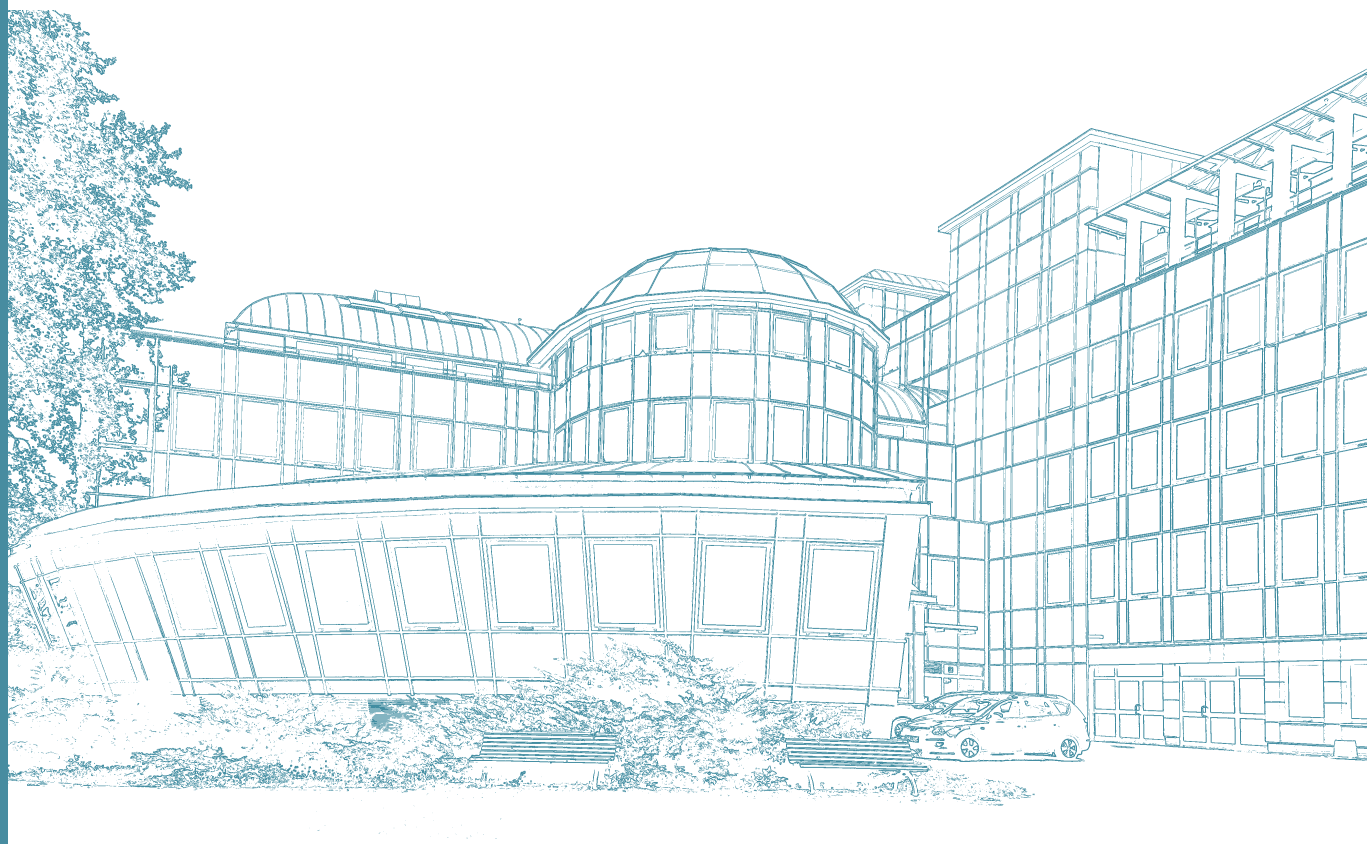
14th Workshop on Current Problems in Physics

BOOK OF ABSTRACTS



24 - 27 October 2022, Zielona Góra, Poland

UNIVERSITY
OF ZIELONA GÓRA

The Workshop on Current Problems in Physics 2022 (WCPP'22) is already the fourteenth in a series of meetings which represent annual forum for the Polish and Ukrainian physicists community to present their latest scientific results. Usually, the meetings are attended by representatives of other countries, too. An important feature of the conference is the possibility for young scientists to present their research results and interact with the more experienced colleagues from other countries.

The topics of WCPP'22 will cover a broad range of subjects, from physics to astronomy in both theoretical and experimental fields. The particular sessions will cover such subjects as: mathematical physics, quantum physics (including quantum optics, quantum information theory), nanotechnology and bionanotechnology, spectroscopy, astrophysics and cosmology and others.

The conference is organized under the auspices of His Magnificence Rector of the University of Zielona Góra, professor Wojciech Strzyżewski.

CONFERENCE PROGRAMME

Tuesday, October 25, 2022

Building A-29, Lecture room 106

8.30 – 9.00 REGISTRATION

Session I — *Chairman: Z. Ficek*

9.00 – 9.10 OPENING CEREMONY

9.10 – 9.45 V. TKACHUK (Keynote speaker)
Studies of the spin-1 tunneling on IBM's quantum computer

9.45 – 10.20 W. LEOŃSKI (Keynote speaker)
Quantum steering transfer along two non-interacting qubit chains

10.20 – 10.40 Y. YAREMKO
Radiation reaction in de Sitter space

10.40 – 11.00 S. KONDEJ
Quantum systems with wires in R^3

Coffee Break

Session II — *Chairman: V. Tkachuk*

11.30 – 12.05 J. KŘÍŽ (Keynote speaker)
Bound states in soft quantum waveguides and layers

12.05 – 12.25 A. KOWALEWSKA-KUDŁASZYK
Photon blockades in optical and hybrid opto-mechanical systems

