Yuri Gaididei Memorial Workshop

2-3 February 2022

National Academy of Sciences of Ukraine,

Bogolyubov Institute for Theoretical Physics, Kyiv, Ukraine

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Program

Wednesday, 2 February 2022		
09:30-09:35	**Chair Vadim Loktev**	Opening
09:35-09:45	Anatoly Zagorodny	Welcome
09:45-10:10	Elmar Petrov *(Ukraine)*	Tunnelling magnons as coherent energy carriers through a ferromagnetic chain
10:10-10:40	Peter Leth Christiansen *(Denmark)*	25 Years of Collaboration with Yuri B. Gaididei
10:40-11:10	Mads Peter Sørensen *(Denmark)*	Nonlinear sine-Gordon soliton waves and acoustic shock waves
11:10-11:40	Jens Juul Rasmussen *(Denmark)*	Localization dynamics in the framework of the generalized two-dimensional nonlinear Schrödinger equation
11:40-12:00	***Coffee break***	
	Chair Olena Gomonay	
12:00-12:30	Bohdan Lev *(Ukraine)*	Well-known but unknown phenomenological theory of phase transitions
12:30-13:00	Juan F.R. Archilla *(Spain)*	Frequency-momentum representation of soliton-breathers in a 2D hexagonal crystal lattice
13:00-13:30	Alexander Zolotaryuk *(Ukraine)*	Existence of a bound state for the $\gamma\delta'(x)$ potential
13:30-14:30	***Lunch***	
	Chair Elmar Petrov	
14:30-15:00	Franz G. Mertens *(Germany)*	Soliton dynamics in a novel nonlinear spinor model with external fields
15:00-15:30	Sergey N. Volkov *(Ukraine)*	The possible role of hydrogen peroxide molecules in ion beam therapy of cancer cells

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Thursday, 3 February 2022		
	Chair **Peter L. Christiansen**	
09:30-10:00	Avadh Saxena *(USA)*	Hopfions in anisotropic Heisenberg Magnets
10:00-10:30	Denis Sheka *(Ukraine)*	Nanomagnetism work of Yuri Gaididei
10:30-11:00	Volodymyr Kravchuk *(Ukraine)*	Properties of magnetic skyrmions induced by the curvature of the magnetic film
11:00-11:30	Denys Makarov *(Germany)*	From curvilinear magnetism to shapeable magnetoelectronics
11:30-12:00	***Coffee break***	
	Chair **Juan F.R. Archilla**	
12:00-12:30	Olena Gomonay *(Germany)*	Current-induced switching in antiferromagnets: role of thermal heating and strain effects
12:30-13:00	Oleksii Volkov (Germany)	Current-induced magnetization superlattices in nanomagnets
13:00-13:30	Oleksandr Pylypovskyi *(Germany)*	Exchange and anisotropy-driven effects in antiferromagnetic spin chains
13:30-15:00	***Lunch***	
	Chair **Jens Juul Rasmussen**	
15:00-15:30	Kostiantyn Yershov *(Ukraine)*	Curvature-induced effects in one-dimensional magnetic wires
15:30-16:00	Larissa Brizhik *(Ukraine)*	Nonlinear charge transport in Donor – Polymer – Acceptor Systems on macroscopic distances
16:00-16:30	Jean-Guy Caputo *(France)*	Dynamics of miscible flows on networks
16:30-16:40	Closing remark	

Frquency- momentum representation of soliton-breathers in a 2D hexagonal crystal lattice

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In this work we study spectral properties of exact travelling waves in a 2D hexagonal crystal lattice model of muscovite mica [1]. The theory of exact traveling waves [2] is extended to two dimensions and can also be easily extended to three [3]. Generically, these waves are composed of a localized solution and a wing, that is, an extended solution of constant amplitude. In the $\omega - k$ representation, they are within resonant planes, each plane corresponding in the moving frame to a single frequency. These frequencies are integer multiples of a frequency called the fundamental frequency. A discrete breather is within a resonant plane called the breather plane and has a single frequency in the moving frame. The spectral representation of a soliton-breather can be seen in the figure.

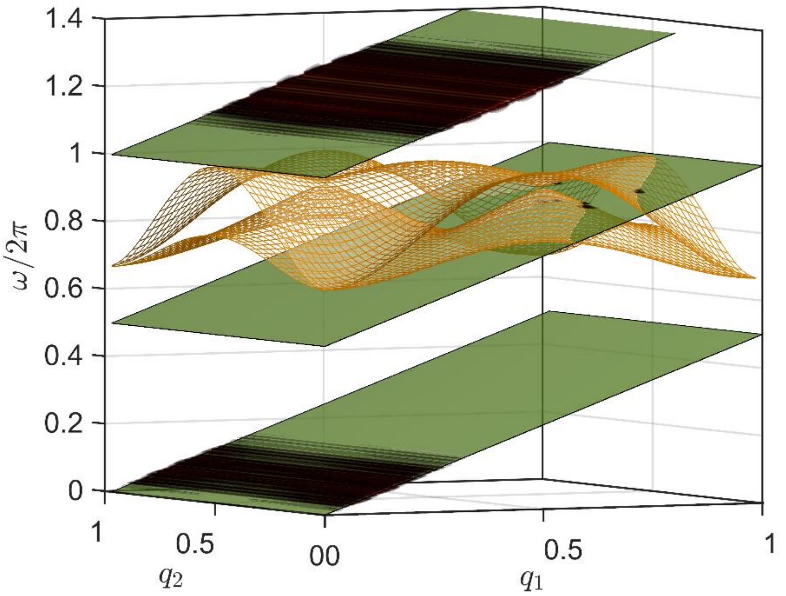

Fig. 1. Isosurface of the XYTFT of an exact soliton-breather, together with the resonant planes and the phonon surfaces.

