Faculty of Physics, Adam Mickiewicz University, Poznań
Institute of Molecular Physics, Polish Academy of Sciences

The European Conference

PHYSICS OF MAGNETISM 2023

June 26-30, 2023, Poznań, Poland

ABSTRACTS

Poznań, 2023

Faculty of Physics, Adam Mickiewicz University, Poznań
Institute of Molecular Physics, Polish Academy of Sciences

The European Conference

PHYSICS OF MAGNETISM 2023 (PM'23)

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Abstracts

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The European Conference

PHYSICS OF MAGNETISM 2023

June 26-30, 2023
Poznań, Poland

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IN MEMORIAM

1947 - 2022

Professor Roman Micnas, one of the most distinguished scholars of Adam Mickiewicz University, Poznań, and a well-recognized international scientific authority. Main organizer and co-chairman of the series of meetings "The European Conference PHYSICS OF MAGNETISM" between 1993 and 2021.

Roman Micnas was born on November 4, 1947 in Nowice, Poland, and died on January 13, 2022 in Poznań, aged 74. He graduated from the Faculty of Mathematics, Physics and Chemistry, Adam Mickiewicz University in 1970. In 1978 he defended his PhD thesis entitled *"The Influence of Crystal Fields on Collective Magnetic Excitations in Systems of Rare Earth Ions"*, under the supervision of Prof. Leon Kowalewski. This work, in the opinion of the thesis committee, contained original scientific achievements at the level of habilitation theses and was awarded an *individual prize by the Minister of Science, Higher Education and Technology.*

At that time his scientific interests were focused on the study of phase transitions and critical phenomena in electron and spin systems, the theory of electron systems with strong electron correlations and the theory of superconductivity. He developed functional integration methods to study classical and quantum spin models. He used the Mori-Zwanzig technique in generalized Green's function theory to study systems with multilevel energy structure in anisotropic magnets, systems with quadrupole couplings, the Hubbard model, as well as to analyze impurity conduction in semiconductors. He developed the theory of so-called quantum critical phenomena in the presence of random magnetic fields using the renormalization group method and obtained a number of interesting results, e.g., novel dimensional dependence of critical exponents in quantum spin models, band magnets and quantum ferroelectrics.

In his subsequent publications, Dr. Roman Micnas presented the results of studies of the influence of structural disorder on electron ordering and superconductivity in narrow band systems. In these works, phase diagrams of the Hubbard model with structural disorder were developed and the influence of random magnetic fields on first order phase transitions and multi-critical phenomena in equivalent pseudospin models was investigated.

The results of this research constituted the basis of his habilitation thesis entitled: *"Study of phase transitions and critical phenomena of electron and spin systems incorporating quantum and disorder effects"*, which he submitted in 1986. Dr. Roman Micnas received his habilitation degree (dr hab.) in 1988. The scientific achievements presented in the habilitation dissertation were deemed to be of such a rank as to subsequently justify the commencement of proceedings for the conferment of the title of Professor. And indeed, in May 1990 he was awarded the scientific title of Professor of the Physical Sciences. At that time he took up the position of Associate Professor (Professor Extraordinarius), and in 1996 that of Full Professor (Professor Ordinarius) at our University.

In the years 1980 -1987, R. Micnas and S. Robaszkiewicz in collaboration with K. A. Chao (University of Linköping, Sweden) and J. Ranninger (CNRS – Grenoble, France) developed the foundations of the theory of superconductivity and charge ordering in narrow band systems with local attractive interactions, including the model of superconductivity of local pairs and the boson-fermion model. These published works were pioneering in many aspects. The theory of coexisting local pairs (bipolarons) and itinerant electrons, developed by R. Micnas, J. Ranninger and S. Robaszkiewicz, showed the possibility of the occurrence of a completely new kind of superconductivity, viz. of the charge exchange type in materials in which local electron pairing occurs. This work was actually submitted for publication before the experimental discovery of high temperature superconductivity in 1986. Since then, Prof. Roman Micnas and his collaborators continued very intensive research on various mechanisms of superconductivity and the resulting published papers gained wide international resonance.

Prof. Roman Micnas, together with J. Ranninger and S. Robaszkiewicz, were invited by the editors of the renowned American scientific journal *Review of Modern Physics* to write an extensive review article summarizing the current state of the theory of electron systems with local pairing interactions, which was published in 1990: *Superconductivity in narrow-band systems with local nonretarded attractive interactions*, Rev. Mod. Phys. 61, 113 (1990).

Professors Roman Micnas and Stanislaw Robaszkiewicz received the Maria Sklodowska-Curie Scientific Award of the Polish Academy of Sciences in 1989 for their work on the theory of superconducting systems with local electron pairing.

At the Faculty of Physics, Adam Mickiewicz University, Prof. Roman Micnas headed the Doctoral Studies Programme from 1991 to 2002 and was vice-dean for scientific affairs during the 1999-2002 term. In the subsequent terms from 2005 to 2012, he was a member of the Senate of the Adam Mickiewicz University, where he was part of the Senate Committee for Development. From 1998 until his retirement in 2018 he was the head of the Department of Solid State Theory (which has since been transformed into the Department of Condensed Matter Theory).

During his scientific career, Prof. Roman Micnas published over 140 scientific articles mainly in foreign scientific journals and presented over 50 communications at international and national scientific conferences. These works are widely recognized around the world and so far have been cited about 3300 times by other authors. He presented the results of his scientific achievements at numerous international and national conferences, international schools of theoretical physics and symposia on high temperature superconductivity, magnetism, many-body systems physics and electron correlations. He had a total of over 60 invited lectures at, among others, the International Conference on Magnetism in Paris, conferences in Les Houches and thrice at the E. Majorana Center (Erice, Sicily), in Switzerland, France, the Netherlands, USA, China, the NATO Conference in Greece as well as in Poland – e.g. a plenary lecture at the *Jubilee XXXIII Congress of Polish Physicists*. In addition, he presented the results of his research at over 40 seminars and departmental colloquia at leading scientific institutions in Europe and the USA. He gave 5 series of lectures abroad, in Sweden (University of Linköping, 1978), Brazil (1980) and in France (Grenoble, 1987).

Prof. Roman Micnas co-organised 35 international and national scientific conferences and schools of theoretical physics. Since 1993 he co-chaired the European Conference *"Physics of Magnetism"* held every three years in Poznań, in 1993, 1996, 1999, 2002, 2005, 2008, 2011, 2014, 2017, and in 2021 due to Covid pandemic delayed one year and in online form. It was thanks to his untiring work, personal charm and prestige that the conference became a first rank event, one of the largest conference of its kind in Poland, and attracted hundreds of specialists from every continent, including Nobel Prize winners.

Closing ceremony of The European Conference Physics of Magnetism 2017. From right: Prof. Roman Micnas, Prof. Bogdan Idzikowski (chairmen), and Prof. Andrzej Szajek (conference secretary).

He received many awards for his achievements. In the years 2003-2006 he was a beneficiary of the Professorial Grant programme "Master" of the *Foundation for Polish Science*. Six candidates obtained their Ph. D. degrees under the supervision of Prof. Roman Micnas. He directed 10 research grants. Prof. Roman Micnas conducted research centered around the most important and frontier topics of condensed matter physics. Apart from the earlier mentioned directions, he also conducted research on models of many body physics describing ultracold quantum, fermionic or bosonic atomic gases trapped in optical lattices.

Professor Roman Micnas was one of the most outstanding scholars of Adam Mickiewicz University. A person endowed with extraordinary talent and enormous diligence, organizer and promoter of physics, in particular physics of magnetism, an internationally recognized scientific authority with extensive and profound scientific knowledge in theoretical condensed phase physics, the theory of many-body systems and statistical physics. His scientific output will remain for years in the educational canon of every scientist conducting research in these fields.

Tomasz Kostyrko and PM'23 chairmen

1932 - 2022

Professor Janusz Andrzej Morkowski, was the founder, together with Prof. Bogdan Fechner, of the first Physics of Magnetism Conference in 1975 and the co-chairman of its first six editions. He was also the organizer and chairman of many international conferences, schools and workshops, including International Conference on Magnetism (ICM) in 1993 in Warsaw, Poland.
Prof. Morkowski was also a person of tremendous importance to the history of the Institute of Molecular Physics of the Polish Academy of Sciences (IMP PAS). He joined the nascent Institute in 1956, shortly after its foundation, and in time he became the head of the Department of Ferromagnetics and the Director of the Institute (1985-1991). He was a long-time member of IMP PAS Scientific Council and also serving as its vice-chairman (1984-86) and chairman (1999-2002).
He was the pioneer of theoretical studies on ferromagnetism in Poland and will remain in our memory forever as a scientist with extensive knowledge, internationally recognized achievements and great authority.

PM'23 chairmen

SCHEDULE

Monday, June 26, 2023

10^{00} - 10^{20} **Opening**
Maciej Krawczyk, Tomasz Toliński, Bogdan Idzikowski

Opening Lecture
Chairmen: Maciej Krawczyk, Tomasz Toliński, Bogdan Idzikowski

10^{20} - 11^{00} **J. Michael D. Coey**
School of Physics, Trinity College Dublin
Dublin, Ireland
Ferrimagnetic Spintronics

Plenary session I

11^{00} - 11^{30} **Andreas J. Heinrich**
Center for Quantum Nanoscience (QNS), Institute for Basic Science (IBS) & Department of Physics, Ewha Womans University
Seoul, South Korea
Towards Quantum Computing with Spins on Surfaces

11^{30} - 12^{00} **Sebastiaan van Dijken**
Department of Applied Physics, Aalto University, Aalto, Finland
Solid-State Lithium-Ion Battery and Supercapacitor Structures for Voltage Control of Magnetism

12^{00} - 12^{30} **Mari Carmen Bañuls**
Max Planck Institute of Quantum Optics, Garching, Germany
Accessing finite energy density with tensor networks and quantum devices

12^{30} - 13^{00} **Itziar Oyarzabal Epelde**
BCMaterials, Basque Center on Materials, Applications and Nanostructures
Leioa, Spain
When chemistry meets physics: high-performance molecule-based magnets

13^{00} - 14^{15} lunch break

14^{15} - 16^{00} **ORAL SESSION I**

(Session A)

Johannes Richter (O-2-01), Piotr Kozłowski (O-2-02), Gael Bastien (O-2-04), Maciej Maśka (O-2-05), Ross H Colman (O-2-08), Dara Marin (O-2-10), Konrad Puzniak (O-2-11)

(Session B)

Stanisław Baran (O-3-16), Krzysztof Sobucki (O-3-18), Monika Oboz (O-3-19), Wojciech Rudziński (O-3-26), Michał Rams (O-3-27), Thi Thu Ha Nguyen (O-3-28), Mirali Jafari (O-3-29)

16^{00} - 16^{15} short break

Monday, June 26, 2023

PLENARY SESSION II

16^{15} - 16^{45} **Bella Lake**
Helmholtz-Zentrum Berlin fur Materialien und Energie
& Institut für Festkorperphysik, Technische Universitat Berlin,
Berlin, Germany
Excitations of the antiferromagnetic XXZ spin-1/2 spin chain - spinons and Bethe strings

