IVAN FRANKO NATIONAL UNIVERSITY OF LVIV

WORKSHOP ON CURRENT PROBLEMS IN PHYSICS

PROGRAM AND ABSTRACTS

Lviv, 03–04 July 2018

03 July 2018

09:00–09:30 Registration and opening
(8, Kyryla i Mefodia St., "Velyka Fizychna" Lecture Hall)

Chairman: **V. Tkachuk**

09:30–10:00 *A. Duviryak*, Dynamics of a charged spinning top under the radiation reaction

10:00–10:30 *B. Brzostowski, G. Banach, P. Dereń, D. Stefańska*, The role of defects in Eu doped akermanite-gehlenite

10:30–11:00 *R. de Regt, C. von Ferber, Yu. Holovatch, M. Lebovka*, Topological and spatial aspects of public transportation in UK viewed as a complex network

11:00–11:30 Coffee break

Chairman: **A. Gavrilik**

11:30–12:00 *A. Yu. Yaremko*, Electrodynamics in flat spacetime of six dimensions

12:00–12:15 *A. Kuzmak*, Observation of Lee-Yang zeros of an arbitrary spin bath

12:15–12:30 *K. Haydukivska, V. Blavatska*, Universal properties of complex polymers with more then one branching point

12:30–12:45 *I. I. Kindrat, B.V. Padlyak, R. Lisiecki, V. T. Adamiv, I. M. Teslyuk*, Luminescence properties of the $Li_2B_4O_7$ glasses co-doped with Er and Ag

Lunch

Chairman: **B. Brzostowski**

14:30–15:00 *A. M. Gavrilik, I. I. Kachurik, M. V. Khelashvili, A. V. Nazarenko*, Modeling dark matter with μ-Bose gas condensate

15:00–15:30 *T. Verkholyak, J. Strečka*, Effect of quantum XY interdimer coupling on the low-field magnetization of the Shastry–Sutherland model

15:30–15:45 *J. K. Kalaga, W. Leoński*, Three-qubit system — steering parameter and degree of mixedness

15:45–16:00 *Kh. Gnatenko*, Effect of noncommutativity of coordinates and noncommutativity of momenta on free particles system motion

16:00–16:15 *S. Smerechynskyi, M. Tsizh, Kh. Kobyrynka, B. Novosyadlyj*, Dark energy inside compact astrophysical objects

16:15–16:30 *I. V. Stasyuk, V. O. Krasnov*, Repulsion–attraction asymmetry in the Bose–Fermi–Hubbard model

17:00 Informal meeting

04 July 2018

Chairman: **B. Padlyak**

09:30–10:00 *B. Novosyadlyj, V. Shulga, W. Han, Yu. Kulinich, M. Tsizh*, Molecules in the virialized halos of Dark Ages

10:00–10:30 *M. M. Stetsko*, Charged black hole in the theory with nonminimal derivative coupling and Born–Infeld term and its thermodynamics

10:30–11:00 *M. Dudka*, Two-dimensional spin models, fermions and correlated disorder

11:00–11:30 Coffee break

Chairman: **Yu. Yaremko**

11:30–12:00 *Yu. Sitenko*, Self-adjointness and boundary effects for confined quantum matter

12:00–12:15 *M. Krasnytska, B. Berche, Yu. Holovatch*, New critical behaviour in a complex system induced by two competing power laws

12:15–12:30 *Yu. A. Mishchenko, A. M. Gavrilik*, Special relation between deformed Bose gas models

12:30–12:45 *D. Sztolberg, B. Brzostowski, A. Drzewiecki, P. J. Dereń*, Optical and paramegnetic properties of manganese ions in the rhombohedral $LaAlO_3$ perovskite

Lunch

Chairman: **Yu. Sitenko**

14:30–15:00 *O. R. Baran, O. V. Velychko*, Intercalation of the stage ordered layered structures by complex particles: A theory

15:00–15:15 *V. Pastukhov, O. Hryhorchak*, Large-N properties of a Bose gas in the condensate phase

15:15–15:30 *M. Tsizh*, Evolution of Cosmic web as complex network

15:30–16:00 *B. V. Padlyak, V. T. Adamiv, T. B. Padlyak, I. I. Kindrat, A. Drzewiecki, V. Ya. Tataryn, I. M. Teslyuk, S. P. Dubelt*, Spectroscopy of the Ag-doped borate glasses

16:00–16:30 *H. P. Laba, V. M. Tkachuk*, The degree of mixing of a quantum state: A geometric measure

16:15 Closing

SELF-ADJOINTNESS AND BOUNDARY EFFECTS FOR CONFINED QUANTUM MATTER

Yu. Sitenko
Bogolyubov Institute for Theoretical Physics, NAS of Ukraine, Kyiv, Ukraine

We study the influence of a background magnetic field and boundary conditions on quantum charged spinor matter. The admissible set of boundary conditions is determined by the requirement that the operator of one-particle energy be self-adjoint. A generalization of the MIT bag boundary condition is proposed. In the case of matter confined within two parallel plates and a sufficiently strong magnetic field directed orthogonally to the plates, the Casimir force is shown to be repulsive, being independent of the choice of a boundary condition, as well as of the distance between the plates [1]. Moreover, this allows us to elucidate the properties of hot dense ultrarelativistic spinor matter in a slab of finite width, placed in a transverse magnetic field.

We show that the chiral separation effect in thermal equilibrium in the slab depends both on temperature and chemical potential; this is distinct from the unrealistic case of the magnetic field filling the unbounded (infinite) medium, when the effect is temperature-independent. In the realistic case of the slab, as temperature increases from zero to large values, a stepped-shape behavior of the axial current density as a function of chemical potential is changed to a smooth one. A choice of the boundary condition can facilitate either amplification or diminution of the chiral separation effect; in particular, the effect can persist even at zero chemical potential, if temperature is finite [2]. This points at a significant role of boundaries for physical systems with hot dense magnetized spinor matter, i.e. compact astrophysical objects (neutron stars and magnetars), relativistic heavy-ion collisions, novel materials known as the Dirac and Weyl semimetals.