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References

[1] J Bajārs, JC Eilbeck, B Leimkuhler, Physica D 301-302 (2015) 8.
[2] JFR Archilla, Y Doi, M Kimura, Phys. Rev. E 100 (2019) 022206.
[3] J Bajārs, JFR Archilla, arXiv:2201.03207 (2022).

Nonlinear charge transport in Donor – Alpha-Helix Polymer – Acceptor Systems on macroscopic distances

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The long-range electron and energy transfer mediated by solitons on an alpha-helix polypeptide chain coupled to donor and acceptor molecules at opposite ends of the chain, is studied. It is shown that for specific parameters of the system, an electron initially located on the donor, can tunnel onto the alpha-helix, forming a soliton, which then travels to the other extremity of the polypetide chain where it is captured by the acceptor.

Three families of couplings between the donor, acceptor and the chain are studied. The results show that one of them can lead to a 90% efficiency of the electron transport from donor to acceptor. This process is shown to be stable also at physiological temperatures in the presence of thermal fluctuations in the system for parameters of the alpha-helix characteristic for peptides.

Acknowledgments

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Dynamics of miscible flows on networks

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Networks of fluids and energy are ubiquitous in our societies. A natural approach is to describe the network topology using a graph. The fluid like quantity follows conservation laws and constitutive equations such as Kirchoff and Ohm's laws. I will derive and review the main ODE model for these systems, the graph wave equation where the usual (continuous) Laplacian is replaced by the graph Laplacian. The model can be extended by vertex nonlinearities and I will present two classes of nonlinear periodic solutions.

25 Years of Collaboration with Yuri B. Gaididei

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For 25 years Yuri collaborated with my coworkers and me during his visits as a Guest Professor at The Technical University of Denmark on Nonlinearity, Solitons and Chaos theory with applications to superconductivity, optics and optical communication, acoustics, molecular dynamics, biomolecular dynamics, and traffic dynamics.

In this talk I shall present glimpses from our 85 research papers.

Current-induced switching in antiferromagnets: role of thermal heating and strain effects

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Possibility of all-electrical switching makes antiferromagnets promising materials for spintronic devices [1-4]. However, recent experiments question the spin-related mechanisms responsible for the switching and elucidate the role of the domain structure [5], heat effects [6-7] and strain [7]. Here we develop a model of switching in antiferromagnets which puts together current-induced temperature gradients, spin-orbit torques, and magnetoelastic effects. Inhomogeneous volume expansion caused by the temperature gradients creates additional stresses whose relaxation induces redistribution of antiferromagnetic domains seen at a macroscopic level as a switching between different states. We calculate the domain patterns and related observable – magnetoresistance, -- as a function of current, and establish equivalence between the values of current and of the magnetic field in switching phenomena. We show that depending on the geometry of electrodes the stress-related mechanism can either compete with or support the switching mediated by spin-orbit torques thus opening new functionalities of spintronic devices. Moreover, high temperature gradient and related stresses can trigger formation of new domain walls and thus substantially change the domain patterns and corresponding macroscopic response. Thus, this study offers a way to optimize efficiency of antiferromagnetic spintronic devices by tailoring of the geometry and proper choice of the constitutive materials.

[1] P. Wadley, B.Howells, J. Železný, C. Andrews, V. Hills et al, Science, 351 (2016) 587–590.
[2] T. Moriyama, K. Oda, T. Ohkochi, M. Kimata,T. Ono, Sci. Rep., 8 (2018) 14167.
[3] X. Z. Chen, R. Zarzuela, J. Zhang, C. Song, X. F.Zhou et al, Phys. Rev. Lett., 120 (2018) 207204.
[4] L. Baldrati, O. Gomonay, A. Ross, M. Filianina, R. Lebrun, et al, , Phys. Rev. Lett., 123 (2019) 177201.
[5] Z. Kašpar, M. Surýnek, J. Zubáč, F. Krizek, V. Novák, et al, arxiv 1909.09071 (2019).
[6] C. C. Chiang, S. Y.Huang, D.Qu, P. H.Wu, , C. L. Chien, Phys. Rev. Lett., 123 (2019) 227203.
[7] Zhang, P., Finley, J., Safi, T., & Liu, L. Phys. Rev. Lett., 123 (2019) 247206.