12.25 – 12.45 E. LANGE
Tuning unconventional photon blockade in a nonlinear rotation-time-symmetric system

12.45 – 13.05 P. TULEWICZ
Synergic generative quantum machine learning

Lunch Break

Session III *Chairman: J. Kříž*

14.45 – 15.20 KH. GNATENKO (Keynote speaker)
Quantifying of graph properties on a quantum computer

15.20 – 15.55 G. CHIMCZAK (Keynote speaker)
Towards quantum computing based on systems with optical cavities

15.55 – 16.15 N. A. SUSULOVSKA
Quantum Computations of the Geometric Measure of Entanglement of Multi-qubit Graph States

16.15 – 16.50 B. V. PADLYAK (Keynote speaker)
Local structure and spectroscopic properties of the Cu-doped lead-silicate glass with complex composition

19:00 *Conference Dinner*
Ruben Hotel, Aleja Konstytucji 3 Maja 1a Street

Wednesday, October 26, 2022

Building A-29, Lecture room 106

Session IV — *Chairman: Y. Yaremko*

9.00 – 9.35 M. PRZYBYLSKA (Keynote speaker)
Non-integrability of relativistic homogeneous potentia

9.35 – 10.10 P. ROZMEJ (Keynote speaker)
The only valid (2+1)-dimensional KdV, Kadomtsev-Petviashvili, fifth-order KdV, and Gardner equations derived from the ideal fluid model

10.10 – 10.30 K. URBANOWSKI
A universe born in a metastable false vacuum state may survive until late and not die

10.30 – 10.50 A. GRONOWSKA-KOWALSKA
Two q-bit system state classification

10.50 – 11.10 W. SZUMIŃSKI
Double swinging Atwood's machine – from hyperchaos to super-integrability

Coffee Break

Session V — *Chairman: M. Przybylska*

11.40 – 12.15 M. DUDEK (Keynote speaker)
Thin films with magnetic nanoparticles as magnetocaloric materials

12.15 – 12.35 S. MUDRY
Inhomogeneous metallic liquids: experimental studies and model description

12.35 – 12.55 M. MARĆ
Preparation methods of magnetic nanoparticle layers

12.55 – 13.15 M. KOSTRZEWA
Possibility of obtaining the room-temperature superconductors among hydrogen-rich compounds

Lunch Break

Session VI *Chairman: M. Dudek*

14.45 – 15.05 K. DUDEK
Magnetically-controlled magneto-mechanical metamaterials

15.05 – 15.25 A. DRZEWIŃSKI
An aqueous suspension of magnetic nanoparticles: magnetic heating vs. ultrasonic treatment

15.25 – 15.45 W. WOLAK
Nanoparticles' aqueous solution stability for different pH values and salt concentrations

15.45 – 16.05 D. N. TRONG
Effect of shape and matrix size of thin film on the mechanical properties of 2D epoxy thin film by the Monte Carlo simulation method

Online Sesion *Chairman: S. Mudry*

16.15 – 16.35 I. KINDRAT
Optical-luminescent and structural properties of the Pb-containing germanate and silicate oxyfluoride glasses

16.35 – 16.55 A. DUVIRYAK
Spindown of nanoparticles under the radiation reaction torque

16.55 – 17.15 B. AHMADI
Catalysis in Charging Quantum Batteries

17.15 – 17.35 A. R. KUZMAK
Entanglement in the rhombic spin cluster

17.35 – 17.55 Y. V. KALYUZHNYI
Empty liquid state and re-entrant phase behavior of the patchy colloids confined in porous media

INVITED TALKS

Towards quantum computing based on systems with optical cavities

Grzegorz Chimczak[1]

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Quantum systems containing optical cavities are very useful in quantum state engineering. The advantages of such systems are based on the ability to achieve strong coupling between the electromagnetic field and the qubit. This makes it possible to simultaneously use atomic states, which are ideal for storing quantum information, and photon states, which are the best carriers of quantum information over long distances. Unfortunately, there are also phenomena in atom-cavity systems that reduce the fidelity of quantum operations. Such phenomena include rapid oscillations of the population of the auxiliary level and the destruction of the system's periodic behavior by damping. Here, methods will be presented by which the effects of these two undesirable phenomena on the fidelity of quantum information processing can be eliminated. These methods are the fine tuning method and the use of Hamiltonians that are passive pseudo-Hermitian.

References

[1] Chimczak, G., Bartkiewicz, K., Ficek, Z. and Tanaś, R., Creating a switchable optical cavity with controllable quantum-state mapping between two modes, *Sci. Rep.*, 2018, **8**, 14740.

[2] Chimczak, G., High fidelity state mapping performed in a v-type level structure via stimulated raman transition, *J. Phys. B*, 2015, **48**, 055502.

[3] Chimczak, G. and Tanaś, R., Fine tuning of quantum operations performed via Raman transitions, *PRA*, 2008, **77**, 032312.

Thin films with magnetic nanoparticles as magnetocaloric materials

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The results of theoretical research on the use of thin elastic films with embedded magnetic nanoparticles as a strong magnetocaloric material are presented. These results are based on the paper [1], which showed with the Monte Carlo method that such materials can have strong magnetocaloric properties also at room temperatures. The current state of research on the magnetocaloric effect in the field of composite materials with magnetic nanoparticles will also be summarized.

Acknowledgments: This research was funded by the Ministry of Education and Science under the program "Regional Initiative of Excellence" in 2019-2023, project No. 003/RID/2018/19, funding amount PLN 11,936,596.10.