[1] Yu. A. Sitenko, Phys. Rev. D **91**, 085012 (2015).
[2] Yu. A. Sitenko, Phys. Rev. D **94**, 085014 (2016).

THE ROLE OF DEFECTS IN EU DOPED AKERMANITE-GEHLENITE

B. Brzostowski[1], *G. Banach*[2], *P. Dereń*[3], *D. Stefańska*[3]
[1]Institute of Physics, University of Zielona Góra, Poland
[2]Physiolution Polska sp. z o.o., Wrocław, Poland,
[3]Institute of Low Temperatures and Structure Researches, Polish Acad. Sci., Wrocław, Poland

We present a density functional theory (DFT) study of the electronic and optic properties of the Eu doped $Ca_2[Mg_xAl_{1-x}][Si_{1+x}Al_{1-x}]O_7$ aluminosilicate. The host investigated in this study belongs to the melilites family and its crystal structure is a solid solution of akermanite ($Ca_2MgSi_2O_7$) and gehlenite ($Ca_2Al_2SiO_7$). Standard generalized gradient approximation calculation with PBE functional and spin-obit interaction taken into account were performed for supercell consisting of 96 atoms and being four times large than elementary cell. One of Ca ions was replaced by Eu dopant ion. The calculations were performed to determine the factors affecting the position of the Eu states in the host matrix band structure for different value of x.

Additionally different environment were realized by changing the position of ions of silicon and aluminum, as is allowed by the original cif (67689-ICSD). The density of states associated with the ions of the host akermanite-gehlenite structure is similar in both cases, but we noticed differences in the position of Eu dopant states in the band gap. For different cases distance of Eu states to the top of the valence band changes by 0.5 eV. Optical properties were calculated in terms of the imaginary part of the dielectric constant. From Tauc plot optical absorption edge has in aluminosilicate been determined. Absorbance of undoped and Eu doped aluminosilicate is presented.

TOPOLOGICAL AND SPATIAL ASPECTS OF PUBLIC TRANSPORTATION IN UK VIEWED AS A COMPLEX NETWORK

R. de Regt[1,2], *C. von Ferber*[1,2], *Yu. Holovatch*[2,3], *M. Lebovka*[4,5]
[1]Applied Mathematics Research Centre, Coventry University, Coventry, UK
[2]$\mathbb{L}^4$ Collaboration & Doctoral College for the Statistical Physics of Complex Systems, Leipzig–Lorraine–Lviv–Coventry, Europe
[3]Institute for Condensed Matter Physics, NAS of Ukraine, Lviv, Ukraine [4]F. D. Ovcharenko Institute of Biocolloidal Chemistry, NAS of Ukraine, Kyiv, Ukraine [5]Sorbonne Universités, Université de Technologie de Compiégne, EA 4297, Centre de Recherches de Royallieu, Compiégne Cedex, France

We investigate topological and spatial features of public transport networks (PTN) within the UK on both a national and local scale. The networks studied include those of Greater London, Greater Manchester, West Midlands, Bristol, the national rail and coach networks of mainland UK for the period of 2011. Using methods developed in complex network theory [1,2] we analyse and compare the statistics of previous studies on other PTN [2] with the results obtained in the present study [3]. In particular our analysis allows to discriminate PTN in respect to their stability to targeted attacks and random failures. Such behaviour has a close analogy to the physical process known as percolation. Based on other analogies in behaviour of interacting many-particle systems and systems of many interacting agents of non-physical nature, we use framework of statistical physics to further quantify public transport networks. In particular, we suggest to quantify PTN shape by familiar shape characteristics of particle aggregates. In turn, analysis of their scaling properties leads to fractal measures of public transportation networks that enable one to gain useful insights into the serviceable area of stations. Moreover, we investigate universal load dynamics of these systems. These features can be employed as key performance indicators in aid of further developing efficient and stable PTN.

[1] Yu. Holovatch, R. Kenna, S. Thurner, Eur. Journ. Phys. **38**, 023002 (2017).
[2] B. Berche, C. von Ferber, T. Holovatch, Yu. Holovatch, Advances in Complex Systems **15**1250063 (2012).
[3] R. de Regt, C. von Ferber, Yu. Holovatch, M. Lebovka, Transportmetrica (submitted); arXiv:1705.07266.

ELECTRODYNAMICS IN FLAT SPACETIME OF SIX DIMENSIONS

Yu. Yaremko
Institute for Condensed Matter Physics, NAS of Ukraine, Lviv

We consider dynamics of a point-like charge in spacetime of six dimensions acted upon a static homogeneous electromagnetic field. Charge's electromagnetic field satisfies the Maxwell equations. A consistent regularization procedure which exploits the Poincaré symmetry of the theory results the particle action which contains, apart from usual "bare" mass, an additional renormalization constant coupled with the curvature of the world line. The mass shell of a free charge depends on the squared six-acceleration. If the second regularization constant is negative, an accelerated motion exists which belongs to the mass shell. It is the periodic orbit parameterized by the Jacobian elliptic functions. Using the basic algebraic properties of the electromagnetic field tensor we analyze the motion of a charge in a constant electromagnetic field.

OBSERVATION OF LEE–YANG ZEROS OF AN ARBITRARY SPIN BATH

A. Kuzmak
Department for Theoretical Physics, Ivan Franko National University of Lviv, Ukraine

Recently in paper [Peng *et al.*, Phys. Rev. Lett. **114**, 010601 (2015)] the experimental observation of Lee-Yang zeros of an Ising-type spin-1/2 bath, by mesuring coherece of a probe spin, was reported. We generalize this problem on the case of an arbitrary spin bath. Namely, we consider the evolution of arbitrary probe spin s' which interacts with bath composed by the spins of an arbitrary value s. As a result, a connection between the observed values of probe spin, such as magnetization and susceptibility, and Lee–Yang zeros is found. Also we consider these results for some physical systems.