Properties of magnetic skyrmions induced by the curvature of the magnetic film

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We collaborated with Yuri Gaididei for more than ten years considering a wide spectrum of problems in nanomagnetism. This collaboration resulted in 44 joined papers which cover three main directions: (i) control of magnetic vortices in ferromagnetic nanodots by means of ac magnetic field and spin-polarized current; (ii) vortex-antivortex crystals generated by spin-polarized currents in magnetic films, (iii) curvature-induced properties of low-dimensional magnets (films and wires).

Here I present the results of a number of our works about magnetic skyrmions in curvilinear films. An isolated magnetic skyrmion is a topologically nontrivial excitation of perpendicularly magnetized film. Dzyaloshinskii-Morya interaction (DMI) is a common mechanism of the skyrmion stabilization. However, in a curvilinear film, e.g. spherical shell, skyrmion can be stabilized by the curvature effects even for a DMI-free magnet [1]. This effect can be explained as the emergence of the curvature induced effective DMI, which originates from the exchange interaction [2].

Local curvilinear defect (bump) of the magnetic film may create pinning as well as depinning potential for a Néel skyrmion [3]. For the low-amplitude defect, the pinning/depinning effect is determined by the sign of the product of three quantities: topological charge and helicity of the skyrmion and mean curvature of the bump. Interestingly that the pinned skyrmion can be the ground magnetization state of the bump. Thus, the bumps arranged in the periodical array may induce the skyrmion lattice [3]. Such a kind of skyrmion lattice does not require an external magnetic field and can be of arbitrary symmetry. This is in strong contrast to the common skyrmion lattices in planar films. Skyrmion pinned on a large-amplitude bump can demonstrate a multiplet of states differing in the radius of the skyrmion. Each state corresponds to a local energy minimum. The switching between the states can be controlled by the pulses of the external magnetic field [3]. The latter effect potentially can be utilized for information storing.

Curvature influences skyrmion dynamics. The spectrum of the linear magnon excitations of the skyrmion pinned on the bump is significantly modified because of the curvature [4,5]. Due to translation symmetry breaking, the translational zero mode is transformed into the low-frequency gyromode which corresponds to the uniform rotation of the skyrmion center around the bump extremum point. Also, new modes with higher azimuthal symmetry can be induced by the curvature [5]. The gradient of the mean curvature plays the role of the driving force acting on the skyrmion resulting in the skyrmion drift along the curvilinear surface. The curvature-induced driving force essentially depends on skyrmion type: it is much stronger for Neel skyrmions as compared to Bloch skyrmions [6].

[1] V. Kravchuk, U. Rößler, O. Volkov, D. Sheka, J. van den Brink, D. Makarov, H. Fuchs, H. Fangohr, Yuri Gaididei, Phys. Rev. B **94**, 144402 (2016).
[2] Yuri Gaididei, V. Kravchuk, D. Sheka, Phys. Rev. Lett. **112**, 257203 (2014).
[3] V. Kravchuk, D. Sheka, O. Volkov, A. Kákay, U. Rößler, J. van den Brink, D. Makarov, Yuri Gaididei, Phys. Rev. Lett. **120**, 067201 (2018).
[4] V. Kravchuk, D. Sheka, U. Rößler, J. van den Brink, Yuri Gaididei, Phys. Rev. B **97**, 064403 (2018).
[5] A. Korniienko, A. Kákay, D. Sheka, V. Kravchuk, Phys. Rev. B **102**, 014432 (2020).
[6] K. Yershov, A. Kakay, V. Kravchuk, arXiv:2111.07349 (2021).

Well-known but unknown phenomenological theory of phase transitions

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Within the context of the general theory of phase transitions, a system treated as a continuous medium is assumed to have a ground state which can always be described in terms of the order parameter. This order parameter can have various geometrical presentations, for example, a scalar field in the case of condensed matter, a fundamental scalar field in the quantum field theory, a magnetization vector in the theory of magnetism, a second-rank tensor in the liquid crystal, etc.

To full consideration the order parameter that determines a stable state of condensed matter, we have to consider probable deformations of the field distribution, in particular, the disordered configuration of the ground state. This distribution of the order parameter can be observed experimentally and thus the theory should provide an appropriate explanation of the observed behavior of the order parameter. Today there exist many phenomenological models which claim to give a general description of the first order phase transitions and to predict spatial distributions of the order parameters before and after phase transitions. These are the well-known phenomenological models, e.g., the Landau theory of phase transitions and the gradient theory of phase transitions. Both models efficiently describe many details of phase transitions and the behavior of the order-parameter spatial distributions after the phase transition.

In this presentation take into account not only acting competing gradient of the order parameter, but also shown the possibility of the non-uniform pattern formation are shown for phase transition. The purpose of the presentation is to establish the relation between higher derivative terms in the free energy expansion and the coefficients that govern the spatial distribution of the order parameter after the first order phase transition. In such a way the standard model of phase transitions was unified with the gradient theory of phase transitions and thus a possible spatial distribution of the order parameter after phase transition was described.

We obtain an exact solution for this model, and predict experimental observation of the order parameter behavior in the case of spinodal decomposition. The proposed model has the mechanical analogy, namely the mechanical nonlinear oscillator with the coordinate-dependent mass or model with velocity-dependent elastic module.