References

[1] M. R. Dudek, K. K. Dudek, W. Wolak, K. W. Wojciechowski, and J. N. Grima, Magnetocaloric materials with ultra-small magnetic nanoparticles working at room temperature, *Scientific Reports* **9** (2019) 17607 | https://doi.org/10.1038/s41598-019-53617-0

Quantifying of graph properties on a quantum computer

Kh. P. Gnatenko[1], H. P. Laba [2], V. M. Tkachuk [1]

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Relation of the geometric characteristics of evolutionary graph states of spin systems generated by the operator of evolution with Ising Hamiltonian with properties of the corresponding graphs is obtained [1]. We show that the velocity of quantum evolution, the curvature and the torsion of the states are related with the total number of edges, triangles and squares in the corresponding graphs. Quantum graph states that correspond to a chain, a triangle, and a square are examined and their geometric characteristics are detected with quantum calculations on ibmq manila [2]. On the basis of the obtained results we propose algorithm to quantify the number of edges, triangles and squares in a graph on a quantum computer. The algorithm opens a possibility to achieve a quantum supremacy with the development of a multi-qubit quantum computer.

References

[1] Gnatenko, Kh. P. Laba H. P. and Tkachuk V. M., Geometric properties of evolutionary graph states and their detection on a quantum computer, *Phys. Lett. A.*, 2022, **452**, Art. 128434.

[2] IBM Q experience. https://quantum-computing.ibm.com/.

Bound states in soft quantum waveguides and layers

Jan Kříž[1],

[1] *Department of Physics, Faculty of Science, University of Hradec Králové, Rokitanského 62, Hradec Králové, CZ500 03, Czech Republic*

We consider Schrödinger operator with confining potentials depending on the distance to the planar curve or spatial surface. For special geometries we localise the essential spectrum and establish the existence of discrete eigenvalues. This is a joint work with David Krejčiřík and Sylwia Kondej.

Quantum steering transfer along two non-interacting qubit chains

Joanna K. Kalaga, Małgorzata Kostrzewa, **Wiesław Leoński**

Quantum Optics and Engineering Division, Institute of Physics, University of Zielona Góra
Prof. Z. Szafrana 4a, 65-516 Zielona Góra, Poland

In our communication, we discuss a system of two noninteracting chains of qubits. Each chain is modeled by N interacting anharmonic Kerr-type quantum oscillators or their harmonic counterparts. We analyze the time evolution of parameters proposed in [1], describing quantum steering between qubits. The qubits belong to the same or two different chains constituting the system. We show that if the first pair of noninteracting qubits belonging to the two chains are prepared in a steerable state, then such a state can be successfully transferred from the one end of the chain pair to the second one.

Acknowledgments: This research was funded by the Ministry of Education and Science under the program "Regional Initiative of Excellence" in 2019–2023, project No. 003/RID/2018/19, funding amount PLN 11,936,596.10.

References

[1] Cavalcanti E. G., He Q. Y., Reid M. D., Wiseman H.M., Unified criteria for multipartite quantum nonlocality, *Phys. Rev. A*, 2011, **84**, 032115.

Local structure and spectroscopic properties of the Cu-doped lead-silicate glass with complex composition

B.V. Padlyak[1,2], I.I. Kindrat[1], Y.O. Kulyk[3], S.I. Mudry[3], Y.S. Hordieiev[4], V.I. Goleus[4], A. Drzewiecki[1], R. Lisiecki[5]

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The glasses with 0.521PbO-0.371SiO_2-0.068ZnO-0.027K_2O=0.013BaO basic composition, doped with CuO (or PbSiZnKBaO:CuO), were obtained by standard glass melting technique using technological conditions for lead-silicate glasses, developed in the Ukrainian State University of Chemical Technology (Dnipro, Ukraine) [1]. The XRD, EPR, IR transmission, optical absorption, photoluminescence and its decay kinetics in the PbSiZnKBaO:CuO glass were studied. Average interatomic distances and coordination numbers for main structural units, SiO_4 and PbO_n (n = 3 – 6), as well as Pb-Pb and Pb-Si interatomic distances in the network of studied glass were determined from radial distribution functions. The observed characteristic EPR spectra of the Cu^{2+} ($3d^9$, $^2D_{5/2}$) and Fe^{3+} ($3d^5$, $^6S_{5/2}$) paramagnetic ions were adequately described using the spin Hamiltonian formalism. The IR transmission spectrum of studied glass in the 400 – 4000 cm^{-1} range was registered and interpreted. Observed broad absorption band, peaked near 870 nm, was ascribed to the $^2B_{1g} \rightarrow {}^2B_{2g}$ transition of the Cu^{2+} centres. Using analysis of the fundamental absorption edge the optical band gap and Urbach energy of the studied glass were evaluated. Photoluminescence (excitation and emission) spectra and decay curve of the Cu^+ ($3d^{10}$, $^1S_0$) centres in the PbSiZnKBaO:CuO glass were registered and interpreted. The PbSiZnKBaO:CuO glass upon UV photoexcitation also demonstrates broad intense emission band, peaked about 575 nm. This emission band with fast decay kinetics was assigned to intrinsic band-to-band recombination luminescence. The CIE chromaticity diagram for Cu^+ and intrinsic emission bands in the studied glass was built and discussed.

Non-integrability of relativistic homogeneous potential

Maria Przybylska[1], Wojciech Szumiński[1], Andrzej J. Maciejewski[2]

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[2] *Janusz Gil Institute of Astronomy, University of Zielona Góra, Licealna 9, PL-65–417, Zielona Góra, Poland*

Necessary integrability conditions for a relativistic particle moving in an external homogenous potential in the limit of a weak external field are formulated. They were obtained by means of differential Galois obstructions for variational equations recived by linearisation of Hamiltonian equations along straight-line particular solutions directed along Darboux points of the potential. Two different types of particular solutions were analysed and the corresponding integrability obstructions and conditions under that both obstructions are satisfied. The relation between the integrability of relativistic and non-relativistic Hamiltonian systems is formulated. For non-relativistic Hamilton equations with homogeneous potentials differential Galois integrability obstructions are well know, see Chapter 5 of [1]. The final conditions were obtained as the intersection of conditions obtained from analysis of variational equations along two types of particular solutions and these for non-relativistic potentials. Application of obtained conditions to relativistic Hamiltonian systems with homogeneous potentials for two degrees of freedom is shown.