UNIVERSAL PROPERTIES OF COMPLEX POLYMERS WITH MORE THEN ONE BRANCHING POINT

K. Haydukivska, V. Blavatska
Institute for Condensed Matter Physics, NAS of Ukraine, Lviv

We analyze the conformational properties of complex branched polymers with more then one branching point analytically within the frames of continious chain model. This type of topology can be found in melts of low-density polyethylene (LDPE) and is closely connected with star dymers polymers (so called pom-pom molecules). Applying the direct polymer renormalization approach, we evaluate the universal size and shape properties of such structures and qualitatively compare them with those of polymers of simpler topologies. The behaviour of macromolecules both in pure solutions and in presence of long range correlated structural obtacles is analyzed.

LUMINESCENCE PROPERTIES OF THE $Li_2B_4O_7$ GLASSES CO-DOPED WITH Er AND Ag

I. I. Kindrat[1], *B. V. Padlyak*[1,2], *R. Lisiecki*[3], *V. T. Adamiv*[2], *I. M. Teslyuk*[2]
[1]University of Zielona Góra, Institute of Physics, Division of Spectroscopy of Functional Materials, Zielona Góra, Poland
[2]Vlokh Institute of Physical Optics, Lviv, Ukraine
[3] Institute of Low Temperature and Structure Research of the Polish Acad. Sci., Wrocław, Poland

The luminescence properties of the Er-doped and Er-Ag co-doped glasses with $Li_2B_4O_7$ ($Li_2O{-}2B_2O_3$) basic composition were investigated using optical absorption and photoluminescence (excitation, emission, decay kinetics) experimental techniques as well as Judd-Ofelt analysis. The $Li_2B_4O_7$:Er and $Li_2B_4O_7$:Er Ag glasses of high chemical purity and optical quality were obtained by standard glass technology, described in [1, 2].

Optical absorption spectra of the Er-doped and Er-Ag co-doped $Li_2B_4O_7$ glasses consist of several narrow bands in the visible and infrared spectral ranges, which belong to characteristic $f - f$ transitions of the Er^{3+} ions. The Judd-Ofelt intensity parameters (Ω_2, Ω_4, and Ω_6) have been calculated using the spectral intensities of the observed absorption bands and least-square fitting. Absorption spectrum of thermally annealed $Li_2B_4O_7$:Er Ag glass shows additional broad band in the range of 400–430 nm that is attributed to the surface plasmon resonance band of the silver metallic nanoparticles.

The photoluminescence spectra of the Er-doped and Er-Ag co-doped $Li_2B_4O_7$ glasses reveal infrared ($^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition, $\lambda_{max} = 1530$ nm) and green ($^4S_{3/2} \rightarrow {}^4I_{15/2}$ transition, $\lambda_{max} = 545$ nm) emission bands. Radiative properties such as transition probabilities (A_{rad}), branching ratios (β), stimulated emission cross-sections (σ_e), and radiative lifetimes (τ_{rad}) are estimated for observed emission transitions of the Er^{3+} ions and compared with corresponding radiative properties of the $Li_2B_4O_7$:Er glasses, obtained in [1].

The luminescence kinetics of the Er^{3+} infrared emission band were satisfactory described by single exponential decay with lifetime about 350 μs, whereas the luminescence kinetics of the Er^{3+} green

emission band are slightly non-exponential with average lifetime value about 60 μs. Experimental and radiative lifetimes were compared and quantum efficiency (η) for green ($^4S_{3/2} \rightarrow {}^4I_{15/2}$ transition) and infrared ($^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition) emission bands have been estimated.

The Ag impurity in the Er-Ag co-doped $Li_2B_4O_7$ glasses shows broad emission band with a maximum about 395 nm that can be efficiently excited in the 330–350 nm spectral range. The observed luminescence emission and excitation bands are assigned to $4d^{10} \leftrightarrow 4d^9 5s^1$ transition of the isolated Ag^+ ions. Luminescence kinetics of the Ag^+ emission is characterised by slightly non-exponential decay with average lifetime about 140 μs.

The enhancement of Er^{3+} luminescence in the $Li_2B_4O_7$:Er Ag glasses has been observed. The observed enhancement is attributed to energy transfer from the Ag^+ to the Er^{3+} centres as well as local field effects induced by surface plasmon resonance of the silver metallic nanoparticles.

[1] B. V. Padlyak, R. Lisiecki, W. Ryba-Romanowski, Opt. Mater. **54**, 126 (2016).

[2] V. Adamiv, R. Gamernyk, I. Teslyuk, Appl. Opt. **56** 5068 (2017).

MODELING DARK MATTER WITH μ-BOSE GAS CONDENSATE

A. M. Gavrilik, I. I. Kachurik, M. V. Khelashvili, A. V. Nazarenko

Bogolyubov Institute for Theoretical Physics, NAS of Ukraine, Kyiv, Ukraine

Though being in good agreement with large scale observational data, the Cold Dark Matter (DM) model faces some difficulties on the small (< 1 Mpc) scales. Another popular class of DM models namely Bose-Einstein condensate (BEC) DM model when applied to DM halos of dwarf galaxies solves, see [1], the core-cusp problem arising within CDM. In our work, we extend BEC DM model by replacing it with μ-deformed ($\mu > 0$) analog of Bose gas, whose particles obey non-standard statistics and which at $\mu \rightarrow 0$ turns into usual Bose gas. Within μ-Bose gas model (μ-BGM), all thermodynamical functions are derived by means of so-called μ-calculus [2] and due to this, dependence on the deformation parameter μ does appear. Using thermodynamical geometry, from singularity of scalar curvature we confirm the existence [3] of phase transition — Bose-like condensation in the μ-BGM. The critical temperature $T_c^{(\mu)}$ exceeds the standard Bose T_c and grows with enhancing deformation measured by μ. We examine basic parameters of DM halo and demonstrate [3] that their dependence on the parameter μ enables to treat weak points of BEC DM model (e.g. overestimated mass of dwarf galaxy DM halo).