From curvilinear magnetism to shapeable magnetoelectronics

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I had a pleasure and honor to work with Yuri Gaididei on the topic of curvature effects in magnetism, which is now emerged in a new research field known as curvilinear magnetism. Our cooperation started back in 2013 with a visit of Prof. Gaididei and his team to the Leibniz Institute for Solid State and Materials Research Dresden. The outcome of numerous discussions, which we had during that visit, was the foundational work on the description of curvature effects in magnetic thin films [1]. This work pushed the understanding of the experimental data to the qualitatively new level and predicted numerous effects stemming from the geometry induced anisotropic and chiral interactions. In my talk, I will discuss the experimental realisations of geometrically curved low-dimensional architectures and their characterization, which among others resulted in the experimental confirmation of the geometrically induced chiral effects [2] predicted by Yuri Gaididei. Geometrically curved magnetic thin films are interesting not only fundamentally. They are the key component of mechanically flexible magnetic field sensors. I will briefly outline our activities on the so-called shapeable magnetoelectronics, which includes flexible, stretchable and printable magnetic field sensors for the realisation of human-machine interfaces [3,4], interactive electronics for virtual [5] and augmented [6] reality applications and soft robotics [7] to mention just a few. The presence of the geometrical curvature in a magnetic thin film influences pinning of magnetic domain walls and in this respect it affects the sensitivity of mechanically flexible magnetic field sensors. This is an intimate link between the fundamental topic of curvilinear magnetism and application-oriented activities on shapeable magnetoelectornics. This link will be discussed in the presentation as well.

[1] Y. Gaididei et al., *“Curvature Effects in Thin Magnetic Shells”*, Physical Review Letters **112**, 257203 (2014).
[2] O. Volkov et al., *“Experimental observation of exchange-driven chiral effects in curvilinear magnetism”*, Physical Review Letters **123**, 077201 (2019).
[3] P. Makushko et al., *“Flexible Magnetoreceptor with Tunable Intrinsic Logic for On-Skin Skin Touchless Human-Machine Interfaces”*, Advanced Functional Materials **31**, 2101089 (2021).
[4] J. Ge et al., *“A bimodal soft electronic skin for tactile and touchless interaction in real time”*, Nature Communications **10**, 4405 (2019).
[5] G. S. Canon Bermudez et al., *“Electronic-skin compasses for geomagnetic field driven artificial magnetoception and interactive electronics”*, Nature Electronics **1**, 589 (2018).
[6] G. S. Canon Bermudez et al., *“Magnetosensitive e-skins with directional perception for augmented reality”*, Science Advances **4**, eaao2623 (2018).
[7] M. Ha et al., *“Reconfigurable Magnetic Origami Actuators with On-Board Sensing for Guided Assembly”*, Advanced Materials **33**, 2008751 (2021).

Soliton dynamics in a novel nonlinear spinor model with external fields

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We consider a novel nonlinear model for Dirac spinors recently introduced by Alexeeva et al (Ann. Phys., NY 403 198), which admits an exact explicit solitary-wave (soliton for short) solution. The charge, the momentum, and the energy of this solution are conserved. We investigate the dynamics of the soliton subjected to several potentials: a ramp, a harmonic, and a periodic potential. We develop a collective coordinates (CCs) theory by making an ansatz for a moving soliton where the position, rapidity, and momentum are functions of time.We insert the ansatz into the Lagrangian density of the model, integrate over space and obtain a Lagrangian as a function of the CCs. This Lagrangian differs only in the charge and mass with the Lagrangian of a CCs theory for the Gross–Neveu equation. Thus the soliton dynamics in the novel spinor model is qualitatively the same as in the Gross–Neveu equation, but quantitatively it differs.These results of the CCs theory are confirmed by simulations, i.e. by numerical solutions for solitons of the novel spinor model, subjected to the above potentials.

Tunnelling magnons as coherent energy carriers through a ferromagnetic chain

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The efficiency of energy transfer from one ferromagnet to another has been studied within the framework of the spin excitation (magnon) transfer model [1] in the nanoscale structure "ferromagnet-wire-ferromagnet", where the wire is a ferromagnetic chain. The mechanism of non-dissipative coherent transfer is considered when the magnon energy in the chain differs from the spin excitation energy in ferromagnetic contacts. At the same time, the indicated energy difference in absolute magnitude exceeds the broadening of the magnon's energy levels caused by the interaction of the terminal atoms of the chain with the surface atoms of ferromagnetic contacts.

It is assumed that the temperatures are such that magnons can be considered as a gas of quasiparticles obeying Bose statistics. This made it possible to obtain expressions for the power of the transferred energy under conditions when there is a difference in the temperatures of ferromagnetic contacts. Despite the exponential decrease in the power of energy transfer with increasing chain length, the mechanism of coherent magnon transfer remains effective at the nanoscale up to 10 structural units of the chain. It is shown how the relationship between the parameters (exchange interactions between paramagnetic ions, one-ionic anisotropy) affects the tunneling of magnons and how the magnetic field controls this tunneling [2].

The use of uncharge elementary excitations as information carriers opens up wide possibilities for quantum communication. One of the ways may be related to magnons.