16^{45} - 17^{15} **Andrii Chumak**
Faculty of Physics, University of Vienna
Vienna, Austria
Magnon transport in YIG/GGG at millikelvin temperatures

17^{15} - 17^{45} **Andrzej Szewczyk**
Institute of Physics, Polish Academy of Sciences
Warsaw, Poland
Quantum and classical aspects of a low-temperature ($\sim$500 mK) magnetic phase transition in aluminoborates

17^{45} - 18^{15} **Manuel Bibes**
Unité Mixte de Physique CNRS/Thales, Université Paris-Saclay
Palaiseau, France
Ferroelectric and multiferroic two-dimensional electron gases for oxide spin-orbitronics

18^{15} - 18^{30} coffee break

18^{30} - 20^{00} **ORAL SESSION II**

(Session A)

Andrzej Szytuła (O-3-17), Krzysztof Szulc (O-3-14),
Andrzej Janutka (O-3-21), Jarosław W. Kłos (O-3-22),
Mateusz Zelent (O-3-23), Gabriel D. Chaves-O'Flynn (O-3-25)

(Session B)

Bohdana Blyzniuk (O-5-06), Emil Siuda (O-5-08),
Jan Barański (O-5-11), Daniel Kiphart (O-5-14),
Silvia Gallego (O-5-15), Anuj Kumar Dhiman (O-5-16)

20^{15} - ... welcome party

Tuesday, June 27, 2023

PLENARY SESSION III

8^{30} - 9^{00} **Dirk Grundler**
Laboratory of Nanoscale Magnetic Materials and Magnonics, Institute of Materials, EPFL & Institute of Electrical and Micro Engineering, EPFL Lausanne, Switzerland
Magnon Induced Reversal, Steering, and Interference in Ferromagnet/Ferrimagnet Hybrid Structures

9^{00} - 9^{30} **Fèlix Casanova**
CIC nanoGUNE BRTA, San Sebastian, Basque Country (Spain) & IKERBASQUE, Basque Foundation for Science, Bilbao, Basque Country (Spain)
Spintronics with low-dimensional materials

9^{30} - 10^{00} **Peter Oppeneer**
Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden
A first-principles approach to orbital accumulation and orbital transport

10^{00} - 10^{30} **Vitalii Zablotskii**
Institute of Physics, Czech Academy of Sciences, Prague, Czech Republic
Toward Magnetogenetics: Effects of Magnetic Fields on Living Cells

10^{30} - 11^{00} coffee break

11^{00} - 12^{45} **POSTER SESSION I**

Categories 1, 3, 5

plus P-6-02, P-6-03

12^{45} - 14^{00} lunch break

14^{00} - 16^{15} **ORAL SESSION III**

(Session A)

J. Micheal D. Coey (O-7-01), Adam Rycerz (O-5-18), Stefan Krompiewski (O-5-02), Kostyantyn Gusliyenko (O-5-03), Karol Szałowski (O-5-04), Andrzej Majhofer (O-5-10), Bogdan Bułka (O-5-13), Piotr Trocha (O-5-17), Fabrizio Cossu (O-5-01)

(Session B)

Karel Vyborny (O-4-03), Marta Gryglas-Borysiewicz (O-4-04), Orest Pavlosiuk (O-4-05), Piotr Graczyk (O-4-06), Karan Singh (O-4-07), Piotr Majek (O-4-12), Maciej Chrobak (O-4-13)

16^{15} - 16^{30} coffee break

Tuesday, June 27, 2023

YOUNG & BRILLIANT SESSION I

Session under the patronage of the POLISH YOUNG ACADEMY, PAS

16^{30} - 16^{50} **Marlena Dziurawiec**
Institute of Theoretical Physics, Wroclaw University of Science and Technology, Wrocław, Poland
Detecting localization in 1D lattices through strong light-matter interactions

16^{50} - 17^{10} **Mateusz Gołębiewski**
Faculty of Physics, Adam Mickiewicz University, Poznań, Poland
Gyroid Nanostructures in Magnonics

17^{10} - 17^{30} **Ankit Labh**
Charles University, Prague, Czech Republic
Field-Dependent Magnetic Ordering Dome and Quantum Spin Fluctuations in the Natural Mineral Henmilite

17^{30} - 17^{50} **Björn Niedzielski**
Institut für Physik, Martin-Luther Universität Halle-Wittenberg Halle/Saale, Germany
Magnon-Fluxon Interaction in Coupled Superconductor/Ferromagnet Hybrid Periodic Structures

17^{50} - 18^{10} **Nozomi Soya**
Department of Applied Physics and Physico-Informatics Keio University, Tokyo, Japan
Generation and transport of spin current in $SrTiO_3$-based magnetic heterostructure

18^{10} - 18^{30} **Adam Pacewicz**
Warsaw University of Technology, Institute of Radioelectronics and Multimedia Technology, Warsaw, Poland
Electrodynamic theory of resonances in gyromagnetic materials: insights and applications

Wednesday, June 28, 2023

PLENARY SESSION IV

PROF. J.A. MORKOWSKI MEMORIAL SESSION

8^{30} - 9^{15} **Józef Spałek**
Institute of Theoretical Physics, Jagiellonian University
Kraków, Poland
Strong electronic correlations, exchange and superconductivity: Theory and experiment match for the cuprates

9^{15} - 9^{45} **Daniel Agterberg**
Department of Physics, University of Wisconsin-Milwaukee
Milwaukee, WI, USA
Superconductivity with strong spin-orbit coupling: application to $CeRh_2As_2$

9^{45} - 10^{15} **Christos Panagopoulos**
Division of Physics and Applied Physics, School of Physical and Mathematical Sciences, Nanyang Technological University
Singapore
Quantum hybrids of superconductivity and magnetism via topological solitons

10^{15} - 10^{45} conference photo

10^{45} - 11^{15} coffee break

11^{15} - 13^{00} **ORAL SESSION IV**

(Session A)

Jerzy Goraus (O-3-01), Ruben Leenders (O-3-02), Ewa Młyńczak (O-3-04), Loghman Jamilpanah (O-3-05), Giuseppe Cuono (O-3-12), Adam S. Sajna (O-3-13), Jan Kisielewski (O-3-20)

(Session B)

Anna Bajorek (O-6-01), Sergiu Arapan (O-6-02), Justyn Snarski-Adamski (O-6-04), Alexander Chizhik (O-6-05), Uladzislaw Gumiennik (O-6-06), Andrzej Wiśniewski (O-6-07), Wojciech Marciniak (O-6-08)

13^{00} - 14^{15} lunch break

Wednesday, June 28, 2023

14^{15} - 16^{15} **ORAL SESSION V**

(Session A)

Marek Przybylski (O-7-02), Dariusz Kaczorowski (O-4-08), Jakub Pawlak (O-4-09), Karol Załęski (O-5-09), Mujeeb Ahmad (O-4-15), Krzysztof Ptaszyński (O-4-01), Damian Krychowski (O-4-10), Piotr Busz (O-4-11)

(Session B)

Dimitrios Papadopoulos (O-8-01), Bernadeta Dobosz (O-8-02), Shalini Badola (O-2-03), Vadim Ohanyan (O-2-09), Abhishek Pandey (O-1-04), Bincy S. Jacobs (O-1-05), Valeriia Bilokon (O-1-06), Priyanka Garg (O-4-02)

16^{15} - 16^{30} coffee break

YOUNG & BRILLIANT SESSION II

Session under the patronage of the POLISH YOUNG ACADEMY, PAS

16^{30} - 16^{50} **Anand Manaparambil**
Institute of Spintronics and Quantum Information, Adam Mickiewicz University, Poznań, Poland
Nonequilibrium Kondo effect under finite thermal bias: An accurate treatment of electronic correlations

16^{50} - 17^{10} **Jarosław Juraszek**
Institute of Low Temperature and Structure Research Polish Academy of Sciences, Wrocław, Poland
Two-band superconductivity in the prototypical heavy-fermion compound $CeCu_2Si_2$ studied by local magnetization measurements

17^{10} - 17^{30} **Aritra Sinha**
Jagiellonian University, Institute of Theoretical Physics Kraków, Poland
Wrestling with the finite temperature two dimensional Fermi-Hubbard Model: A Tensor Network Approach

17^{30} - 18^{00} transportation to the concert hall

19^{00} - ... **concert**

Thursday, June 29, 2023

PLENARY SESSION V

8^{30} - 9^{00} **Tomáš Jungwirth**
Institute of Physics, Czech Academy of Sciences
Prague, Czech Republic
Altermagnetism and spintronics without magnetization and relativity

9^{00} - 9^{30} **Witold Skowroński**
Department of Electronics, AGH University of Science and Technology
Kraków, Poland
Magnetization dynamics in magnetic heterostructures

9^{30} - 10^{00} **Roman Sobolewski**
Department of Electrical and Computer Engineering
University of Rochester, Rochester, NY, USA
Terahertz Inverse Spin Hall Effect in Spintronic Nanostructures

10^{00} - 10^{30} **Andrzej Stupakiewicz**
Faculty of Physics, University of Bialystok, Białystok, Poland
Cold ultrafast all-optical switching of magnetization

10^{30} - 11^{00} coffee break

11^{00} - 12^{45} **POSTER SESSION II**

Categories 2, 4, 6, 7, 8

excl. P-6-02, P-6-03

12^{45} - 14^{00} lunch break

14^{00} - 15^{45} **ORAL SESSION VI**

(Session A)

Marco Lo Schiavo (O-1-01), Krzysztof P. Wójcik (O-1-02), Agnieszka Cichy (O-1-03), Matus Mihalik (O-1-08), Imre Hagymási (O-1-09), Piotr Stefański (O-1-10), Ryszard J. Radwański (O-1-11)

(Session B)

Abdul Khaliq (O-3-06), Grzegorz Centała (O-3-07), Konrad J. Kapcia (O-3-08), Sana Zakar (O-3-09), Altifani Rizky Hayyu (O-3-10), Alban Simonnot (O-3-11), Bivas Rana (O-3-15)

15^{45} - 16^{15} transportation

19^{00} - ... **banquet**

Friday, June 30, 2023

PLENARY SESSION VI

8^{30} - 9^{00} **Thomas Schrefl**
Christian Doppler Laboratory for Magnet design through physics informed machine learning & University for Continuing Education Krems, Wiener Neustadt, Austria
The coercivity of permanent magnets: Insights from micromagnetics and machine learning

9^{00} - 9^{30} **Tadeusz Domański**
Faculty of Mathematics, Physics and Computer Science University of Maria Curie-Skłodowska, Lublin, Poland
Dynamical effects of correlated superconducting nanostructures

9^{30} - 10^{00} **Olena Gomonay**
Institut für Physik, Johannes Gutenberg Universität Mainz, Mainz, Germany
Gradient magnetoelasticity: tailoring of antiferromagnetic textures

10^{00} - 10^{30} **Zbigniew Śniadecki**
Institute of Molecular Physics, Polish Academy of Sciences Poznań, Poland
In search of new hard magnetic materials - an experiment supported by semi-empirical calculations