[1] T. Harko, JCAP **05**, 022 (2011).

[2] A. P. Rebesh, A. M. Gavrilik, I. I. Kachurik, Ukr. J. Phys. **85**, 041123 (2013).

[3] A. M. Gavrilik, I. I. Kachurik, M. V. Khelashvili, A. V. Nazarenko, Physica A **506**, 835 (2018).

EFFECT OF QUANTUM XY INTERDIMER COUPLING ON THE LOW-FIELD MAGNETIZATION OF THE SHASTRY-SUTHERLAND MODEL

T. Verkholyak[1], J. Strečka[2]

[1]Institute for Condensed Matter Physics, NAS of Ukraine, Lviv, Ukraine

[2]Department of Theoretical Physics and Astrophysics, Institute of Physics, P. J. Šafárik University, Slovak Republic

The ground state of the Shastry-Sutherland model is considered within the many-body perturbation method developed on the exact eigenstates of the hybrid model with the Heisenberg intradimer and Ising interdimer couplings. The interplay of the frustration and quantum correlations present in the model leads to the distinctive ground-state phases characterized by the dimer or plaquette crystal ordering. The application of the magnetic field gives rise to even more complicated periodic structures which manifest themselves in the fractional magnetization plateaux at 1/2, 1/3, 1/4, 1/6 and other smaller

values of the saturation magnetization. Such plateaux have been also observed experimentally in the layered compound $SrCu_2(BO_3)_2$ which has the magnetic structure of the Shastry-Sutherland model.

We focus on the case of the strong intradimer interaction with the singlet-dimer phase in the ground state and relatively small magnetic fields. Using the perturbation theory we obtain the effective model of the interacting triplet excitations with hard-core repulsion and recover the fractional plateaux of 1/8, 1/6, 1/4 and 1/3 of the saturation magnetization. The obtained value of the critical fields corresponding to the magnetization jumps are in good agreement with the available numerical data. The possibility of the realization of the delocalized bound states of triplet is revealed that indicates the emergence of the quantum-correlated phase at a very low field.

THREE-QUBIT SYSTEM — STEERING PARAMETER AND DEGREE OF MIXEDNESS

J. K. Kalaga, W. Leoński
Institute of Physics, University of Zielona Góra, Poland

We consider a model of three qubits. For such a model, we examine the possibility of the generation of the steering between two qubits. We discuss the possible relations between the entanglement measures and the steering parameter for two-mode, mixed states corresponding to the qubit-qubit subsystem [1]. As a measure of the steering effect, we apply the parameter based on the Cavalcanti inequality [2]. Additionally, we discuss the conditions determining the manifestation of steering effects. We show the relations between the steering and the mixedness, parametrized by the concurrence and negativity for the both: steerable and unsteerable two-qubit mixed states. To quantify the mixedness, we use the linear entropy defined with an application of the purity [3].

[1] J. K. Kalaga, W. Leoński, Quantum Inf. Process. **16**, 175 (2017).
[2] E. G. Cavalcanti, Q. Y. He, M. D. Reid, H. M. Wiseman, Phys. Rev. A **84**, 032115 (2011).
[3] T. C. Wei, K. Nemoto, P. M. Goldbart, P. G. Kwiat, W. J. Munro, F. Verstraete, Phys. Rev. A **67**, 022110 (2003).

EFFECT OF NONCOMMUTATIVITY OF COORDINATES AND NONCOMMUTATIVITY OF MOMENTA ON FREE PARTICLES SYSTEM MOTION

Kh. P. Gnatenko
Department for Theoretical Physics, Ivan Franko National University of Lviv, Ukraine

We consider features of free particles system motion in quantum space with the following commutation relations for coordinates and momenta

$$[X_1, X_2] = i\hbar\theta, \tag{1}$$

$$[X_i, P_j] = i\hbar\delta_{ij}, \tag{2}$$

$$[P_1, P_2] = i\hbar\eta, \tag{3}$$

where $\theta = const$ is parameter of coordinate noncommutativity, $\eta = const$ is parameter of momentum noncommutativity.

We obtained that in noncommutative phase space a system of free particles flies away even in the case when initial velocities of the particles are the same. It is shown that the trajectory of free particle does not depend on its mass and a system of free particles does not fly away when parameters of noncommutativity satisfy the following conditions

$$\frac{\eta_a}{m_a} = \alpha = \text{const}, \tag{4}$$

$$\theta_a m_a = \gamma = \text{const}, \tag{5}$$

here α, γ being constants which are the same for particles with different masses [1]. In addition when these conditions hold the total momentum of composite system can be introduced as integral of motion.

We would like to note that in papers [2,3] we showed that on the same conditions (4), (5) a list of important results can be obtained in noncommutative phase space. Among them are recovering of the weak equivalence principle, preserving of the properties of kinetic energy, solving the problem of kinematic variables.

[1] Kh.P. Gnatenko, H. P. Laba, V. M. Tkachuk, (accepted for publication in Mod. Phys. Lett. A); arXiv:1805.08470.

[2] Kh.P. Gnatenko, V.M. Tkachuk, Phys. Lett. A **381**, 2463 (2017).

[3] Kh.P. Gnatenko, Mod. Phys. Lett. A **32**, 1750166 (2017).

DARK ENERGY INSIDE COMPACT ASTROPHYSICAL OBJECTS

S. Smerechynskyi[1], *M. Tsizh*[2], *Kh. Kobyrynka*[1], *B. Novosyadlyj*[2],
[1]Department of Astrophysics, Ivan Franko National University of Lviv, Ukraine
[2]Astronomical Observatory, Ivan Franko National University of Lviv, Ukraine

Dark energy is believed to be responsible for accelerated expansion of the Universe, but its nature is poorly understood. In our work we aimed to constrain one of the parameters of equation of state for dark energy, namely effective speed of sound c_s, using compact objects (white dwarfs and neutron stars). We have investigated the impact of dark energy inside compact object on its structure and derived the minimal value of c_s which corresponds to the onset of instability of an object. It was shown that influence of dark energy is stronger for neutron stars, however, obtained constraints are weak for both types of compact objects.