[1] E.G.Petrov and V. Ostrovsky, Low Temp. Phys. **36**, 761 (2010).
[2] E.G. Petrov, Low Temp. Phys. **46**, 991 (2020).

Exchange and anisotropy-driven effects in antiferromagnetic spin chains

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Antiferromagnets (AFMs) represent a class of materials with complex magnetic subsystem involving more than one ferromagnetically ordered sublattice. Such properties as high resonance frequencies in THz range, negligible net magnetic moment and respective weak stray fields, strong spin-orbit interaction make them promising for applications. The field of curvilinear magnetism offers additional degrees of freedom to tailor chiral and anisotropic responses of magnets and is well-established for ferromagnetic materials. Curvilinear AFMs possess additional features, important for for spintronic and spin-orbitronic applications [1].

The simplest curvilinear AFM is a spin chain arranged along flat or space curve. This geometry is characterized by the scalar functions of curvature K(s) and torsion T(s) with s being a coordinate along the curve. In the absence of intrinsic anisotropy, the dipolar interaction renders the tangential direction as the hard axis of the anisotropy [2]. Competition of this geometry-tracking interaction with the nearest-neighbor exchange leads to the emergence of additional anisotropic and chiral energy terms, whose coefficients are determined by K and T only. The geometry-driven anisotropic term brings about the easy axis determining direction of the order parameter within the dipole-driven easy-plane. The geometry-driven inhomogeneous Dzyaloshinskii-Moriya interaction (DMI) renders the curvilinear spin chain as a chiral helimagnet. For example, the spin chain along the helix with the given radius and pitch possesses one of two magnetic states depending on the geometrical parameters. For a dominating curvature K, the ground state is the homogeneous in the local reference frame, while for the dominating torsion T, the ground state is helicoidal. In contrast to ferromagnetic nanowires [3], there is no critical curvature, separating the ground states in the limiting case of small torsion. This reflects the presence of the only one ground state along the binormal direction for the spin chains along the flat curves [2].

The local variation of the anisotropy axis can result in the non-collinearity of the neighboring spins in curvilinear chains. 1D AFMs exhibit the parity-breaking effect, which forbids to exchange sublattices once they are selected. This leads to the emergent magnetization at non-collinear AFM textures [4]. Therefore, in any spin chain arranged along the space curve, there is a weak ferromagnetism proportional to the curvature and torsion of the curve [5].

In the presence of strong intrinsic anisotropy in AFM spin chain with the anisotropy axis following the tangential direction, one can observe the effects of geometry proportional to the anisotropy constant and curvature K [5]. Both models of the single- and inter-ion anisotropies lead to the tilt of the anisotropy axes, which is pronounced in the spin-flop phase. In addition, the single-ion anisotropy leads to the emergence of the additional anisotropic term of the homogeneous DMI symmetry. The latter is described by the tensor product of the ferro- and antiferromagnetic order parameters, which scales with K.

[1] V. Baltz, A. Manchon, M. Tsoi et al, Rev. Mod. Phys. Vol. 90, P. 015005 (2018); H. Yan, Z. Feng, P. Qin et al, Avd. Mat. Vol. 32, P. 1905603 (2020); D. D. Sheka, Appl. Phys. Lett. Vol. 118, P. 230502 (2021).
[2] O. V. Pylypovskyi, D. Y. Kononenko, K. V. Yershov et al, Nano Lett. Vol. 20, P. 8157 (2020).
[3] D. D. Sheka, V. P. Kravchuk, K. V. Yershov, Y. Gaididei, Phys. Rev. B Vol. 92, P. 054417 (2015).
[4] N. Papanicolaou, Phys. Rev. B Vol. 51, P. 15062 (1995); E. G. Tveten, T. Mueller, J. Linder et al, Phys. Rev. B Vol. 93, P. 104408 (2016).
[5] O. V. Pylypovskyi, Y. A. Borysenko, J. Fassbender et al, Appl. Phys. Lett., Vol. 118, P. 182405 (2021).

Localization dynamics in the framework of the generalized two-dimensional nonlinear Schrödinger equation

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The dynamics of two-dimensional excitations in various media described by the generalized discrete two-dimensional nonlinear Schrödinger equation (DNLS) will be discussed. This includes the localization dynamics of discrete structures and their stability for the DNLS in various forms. The results, which includes detailed analytical investigations combined with full numerical simulations, are described in the key references below, which are based on the very fruitful collaborations with Yuri Gaididei.

[1] Christiansen, P. L., Gadidei, Yu.B., Rasmussen, K.Ø., Mezentsev, V.K., and Rasmussen, J. Juul. Dynamics in discrete two-dimensional nonlinear Schrödinger equations in the presence of point defects. Phys. Rev. B (1996), **54,** 900-912.

[2] Christiansen, P. L., Gadidei, Yu.B., Johannesen, M, Rasmussen, K.Ø., Mezentsev, V.K., and Rasmussen, J. Juul. Solitary excitations in discrete two-dimensional nonlinear Schrödinger models with dispersive dipole-dipole interactions. Phys. Rev. B (1998), 57**,** 11303-11318.