10^{30} - 11^{00} coffee break

PLENARY SESSION VII

11^{00} - 11^{30} **Jiří Chaloupka**
Department of Condensed Matter Physics, Faculty of Science Masaryk University, Brno, Czech Republic
Unusual magnetic models emerging in d4 spin-orbit Mott insulators

11^{30} - 12^{00} **Raymond Frésard**
Normandie University, ENSICAEN, UNICAEN, CNRS, CRISMAT, Caen, France
Functionality-oriented properties induced by strong electronic correlations

12^{00} - 12^{30} **Arkadiusz Józefczak**
Faculty of Physics, Adam Mickiewicz University, Poznań, Poland
Magnetic mediators for ultrasound theranostics

12^{30} - 12^{45} coffee break

Friday, June 30, 2023

CLOSING SESSION

12^{45} - 13^{30} **Tomasz Cichorek**
Institute of Low Temperature and Structure Research
Polish Academy of Sciences, Wrocław, Poland
Detection of relativistic fermions in topological semimetals by magnetostriction measurements

13^{30} - 14^{00} **AWARDS, SUMMARY and CLOSING**

14^{00} - ... lunch

INVITED LECTURES

Ferrimagnetic Spintronics

J.M.D. Coey

School of Physics, Trinity College Dublin, Ireland

Spin electronics is largely concerned with spin polarized electron transport in thin films of ferromagnets and paramagnets with strong spin-orbit coupling. Antiferromagnets have attracted attention in recent times on account of their high frequency spin dynamics, the absence of any stray field and the possibility of switching the antiferromagnetic axis through 90° in crystal structures of appropriate symmetry. Metallic ferrimagnets offer the best of both worlds, and some unique properties of their own. When half-metallic, they combine high spin polarization with little or no net magnetization or stray field near compensation. Domains can be imaged directly. The magnetization can be switched by spin-orbit torque, resonance frequencies are high, coercivity and anisotropy field can be huge, there are prospects of switching a single layer by spin-orbit torque and ultra-fast all-optical toggle switching can be observed, with re-switching on a 10 ps timescale. These features will be illustrated with reference to the original zero moment half metal, Mn_2Ru_xGa with the XA Heusler structure, and also with reference to amorphous rare-earth transition metal ferrimagnets. Future prospects and challenges will be outlined.

Towards Quantum Computing with Spins on Surfaces

A.J. Heinrich[1,2]

[1] *Center for Quantum Nanoscience, Institute for Basic Science (IBS), Seoul 03760, Republic of Korea.*

[2] *Department of Physics, Ewha Womans University, Seoul 03760, Republic of Korea.*

There is a strong international research effort in the area of quantum information science. Here, the concepts of quantum coherence, superposition and entanglement of quantum states are exploited. These concepts were originally shown with photons as well as atoms and ions in vacuum traps. Over the past two decades, many advances at studying such quantum coherence in solid-state and molecular architectures have evolved [1].

In this talk we will focus on my own research efforts in Scanning Tunneling Microscopy (STM). STM enables the study of surfaces with atomic-scale spatial resolution and offers the ability to study individual atoms and molecules on surfaces. Here at Ewha, we have one of the world's best facilities for such studies. STM can also be used to move atoms with atomic-scale precision, which enables us to build engineered nanostructures where each atom is in the exactly correct place.

In order to study qubits with STM, we recently learned how to combine STM with electron spin resonance [2,3]. Spin resonance gives us the means to quantum-coherently control an individual atomic or molecular spin on a surface. Using short pulses of microwave radiation further enables us to perform qubit rotations and learn about the quantum coherence times of our spins [4]. Finally, we will finish with unpublished results on multi-qubit operations with spins on surfaces.

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Solid-State Lithium-Ion Battery and Supercapacitor Structures for Voltage Control of Magnetism

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Ionic control of magnetism gives rise to high magnetoelectric coupling efficiencies at low voltages [1-3], which is relevant for low-power magnetism-based memory and computing technologies. Unfortunately, magneto-ionic devices do often suffer from slow kinetics, poor cyclability, impractical liquid architectures, or strong ambient effects. As a route to overcoming these problems, I will demonstrate voltage control of magnetism by reversible cycling of Li ions in LiPON-based solid-state ionic batteries and supercapacitors. The following magneto-ionic effects will be presented; (1) reversible switching of magnetization between in plane and perpendicular states in thin Co films [4]; (2) voltage control over the nucleation and annihilation of magnetic skyrmions in Pt/$Co_{40}Fe_{40}B_{20}$/Pt [5]; and (3) Li-ion-induced manipulation of the Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction in perpendicularly magnetized Co/Pt layers [6]. As key outcomes, I will show that Li-ion-based heterostructures provide remarkably high magnetoelectric coupling efficiency, fast voltage control by 60 μs pulses at room temperature, and excellent device endurance up to 750000 voltage cycles.

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Accessing finite energy density with tensor networks and quantum devices

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Tensor networks are a family of ansatzes that provide efficient approximations for the low energy and thermal equilibrium states of low-dimensional quantum many-body systems. But describing highly excited states or out-of-equilibrium setups with them is much harder. These are therefore the natural problems in which quantum devices can potentially find the earliest advantage.

Energy filters allow us to access properties of the system at finite energy densities. They can be efficiently realized by quantum simulators or computers, which simulate the quantum dynamics, combined with classical filtering and sampling. But also replacing the quantum evolution by its classical simulation with tensor networks provides a new tool to classically compute dynamical and finite energy properties of much larger systems than allowed by other methods.

When chemistry meets physics: high-performance molecule-based magnets

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Magnets derived from molecule-based precursors have been viewed as emerging materials for next-generation technologies. These materials offer several commercial advantages compared to their inorganic counterparts such as reducing device fabrication costs (e.g., low-energy production, high abundance of elemental sources) and combining magnetic properties with other physical properties (e.g., conductive, mechanical). In this presentation, I will talk about a general, simple and efficient methodology to synthesize lightweight molecule-based magnets. The resulting metal-organic ferrimagnets will feature critical temperatures up to 242°C and a 7500-oersted room-temperature coercivity [1].

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Excitations of the antiferromagnetic XXZ spin-1/2 spin chain - spinons and Bethe strings

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The antiferromagnetic spin-1/2 spin chain with Heisenberg-Ising (XXZ) anisotropy is a rich source of novel phenomena. Good physical realizations are the compounds $SrCo_2V_2O_8$ and $BaCo_2V_2O_8$ where the Co^{2+} ions have effective spin-1/2 and are coupled by antiferromagnetic interactions into chains while long-range magnetic order occurs at $T_N = 5$ K due to weak interchain coupling. The excitations are spinons which become bound into pairs to form magnons below T_N. In a longitudinal magnetic field applied along the easy axis, the magnetic order is suppressed and using inelastic neutron scattering and optical spectroscopy we find the first evidence for complex bound states of magnetic excitations, known as Bethe strings [1,2]. Furthermore, the characteristic energy, scattering intensity and linewidth of the observed string states exhibit excellent agreement with precise Bethe ansatz calculations. Our results confirm the existence of the long-sought Bethe string excitations which were predicted almost a century ago [3], establish their role in the quantum spin dynamics of one-dimensional systems and reveal the effectiveness of new measurement and calculation techniques.

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Magnon transport in YIG/GGG at millikelvin temperatures

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Yttrium-iron-garnet (YIG) is the ideal choice of material to build and develop classical and novel quantum technologies [1]. Performing propagating spin-wave spectroscopy on thin films at millikelvin temperatures is the next step toward the realization of large-scale integrated magnonic circuits for quantum applications. In the talk, I will demonstrate spin-wave propagation in a 100 nm-thick YIG film at temperatures down to 45 mK [2]. The clear transmission characteristics over the distance of 10 μm are measured from which the extracted spin-wave group velocity and the YIG saturation magnetization agree well with the theoretical values. It was also found that the magnetic moment induced in gadolinium-gallium-garnet (GGG) substrate at low temperature disturbs the magnon transport for the applied magnetic fields beyond 75 mT. To address this phenomenon, the magnetization of the GGG substrate was measured via vibrating-sample magnetometry, and the magnetic properties of the YIG film were characterized by ferromagnetic resonance (FMR) measurements. It is found that the magnetization of GGG results in the formation of a stray field oriented in the opposite direction to the external field. Moreover, the magnetization of GGG increases the magnetic damping of YIG by more than eight times compared to measurements at room temperature.

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Quantum and classical aspects of a low-temperature (∼500 mK) magnetic phase transition in aluminoborates

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Specific heat, C_B, of $R\mathrm{Al_3(BO_3)_4}$ single crystals with R = Tb, Dy, Gd was studied for 50 mK $< T <$ 300 K, with emphasis on the $T < 1$ K range, where a phase transition was found. For the Tb compound, which will be analyzed further as an example, the transition appears at $T_c = 0.68$ K. Nuclear, non-phonon, and lattice contributions to C_B were separated. Based on C_B and magnetization, M, studies, we established that the phase transition shifts to lower temperatures with increase in magnetic field $\mathbf{B}_{||}$, parallel to the easy magnetization axis. We found that the critical, i.e., related to the transition, contribution to the specific heat, C_{cr}, shows an unusual $C_{\mathrm{cr}} \sim T^{y_0}$ dependence on T, and that the Grüneisen ratio, Γ, defined as:

$$\Gamma = -\frac{1}{T}\frac{(\partial S/\partial B)_T}{(\partial S/\partial T)_B} = -\frac{(\partial M/\partial T)_B}{C_B\,(T)} = \frac{1}{T}\left(\frac{\partial T}{\partial B}\right)_S, \tag{1}$$

where S is entropy, diverges as a function of $B_{||}$ for $B_{||}$ approaching a critical value of 0.6 T. The behaviors of both C_{cr} and Γ as a function of T (especially scaling of Γ for $B_{||} \geq 0.30$ T), and dependence of Γ on $B_{||}$ are characteristic of systems, in which the classical phase transition line is influenced by quantum fluctuations, QF, and ends at quantum critical point. Using the determined y_0 and Γ values, we assessed the dynamical critical exponent z to be $0.82 \leq z \leq 0.96$. Based on these results, we suppose that QF dominate the behavior of the system and destroy the long range order, i.e., we suppose the transition found to have a quantum character. Its physical nature is not clear. The interpretation that this is the transition to the ferromagnetic ordering of Tb^{3+} magnetic moments is the most natural and supported by the M studies. However, such a classical transition should be smeared and shifted to higher T by $B_{||}$, while we observe the opposite effect. It was observed, e.g., in systems, in which exchange and magnetic dipolar interactions were of similar strength [1]. Also the possibility, that the transition is related to any other ordering , e.g., multipolar, and the ordering of the Tb^{3+} moments is a "side effect" only can not be ruled out.