REPULSION-ATTRACTION ASYMMETRY IN THE BOSE–FERMI–HUBBARD MODEL

I. V. Stasyuk, V. O. Krasnov
Institute for Condensed Matter Physics, NAS of Ukraine, Lviv, Ukraine

The creation of the optical lattices with ultracold atoms over the past decades provided a breakthrough in physics of the strongly correlated systems which takes start from the investigations of electron systems in the narrow conductivity bands with strong local correlations. First model, proposed for their description, was the Hubbard model (where the main role is played by the on-site repulsion of electrons with opposite spins. Later, similar models were formulated for optical lattices: the Bose-Hubbard model (BH) for a lattice with Bose-atoms and the Bose-Fermi-Hubbard model (BFH) [1] for lattices with mixtures of Bose- and Fermi-atoms. The main phenomenon that is observed and explored in this case is the phase transition between normal (MI, Mott insulator phase) and superfluid (SF) phases. Transition to SF phase in BH model is well studied and always is of the 2nd order, while such phase transition in BFH model is more complicated due to the fermion presence. The experiments in this direction were performed for the mixture of ^{87}Rb (bosons) and ^{40}K (fermions) atoms [2]; they showed the decay of BE condensate with the raise of the Fermi-atoms concentration. To describe this, the calculations of phase diagrams for BFH model, using different approaches were performed and the difference at the local boson-fermion repulsion or attraction U' in behavior of the boson-fermion mixtures and in the shape of corresponding phase diagrams was noticed.

Majority of the theoretical investigations of BFH model were performed in the regime of the fixed concentrations of fermions. As was shown, only the phase transitions of the 2nd order take place in this case. At the same time, the approach based on the application of the grand canonical ensemble, proposed in [3], reveals the possibility of the change of the phase transition order (from 2nd to the 1st one).

In our work we show, that the fermion-hole symmetry in the Bose-Fermi-Hubbard model allows to establish a correspondence, accompanied by an appropriate transformation of model parameters, between cases of the on-site boson-fermion repulsion and attraction. The conditions of the superfluid phase existence at the boson-fermion attraction or repulsion are analyzed using the phase diagrams, built in [3] for the case $U' > 0$ in the frames of the grand canonical ensemble. We showed that the general shape of the obtained phase diagrams reproduces the observed on experiment [2] asymmetry of the BE condensate appearance scenario in a wide range of negative and positive values of the BF interaction.

[1] A. Albus, F. Illuminati, J. Eisert, Phys. Rev. A, **68**, 023606 (2003).
[2] T. Best, S. Will,U. Schneider et al., Phys. Rev. Lett., **102**, 030408 (2009).
[3] I.V. Stasyuk, V.O. Krasnov, Condens. Matter Phys., **18**, 43702 (2015).

MOLECULES IN THE VIRIALIZED HALOS OF DARK AGES

B. Novosyadlyj[1,3], *V. Shulga*[2,3], *W. Han*[3], *Yu. Kulinich*[1], *M. Tsizh*[1]
[1]Astronomical Observatory of Ivan Franko National University of Lviv, Ukraine,
[2]Institut of Radio Astronomy of NAS of Ukraine, Kharkov, Ukraine,
[3]International Center of Future Science of Jilin University, Changchun, P. R. China

Formation of halos in Dark Ages from initial spherical perturbations is analyzed in four component Universe (dark matter, dark energy, baryon matter and radiation) in the approximation of relativistic hydrodynamics. Evolution of density and velocity perturbations of each component are obtained by accurate integration of system of nine differential equations from $z = 10^6$ up to virialization, which is described phenomenologically. It is shown that number density of collapsed or virialized dark matter halos with masses $M \sim 10^8 - 10^9\,\mathrm{M}_\odot$ is close to the number density of normal galaxies in the comoving coordinates. The dynamical dark energy type classical scalar field does not influence practically on the evolution of other components, but dynamical dark energy with small value of effective sound speed can be important at the late stage of halo formation.

Simultaneously the system of kinetics equations describing the formation and dissociation of the first molecules have been integrated for each step of hydrodynamical part of problem. The results show that number densities of molecules H_2 and HD, which are important coolers in the processes of formation of first stars, are drastically higher in halos than in the cosmological background. It is caused by enhanced density and rates of reactions at quasilinear and nonlinear evolution of density and velocity of baryon component of halos. For example, at the moment of virialization the mean number densities of molecules H_2 and HD are in $\sim 10^3$ and ~ 400 times larger than in cosmological background accordingly. At the end of Dark Ages ($z \sim 10$) the molecular number density contrasts are even greater. It is shown also that the temperature history of the halo is important for calculating the concentration of molecular ions with low binding energy. So, in a halo with virial temperature $\sim 10^5$ K the number density of the molecular ion HeH^+ is approximately 100 times smaller than that on the cosmological background.

CHARGED BLACK HOLE IN THE THEORY WITH NONMINIMAL DERIVATIVE COUPLING AND BORN-INFELD TERM AND ITS THERMODYNAMICS

M. M. Stetsko
Department for Theoretical Physics, Ivan Franko National University of Lviv, Ukraine

Scalar-tensor theories have been investigated very intensively for recent years, they look as a possible generalization of standard General Relativity. In our report we obtain a new static black hole's solution in the theory with nonminimal derivative coupling and Born-Infeld type of electrodynamics. We examine the behaviour of metric functions and electromagnetic field for the black hole. We also study thermodynamic functions for the obtained solution and derive the first law of black hole's thermodynamics.

TWO-DIMENSIONAL SPIN MODELS, FERMIONS AND CORRELATED DISORDER

M. Dudka
Institute for Condensed Matter Physics, NAS of Ukraine, Lviv, Ukraine

Nowadays interest in condensed matter to study two-dimensional systems is constantly growing due to the progress in experimental techniques of producing and studying low-dimensional materials like graphene, two-dimensional crystals or ultrathin ferromagnetic films. Since every material investigated in the laboratory involves some degree of impurities, the effects of quenched structural disorder on phase transitions is a hot topic of research.