References

[1] Morales-Ruiz, J.J., *Differential Galois theory and non-integrability of Hamiltonian systems*, Birkhauser Verlag, Basel, 1999.

The only valid (2+1)-dimensional KdV, Kadomtsev-Petviashvili, fifth-order KdV, and Gardner equations derived from the ideal fluid model

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[2] *Institute of Mathematics, University of Zielona Góra, Poland*

We study the problem of gravity surface waves for an ideal fluid model in the (2+1)-dimensional case. We apply a systematic procedure to derive the Boussinesq equations for a given relation between the orders of four expansion parameters, the amplitude parameter α, the long-wavelength parameter β, the transverse wavelength parameter γ, and the bottom variation parameter δ. In the talk, we indicate the only orderings of small parameters which make Boussinesq's equations compatible and allow us to obtain single (2+1)-dimensional wave equations. In three particular cases, we derived the only true (2+1)-dimensional extensions to the Korteweg-de Vries equation, fifth-order KdV equation, and the Gardner equation. All these equations are non-local. When the bottom is flat, the (2+1)-dimensional KdV equation can be transformed to the Kadomtsev-Petviashvili equation in a fixed reference frame and next to the classical KP equation in a moving frame. In other relations between small parameters Boussinesq's equations can not be reduced to single (2+1)-dimensional wave equations for surface profile. On the other hand, as we have shown in [1], they can be reduced to a single, highly nonlinear partial differential equation for an auxiliary function $f(x, y, t)$ which determines the velocity potential but is not directly observed quantity. The solution f of this equation, if known, determines the surface profile function.

References

[1] Karczewska, A. and Rozmej, P., Boussinesq's equations for (2+1)-dimensional surface gravity waves in an ideal fluid model, *Nonlinear Dynamics*, 2022 **108**, pp 4069-4080.

Studies of the spin-1 tunneling on IBM's quantum computer

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We observe explicitly spin-1 tunneling and splitting of energy levels as a result of tunneling on quantum computer ibmq-bogota [1]. The time-dependence of the mean value of z-component of spin-1 is detected on the IBM's quantum computer. On the basis of the studies the oscillations of spin-1 between the states $|1\rangle$ and $|-1\rangle$ are observed [2]. The eigenvalues of Hamiltonian which describes the spin tunneling are found with quantum calculations of a probe spin evolution [3] and the energy level splitting is observed.

References

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CONTRIBUTED TALKS

Catalysis in Charging Quantum Batteries

R. R. Rodriguez[1], **B. Ahmadi**[1]

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Recently the study of energy transfer has brought forward a diverse and rich set of phenomena, in the context of quantum batteries, to be both theoretically and experimentally investigated. Energy transfer limitations is a crucial issue in the context of charging quantum batteries. Techniques such as quantum correlations and initial quantum coherence in the state of the charger have been proposed by authors to eliminate this issue. We here instead present two different approaches to boost the energy transfer from a quantum charger to a quantum battery such that the transfer of arbitrary amount of energy becomes feasible. The charger is driven by an external laser field. Both the charger and the battery are modeled by quantum harmonic oscillators. The first approach is simply based on tuning the laser field with the system of charger-battery. In the second novel approach a catalyst qubit is added to the process to enhance the amount of energy transfer to the battery while no energy being stored in the catalyst qubit. Benefits of both approaches are compared and discussed .

References

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An aqueous suspension of magnetic nanoparticles: magnetic heating vs. ultrasonic treatment

A. Drzewiński[1], M. Marć[1], W.W. Wolak[1], M.R. Dudek[1]

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Single-domain iron oxide nanoparticles (MNP) can convert AC magnetic field energy into heat. Recently we have reported that the radio frequency magnetic field destabilizes a colloidal suspension of magnetic nanoparticle clusters [1]. In turn this can lead to the agglomeration of the magnetic material and the reduction in the amount of heat generated. Since ultrasonic treatment is considered to be the primary means of dispersing aggregated particles, we investigate its effect on the efficiency of magnetic heating, including the importance of selecting the optimal treatment time [2]. The effect of magnetic colloid aging on magnetic heating was discussed as well. The size distribution of dispersed nanoparticles and the zeta potential were analyzed by dynamic light scattering. The obtained results are important for the development of new materials where magnetic colloids are used and in biomedical applications.

References

[1] Marć, M., Drzewiński, A., Wolak, W.W., Najder-Kozdrowska, L., Dudek, M. R., Filtration of Nanoparticle Agglomerates in Aqueous Colloidal Suspensions Exposed to an External Radio-Frequency Magnetic Field, *Nanomaterials*, 2021, 11, 1737.

[2] Drzewiński, A., Marć, M., Wolak, W.W., Dudek, M. R., Effect of Magnetic Heating on Stability of Magnetic Colloids, A. Drzewiński, M. Marć, W.W. Wolak, M.R. Dudek, *Nanomaterials*, 2022, 12, 3064.