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Ferroelectric and multiferroic two-dimensional electron gases for oxide spin-orbitronics

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Just as the apparent incompatibility between ferroelectricity and magnetism prompted the renaissance of multiferroics[1], the research on «ferroelectric» metals – conjectured in the 1960s by Anderson and Blount[2] – was recently revitalized. Yet, their experimental demonstration remains very challenging due to the contra-indication between the presence of free charge carriers and switchable electric dipoles. In this talk we will report on two-dimensional electron gases (2DEGs) formed on Ca-substituted $SrTiO_3$ (STO). Signatures of the ferroelectric phase transition near 30 K are visible in the temperature dependence of the sheet resistance R_S and in a strong, reproducible hysteresis of R_S with gate voltage[3]. In addition, spectroscopic explorations of the 2DEG region indicate the presence of switchable ionic displacements. Beyond their fundamental interest in materials physics, ferroelectric 2DEGs offer opportunities in spin-orbitronics: we will show how their spin-charge conversion properties, caused by the inverse Rashba-Edelstein effect, can be electrically tuned in amplitude and sign in a non-volatile way[4]. These results open the way to a whole new class of ultralow-power spin-orbitronic devices operating without the need for magnetization switching. Finally, we will describe how one can introduce magnetism into such systems to achieve multiferroic 2DEGs displaying magnetoelectric coupling[5].

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Magnon Induced Reversal, Steering, and Interference in Ferromagnet/Ferrimagnet Hybrid Structures

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Spin-wave based computing gains increasing interest [1]. Recently, a nanoscale neural network was proposed which made use of interfering spin waves (magnons) in yttrium iron garnet (YIG) below an array of ferromagnetic nanomagnets [2]. However, the assumed magnon steering and multi-directional interferometry of coherently scattered short-wave magnons had not been experimentally verified. The so-called extinction ratio which is relevant for binary 1/0 output operations was not known either. Hence, experimental evidence is urgently needed to substantiate the prospects of unconventional computing schemes in nanomagnonics.

We have explored the excitation, transmission and interference of short-wave magnons in YIG films with different thicknesses ranging from 11 and 113 nm. The YIG was covered by different arrays of ferromagnetic nanostructures such as nanostripes [3,4] and nanopillars [5]. The YIG was grown by liquid phase epitaxy on GGG. The ferromagnet was 20-nm-thick polycrystalline $Ni_{80}Fe_{20}$ (Py). We integrated coplanar waveguides with magnonic grating couplers to coherently excite magnons in the GHz frequency regime with wavelengths λ from about 49 nm to a few $_{\mu}$m. For excitation and detection we used a vector network analyzer (VNA) and micro-focus Brillouin (inelastic) light scattering.

Magnons propagating in YIG underneath periodically and aperiodically arranged nanopillars evidenced multi-directional magnon steering into numerous on-chip directions. The extinction (on/off) ratios which we evaluated from interference experiments showed unprecedentedly high values of 26 ($\pm$8) dB [31 ($\pm$2) dB] for magnons with λ = 69 nm (154 nm) [5]. They were obtained over macroscopic propagation lengths of 350 x λ. Experiments involving nanostripes on YIG showed magnon transmission spectra which depended characteristically on the VNA power in the linear excitation regime. We attributed the observation to magnon-induced reversal of Py nanostripes when biased at a small opposing field [4]. We will report on further studies based on different nanomagnets on YIG. In these samples we observed magnon-induced reversal at different threshold amplitudes. For the 11-nm-thick YIG, we found a group velocity asymmetry of counterpropagating magnons which we attributed to Dzyaloshinskii-Moriya interaction similar to Ref. [6]. Our work fuels the experimental realization of magnon-based neural networks and in-memory computation.

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Spintronics with low-dimensional materials

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Two-dimensional materials are an exciting new material family in which the proximity effect is especially important and opens ways to transfer useful spintronic properties from one 2D material into another. For instance, transition metal dichalcogenides (TMD) can be used to enhance the spin-orbit coupling of graphene. We have optimized bilayer graphene/WSe_2 van der Waals heterostructures to achieve magnetic-field-free spin precession. Remarkably, the sign of the precessing spin polarization can be tuned electrically by backgate voltage and drift current, being the first realization of a spin field-effect transistor at room temperature in a diffusive system [1].

The spin-orbit proximity in graphene/TMD van der Waals heterostructures also leads to spin-to-charge conversion (SCC) of out-of-plane spins due to spin Hall effect (SHE), first observed by our group using MoS_2 as the TMD [2]. The combination of long-distance spin transport and SHE in the same material gives rise to an unprecedented figure of merit (product of spin Hall angle and spin diffusion length) of 40 nm in graphene proximitized with WSe_2, which is also gate tunable [3].

The low symmetry present in many of these low-dimensional materials allows the creation of spin polarizations in unconventional directions and enables new fundamental effects and configurations for devices. For instance, we observe SCC of spins oriented in all three directions (x, y, and z) in graphene/$NbSe_2$ heterostructure, due to spin-orbit proximity and broken symmetry at the twisted graphene/$NbSe_2$ interface [4].

In this regard, chiral materials are the ultimate expression of broken symmetry, lacking inversion and mirror symmetry. We have recently demonstrated a gate-tunable chirality-dependent charge-to-spin conversion in Te, a 1D van der Waals material [5], detected by recording a large unidirectional magnetoresistance (up to 7%). The orientation of the electrically generated spin polarization is determined by the nanowire handedness, while its magnitude can be manipulated by an electrostatic gate. These results pave the way for the development of magnet-free chirality-based spintronic devices.

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A first-principles approach to orbital accumulation and orbital transport

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Recent first-principles calculations have predicted that, apart from the electrically induced spin currents and spin polarization, there are in fact much larger orbital angular momentum currents and induced orbital polarizations. A huge orbital Hall effect (OHE) was predicted to exist in 3d metals [1] and a huge orbital Rashba-Edelstein effect (OREE) was predicted for the symmetry-broken antiferromagnets CuMnAs and Mn_2Au [2]. Both effects do not require spin-orbit interaction (SOI) and large effects can be obtained for materials containing light atoms. This provides a perspective for future utilization of orbital angular momentum, instead of spin, as information carrier in the emerging field *orbitronics*.

I will discuss our recent linear-response theory calculations for the electrically induced out-of-equilibrium spin and orbital currents in bulk 3d ferromagnets as well as in Pt/3d-metal bilayer films [3,4]. For bulk 3d ferromagnets as Fe, Co and Ni, we show that there exists a conventional spin Hall effect (SHE), and an OHE, as well as a magnetic spin Hall effect (MSHE) and a magnetic orbital Hall effect (MOHE) [3]. The former two effects are time-reversal even, whereas the MSHE and MOHE are time-reversal odd and exist in ferromagnetic materials. These induce a transverse spin or orbital current with spin/orbital polarization along the applied electric field. The MSHE is strongly electron lifetime dependent, but in general, it is of the same size of the SHE and cannot be neglected. The OHE is the largest quantity as it doesn't require SOI, but the SHE, MSHE, and MOHE all require SOI to be non-zero.

For the Pt/3d-metal (Co, Ni, Cu) bilayer systems we compute the spin and orbital conductivities and the spin/orbital accumulation on the sides of the bilayer. The electrically induced transverse orbital current is larger than the spin current and present even without SOI. This underlines that also in the Pt/3d-metal bilayers the electrically induced orbital effects (OREE and OHE) are the primary responses, whereas the SREE and SHE are generated from these through SOI. We further compute atom-resolved response quantities that allow us to identify the contributions that lead to fieldlike or dampinglike spin-orbit torques and compare their relative magnitude, and dependence on the magnetization direction.

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Toward Magnetogenetics: Effects of Magnetic Fields on Living Cells

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Magnetogenetics is an elegant approach to precisely controlling the biological functions of a cell, group of cells, tissues, and even organisms using magnetic fields and genetic engineering technologies. We discuss new biological and therapeutic effects of magnetic fields (MFs). Spatially modulated gradient MFs can affect cellular functions of human THP-1 leukemia cells in the following ways: i) induce cell swelling, ii) increase ROS production, iii) inhibit cell proliferation, and iv) elicit apoptosis of THP-1 monocytic leukemia cells in the absence of chemical or biological agents [1]. A high static MF can control the diffusion of biologically active molecules including oxygen, hemoglobin, and drugs, thereby affecting many physiological processes in organisms, e.g., wound healing [2]. It is important for clinical applications to treat a number of myopathies associated with the defective calcium regulation in muscle cells that exposure of skeletal muscle cells to a spatiotemporally modulated 70 mT MF triggers a significant increase in cytosolic Ca2+ levels leading to actin polymerization [3]. The analysis performed in [4] showed that specific ion channels in cells can be turned off and on by remotely applying a high gradient magnetic field, thus modulating the cell membrane potentials. The suggested model and mechanisms provide a general framework for identifying possible hidden mechanisms of biomagnetic effects associated with modulation of ion channel activity by high gradient static magnetic fields. Effects of a high static MF on the DNA synthesis and lung cancer-bearing mice were examined in [5,6]. In mice treated 88 h with a 9.4 T static magnetic field, tumor growth and DNA synthesis were significantly inhibited, G2 cell cycle was arrested, while the ROS and P53 levels were increased. Using a static gradient MF, in probiotic bacteria E. coli Nissle 1917, we shortened the duration of the mitotic phase and thereby accelerated cell division [7]. We show how magnetic forces can influence gene expression and propose a mechanism of cell reprogramming: the MF application generates focused magneto-mechanical stress, enhancing actin filament tension, transmitted stress on the cell nucleus and DNA, leading to changes in gene expression, differentiation pathways, or cellular reprogramming [8]. The physiological sequences of the MF – cell interactions for organisms in health and disease are also discussed.

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Strong electronic correlations, exchange and superconductivity: Theory and experiment match for the cuprates

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In my talk I will summarize our approach to the theory of high temperature superconductivity in the cuprates [1] and concentrate on the quantitative comparison to experiment. The most important thing is to combine the strong interelectronic correlations and kinetic superexchange, at least within a variation approach to reach an overall agreement for static (equilibrium) properties and dynamic excitations – paramagnons and plasmons. The single-band (t-J-U model) and three-band versions of the approach are briefly characterized. Some still missing features are discussed at the end.

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Cooperation: Maciej Fidrysiak, Michał Zegrodnik, Andrzej Biborski

Superconductivity with strong spin-orbit coupling: application to $CeRh_2As_2$

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Two key symmetries underlie the formation of superconductivity: parity and time reversal. Breaking time reversal symmetry through the application of magnetic fields is known to be harmful to superconductors. The role of breaking parity symmetry, through the development of spin textures generated by spin-orbit coupling, has more recently been understood. This is known to give rise to unusual superconducting properties, including spin-singlet spin-triplet mixing, high critical fields, residual spin susceptibilities, and symmetry required pair density wave states [1]. When parity symmetry is restored, hidden spin textures can still enable these usual superconducting properties, provided the spin-orbit coupling is sufficiently strong [2]. Furthermore, new physics emerges in this limit: a field induced, possibility topological, odd-parity superconducting state originating from conventional pairing interactions has been predicted. This state has likely been discovered in $CeRh_2As_2$ [3]. Here, after summarizing early results on the interplay of spin textures and superconductivity, I present results on $CeRh_2As_2$, emphasizing the connection between non-symmorphic symmetries and strong spin-orbit coupling [4]. Finally, general properties of the relationship between hidden spin-textures, non-symmorphic symmetries, and superconductivity will be discussed [4].