Here we are interested in the critical properties of two-dimensional Ising model and N-'color' Ashkin-Teller model in a presence of random quenched structural defects correlated with the distance r according to a power-law r^{-a}. In our study we use a mapping of the mentioned spin models onto two-dimensional theory of complex (Dirac) fermionic fields with disorder. To study the critical behaviour we apply the renormalization group approach. Using two-loop approximation for Ising model we find that it belongs to new universality class characterized by the correlation length exponent $\nu = 2/a$ [1]. Applying bosonization, we also calculate the averaged square of the spin-spin correlation function and find an estimate for the critical exponent η. Within one-loop order we find for N-'color' Ashkin-Teller model that a "weakly universal" scaling behavior for $N = 2$ as well as the first-order phase transition for $N > 2$, are transformed by the correlated disorder into a continuous phase transition sharing universality class with previously considered model [2].

[1] M. Dudka, A. A. Fedorenko, V. Blavatska, Yu. Holovatch, Phys. Rev. B **93**, 224422 (2016).
[2] M. Dudka, A. A. Fedorenko, Condens. Matter Phys. **20**, 13603 (2017).

DYNAMICS OF A CHARGED SPINNING TOP UNDER THE RADIATION REACTION

A. Duviryak
Institute for Condensed Matter Physics, NAS of Ukraine, Lviv, Ukraine

Rotation of charged top under the radiation reaction is considered. Dynamics of the spinning top is derived from a balance condition of the angular momentum. It leads to the non-integrable nonlinear 2nd-order equation for the angular velocity. Asymptotics of non-physical and physical solutions of this equation are found. Non-physical solutions describe self-accelerating rotation of the top up to an infinite speed in a finite time. Physical solutions describe power-law or exponential slowdown rotation (this depends on a direction of the angular velocity). Physical solutions are also found by means of an exact integration of the equation of motion with reduced 2nd derivative.

NEW CRITICAL BEHAVIOUR IN A COMPLEX SYSTEM INDUCED BY TWO COMPETING POWER LAWS

M. Krasnytska[1,2], *B. Berche*[3,2], *Yu. Holovatch*[1,2]
[1]Institute for Condensed Matter Physics, NAS of Ukraine, Lviv, Ukraine,
[2]$\mathbb{L}^4$ Collaboration & Doctoral College for the Statistical Physics of Complex Systems, Leipzig-Lorraine-Lviv-Coventry, Leipzig, Germany,
[3]Institut Jean Lamour, CNRS/UMR 7198, Groupe de Physique Statistique, Université de Lorraine, Vandœuvre-les-Nancy Cedex, France

We consider a modification of the Ising model on an annealed scale-free network (with power-law node degree distribution), when spins pointing up or down, as in the usual Ising model, can be however of different length. Moreover, the spin length can differ from site to site being governed by another power-law distribution. We analyze the critical behaviour of the above model. An interplay of two

power laws leads to a rich phase diagram with a variety of phase transitions in few different universality classes.

We discuss possible application of the suggested model to understand peculiarities of ordering in inhomogeneous magnets of complex architecture as well as to for agent based modeling of opinion formation.

SPECIAL RELATION BETWEEN THE TWO DEFORMED BOSE GAS MODELS

Yu. A. Mishchenko, A. M. Gavrilik
Bogolyubov Institute for Theoretical Physics, NAS of Ukraine, Kyiv, Ukraine

The unusual relation between certain two deformed Bose gas models belonging to two different classes is considered: a) the first defined via deformed derivative in the deformed thermodynamics relations [1,2], and b) the second one based on deformed oscillators or distributions [3] in statistical mechanics sector. We also use the term "*duality*" since: at equal deformation structure functions (DSFs) the models have different consequences, and vice versa, for the two matching models (which describe equivalent "physics") they should be in concordance. That is, thermodynamic relations, involving *at least* one-particle distribution (e.g. for total number of particles, thermal capacity, E.O.S.), are to be coinciding, under certain relation on the DSFs of the models. Say, version (b) of the $\tilde{\mu}, q$-deformed Bose gas model from [3], though differs from $\tilde{\mu}, q$-partner model from [1,2], shares with it three things: (i) the same form of DSF; (ii) coinciding one-particle distributions, at differing, but strictly related (in a special way) DSFs in the two models; (iii) common goal of joint effective description of the interaction and composite structure of particles. Between the two versions of $\tilde{\mu}, q$-Bose gas (given by their DSFs) there is a kind of "duality relation" if the coincidence of one-particle deformed distributions is required.

The duality relation holds not only for particular $\tilde{\mu}, q$-deformed Bose gas models, but for general pairs of dual models. Namely, distribution $n_{\mathbf{k}}^{(\varphi)}$ in φ-deformed model defined like in [1,2] (with φ-deformed total number of particles $N^{(\varphi)}$ and the corresponding partition function) is recovered from $N^{(\varphi)} = \sum_{\mathbf{k}} n_{\mathbf{k}}^{(\varphi)}$. On the other hand, – distribution $n_{\mathbf{k}}^{(\tilde{\varphi})} \equiv \langle \tilde{\varphi}(N_{\mathbf{k}}) \rangle$ is defined by DSF $\tilde{\varphi}$, and the both are required to agree. For matching of the models, DSFs φ and $\tilde{\varphi}$ should be related as: $\tilde{\varphi}(n) = \sum_{i=1}^{n} \frac{\varphi(i)}{i}$.

There exist certain "self-dual" deformed models – such that their DSFs under duality preserve their form but involve modified deformation parameters. Note that for the $\tilde{\mu}$-Bose gas, given by $\varphi_{\tilde{\mu},q}(n)|_{q=1} = (1+\tilde{\mu})n - \tilde{\mu}n^2$ ($q=1$ subfamily of $\tilde{\mu}, q$-deformed models), the distributions in the dual version are given by "dual" structure function $\tilde{\varphi}_{\tilde{\mu},q=1}(n) = \varphi_{\overline{\mu},q=1}(n)|_{\overline{\mu}=\tilde{\mu}/2}$.