Magnetically-controlled magneto-mechanical metamaterials

R. Galea[1], **K. K. Dudek**[2], P.-S. Farrugia[1,3], L. Zammit Mangion[4], J. N. Grima[1,5], R. Gatt[1,6]

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In this work [1], it is shown through the use of experiments validated by computer simulations that a novel accordion-like magneto-mechanical metamaterial can change its linear dimensions in a controllable manner upon being subjected to a uniform external magnetic field, a system which essentially acts as an actuator guided by a magnetic field. It is also shown that irrespective of the magnitude of the external magnetic field, this system can return to its initial shape due to the appropriate distribution of magnetic inclusions within the system. Finally, it is presented that the proposed accordion-like system can be considered as a building block for a larger three-dimensional system where its properties may undergo a transition from positive to negative Poisson?s ratio, depending solely on the magnitude and the orientation of the external magnetic field. This concept is very interesting from the point of view of numerous applications such as protective materials or vibration dampers where the mechanical properties of the material could be fine-tuned to increase its efficiency without the need of reconstructing the system.

References

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Spindown of nanoparticles under the radiation reaction torque

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The radiation reaction of a charged particle can be described by the classical Larmor's formula for energy balance and the Abraham-Lorentz expression for the radiation reaction force. The energy loss is proportional to the particle acceleration squared, while the radiation reaction force depends on the time derivative of the acceleration. Both formulae do not agree: the power of radiation reaction force is Larmor's expression plus the time-derivative Schott term. This discrepancy is a subject of discussions; [1] and refs therein. In practice, the Schott term is negligibly small on quasiperiodic particle motions in atoms, traps and accelerators.

Nanoparticles are stable complexes of charges q with masses m at points $\boldsymbol{r}$. A free electrically neutral nanoparticle is modeled as a spinning top possessing the proper dipole moment $\mathfrak{d} = \sum q\boldsymbol{r}$ (summation over constituents). Its translational motion is inertial while the rotary motion is governed by the balance equation for proper angular momentum $\boldsymbol{L} = \sum m\,\boldsymbol{r}\times\boldsymbol{v}$. Two different versions are known from the handbook [2]:

$$\frac{\mathrm{d}\boldsymbol{L}}{\mathrm{d}t} = -\frac{2}{3c^3}\,\dot{\mathfrak{d}}\times\ddot{\mathfrak{d}}, \quad (1) \qquad\qquad \frac{\mathrm{d}\boldsymbol{L}}{\mathrm{d}t} = \frac{2}{3c^3}\,\mathfrak{d}\times\dddot{\mathfrak{d}} \quad = -\frac{2}{3c^3}\,\dot{\mathfrak{d}}\times\ddot{\mathfrak{d}} + \boxed{\frac{\mathrm{d}}{\mathrm{d}t}\frac{2}{3c^3}\mathfrak{d}\times\ddot{\mathfrak{d}}}_{\overset{???}{\longrightarrow}\,0}. \quad (2)$$

One of them, eq. (1), is similar, by its origin and structure, to Larmor's formula. Another one, eq. (2), includes in r.-h.s. the radiation reaction torque of the Abraham-Lorenz type. Both equations are concerted if the last Schott-like term is negligibly small. This assumption, however, fails. In [1] both eqs. (1) and (2) are reduced to nonlinear Euler-type equations which both are integrable provided the inertia tensor and polarization of the spinning top are axially-symmetric. But corresponding solutions are quite different. That one following from the Larmor-like formula is physically unplausible, in contrast to another one. This result is accorded with the reinterpretation of Larmor's formula discussed recently in the literature [1].

If an axial symmetry of nanoparticle is broken, the Euler-type equations from the correct balance condition (2) are not integrable, and one should apply to approximations. The example of the symmetric top with inclined dipole moment is solved numerically and analyzed qualitatively by means of the linearization and the asymptotic methods of celestial mechanics. Solutions describe the asymptotic power-law slowdown to stop or the exponential drift to a residual rotation (depending on initial condition and a shape of the top).

The accurate study of the effect of radiation reaction torque is of not only academic significance. Some artificially created nanoparticles, such as Janus-particles, nanoctristals CdSe and CdS or cellulose carry dozens to thousands Debyes of intrinsic dipole moment [3], and some organic nanocrystals may reach, in principle, 10^7 D [4, pp. 387-390]. At recently achieved gigahertz rotation frequencies of nanoparticles [5] the effect of radiation reaction spindown may become observable in experiments.

References

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Two q-bit system state clasification

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Measures of quantum correlations are mathematical objects that are very difficult to study in analytical way even in small bipartite systems like, e.g. pairs of two spins. We give a method to determine the trace norm discord for arbitrary state of two qubits [1] and develop new mathematical methods to study the corresponding space of states [1]. In particular we present new classifications and indicate some exemplary novel classes of states.

References

[1] Paula F.M., Oliveira T.R., Sarandy M.S, Geometric quantum discord through the Schatten 1-norm, *Phys. Rev. A*, 2013, **87** 064101.

[2] Ługiewicz P., Frydryszak A., Jakóbczyk L., Two-qubit trace-norm geometric discord: the complete solution.*Quantum Inf. Process*, 2019, **18** 185.

Empty liquid state and re-entrant phase behavior of the patchy colloids confined in porous media

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Patchy colloids with three and four equivalent patches, confined in an attractive random porous medium, undergo re–entrant gas–liquid phase separation with the liquid phase density approaching zero at low temperatures. The (bonding) colloid–colloid interaction causes the liquid–gas phase separation, which is modulated by the presence of the randomly distributed hard-sphere obstacles, attracting the colloids via Yukawa potential. Due to this interaction, a layer of mutually bonded colloids around the obstacles is formed. The network becomes nonuniform, with colloid particles locally centered on the obstacles. Features described in this article may open possibilities to produce equilibrium gels with predefined nonuniform distribution of particles and indicate how complicated the phase behavior of biological macromolecules in a crowded environment may be.