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Quantum hybrids of superconductivity and magnetism via topological solitons

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Topological solitons and quantum mechanics have been intertwined for the past 60 years. Even before the term soliton had been coined, Abrikosov theory predicted the formation of vortices in the phase field of superconductors, an exemplar exposition of macroscopic quantum coherence. Recent work shows that solitons are in fact a timely and promising platform for quantum operations. I will demonstrate the viability of using spin topology to influence a superconductor at selective length scales through a completely new material architecture namely, a stack of magnets and a superconductor that shows stable vortices above elongated chiral spin textures, as well as isolated skyrmions. This is an ideal geometry for fluxonics and chiral superconductivity, as well as quantum processes such as non perturbative, non-contact Majorana braiding.

Altermagnetism and spintronics without magnetization and relativity

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Magnetically ordered crystals are traditionally divided into two elementary phases – ferromagnetism and antiferromagnetism. In the first part of the talk, we will recall that the ferromagnetic order offers a range of phenomena for energy efficient IT, while the vanishing net magnetization in antiferromagnets opens a possibility of a breakthrough towards a new-generation IT with ultra-high capacity and speed [1-3]. In the second part of the talk we will move on to the recent predictions of instances of strong time-reversal symmetry breaking and spin splitting in electronic bands, typical of ferromagnetism, in crystals with antiparallel compensated magnetic order, typical of antiferromagnetism [4-6]. This apparent fundamental conflict in magnetism is resolved by symmetry considerations that allow us to classify and describe a third elementary magnetic phase [7]. Its alternating spin polarizations in both crystal-structure real space and electronic-structure momentum space suggest a term altermagnetism. We will demonstrate that altermagnets combine merits of ferromagnets and antiferromagnets, that were regarded as principally incompatible, and have merits unparalleled in either of the two traditional basic magnetic phases. We will introduce the broad materials landscape of altermagnetism and show how its unconventional nature enriches fundamental concepts in condensed matter physics [6,7]. We will show that this underpins a development of a new avenue in spintronics, elusive within the two traditional magnetic phases, based on strong non-relativistic spin-conserving phenomena, without magnetization imposed scalability limitations [1-9].

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Magnetization dynamics in magnetic heterostructures

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Investigation of the magnetization dynamics in thin films and multilayer heterostructures can lead to the determination of several important material parameters, such as magnetization saturation, anisotropy energy or damping. In addition, analyzing the response of the system upon excitation with a spin polarized current, one can get more insight into the origin of the torque which is important for applications [1].

During the talk I will first discuss the ferromagnetic resonance (FMR) in a model system excited by the magnetic field and spin orbit torques in heavy metal/ferromagnetic multilayers [2]. I will extend the model by discussing different sources [3] of the spin current and symmetries of the response [4].

Then I will move to the discussion of the magnetization dynamics in magnetic tunnel junction. Magnetization precession induced by radio-frequency voltage application enables determination of the influence on the electric field on the magnetic anisotropy also in a GHz frequency range [5]. Upon application of the DC current in the optimized structure one can also obtain a stable magnetization precession, which can be further stabilized using the magnetic feedback loop [6].

Finally, I will discuss the FMR in multiferroic heterostructures, where the FMR signal can be measured in both soft and hard-magnetic layers using both spin-torque and spin pumping effects [7]. I will also introduce the cMTJ software which enables fast numerical simulations of the spintronic heterostrucutres [8].

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Terahertz Inverse Spin Hall Effect in Spintronic Nanostructures

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Terahertz (THz) radiation is situated between the infrared and microwave regions in the electromagnetic spectrum with a bandwidth ranging from 0.3 to 30 THz and has numerous applications in various fields, ranging from security screening, e.g., at airports, through ultrafast communications, radioastronomy, to nonionizing biomedical spectroscopy and imaging. One of the most interesting forms of THz radiation are subpicosecond in duration bursts of electromagnetic waves. These, so-called, THz transients are, typically, characterized by approx. a single picosecond time duration and a 0.1 to 6 THz spectral range. Spintronic nanostructures manipulate simultaneously electron's charge and spin and emerge as a new direction in generation of THz transients, due to their robust and simple thin-film technology, low cost, and emission of ultra-broadband signals. The inverse spin Hall effect (ISHE) is the core emission mechanism of THz transients from spintronic nanostructures, such as ferromagnet/heavy metal (FM/HM) nanobilayers. Heavy metals (e.g., Pt, Ir, Pd, or Au) are selected because of their large spin-orbit coupling (SOC). When a femtosecond laser pulse illuminates the FM layer, such as, e.g., Fe, Co, or their alloys, spin-up majority electrons are optically excited to sp-states above the Fermi energy and have a longer mean-free path, as compared to the spin-down minority electrons in d-states. Nonequilibrium spin electrons enter an adjacent HM layer and spin-up and spin-down electrons diffuse in opposite directions due to the SOC. Consequently, the injected transient longitudinal spin current density is converted into a transient (sub-picosecond) transverse charge current leading to emission of an electromagnetic radiation pulse whose power spectrum extends up to the THz frequencies. We performed exhaustive experiments using Pt or Ir as HM nanolayers on top of either soft (FeNi) or hard (FeCo) FM films as spintronic emitters and excited them with 100-fs-wide optical pulses, generated by a commercial Ti:Sapphire laser. As a result, we observed efficient generation of THz transients, fully in agreement with the ISHE model. Our detection scheme was an optical pump-probe sampling arrangement that allowed one to obtain a sub-picosecond time resolution of detected THz transients. We also demonstrated that when in a spintronic emitter, a 2-dimensional (2D) graphene was substituted for HM, one could also observe a large, emitted THz transient, even though the graphene intrinsic SOC energy is extremely low. The reason is the FM-induced Rashba texture in graphene, leading to the enhanced SOC value, and resulting in efficient spin-to-charge current conversion, called the inverse Rashba-Edelstein effect (IREE). In case of IREE, injection of a transient, optically-excited, 3D spin-polarized current (from FM) into a 2D material (graphene) creates an imbalance in the distribution of charge carriers and, consequently, a transient 2D charge current, leading to emission of a THz transient. Finally, we will briefly outline feasibility of implementing oxide perovskite materials for spintronic emitters.

Cold ultrafast all-optical switching of magnetization

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In the last decade, a plethora of fundamental mechanisms for magnetization dynamics induced by laser pulses at ultrashort time scales has been actively discussed [1-4]. The main interest is not only in the excitation of spin precession but in the switching of magnetization between multiple stable states, as it opens up rich possibilities for non-volatile magnetic data storage technology. One of the most intriguing examples is the least-dissipative (cold) mechanisms of all-optical switching of magnetization with laser pulses.

Recently, we demonstrated the nonthermal all-optical photo-magnetic switching in Co-ions doped garnet films using a time-resolved magneto-optical spectroscopy and single-shot ultrafast imaging of magnetic domains [4]. The photo-magnetic effect is a general phenomenon in numerous dielectrics. However, by using ultrashort laser pulses and precisely tuning to optical resonances we vastly enhance the effective light-induced field amplitude [5]. The switching properties at the observed resonances are vastly different, related to the crystal site hosting the excited Co-ions. As these ions are the source of the strong magnetic anisotropy in a garnet, their excitation between the crystal filed split states results in a coherent and ultrafast manipulation of spin-orbital interaction. Moreover, another non-thermal mechanism of ultrafast magnetization switching was found in these garnets by resonant pumping of optical phonon modes [6].

Additionally, we demonstrated that with femtosecond pulses it is possible to write and rewrite magnetic bits with a frequency of up to 20 GHz, with the maximum repetition rate being defined by the frequency of ferromagnetic resonance in the field of photo-induced magnetic anisotropy [7]. Our results reveal the principles to be employed in achieving cold and ultrafast magnetic recording.

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The coercivity of permanent magnets: Insights from micromagnetics and machine learning

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Permanent magnets are of utmost importance for the transition to a carbon free economy. Permanent magnets are essential for effective power generation and transformation. A key property of a permanent magnet is its coercive field. Micromagnetic simulations and machine learning help to understand the coercivity mechanism of permanent magnets, which in turn can guide the optimization of magnetic materials for specific applications.

Magnetization reversal starts locally. Simulations of the demagnetization process of (NdLaCe)FeB-based magnets show that the sum of the external field and the demagnetizing field evaluated at a distance of 1.44 times the exchange length determines the switching field of a grain [1]. This finding expresses the balance of exchange and magnetostatic interactions which in turn leads to a decrease of the coercive field with increasing grain size. Furthermore, magnetostatic interactions cause a cascade type magnetization reversal in large-grained magnets. Once a grain is reversed, its magnetostatic field triggers the reversal of its neighbours. Simulations of the coercive field of magnets with an ideal microstructure, in which the grains are separated by a non-magnetic grain boundary phase, show that demagnetizing fields and misalignment cause a drastic reduction of the coercive field. For uniformly distributed anisotropy directions with a maximum misorientation of 35 degrees, the computed coercive field is 3.4 T, 2.8 T, 2.3 T, 1.8 T, and 1.3 T for an average grain size of 0.1 μm, 0.5 μm, 1.8 μm, 7.3 μm, and 29.3 μm, respectively.

Micromagnetic simulations show, that already a thin anisotropy defect reduces the switching field compared to its value expected from the Stoner-Wohlfarth theory. Deviations from the angle dependence of the switching field from the Stoner-Wohlfarth curve indicate the presence of defects.

Machine learning combines available data sets into coercivity models. Model interpretation helps to identify trends and show how key material properties such as the chemical composition, grain size, and defect thickness, influence the coercive field.

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Dynamical effects of correlated superconducting nanostructures

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We discuss non-equilibrium effects imposed on the superconducting hybrid structures. Specifically, we consider abrupt changes (quantum quenches) which give insight into characteristic time-scales of the related (Andreev or Majorana) quasiparticles. Sudden changes of the physical conditions in bulk superconductors usually affect the complex order parameters, activating the amplitude (Higgs-type) and phase (Nambu-Goldstone) collective modes [1]. In superconducting hybrid systems there is opportunity to empirically design any perturbation at will and measure the resulting response, exploring post-quench dynamics across different phases [2]. In particular, one can drive transition from the BCS-type to the singly occupied (unpaired) configurations. Signatures of the dynamical phase transition are manifested at critical time instants by parity crossings of the in-gap bound states [3], that chould be observed by the Andreev and magnetic spectroscopies.

Study of dynamical phenomena driven of the superconducting hybrid structures is motivated by a prospect to construct the quantum bits out of the conventional (Andreev) or topological (Majorana) bound states [5]. Practical use of such qubits would require either the charge or spin manipulations [6], therfore it is of essential importance to establish how the in-gap bound states react upon applying external fields.

