшим науковим співробітником НДС Львівського університету імені Івана Франка. Від 1980 року — доцент, а від 1987 до 2016 року — завідувач кафедри фізики напівпровідників. Від 1995 до 2002 року був деканом фізичного факультету Львівського університету імені Івана Франка.

У 1966 році Йосип Михайлович захистив дисертацію на тему "Дослідження напівпровідникових властивостей селеніду індію In_2Se_3" і 1967 року отримав звання доцента. У 1986 році успішно захистив докторську дисертацію на здобуття ступеня доктора фізико-математичних наук на тему "Розупорядкування і електронні властивості шаруватих напівпровідників" і 1989 року отримав звання професора.

Наукові інтереси Йосипа Михайловича переважно стосувалися дослідження фізичних властивостей шаруватих напівпровідників, кореляції міжшарової взаємодії з електронними властивостями та створення перспективних електронних приладів на їхній основі.

Талант науковця, професіоналізм, невтомний творчий пошук, компетентність у галузі фізики напівпровідників зробили Йосипа Михайловича авторитетною та шанованою людиною серед студентів, аспірантів та науковців Львівського національного університету імені Івана Франка.

Під його керівництвом виконано 9 дисертацій на здобуття вченого ступеня кандидата фізико-математичних наук. Йосип Михайлович Стахіра був консультантом докторської дисертації В. П. Савчина.

Учений опублікував близько 250 праць, зокрема: "Дослідження адсорбційної активності шаруватих напівпровідникових кристалів селенідів індію та галію" (Український фізичний журнал. 1995. Т. 40. № 3, 4; зі співавт.); "Спектри п'єзофотопровідності в монополярних напівпровідниках" (Журнал фізичних досліджень. 1998. Т. 2. № 3; зі співавт.); "Characteristics of phase formation during indium selenides oxidation" (Materials Chemistry and Physics. 2000. Vol. 65, No. 2; with co-auth.); "The energy structure of free electrons for semiconductor in the field of cylindrical symmetry" (Semiconductor Physics, Quantum Electronics and Optoelectronics. 2003. Vol. 6. No. 1; with co-auth.); "Structure and magnetic properties of InSe single crystals intercalated by nickel" (Semiconductors. 2011, Vol. 45; with co-auth.); "Defect structure of HgCdTe films grown by molecular beam epitaxy on Si substrates" (Semiconductor Science and Technology. 2012. Vol. 27, No. 3; with co-auth.)

Йосип Михайлович Стахіра — член експертної ради ВАК України з фізики, віце-президент Українського фізичного товариства, член наукової ради з фізики напівпровідників НАН України, заступник голови спеціалізованої вченої ради з захисту кандидатських та докторських дисертацій.

У 2001 році він отримав Державну премію України в галузі науки і техніки, а 2002 року — звання заслуженого професора Львівського університету імені Івана Франка.

Від заснування "Журналу фізичних досліджень" до 2020 року був заступником головного редактора.

Відчуття непоправної втрати сповнює друзів, колег та учнів Йосипа Михайловича Стахіри. Його світлий образ назавжди залишиться в нашій пам'яті.