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Optical-luminescent and structural properties of the Pb-containing germanate and silicate oxyfluoride glasses

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This work is focused on study of the X-ray diffraction (XRD), infrared (IR) transmission, electron paramagnetic resonance (EPR), optical absorption, photoluminescence spectra and decay kinetics of un-doped Pb-containing glasses with basic compositions PbO-GeO_2-AlF_3, PbO-SiO_2-AlF_3, PbO-GeO_2, and PbO-SiO_2. The obtained glassy-like XRD patterns for studied glasses were analysed in order to obtain the radial distribution functions and define the average Ge-O, Si-O, Pb-O, O-O, and Pb-Pb interatomic distances and coordination numbers of Ge and Si atoms in the first coordination sphere and Pb atoms in the first and second coordination spheres in the glass network.

The registered IR transmission spectra show that addition of AlF_3 to the Pb-containing germanate and silicate glasses significantly reduces the absorption of the free and bound hydroxyl groups and increases their transmittance cut-off wavelength. The recorded optical absorption spectra show that fundamental absorption edge of the studied glasses is located in the UV - violet spectral range and demonstrates tendency to red shift with the PbO amount increases.

The investigated glasses under UV photoexcitation exhibit intense broad emission band in the blue-green spectral region with lifetime in the nanosecond range. The Ge-containing glasses show also the shoulder near 610 nm with lifetime in the microsecond range. Fast (band-to-band recombination) and slow (recombination with point defects) mechanisms of intrinsic luminescence in the studied glasses were proposed based on the analysis of the photoluminescence spectra and decay kinetics curves. The CIE chromaticity diagram shows a variation in emission colour of studied glasses with changing their composition.

Quantum systems with wires in R^3

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We consider two types of quantum systems governed by the Schrödinger operators with an attractive delta interaction supported on lines in R^3. In the first class of models we analyze a star-shaped potential localized on segments. Our aim is to show that the configuration of star arms realizing the maximum of the ground state energy are related to the famous Thomson problem. In the second class of models we consider delta potential supported on infinite lines which do not admit a crossing point. We derive the asymptotics of the eigenvalues number if the lines tend to be parallel.

Possibility of obtaining the room-temperature superconductors among hydrogen-rich compounds

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The LaH_{10} is characterized by a very high critical temperature of the metal-superconductor phase transition: $T_C^a = 215$ K for $p_a = 150$ GPa [1] and $T_C^b = 260$ K for $p_b = 190$ GPa [2]. That compound belongs to the group of superconductors with a strong electron–phonon coupling ($\lambda_a \sim 2.2$ and $\lambda_b \sim 2.8$). We calculated thermodynamic parameters of this high-temperature superconductor and found that the values of the order parameter, the thermodynamic critical field, and the specific heat differ significantly from the values predicted by the conventional BCS theory.

Experimental results obtained for lanthanum have significantly brought closer the possibility of obtaining a superconducting state in hydrogen-rich materials at room temperature. The qualitative analysis suggests that the superconductors of the $La_\delta X_{1-\delta}H_{10}$–type (LaXH–type) structure, would exhibit significantly higher critical temperature than T_C obtained for LaH_{10}. This is due to the different atomic masses which influence the maximum phonon frequency which in turn is related to the specific structure of the Eliashberg function for the hydrogenated compounds. Filling in the empty area of the Eliashberg function located between the La- and H-derived parts has a positive effect on increasing the critical temperature value. Numerical calculations performed suggest that the right elements to use as dopants are scandium and yttrium [3].

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Photon blockades in optical and hybrid opto-mechanical systems

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Photon blockades, also reffered as quantum scissors or quantum state truncation, are the bosonic analogues of well known Coulomb blockades for electrons. Systems in which photon blockades appear may be used for example as single (or two) photon sources due to the fact that generation of one (or two) photons blocks generation of more photons in the same system. For succesful blockades a nonlinearity is necessary.

We will show the possibility of obtaining single and two photon blockades in an optical system in which nonlinearity is induced via squeezed reservoir [1]. Additionaly various types of correlations, related to photon, phonon blockades or photon induced tunneling in optical, mechanical and hybrid modes of opto-mechanical system will be presented [2].

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Entanglement in the rhombic spin cluster

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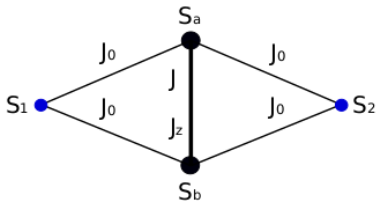
We consider the system which consists of two spin-$1/2$ S_a and S_b described by anisotropic Heisenberg Hamiltonian and two spin-$1/2$ S_1 and S_2 which interact with spins S_a, S_b via the Ising interaction. The geometry of the spin cluster is shown in Figure. The time evolution of entanglement between spins S_a,



S_b and S_1, S_2 is separately investigated. The influence of the coupling parameter J_0 on the entanglement between spins S_a and S_b is studied. Finally, we examine the entanglement between the subsystems consist of S_a, S_b and S_1, S_2 spins.

Tuning unconventional photon blockade in a nonlinear rotation-time-symmetric system

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The concept of parity-time (PT) symmetry, introduced by C. M. Bender and S. Boettcher [1], explains why some particular non-Hermitian Hamiltonians have positive and real spectra. Degenerations of open systems described by non-Hermitian Hamiltonians in which two or more eigenvalues coalesce are known as exceptional points (EPs). EPs are widely studied especially in optics, as they are a source of interesting physical effects.

We have proposed the rotation-time (RT) symmetry which is a superset of the PT symmetry in bosonic systems [2]. This provides a framework for exploring the physics of singular energy spectra in terms of symmetries in a range of bosonic systems.

Here, we present a non-linear, passive RT-symmetric system with EPs. This system can be considered as a single-photon source, as it exhibits conventional and unconventional photon blockade. Furthermore, we can tune photon blockade due to the presence of an exceptional point.