Hopfions in Anisotropic Heisenberg Magnets

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We find exact static soliton solutions for the unit spin vector field of an inhomogeneous, anisotropic three-dimensional (3D) Heisenberg ferromagnet. Using Whitehead's integral expression, we calculate the corresponding Hopf invariant H analytically and obtain an integer, showing that these solitons are Hopfions. H is a product of two integers, the first being the usual winding number of a baby Skyrmion in two dimensions, while the second encodes the periodicity in the third dimension. We study the underlying geometry of H, by mapping the 3D unit vector field to tangent vectors of three appropriately defined space curves. Our analysis shows that a certain intrinsic twist is necessary to yield a nontrivial topological invariant. We illustrate our results using the invariant H of the exact Hopfions we have found.

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Nanomagnetism work of Yuri Gaididei

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In this talk, I will sketch the seminal contribution of Yuri Gaididei to two fields of magnetism: nonlinear dynamics of magnetic vortices in nanomagnets and curvilinear magnetism. The story of the RiTM-team, which unite several theoreticians and young students, will be also presented.

Nonlinear sine-Gordon soliton waves and acoustic shock waves

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During the many years of collaboration with Yuri Gaididei a rather broad spectrum of problems had been investigated. Gaididei's broad interest and deep knowledge were great inspiration for our research in the nonlinear dynamics group at the Technical University of Denmark. In the current presentation this is illustrated by our joint work on sine-Gordon magnetic fluxons in curved Josephson junctions [1] and acoustic shock waves [2]. Focus is on approximate analytical results for sine-Gordon kink solitons and acoustic shock waves combined with numerical simulations. Pattern similarities between oscillating shocks and oscillating Josephson fluxons are discussed.

[1] Gorria, C., Gaididei, Y. B., Sørensen, M. P., Christiansen, P. L., and Caputo, J. G. (2004). Kink propagation and trapping in a two-dimensional curved Josephson junction. *Physical Review B*, *69*(13), 134506.

[2] Gaididei, Y., Rasmussen, A. R., Christiansen, P. L., and Sørensen, M. P. (2016). Oscillating nonlinear acoustic shock waves. *Evolution Equations & Control Theory*, *5*(3), 367.

The possible role of hydrogen peroxide molecules in ion beam therapy of cancer cells

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To date one of the most promising treatments of cancer diseases is radiation therapy. In this approach the tumor is irradiated with a beam of particles (protons, electrons, neutrons, ions, etc.), which leads to its destruction. Irradiation with protons and heavy ions is the most effective, since these particles passing through a medium loses most of its energy in a certain small area inside the body (at so-called Bragg peak). Thus, there is the possibility of precise alignment of the beam energy peak with the position of cancerous tumor and to transfer most of the beam energy directly to the tumor, minimally damaging adjacent healthy tissue. The approach of ion therapy is now considered an effective and safe method for cancer treatment. But the processes of the deactivation of cancer cells during ion therapy are still poorly understood.

In the presented work the possible mechanisms of action of hydrogen peroxide molecules on DNA activity in the biological cell are studied. Using quantum-mechanical approach the competitive interactions of water and hydrogen peroxide molecules with DNA recognition sites have been analyzed and the advantage of hydrogen peroxide molecules in the formation of complexes with DNA nucleic bases is shown. Considering the complexes of DNA nucleic bases with peroxide, or with water molecules, it was taken into account that at least two hydrogen bonds are necessary for the formation of such stable complexes.

The estimation of lifetimes of the complexes of peroxide molecules with DNA atomic groups allow formulating the hypothesis about the mechanism of blocking of DNA genetic activity in cancer cells by hydrogen peroxide molecules. As follows from the analysis of obtained theoretical and known experimental data, a sufficiently large number of hydrogen peroxide molecules can be formed. These molecules compete with water molecules for interaction with DNA sites and can form long-lived molecular complexes with nucleic bases of the macromolecule.

The results of our calculation show that the coupling energy between DNA atomic groups and hydrogen peroxides are always more than the same energy for the interaction of DNA sites with water molecules. So, the value of lifetime for the complex of a guanine base with water molecules can be more than in **50** times longer than with water, and with an adenine base - more than in **30** times. Thus, hydrogen peroxide molecules due to formation of stable complexes with DNA atomic groups, can block the processes of genetic activity of DNA macromolecule as a whole.

Current-induced magnetization superlattices in nanomagnets

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Appearance of periodic superlattices in the spatial distribution of the order parameter is ubiquitous in condensed matter physics and could be found in type II superconductors [1], in superfluidic helium [2] and Bose-Einstein condensates [3]. In particular in magnetism, such periodic superlattices appear usually in magnetic material with the inversion symmetry breaking, which induces noncolinear chiral magnetic textures, e.g. skyrmions [4-6] and skyrmions bubbles [7]. In the case of conventional thin-film soft ferromagnetic materials, the long-range magnetostatic and the short-range exchange interactions induce the appearance of closed-flux magnetic textures, which resemble a confined sample geometry [8]. Namely, in disk-shape geometries appear magnetic vortex states with the localized out-of-plane component and delocalized in-plane part [9]. One of the most prominent ways to control the behaviour of magnetic vortices is the utilization of spin-polarized current, which flows through the magnetic nanolayer. In line with the predictions of Slonczewski [10] and Berger [11] the spin-polarized current acts as an additional spin torque, which effectively excites the circular motion of the vortex core with the subsequent switching [12]. Here, we show numerically that for the specific range of current densities in magnetic nanodisk could be obtained stable vortex-antivortex structures of various symmetry and structure [13]. Moreover, we prove theoretically the possibility to induce such superlattices in ordinary isotropic magnetic films and build the full theory of its saturation under the action of a transverse spin-polarized current [14]. In particular, we show that loss of stability of the saturated state leads to the appearance of stable square vortex crystals.