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In search of new hard magnetic materials - an experiment supported by semi-empirical calculations

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The development of hard and semi-hard magnetic materials is driven by the continous growth of the global market of permanent magnets. Although it is always possible to manufacture new systems with improved properties, there is a group of metastable phases that are difficult to synthesize. Several methods are used to determine the optimal compositions, not only to improve magnetic performance but also structural stability. A relatively simple and affordable approach based on the semi-empirical Miedema's model with various modifications and extensions will be discussed. This approach is useful to mimic the synthesis process, where various intermetallic phases, the solid solution, and the glassy state compete.

The results of calculations will be presented together with the experimental evidence for various groups of alloys, *e.g.* (Hf,Cr)-Co-B system, for which the synthesis route involving rapid quenching and isothermal annealing of an initially amorphous precursor has been proposed. Another group of alloys that crystallize in a tetragonal $ThMn_{12}$-type (space group $I4/mmm$) structure and are based on Fe and rare earth elements is considered to have a potential to bridge the performance gap between ferrite and Nd-based magnets. Their progress is also hindered by low structural stability, compared to other phases competing in the synthesis process, *e.g.* Th_2Zn_{17}-type. The enthalpies of formation of the different phases in (Zr, Nd, Ce)-Fe-Si systems will be presented with a focus on the Fe-rich compositions to analyze the stability range and to propose stabilization routes.

Magnetic mediators for ultrasound theranostics

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The theranostics paradigm is based on the concept of combining therapeutic and diagnostic modalities into one platform to improve the effectiveness of treatment. Combinations of multiple modalities, enabled by nano- and micron-sized mediators, provide numerous medical advantages. Ultrasounds are used in many biomedical applications, such as imaging and therapy, therefore they are the perfect candidate for theranostic treatment.

Hyperthermia is one of the earliest medical applications of ultrasound. The efficiency of ultrasound heating can be improved by using mediator materials called sonosensitizers, materials that enhance the attenuation and dissipation of acoustic energy. Herein, we propose the use of magnetic nanoparticles as sonosensitizers owing to their biocompatibility, nontoxicity, and common use in various medical applications. We showed that sonosensitizers improve heat generation in tissue-mimicking phantoms due to the increase in ultrasonic attenuation.

Recently, a lot of effort has been put into combining more modes of heating into one treatment. Multimodal hyperthermia provides a better alternative to a single heating method. We showed that the application of dual sono-magnetic heating gives better results than either of them used independently. The advantage of the sono-magnetic bimodal treatment lies not only in the cumulative heating of target volume, but also in the synergistic interaction between the two mechanisms. Ultrasound sonication can improve the thermal effect of magnetic hyperthermia through the unblocking of the Brown relaxation mechanism.

Unfortunately, multimodal approaches remain limited, due to difficulties associated with the lack of accurate control of their therapeutic efficiency. Thus, we propose the use of ultrasound transmission tomography (UTT) measurements to track nano mediator-based ultrasonic heating. Our results showed that UTT is sensitive to the presence of magnetic nanoparticle-based materials and induced temperature rises.

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Unusual magnetic models emerging in d^4 spin-orbit Mott insulators

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Mott insulators containing t_{2g}^4 ions with strong spin-orbit coupling may host an unusual "soft" magnetism based on a dynamic mixing of low-energy ionic states via exchange processes. The magnetic moment in this situation is not carried by a "rigid" spin $\boldsymbol{S}$ or pseudospin $\boldsymbol{J} = \boldsymbol{L} + \boldsymbol{S}$ but is of Van Vleck type residing on a transition between ionic states at different energy levels. In the case of degenerate t_{2g} orbitals, the relevant ones are the non-magnetic $J = 0$ ionic ground state and $J = 1$ triplet excitations. Instead of the familiar spin interactions such as those encountered in the Heisenberg model, the exchange in these systems takes a form of bond processes involving triplets described as hardcore particles, most importantly their hopping or pairwise creation and annihilation. The particular set of exchange processes depends on the lattice geometry and the available hopping channels, leading to models with very distinct properties. The general feature is the competition of the singlet-triplet level splitting and exchange interactions that leads to quantum critical behavior where long-range magnetic order is associated with a condensation of triplets unless it is prevented by frustration. Further complexity is brought by tetragonal/trigonal splitting of t_{2g} orbital levels arising in lattices made of corner-sharing/edge-sharing octahedra which – by lifting up part of the triplet states – gives rise to effective spin-1 or spin-1/2 models with diverse interactions, ranging from honeycomb spin-1 models with Kitaev-type anisotropy to transverse-field Ising models on various lattices. In the talk, an overview of the various options will be given, focusing on the rich phase diagrams and peculiar features in the excitation spectra such as the amplitude mode present in condensed phases.

Gradient magnetoelasticity: tailoring of antiferromagnetic textures

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Nowadays antiferromagnets are considered as important constituents of the spintronic devices. They show fast magnetic dynamics and can be effectively manipulated by the electric current or laser pulses. Many of technologically attractable antiferromagnets also show strong magnetoelastic effects, which can prevail over the direct spin-torque mechanism and can be used for control and manipulation of the devices. However, an important prerequisite of such thermomagnetoelastic effects is inhomogeneous distribution of strains. In this presentation we discuss the effects associated with the strain gradients that appear in antiferromagnetic devices due to the clamping by nonmagnetic substrate, patterning, or current/temperature gradients. We introduce the concept of magnetoelastic charges that are associated with the magnetic inhomogeneities and with incompatibility (break of continuity) of the related spontaneous strains. Such magnetoelastic charges produce a long-range strain field, which, similar to magnetostatic stray field in ferromagnets, controls distribution of antiferromagnetic domains and orientation of the domain walls, and modifies local magnetic anisotropy. Inspired by the gradient elasticity approach we generalize it to include magnetoelastic effects and apply it to interpretation of the observed magnetic textures in different antiferromagnets relevant for spintronic applications. Our findings open new ways to manipulate antiferromagnetic textures by proper tailoring of the magnetic and magnetoelastic gradients.

Functionality-oriented properties induced by strong electronic correlations

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This talk is focused on a pair of functionality-oriented properties arising from strong electronic correlations (SCE). Its first part is motivated by the long sought size reduction of micro-electronics components and we show that SCE may help reaching it. With this goal we consider capacitors made of a dielectric material surrounded by metallic plates. As emphasized in Ref.[1], negative electronic compressibility of the plates leads to an enhancement of the capacitance of such a capacitor as compared to non-interacting plates, thereby allowing for size reduction. A series of situations where this happens has been recently discovered [2, 3, 4], that we review.

The second part of the talk is motivated by resistive switching, which is central to reduce the energy consumption arising from the training of neural networks, for instance. To that aim we address spin and charge ordered phases entailed in an extended half-filled Hubbard model [5]. Their sensitivity on the crystal field, as well as on local and non-local interactions will be discussed. We furthermore present the discontinuous transitions harbored in this model, together with their connection with resistive switching. The latter is shown to occur in a model presented in the first part as well [4].

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Detection of relativistic fermions in topological semimetals by magnetostriction measurements

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Detection of Dirac or Weyl fermions in topological semimetals remains often elusive, since in these materials conventional charge carriers exist as well. Here, we draw attention to the magnetostriction, i.e., to the field-induced length change, which results from the interaction between the electron and elastic degrees of freedom in a diamagnetic crystal. Using the prototype Weyl semimetal TaAs as an example and performing measurements at low temperatures, we show that this thermodynamic quantity can be an effective probe of the massless quasiparticles in Weyl semimetals, if the Weyl points lie near the Fermi level. In this situation, even in moderate magnetic fields, which are too weak to confine large groups of massive quasiparticles at their zeroth Landau levels, the magnetostriction contains a linear-in-field term that identifies the presence of relativistic fermions. Specifically, a firm evidence for Weyl fermions is found with the measurements along the [001] direction where the largest length changes are observed. By contrast, the longitudinal expansion along the [100] direction is by an order of magnitude smaller in the highest field applied of 16 T, and this a-axis magnetostriction experiences immense changes from large positive to large negative values with minute deviations of the applied magnetic field from the [001] direction [1]. In addition to this, we discuss the longitudinal and transverse magnetostriction of the topologically trivial semimetal LuAs with a cubic structure [2] to demonstrate that subtle parameters characterizing not only Weyl electrons but also trivial charge carriers can be extracted from the magnetostriction measurements.

Our study shows how dilatometry can be used to unveil Weyl fermions in candidate topological semimetals. In a broader perspective, detection of relativistic quasiparticles in candidate topological materials with the magnetostriction can set the stage for their further investigations, and the observed anisotropic magnetostrictive stress can be relevant for future high-field Weyltronic devices.

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YOUNG & BRILLIANT LECTURES

Detecting localization in 1D lattices through strong light-matter interactions

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The interaction between a strong laser field and a material results in a nonlinear optical process that gives rise to the generation of high harmonics of the incident frequency. Recently, there has been a growing interest in the use of high harmonic generation (HHG) to probe various properties of matter, as it can track the electronic motion at the attosecond time scales in both gases and solid state systems. Spectroscopy based on the HHG can serve as a tool of ultrafast imaging to detect signatures of quantum phase transitions in high-temperature superconductors[1], distinguish between trivial and nontrivial topological phases[2,3], and probe dynamical and structural properties of electrons. Here, we present theoretical results for high-harmonic spectroscopy on three distinct condensed matter platforms. In particular, we show that HHG can be used to distinguish between topological phases with different numbers of edge modes in the long-ranged Su–Schrieffer–Heeger model and detect quantum phases of the generalized Aubry-André-Harper model and the Hubbard model with intersite interaction.

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Gyroid Nanostructures in Magnonics

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Artificial media with topological or non-uniform geometrical characteristics may provide new possibilities for manipulating spin waves (SWs) [1]. A fully connected 3D network enables interactions and collective effects in all three dimensions, offering vibrant perspectives on new phenomena [2]. Gyroids were first discovered and presented in 1970 [3] and are a promising yet almost unexplored structure in magnetism. It is defined by chiral triple junctions and periodicity in all three spatial directions, classified as the $I4_132$ space group [4].

The analyzed nickel (Ni) gyroid nanostructure was fabricated by thermally annealing a block copolymer template, selectively dissolving one of the gyroid-forming blocks, and filling the voided right-handed gyroid network with Ni by electrodeposition. For broadband ferromagnetic resonance measurements (BBFMR), the orientation of the gyroid network toward the static magnetic field axis is significant. We have observed a strong impact of crystallography to the BBFMR spectra signals as a variation in its main intensities. To better understand and explain the experimental results, we performed micromagnetic simulations of gyroid systems in the finite element method solver. They qualitatively confirmed our findings from the BBFMR and determined how complexity, chirality, and curvature allow the crystallographic direction to affect the resonance frequency.

The results demonstrate that geometric anisotropy can contribute significantly to the alternation in the power of resonance signals in rotating gyroid samples. Furthermore, with FMR measurements and micromagnetic simulations, we showed that SW spectra of nm-scale gyroids depend on the orientation of the external magnetic field to the crystallographic structure. The results offer much potential for developing 3D nanomaterials for magnonic applications.