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Preparation methods of magnetic nanoparticle layers

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Preparation of thin uniform layers of nanoparticles are of great interest for manufacturing and biomedical fields, including protecting layers and functional materials or active molecules immobilization.

In the study, several well-known methods for obtaining thin nanoparticle films were used. Thin layers of magnetic nanoparticles were formed during evaporation of a sessile droplet [1], with the spin coating method and Langmuir Schaefer method. These methods require the use of nanoparticle suspension, where the key element is the stabilization of such a suspension, which can be achieved by modifying the surface with chemical compounds or changing the electrostatic charge at the nanoparticle surface.

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Inhomogeneous metallic liquids: experimental studies and model description

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Most of liquid metals and their alloys show the high electro- and thermal conductivity, good fluidity, low vapor pressure and other properties, which allowed to consider this group of liquids as one, interesting both from fundamental and practical application viewpoints. Theoretical description of liquids generally is based on various approaches, among which one, most widely used is known as simple liquid approach, which allowed predicting the structure, thermodynamics and kinetic properties of many liquids, including the low valence liquid metals. Such melts reveal the close packed atomic structure free electron interaction. But for many other molten metals and their alloys this model is not applicable. On that reason there are few attempts to make possible the prediction of structure and properties with accounting the features of atomic structure and more complicated behavior of electronic subsystem In order to make such attempts successful it is needed first of all to have the detail information on structure evolution at transition from simple liquids to more complicated ones.

We have analyzed our early results on XRD- studies and computer simulation of metallic melts and use the method of interpretation to study the effect of atomic clustering on total structure and properties. The attention was particularly focused on the prediction of such structural states when the clustering of atoms or addition of another kind nanoscale structural units, will promote the significant changes the structure, resulting the formation of desired properties after solidification.

Effect of shape and matrix size of thin film on the mechanical properties of 2D epoxy thin film by the Monte Carlo simulation method

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In this research we study the shape of the 2D epoxy thin film with equilateral triangle structure, square structure, and matrix size $L_x \times L_y$ of $(10 \times 9), (20 \times 19), (30 \times 29), (40 \times 39)$ with equilateral triangle structure, and $(10 \times 10), (20 \times 20), (30 \times 30), (40 \times 40)$ with the square structure, on the mechanical properties (such as strain (ε), stress (σ), Young stress (E), and shear strain (G)) by the Monte Carlo (MC) simulation method. The obtained results show that when changing the shape of the 2D epoxy thin film from an equilateral triangle structure to a square structure σ increased sharply, E, and G decrease sharply. When increasing the matrix size from (10×9) to $(20 \times 19), (30 \times 29), (40 \times 39)$ with equilateral triangle structure, and (10×10) to $(20 \times 20), (30 \times 30), (40 \times 40)$ with square structure, σ slightly increased, E and G decreased slightly, which proves that the influence of structure shape on mechanical properties of the 2D epoxy thin film is very large. The strain stress of epoxy 2D thin film with an equilateral triangle structure with a matrix size (30×29) has the value $\sigma = 63.3$ MPa. This result is consistent with the experimental result when the value σ is the maximum value, $\sigma_{\max} = 64.76$ MPa. The obtained results are the basis for experimental research results in future studies on applications of epoxy thin films in life.

Optimal Quantum Control of Charging Quantum Batteries

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Quantum control allows to address the problem of engineering quantum dynamics for special purposes. While recently the field of quantum batteries has attracted much attention, optimization of their charging has not benefited from the quantum control methods. Here we fill this gap. The two-partite charger plus battery system is considered where the energy is pumped to a charger by an external electromagnetic field. We apply for the first time the convergent iterative method for control of the population of a quantum system [1–3] for two cases. First, we apply it for a qubit-qubit case. Next, we systematically develop the formulation of the method for two-oscillators in the Gaussian regime. In both cases the charger is an open dissipative system. Our optimization considers the experimentally viable problem of turning on and off of the external laser field. Optimizing the shape of the pulse significantly boosts both power and efficiency of the charging process in comparison to the known results [4, 5].

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Quantum Computations of the Geometric Measure of Entanglement of Multi-qubit Graph States

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In recent years considerable attention has been devoted to discovering new efficient ways to leverage powerful features of quantum mechanics when solving a range of complex computational problems. In the light of this pursuit, entangled quantum states are viewed as a key ingredient in a variety of quantum algorithms, opening possibilities beyond the reach of classical physics. In particular, many studies have focused on graph states, which are applicable in the rapidly developing fields like quantum machine learning and quantum error correction. Quantifying the entanglement of such states becomes an important task. In this context, using the geometric measure of entanglement, with its simple relationship to the mean spin value, proves to be an optimal choice when studying the entanglement on quantum devices [1].

In the present study we elaborate on our previous findings regarding the geometric measure of entanglement of graph states [2]. Multi-qubit graph states generated by the action of controlled phase shift operators remain the object of our investigation. However, we examine the case where each qubit of the system is initially prepared in an arbitrary state defined by its respective parameter. Furthermore, parameters of the phase shift operators responsible for generating graph edges take independent arbitrary values. As a result of analytical considerations, we obtain an expression for the geometric measure of entanglement of an arbitrary qubit with the rest of the qubits in a graph state represented by an arbitrary weighted graph. It is shown that this quantity depends on the set of parameters of the initial state of the multi-qubit system as well as the set of parameters of the phase shift operators acting on it.

In addition, a two-qubit graph state corresponding to a chain graph is studied on IBM's superconducting gate-based quantum computer *ibmq_lima* [3]. A protocol for preparing this state is proposed and implemented with the help of *Qiskit* software development kit. Finally, the geometric measure of entanglement is calculated on the basis of mean spin measurements. Two specific classes of graph states are investigated in detail. In the first case we initially prepare both qubits in the same state $|+\rangle$ and track the dependency of the geometric measure of entanglement on the phase shift gate parameter. In the second case, we showcase the dependency of the geometric measure of entanglement on two parameters of the initial state by letting them vary independently, while graph edge is generated by CZ gate. The obtained results of quantum computations verify our analytical predictions.