References:

[1] A. A. Abrikosov, Rev. Mod. Phys. 76, 975 (2004).
[2] R. J. Donnelly, Quantized Vortices in Helium II, Cambridge Studies in Low Temperature Physics, Vol. 3 (Cambridge University Press, Cambridge, 1991), p. 346.
[3] A. L. Fetter, Rev. Mod. Phys. 81, 647 (2009).
[4] A. Fert, N. Reyren, and V. Cros, Nat. Rev. Mater. 2, 17031 (2017).
[5] N. Nagaosa and Y. Tokura, Nat. Nanotechnol. 8, 899 (2013).
[6] W. Legrand, D. Maccariello, N. Reyren, K. Garcia, C. Moutafis, C. Moreau-Luchaire, S. Collin, K. Bouzehouane, V. Cros and A. Fert, Nano Lett. 17, 2703 (2017).
[7] W. Jiang, P. Upadhyaya, W. Zhang, G. Yu, M. B. Jungfleisch, F. Y. Fradin, J. E. Pearson, Y. Tserkovnyak, K. L. Wang, O. Heinonen, S. G. E. te Velthuis, and A. Hoffmann, Science 349, 283 (2015).
[8] A. Hubert and R. Schäfer, Magnetic domains: The analysis of magnetic microstructures, Springer Berlin Heidelberg (2009).
[9] N. A. Usov and S. E. Peschany, J. Magn. Magn. Mater. 118, L290 (1993).
[10] J. C. Slonczewski, J. Magn. Magn. Mater. 159, L1 (1996).
[11] L. Berger, Phys. Rev. B 54, 9353 (1996).
[12] V. S. Pribiag, I. N. Krivorotov, G. D. Fuchs, P. M. Braganca, O. Ozatay, J. C. Sankey, D. C. Ralph, and R. A. Buhrman, Nat. Phys. 3, 498 (2007).
[13] O. M. Volkov, V. P. Kravchuk, D. D. Sheka and Y. Gaididei, Phys. Rev. B 84, 052404 (2011).
[14] Y. Gaididei, O. M. Volkov, V. P. Kravchuk and D. D. Sheka, Phys. Rev. B 86, 144401 (2012).

Curvature-induced effects in one-dimensional magnetic wires

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The interaction of curvature and topologically nontrivial magnetization structures, e.g. domain walls (DW), attracts growing interest in fundamental studies and applications. For the one-dimensional magnetic systems nontrivial geometry results in novel effects, including pinning of transversal DWs on a localized curvature of the nanowire [1]; motion of transversal DWs in wires without external stimuli, i.e. gradient of the curvature results in a driving force [2]; appearance of curvature-induced Walker limit in a uniaxial wires [3]; torsion-induced negative DW mobility in he-lices [3]; and DW motion in helix wires relying on the Rashba effect even in the case of the parallel charge current injection [4]. On the other hand, soft condensed matter systems such as membranes and wires are of great importance both in biological context and in industrial applications.

Basic models for description of nanoscaled magnetoelastic system include two sub-systems: the precession Landau-Lifshitz dynamics of magnetic subsystem is coupled with the Newtonian dynamics of elastic substrate. The development of this approach for a Heisenberg magnet on elastic membranes and wires resulted in novel effects, including magnetization induced deformation of ferromagnetic ring [5], periodic shrinking of the membrane due to soliton-soliton interaction [6], the curvature-induced geometrical frustration in magnetic systems [7], and deformations of ferromagnetic ribbons induced by Dzialoshinskii-Moria interaction [8].

[1] K. V. Yershov, V. P. Kravchuk, D. D. Sheka, Yu. Gaididei, PRB **92**, 104412, (2015).
[2] K. V. Yershov, V. P. Kravchuk, D. D. Sheka, O. V. Pylypovskyi, D. Makarov, Yu. Gaididei, PRB **98**, 060409(R), (2018).
[3] K. V. Yershov, V. P. Kravchuk, D. D. Sheka, Yu. Gaididei, PRB **93**, 094418, (2016).
[4] O. V. Pylypovskyi, D. D. Sheka, V. P. Kravchuk, D. D, K. V. Yershov, D. Makarov, Yu. Gaididei, Sci Rep **6**, 23316, (2016).
[5] Yu. Gaididei, K. V. Yershov, D. D. Sheka, V. P. Kravchuk, A. Saxena, PRB **99**, 014404, (2019).
[6] R. Dandoloff, S. Villain-Guillot, A. Saxena, A. R. Bishop, PRL. **74**, 813 (1995).
[7] A. Saxena, R. Dandolo, T. Lookman, Physica A 261, **13** (1998).
[8] K. V. Yershov, V. P. Kravchuk, D. D. Sheka, J. van den Brink, Yu. Gaididei, PRB **100**, 140407(R) (2019).