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Magnon-Fluxon Interaction in Coupled Superconductor/Ferromagnet Hybrid Periodic Structures

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Over the past decades the interest in coupled superconductor/ferromagnet (SC/FM) materials has continuously increased. Hybrid structure of this form are not only interesting from fundamental point of view but also provide promising prospects for information technology. One key idea is to use the stray field interaction between superconducting matter and ferromagnets to manipulate the propagation of spin waves in a magnonic wave guide. In this way a superconducting vortex lattice can act as a building block for a reconfigurable magnonic crystal with unique properties. Despite intensive research on this subject the fascinating nature of the coupled dynamics of SC/FM hybrids is not fully understood yet and only recently the first experimental evidence for magnon-fluxon-interaction has been found so far by Dobrovolskiy et al. (Nature Physics, 15, 477 (2019)).

Here we are aiming to obtain a deeper insight into the magnetization dynamics of a SC/FM bilayer by simulating such a structure under realistic conditions. To this end we solve the coupled time-dependent Ginzburg-Landau equations [1,2] for superconductivity and the Landau-Lifschitz-Gilbert equation for the magnetization dynamics. In accordance with the experiment we found that the presence of the vortices leads to the formation of a Bloch-like band structure in the magnonic spectrum. The width and position of these bands was observed to be highly susceptible to various system parameters like the FM layer thickness and width, structural imperfections in the vortex lattice, and on the strength of the vortex-field. In addition, we observed a tendency for magnon-confinement and band shifts towards lower frequencies of the low-energy modes above the location of individual vortices. In our simulations we found that the stray field of a periodic vortex lattice can be well approximated by an arrangement of air-separated ferromagnetic nano-cubes. Especially for large scale systems this approach substantially simplifies the task of solving the full system of coupled partial differential equations and paves the way for further research on the subject.

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Generation and transport of spin current in $SrTiO_3$-based magnetic heterostructure

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The generation and manipulation of a spin current is fundamental for the spintronics devices. The conversion phenomena between spin and charge currents in solids have been intensely investigated in a wide variety of systems. One of the promising candidates is the two-dimensional electron gas (2DEG) in $SrTiO_3$-based structures with a strong Rashba spin-orbit coupling. In a Rashba system, an in-plane charge current generates a transverse spin density, which is known as the Edelstein effect (EE). An efficient spin-to-charge conversion through the inverse EE has been demonstrated in metal oxide/$SrTiO_3$ heterostructures with 2DEGs at the interfaces[1]. However, evidence for the charge-to-spin conversion, a technologically more important process, has been lacking. Furthermore, the spin transport mechanism in this system has been unclear.

In this research, we demonstrate the highly efficient charge-to-spin conversion by the direct EE in a 2DEG at an $AlO_x/SrTiO_3$ interface[2]. We conduct the spin torque ferromagnetic resonance measurements on $Ni_{81}Fe_{19}$ (4.2 nm)/AlO_x (2 nm)/$SrTiO_3$ devices. The effective charge-to-spin conversion efficiency of the 2DEG exceeds 10% at room temperature, which is comparable to that of the archetypal charge-spin converter, Pt. The effective charge-to-spin conversion efficiency is found to be suppressed by decreasing temperature, which is ascribed to the decrease of the spin transmission through the AlO_x layer. We analyze the measured effective charge-to-spin conversion efficiency taking into account the temperature dependence of the tunneling conductance of the elastic and inelastic tunneling. Our results demonstrate a crossover of the dominant spin transport mechanism from the inelastic tunneling to elastic tunneling induced by decreasing temperature.

These findings will provide a clue to unlock the full potential of oxide-based spin-orbitronic devices.

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Electrodynamic theory of resonances in gyromagnetic materials: insights and applications

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Recent work on electrodynamic theory of ferromagnetic resonance in gyromagnetic materials has led to the formulation of a transcendental equation for a spherical sample. It aided in the discovery that multiple FMR modes in spheres, including the dominant one, have magnetic plasmon properties with negative effective permeabilities [1,2,3]. On the grounds of the theory, the first direct broadband measurements of the intrinsic ferromagnetic linewidth of monocrystalline garnet spheres have been reported [4]. Measuring the intrinsic linewidth vs. the internal field, as opposed to the extrinsic linewidth vs. frequency, removes inconsistencies such as negative non-physical intercepts and non-linearity [5]. In addition, the theory has been applied to extend the accuracy of resonant-cavity based methods for broad-linewidth samples, where direct broadband measurements are hindered due to low signal-to-noise ratio and the influence of metal coupling structures. The electrodynamic model has also been used for accurate measurements of saturation magnetization [3] since it allows one to consider the permittivity of the surrounding medium and the presence of surrounding metals. Moreover, an electrodynamic model of cavity-coupled films has been proposed and validated [6]. Experimentally observed higher order FMR modes can be attributed to extremely short-wavelength modes distributed across the thickness of the film. Such volume modes in the film coupled to a cavity are different than in a film open to the free space.

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Nonequilibrium Kondo effect under finite thermal bias: An accurate treatment of electronic correlations

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Quantum dot systems have been considered as prospective heat engines that can provide high efficiency due to the considerable thermoelectric figure-of-merit they can achieve. Theoretical description of such nanoscale systems in the presence of strong correlations have been limited to the linear response regime or with serious approximations on the correlations. A recent method incorporating the Numerical Renormalization Group (NRG) and the time-dependent Density Matrix Renormalization Group (tDMRG) based on a thermofield quench approach has been shown to be able to treat strong correlations exactly out of equilibrium far from the linear response regime [1,2]. By reaching sufficiently long time windows, this permits us to extract steady-state non-equilbrium behavior. We use this hybrid NRG-tDMRG method to study the thermoelectric and heat transport through a quantum dot coupled to metallic leads kept at different temperatures and/or potential bias. In particular, we focus on the regime where Kondo effect emerges, and examine how the nonlinear conditions affect the Kondo resonance and its thermoelectric signatures. We present the first quantitatively accurate results for the nonequilibrium Kondo effect under finite thermal bias and its dependence on the potential and temperature on each individual leads.

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Two-band superconductivity in the prototypical heavy-fermion compound $CeCu_2Si_2$ studied by local magnetization measurements

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The discovery of the first heavy-fermion superconductor $CeCu_2Si_2$ was a turning point in the history of superconductivity because it led to the birth of research on unconventional pairing [1]. While the superconductivity of $CeCu_2Si_2$ is closely linked to an antiferromagnetic quantum critical point, the unexpected observations of the multiband superconductivity with absence of nodal quasiparticles have challenged the long-held dichotomy between simple *s*- and *d*-wave spin-singlet pairing states [2,3].

We present in- and out-of-plane temperature dependencies of the lower critical field $H_{c1}(T)$ of $CeCu_2Si_2$ (a critical temperature $T_c \simeq 0.58\,\mathrm{K}$, *S*-type sample) probed by local magnetization measurements performed down to 7 mK using a newly-developed Hall-probe magnetometry [4]. For both the [100] and [001] directions, we found sharp anomalies (at $\simeq 0.34T_c$ and $\simeq 0.41T_c$, respectively) followed by moderate enhancements, indicative of two nearly decoupled bands. Moreover, the $H_{c1}(T)$ curves saturate in the limit $T = 0$, providing a further support for the absence of nodal quasiparticles. A result of our fitting of the $H_{c1}(T)$ curves with a self-consistent γ-model turns out to be more consistent with an $s_{\pm}$-wave scenario with weak interband coupling than a $d_{xy} + d_{x^2-y^2}$ model. In addition to this, we studied the effect of electron irradiation on $H_{c1}(T)$. We observe irradiation to strongly suppress the enhancement of H_{c1} connected with the small gap and this enhancement for $H \parallel [001]$ is hardly visible for a dose as small as $0.8\,\mathrm{C/cm^2}$. However, the $H_{c1}(T)$ dependence above $\simeq 0.4T_c$, which is well described by a single-band BCS-like relation, is robust against disorder for both the crystallographic directions. In addition, the el-irradiation effect on T_c is small and nearly isotropic with a rate of $0.027(2)\,\mathrm{Kcm^2/C}$. Summing up, the saturation of $H_{c1}(T)$ at the lowest temperatures and the strong effect of nonmagnetic disorder on the H_{c1} enhancement at $T \ll T_c$ seem to favor an $s_{\pm}$-wave scenario.

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Wrestling with the finite temperature two dimensional Fermi-Hubbard Model: A Tensor Network Approach

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The Fermi Hubbard Model is a simple model of interacting electrons on a lattice. However, solving it in two dimensions has been a long-standing challenge. Recent advancements in numerical tools like tensor network methods, specifically infinite projected entangled pair states (iPEPS), have enabled a better understanding of the ground states of the model [1] in the thermodynamic limit (infinite size). Finding solutions at finite temperature, however, has seen limited success, and even then only for small lattices. In our work, we leverage the newly developed Neighborhood Tensor Update (NTU) [2] and imaginary time evolution with iPEPS to reach temperatures as low as 0.17 times the hopping rate working in the thermodynamic limit. Our findings [3] reveal disruption in the antiferromagnetic background with mobile holes in a slightly doped Hubbard model, as well as the presence of hole-doublon pairs and signatures of hole-hole repulsion. Currently, we are developing algorithms to reach lower temperatures by repurposing NTU to work with pure states on finite PEPS and computing the thermal observables. Simultaneously, we have made considerable progress in simulating the short real-time dynamics of the Fermi-Hubbard model [manuscript in preparation]. Our objective is to compute the spectral function of a single hole doped half-filled Hubbard model, in order to establish connections with angle-resolved photoemission spectroscopy (ARPES) experiments involving mobile dopants in correlated antiferromagnets. During my presentation, I will give highlights of the numerical challenges that we have faced and outline our efforts to overcome these challenges through the construction of new tensor network algorithms. The application of these algorithms not only provides valuable insights into the physics of the under-doped Hubbard model, but can also be applied to the study of other bosonic and fermionic models. Our findings serve as reliable benchmarks for both theoretical work and experiments with ultracold atoms.

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Field-Dependent Magnetic Ordering Dome and Quantum Spin Fluctuations in the Natural Mineral Henmilite

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Quantum materials have been playing a crucial role in the development of next-generation technologies and devices including quantum computers. Such materials are usually prepared under laboratory conditions. However, some naturally occurring minerals, have also been found to feature complex magnetic ground states, such as Henmilite [2], or Herbertsmithite [1,8]. They possess spin ½ Cu ions which exhibit a magnetic ground state favouring the creation of quantum fluctuations, hinting at a possible quantum spin liquid state [2].

Henmilite is a bright blue-violet colour mineral, which has been suggested to consist of coupled two-leg ladders, where strong quantum fluctuations suppress (AF) magnetic order at low temperatures [2]. It is an extremely rare mineral only found in the Fuka mines of Japan [6]. In Henmilite, the B-T phase diagram has an unusual antiferromagnetic dome [2]. The nuclear crystal structure is complex and contains well-separated sheets of $Cu(OH)_4$ square-planar plaquettes, separated by a network of $Ca(OH)_8$ and $B(OH)_4$ polyhedra. DFT (GGA+U) calculations found interlayer magnetic coupling less than 1% of the dominant intra-plane coupling, confirming the magnetic 2-dimensionality of the material [2].