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Double swinging Atwood's machine – from hyperchaos to super-integrability

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We study dynamics and integrability of the double swinging Atwood?s machine with additional Hooke's interactions. Complexity of this system is presented with the help of Lyapunov's exponents spectrum's, phase-parametric diagrams and Poincaré cross sections. They show that the system possesses chaotic and hyper-chaotic dynamics, which suggest its non-integrability. We give the analytical proof of this fact via the differential Galois approach and the Kovacic algorithm in dimension four. In the absence of gravity, and for certain values of remaining parameters the considered model is integrable and super-integrable.

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Synergic generative quantum machine learning

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We present a new approach to generative quantum machine learning and describe a proof-of-principle experiment demonstrating our approach. We call our proposed approach quantum synergic generative learning because the learning process is based on the cooperation between the generators and the discriminator. The goal of the learning is for the quantum computer implementing the generative learning algorithm to learn a concept of a Bell state. After the learning process, the network is able to recognize as well as generate the entangled state. We compare our approach with the recently proposed quantum generative adversarial learning (QGAN). We present numerical proofs, obtained using quantum simulators, for single qubits as well as more qubits, and we also present experimental results obtained on a real programmable quantum computer.

The aim of QGAN which is the quantum equivalent of GAN learning, is to find a Nash equilibrium in a two player game. One player (the discriminator) generates some output, while the other player tries to determine whether the output is generated by the first player (generator) or comes from an external source. This corresponds to the min-max problem, in which the statistical distance between the outputs of generator and an external source is minimized relative to the generator strategy, while maximizing the distance between the outputs discriminator for generator and an external source relative to the discriminator strategy. It turns out that it is difficult to ensure the stability of the process in this type of optimization. In our work, we consider a conditional equilibrium state. Training such a system is based on increasing the probability of descending to the equilibrium state, which distinguishes it from learning a standard GAN, in which training is done by counting the probability of the system's exit from the equilibrium state.

We propose a new type of machine learning for quantum GANs in which a conceptually simpler problem is solved during training than in the typical QGAN approach. Our approach assumes the reversibility of the discriminator and exploits the relative entropy property and the time reversal property in unitary transformations. In the learning process, we try to minimize the cost function while making the discriminator work correctly.

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A universe born in a metastable false vacuum state may survive until late and not die

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We present an attempt to find a condition, the fulfillment of which allows a universe born in a metastable false vacuum state to survive and not to collapse. The condition found has a form of an inequality linking the depending on time t instantaneous decay rate $\Gamma(t)$ of the false vacuum state and the Hubble parameter $H(t)$. Properties of the decay rate of a quantum metastable states are discussed and then the possible solutions of the condition found are analyzed and discussed. Within the model considered it is shown that a universe born in the metastable vacuum state has a very high chance of surviving until very late times if the lifetime, τ_0^F, of the metastable false vacuum state is comparable to (or even shorter), than time when the inflation process begins. Our analysis shows that the instability of the electroweak vacuum does not have to result in the tragic fate of our Universe leading to its death.

The talk is based on papers [1, 2].

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Nanoparticles' aqueous solution stability for different pH values and salt concentrations

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We considered Derjaguin, Landau, Verwey, and Overbeek's (DLVO) theory with magnetic interactions between nanoparticles integrated over thermal fluctuations to analyze the stability of magnetic nanoparticle solutions. I will show how magnetic interaction influences the total energy between nanoparticles. I will present the connection between interaction energy and separation conditions.

Radiation reaction in de Sitter space

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The motion of a point electric charge in de Sitter spacetime is studied. A point particle of mass m and charge q moving on a geodesic produces electromagnetic field that diverges on a particle. The field is determined by the electromagnetic Green's function by Higuchi and Cheong [1]. We insert the expressions for the field strengths in Nöther quantities which correspond to the group of isometry of de Sitter space. We decompose these quantities into bound (divergent) and radiative (finite) parts. The divergent terms are absorbed by kinematic particle's characteristics within the renormalization procedure. Radiative terms together with already renormalized particle's individual characteristics constitute the total conserved quantities of closed particle plus field system. Their differential consequences yield the effective equations of motion of radiating charge in an external electromagnetic field:

$$\begin{aligned} & m\left\{a^\beta - \frac{H^2}{2}\Omega(z)\left[2(z\cdot u)u^\beta + \Omega^{-2}(z)z^\beta\right]\right\} \\ & - \frac{2q^2}{3}\dot{a}^\beta + \frac{2q^2}{3}\Omega^2(z)(a\cdot a)u^\beta + q^2H^2\Omega(z)(z\cdot u)a^\beta \\ & + \frac{q^2}{3}H^2\Omega(z)\left[-\Omega^{-2}(z) + (z\cdot a) - H^2\Omega(z)(z\cdot u)^2\right]u^\beta = f^\beta_{\rm ext}. \end{aligned} \tag{1}$$

Here H is the Hubble constant; $\Omega(z) = \left[1 + \frac{1}{4}H^2(z\cdot z)\right]^{-1}$ is related to the conformal factor of de Sitter metric $g_{\alpha\beta}(x) = \Omega^2(x)\eta_{\alpha\beta}$. The equation governs the evolution of a point charged particle subject to background gravity, external electromagnetism $f^\beta_{\rm ext} = g^{\beta\mu}F_{\mu\nu}u^\nu$, and its own electromagnetic field. All tensors are evaluated at $z(s)$, the current position of the particle on the world line parameterized by the proper time s.

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