[1] A. M. Scarfone, P. N. Swamy, J. Stat. Mech. **2009**, P02055 (2009).
[2] A. M. Gavrilik, Yu. A. Mishchenko, Phys. Rev. E **90**, 052147 (2014).
[3] A. M. Gavrilik, Yu. A. Mishchenko, Nucl. Phys. B **891**, 466 (2015).

OPTICAL AND PARAMEGNETIC PROPERTIES OF MANGANESE IONS IN THE RHOMBOHEDRAL $LaAlO_3$ PEROVSKITE

D. Sztolberg[1], *B. Brzostowski*[1], *A. Drzewiecki*[1], *P. J. Dereń*[2]
[1]Institute of Physics, University of Zielona Góra, Poland [2]Institute of Low Temperatures and Structure Researches, Polish Acad. Sci., Wrocław, Poland

We present the spectroscopic and paramagnetic properties of manganese ions in the rhombohedral $LaAlO_3$ perovskite. Nanopowders were prepared by zol-gel Pechini method in an oxygen atmosphere. Absorption, emission and lumienescence decay profiles were measured at room temperature and exhibit presence of Mn^{4+} ions in host lattice. The electron paramagnetic resonance (EPR) measurements at the X-band frequency were made and shows existence of Mn^{2+} ions.

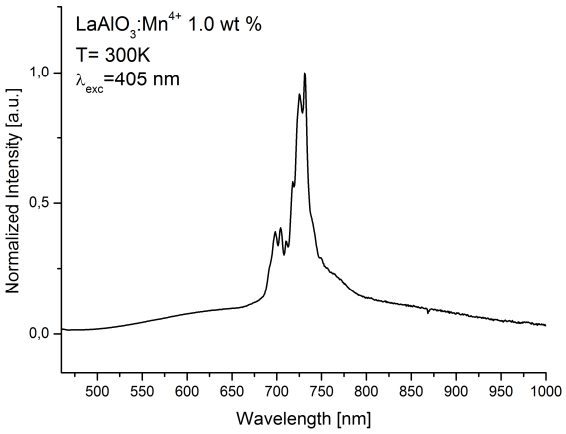

Fig. 1. The emission spectra of $LaAlO_3$ nanopowders doped with manganese ions,

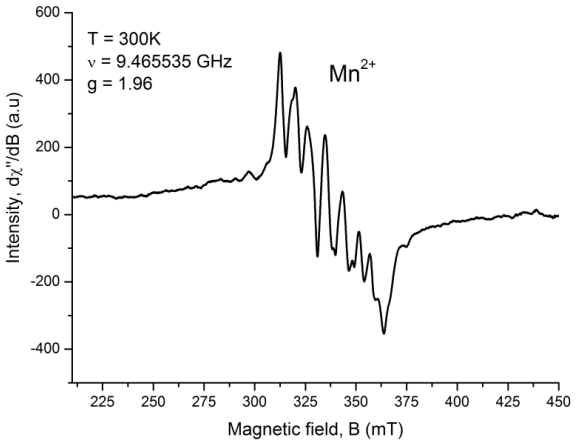

Fig. 2. The EPR spectra of $LaAlO_3$ nanopowders doped wtih manganese ions.

[1] A. M. Srivastava, M. G. Brik, Opt. Mat. **63** 207 (2017) .
[2] A. M. Srivastava, M. G. Brik, Opt. Mat. **35** 1544 (2013).
[3] Yu. D. Ivankin, M. N. Danchevskaya, G. P.Murav'eva, Mosk. Univ. Chem. Bulletin **66**, No.3, 151 (2011).
[4] D. Yamasaka, Y. Hori, T. Morimoto, Y. Ohiki, Jap. J. Appl. Phys. **52**, 071501 (2013).
[5] V. I. Burkov, S. V. Gudenko, L. N.Alyabyeva, J. Exp. Theor. Phys. **119**, 723 (2014).

INTERCALATION OF THE STAGE ORDERED LAYERED STRUCTURES BY COMPLEX PARTICLES: A THEORY

O. R. Baran, O. V. Velychko
Institute for Condensed Matter Physics, NAS of Ukraine, Lviv, Ukraine

Layered semiconductors are popular materials with an easy intercalation in the space between layers without significant change in volume. A stage ordering of the host compound is aimed at a better penetration of particles into the matrix as well as a possibility of intercalation of large molecular groups like oligo-dimethylamino-methacrylate. The stage ordering is perpendicular to host layers with a significant increase of the distance between multilayer packets.

Changes in the electronic band structure of the stage ordered layered nanohybrid compound of the GaSe-type due to intercalation of particles having a complex electron spectrum are studied within the model which is a simplified version of the periodic Anderson model. The principal restructuring of the electron spectrum and the respective density of states consists in additional splitting, emergence of gap (pseudogap) and appearance of the single impurity band besides the main one. Being far enough from the main band, the impurity band degenerates into the impurity level. Approaching each other they hybridize.

In the case, when the single-electron energy spectrum of the impurity particle is approximated by the density of states of some model shape, the smearing out of the full spectral density takes place. At increase of the parameter that characterizes the local level broadening degree, the singularities of the total density of states (DOS) gradually smear out, the hybridization gap in the energy spectrum disappears, and the three-step structure of density of states near the energy band edge becomes less distinctive. Similar changes of the DOS take place at increase of the intercalant concentration.

This approach simplifies the internal energy structure of intercalated particles but it provides expressions for the electron excitation spectrum and the density of states in analytic form giving a good qualitative description of the intercalation effect on the electron subsystem of intercalated crystals.

Knowledge of the total density of states allows one to calculate the electron quantum capacitance of the considered intercalated layered compounds. In the low temperature limit the frequency dispersion

of the DOS determines the field (voltage) dependence of the quantum capacitance with respect to localization of impurity bands, strength of electron hybridization and temperature.