Existence of a bound state for the $\gamma\delta'(x)$ potential

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We consider in the limit that neglects the interactions between electrons, the one-dimensional stationary Schrödinger equation

$$-\psi''(x) + \gamma\delta'(x)\psi(x) = E\psi(x), \quad \gamma \in \mathbb{R}, \tag{1}$$

where the prime denotes the differentiation with respect to the spatial coordinate x, $\psi(x)$ is the wave function, $\delta'(x)$ the derivative of Dirac's delta function, γ a strength constant, and $E = -\kappa^2$ negative energy. The bound state κ is defined by the asymptotic relations $\psi(\pm\infty) \sim \exp(-\kappa|x|)$.

It is common knowledge that equation (1) has no finite bound states κ. The standard statement is that all the bound state energy levels for a regularized potential escape to $-\infty$ under the convergence to $\delta'(x)$. However, in general this is not true and this can be demonstrated on a simple example of regularizing the $\delta'(x)$ distribution.

Thus, let us consider the most simple regularization of $\delta'(x)$ by a piecewise constant function

$$\Delta'_{lr}(x) := \frac{1}{l(l+r)} \begin{cases} 1 & \text{for} \quad -l - r/2 < x < -r/2, \\ -1 & \text{for} \quad r/2 < x < l + r/2, \\ 0 & \text{otherwise.} \end{cases} \tag{2}$$

In the particular case $r = 0$, we have the same model studied by Yuri Gaididei with coworkers [1], where the scattering coefficients have been computed under the following constraint on γ:

$$\tan\sqrt{|\gamma|} = \tanh\sqrt{|\gamma|}\,. \tag{3}$$

The countable family of the solutions to this equation is called a *resonance set.*

For the analysis of negative-energy solutions of equation (1), we investigate the squeezing limit $\Delta'_{lr}(x) \to \delta'(x)$ as both the parameters l and r tend to zero simultaneously. This is a *two-scale* convergence scheme and therefore there exists a whole *pencil* of paths on the (l, r)-plane approaching the origin, including the repeated limits: $\lim_{r\to 0}\lim_{l\to 0} \Delta'_{lr} = \lim_{l\to 0}\lim_{r\to 0} \Delta'_{lr} = \delta'(x)$.

For finding the bound state levels κ of potential (2), we use the equation $\lambda_{12}\kappa^2 + (\lambda_{11} + \lambda_{22})\kappa + \lambda_{21} = 0$ [2], where λ_{ij} are the elements of the transmission matrix that connects the values of the wave function $\psi(x)$ and its derivative $\psi'(x)$ at $x = \pm(l + r/2)$:

$$\begin{pmatrix} \psi(l + r/2) \\ \psi'(l + r/2) \end{pmatrix} = \begin{pmatrix} \lambda_{11} & \lambda_{12} \\ \lambda_{21} & \lambda_{22} \end{pmatrix} \begin{pmatrix} \psi(-l - r/2) \\ \psi'(-l - r/2) \end{pmatrix}.$$

In general, the elements λ_{ij} depend on κ, and due to the piecewise constant shape of potential (2), they can be calculated explicitly. In the squeezing limit, the κ-dependence of these elements disappears and $\lambda_{12} \to 0$. As a result, we obtain the asymptotic representation

$$\kappa \simeq \frac{r}{l(l+r)}|\gamma|\tanh^2\sqrt{\frac{l}{l+r}|\gamma|}\,, \tag{4}$$

valid only on the same resonance set as for the existence of scattering coefficients and given by equation (3). It follows from (4) that the level κ will be finite if the convergence to the origin on the (l, r)-plane occurs along the paths $r = cl^2$, where c is an arbitrary constant.

Thus, under constraint (3) on γ, the bound state level for the $\gamma\delta'(x)$ potential is $\kappa = c|\gamma|\tanh^2\sqrt{|\gamma|}$ if the convergence $(l, r) \to 0$ is implemented along the paths $r = cl^2$. More general piecewise constant regularizations than (2) have been considered in publications [3] and [4]. Here, the corresponding resonance sets are found, on which the highest energy level is 'pinned', while all the lowest levels escape to $-\infty$.

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[1] Christiansen P L, Arnbak N C, Zolotaryuk A V, Ermakov V N and Gaididei Y B 2003 *J. Phys. A: Math. Gen.* **36** 7589
[2] Zolotaryuk A V and Zolotaryuk Y 2014 *Int. J. Mod. Phys. B* **28** 1350203
[3] Zolotaryuk A V and Zolotaryuk Y 2020 *Low Temperature Phys.* 2020 **46** 927
[4] Zolotaryuk A V and Zolotaryuk Y 2021 *J. Phys. A: Math. Theor.* **54** 035201