LARGE-N PROPERTIES OF A BOSE GAS IN THE CONDENSATE PHASE

V. Pastukhov, O. Hryhorchak
Department for Theoretical Physics, Ivan Franko National University of Lviv, Ukraine

We rigorously discuss the application of the well-known from a field theory large-N expansion to the Bose gas with a short-range two-body potential. Considering the system as a mixture of N identical components with symmetrical interaction that is characterised only by the s-wave scattering length we performed the full numerical calculations of the critical temperature in the $1/N$-approximation as a function of gas parameter $an^{1/3}$. We also obtained the temperature dependence of leading-order corrections to the thermodynamic characteristics of a non-ideal Bose gas, namely, the depletion of Bose–Einstein condensate and the isothermal compressibility.

EVOLUTION OF COSMIC WEB AS COMPLEX NETWORK

M. Tsizh
Astronomical Observatory of Ivan Franko National University of Lviv, Ukraine

In this work I use catalog based on MultiDark cosmological simulation to track how the complex network, build on halos as vertexes, changes with large scale evolution of simulated Universe. Starting with snapshots at z 2 and up to $z = 0$. I compute different averaged metrics (degree, clustering coefficient, betweeness, closeness, Katz, and eigen centralities) and also assortativity by degree and mass as characteristic of network for each snapshot. I find the Gini index for distribution of every characteristic in each case. Also I argue that graph edit distances do not suit for the purpose of tracking the evolution of Cosmic web-type networks. Only cube of volume $100 \times 100 \times 100h^{-1}$ Mpc of total $1h^{-1}$ Gpc^3 of Multidark simulation was used for computation, several values of linking length for network were tested in range from 1.2 to 2 Mpc.

SPECTROSCOPY OF THE Ag-DOPED BORATE GLASSES

B. V. Padlyak[1,2], V. T. Adamiv[2], T. B. Padlyak[2], I. I. Kindrat[1], A. Drzewiecki[1], V. Ya. Tataryn[3], I. M. Teslyuk[2], S. P. Dubelt[3]
[1]University of Zielona Góra, Institute of Physics, Division of Spectroscopy of Functional Materials, Poland,
[2]Vlokh Institute of Physical Optics, Department of Optical Materials, Lviv, Ukraine,
[3]Lviv Polytechnic National University, Ukraine

The possible silver (Ag) paramagnetic and luminescence centres, their electronic and local structure in oxide crystals and glasses of different compositions are considered based on published articles. The X-band electron paramagnetic resonance (EPR) and optical (absorption, emission, luminescence excitation) spectra and luminescence decay kinetics of the Li2B4O7:Ag glasses are detailed investigated and analysed. The $Li_2B_4O_7$:Ag glasses were obtained using standard glass technology. The Ag impurity was introduced in the $Li_2B_4O_7$ glass composition as $AgNO_3$ compound and as metallic highly dispersed silver (particle size 100 nm) in amount 2.0 mol.%. In all obtained $Li_2B_4O_7$:Ag samples clearly has been observed characteristic EPR signal with $g_{\text{eff}} \simeq 4.29$ at $T = 300\,\text{K}$ that belongs to the Fe^{+3} non-controlled impurity ions in the glass network. Broad asymmetric EPR signal with effective g-factor $g_{\text{eff}} = 2.05$ that also observed at $T = 300\,\text{K}$ is typical for glasses highly doped with Ag and associated with paramagnetic silver centres, coupled by magnetic dipolar and exchange interactions. Based on the EPR spectroscopy data it was shown that the Ag impurity can be incorporated into the network of as-synthesised $Li_2B_4O_7$ glasses as the Ag^{2+} ($4d^9$), Ag^0 ($4d10s^1$), and possibly Ag_2^+ ($Ag^0 + Ag^+$) paramagnetic ions and their clusters. Thermal annealing of the $Li_2B_4O_7$:Ag glasses at $T = 710\,\text{K}$

during 2 hrs in the air, vacuum and hydrogen (H_2) leads to disappearing the main part of complex EPR signal with $g_{\text{eff}} \simeq 2.05$, whereas the Fe^{3+} EPR signal practically is unchanged after the thermal annealing. As-synthesised $Li_2B_4O_7$:Ag glasses were not reveal the band of surface plasmonic resonance of the metallic silver nanoparticles in their optical absorption spectra, but characterised by typical for Ag^+ ($4d^{10}$) centres luminescence (emission and excitation) spectra and exponential decay kinetics with lifetime $\tau \simeq 161\,\mu$s at $T = 300\,$K. Thermal annealing of the $Li_2B_4O_7$:Ag glasses in the air leads to considerably increasing of the relative intensity of emission band and shortening luminescence lifetime ($\tau \simeq 122\,\mu$s) of the Ag^+ luminescence centres. The observed spectroscopic properties of as-synthesised and thermally annealed $Li_2B_4O_7$:Ag glasses are interpreted and discussed based on the published data for other Ag-doped glasses.

THE DEGREE OF MIXING OF A QUANTUM STATE: A GEOMETRIC MEASURE

H. P. Laba[1], *V. M. Tkachuk*[2]
[1]Lviv Polytechnic National University, Ukraine
[2]Department for Theoretical Physics, Ivan Franko National University of Lviv, Ukraine

Pure and mixed states are key concepts in quantum mechanics and in quantum information theory. Therefore the question about the degree of mixing of a quantum state is important and is also interesting on its own right. In quantum mechanics the geometric ideas play important role. For definition the geometry of quantum states we use Hilbert–Schmidt distance. The degree of mixing of quantum states is defined as minimal Hilbert–Schmidt distance between mixed state and a set of pure states. The explicit expression for this geometric measure is obtained. It is interesting that this expression corresponds to squared Euclidean distance in space of eigenvalues of density matrix between mixed state and pure one. As an example the geometric measure of mixing for spin-1/2 states is calculated explicitly.