We will present our experimental results of magnetic susceptibility, heat capacity, and thermal conductivity experiments as well as corresponding theoretical calculations for its magnetic ground structure. A Muon spectroscopy experiment is scheduled at HiFi instrument, ISIS UK, allowing us to study magnetic ground state and spin dynamics in short-range correlation regions above T_N. We will use the newly developed instrument ALSA [7], an AI-controlled robotic arm to co-align smaller crystals into mosaics to use for μSR experiment and later on for neutron spectroscopy.

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ORAL CONTRIBUTIONS

ABSTRACT CATEGORIES

1. Strongly Correlated Electrons and High Temperature Superconductivity

Heavy fermions and Kondo systems; Charge, orbital, and multipole orderings and excitations; Quantum phase transitions; Metal-insulator transitions; Highly correlated metals and insulators; Itinerant electron magnetism; Organic conductors; Low dimensional conductors, Correlation effects in mesoscopic systems; Multiferroics

2. Quantum and Classical Spin Systems

Low dimensional quantum magnets; Frustrated magnets and spin liquids; Quantum phase transitions; Lattice effects and spin Peierls systems; Solitons and nonlinear effects; Statistical mechanics of quantum and classical systems; Molecular magnetism; Quantum tunnelling and coherence; Quantum information; Organic and organo-metallic materials

3. Magnetic Structure and Dynamics

Crystal field and anisotropy; Magnetic structure and spin waves; Dynamic phenomena; Electronic structure; Magnetic interactions; Rare-earth and actinide magnetism; Transition metal alloys and compounds; Spin glasses; Random magnets; Magnonic crystals

4. Spin Electronics and Magneto-Transport

Magnetoresistance effects; Current induced magnetization reversal; Spin injection and accumulation; Spin Hall effect, Magnetic Semiconductors; Optical properties; Quantum computation

5. Nano-structure, Surfaces, and Interfaces

Surfaces and interfaces; Films, multilayers and superlattices; Exchange interaction and anisotropy; Spin dynamics, Patterned films; Nanoparticles; Nanowires and dots

6. Soft and Hard Magnetic Materials

Amorphous and nanocrystalline materials; Granular materials; Ferrites, garnets and microwave materials; Permanent magnets; Magnetization processes; Magneto-elastic and magnetostrictive materials; Modeling and simulations

7. Applications

Magnetic sensors; Ferromagnetic shape-memory materials; Actuators and magnetic drives; Magnetic refrigeration; Magnetic fluids; Magnetic separation and levitation

8. Other Topics

Biomagnetics; Magnetism in medicine; Measuring techniques and instruments; Magnetic recording and memories

Quantum entanglement in an extended Hubbard model as evaluated from a spin concurrence measure

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Quantum entanglement is a peculiar feature of quantum mechanics that turns out a powerful resource in quantum communication and information. For this reason, intense research has recently focused on the robustness of quantum entanglement also in strongly correlated electron systems. Here, we consider an extended Hubbard model on a dimer and evaluate the spin entanglement at finite temperature, under the action of an external magnetic field. We show how magnetic field and intra- and inter-atomic Coulomb interactions modify the spin concurrence, finding out that the magnetic field may act as a switch from a non-entangled to an entangled state.

Spin-split van Hove singularities and Kondo physics

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Despite vast experimental progress in Heavy-Fermion research over last decades, a number of major puzzles remain unsolved. In particular, in some materials (*e.g.* strontium ruthenates) the nature of magnetic-field-driven quantum criticality has not been determined. It may be caused mainly by quantum fluctuations, or rather the van Hove singularity present near the Fermi level may play the major role [1].

To better understand the tension between these two mechanisms, an analysis of a simple impurity model, which can clarify the fate of the Kondo effect in the host exhibiting a spin-split van Hove singularity is proposed. The model is solved with numerical renormalization group. The novel aspect of this study is to include spin-splitting of the band, whose influence on the phase diagram is expected to be as prominent as this of potential scattering braking particle-hole symmetry, which in some cases causes a quantum phase transition between the Kondo and the asymmetric local moment phases [2]. Such splitting is seen experimentally in surface spectroscopy of $Sr_3Ru_2O_7$, even in the absence of external magnetic field [1].

In my presentation I will show the results concerning local spin susceptibility, χ_{loc}, impurity contribution to global susceptibility, χ_{imp}, and impurity contribution to entropy, S_{imp}, as functions of the type and location of singularity (note that $\chi_{\mathrm{imp}} = \chi_{\mathrm{loc}}$ only in the flat-band limit [3]), identifying all the relevant phases.

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Connection between the semiconductor–superconductor transition and the spin-polarized superconducting phase in the honeycomb lattice

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The realization of the honeycomb lattice in graphene draws a lot of attention of the scientific community. The extraordinary properties of the honeycomb lattice are mainly associated with massless Dirac fermions, which are located in the corners of the Brillouin zone. As a consequence, fermions in this lattice manifest a semiconducting behavior below some critical value of the onsite attraction, U_c. However, above U_c, the superconducting phase can occur. This lattice exhibits also topological properties manifested by the existence of zero-energy edge states or in the quantum Hall effect, associated to the finite Berry curvature in these systems. The electronic properties of the honeycomb lattices has opened new avenues of research in which applications play a very important role, i.e., spintronics or valleytronics.

Here, we discuss an interplay between the semiconductor–superconductor transition and the possibility of realization of the spin-polarized superconductivity (the so-called Sarma phase) [1]. We show that the critical interaction can be tuned by the next-nearest-neighbor (NNN) hopping in the absence of the magnetic field. Moreover, a critical value of the NNN hopping exists, defining a range of parameters for which the semiconducting phase can emerge. In the weak coupling limit case, this quantum phase transition occurs for the absolute value of the NNN hopping equal to one third of the hopping between the nearest neighbors. Similarly, in the presence of the magnetic field, the Sarma phase can appear, but only in a range of parameters for which initially the semiconducting state is observed. Both of these aspects are attributed to the Lifshitz transition, which is induced by the NNN hopping as well as the external magnetic field.

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Evolution of magnetic ground state in $A\mathrm{Co_2As_2}$ (A = K, Ca, Sr, Ba) system

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$A\mathrm{Co_2As_2}$ (A = K, Ca, Sr, Ba) and $\mathrm{BaMn_2}X_2$ (X = P, As, Sb, Bi) compounds that both crystallize in $\mathrm{ThCr_2Si_2}$-type tetragonal structure together present a text-book type example of how the structural parameters and electronic band structure can indirectly govern the magnetic ground state of a crystalline system. $A\mathrm{Co_2As_2}$ compounds exhibit properties that delicately depend upon the interlayer As-As distance $d_{\mathrm{As-As}}$ which regulates the oxidation state of Co-ions by controlling the extent of the interlayer As-As bonds. As a result, it controls the magnetic ground state of these materials [1]. On the other hand, d_{X-X} does not show any significant variation within $\mathrm{BaMn_2}X_2$ compounds and because of the localized nature of d-bands, it does not affect the oxidation state of the Mn-ions as well as the magnetic ground state of these compounds [2]. In this work, we present a comparative study on $A\mathrm{Co_2As_2}$ and $\mathrm{BaMn_2}X_2$ systems. Further, we explore the combined effect of the change of electron count as well as the increase in $d_{\mathrm{As-As}}$ introduced through the partial substitution of alkaline-earth ions in the $A\mathrm{Co_2As_2}$ system. We report on the magnetic characteristics and electron transport properties of this hole-doped system and explore the interdependency of structural parameters, charge density and many-body interactions within the material.

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Structural, electronic and magnetic properties of doped CrAs

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Transition metal pnictides are an important family of compounds with several applications such as in photovoltaics [1], spin-dependent transport [2] and optoelectronics [3] to name a few. High temperature superconductivity discovered in Fe-based pnictides renewed excitement and interest in these materials [4-6]. Binary CrAs is an interesting system as it exhibits an interplay between lattice and magnetic structures and superconductivity (SC), where a spin reorientation transition induced by pressure results into anti-parallel alignment of nearest neighbour spins in the vicinity of SC [7]. The compound exhibits highly tuneable magnetic moment and propagation vector. Although application of pressure allows a cleaner method of tuning, it would be interesting to investigate the effect of dopants on CrAs. Controlling the electron count through doping have been successful in achieving SC in compounds containing FeAs [4-6]. We report the effect of doping CrAs with Mn, Fe, Co and Ni. X-ray diffraction measurements indicate that all the doped samples crystallize in the orthorhombic MnP type crystal structure with space group *Pnma*. Electrical resistivity data measured at $\mu_0 H = 0$ and 8 T show metallic behaviour and indicate the presence of a sizable magnetoresistance in all the four doped samples. Electrical resistivity and magnetic susceptibility results reveal that the antiferromagnetic ordering observed at Néel temperature $T_N \approx 260$ K in CrAs is absent in the doped samples. Additionally, evolution of ferromagnetic ordering below ~ 50 K is observed in the Mn doped sample. These results will be analysed and reported in detail in this contribution.

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Many-body correlations in one-dimensional optical lattices with alkaline-earth(-like) atoms

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We explore the rich nature of correlations in the ground state of ultracold atoms trapped in state-dependent optical lattices [1]. In particular, we consider interacting fermionic ytterbium or strontium atoms, realizing a two-orbital Hubbard model with two spin components. We analyze the model in one-dimensional setting with the experimentally relevant hierarchy of tunneling and interaction amplitudes by means of exact diagonalization and matrix product states approaches, and study the correlation functions in density, spin, and orbital sectors as functions of variable densities of atoms in the ground and metastable excited states. We show that in certain ranges of densities these atomic systems demonstrate strong density-wave, ferro- and antiferromagnetic, as well as antiferroorbital correlations.

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Vacancy-driven magnetism of $GdMnO_{3+\delta}$ multiferroic compound

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Multiferroic $GdMnO_3$ compound orders antiferromagnetically below $T_N = 40$ or 44 K [1] and undergoes order-to-order magnetic phase transition into low temperature canted magentic phase at T_{lock}. Transition at T_{lock} is hysteretic and it occurs at 20 or 25 K during the heating, but at 15 or 20 K during the sample cooling [2]. The ferroelectricity can be observed if the magnetic field is applied along the a-axis (using description within the *Pnma* space group) [3], but some authors report the ferroelectricity also at zero magnetic field and in temperature range 5.1 – 7.5 K [2]. $GdMnO_3$ belongs to orthorhombically distorted, $GdFeO_3$-type perovskites. This family of compounds is naturally vacant, so the well-established general notation for these compounds is $ABO_{3+\delta}$. The physical properties can be very sensitive to δ. For example, in $LaMnO_{3+\delta}$ the magnetic ordering temperature varies from 139 K to 154 K, depending on δ [4]. The impact of δ to "$GdMnO_3$" physical properties was not studied yet, but we hypothesize and we will try to proof that the huge discrepancies in the literature are in fact the impact of δ on $GdMnO_{3+\delta}$ magnetism.

Three different samples were prepared by a vertical floating zone method. All growing conditions except for the preparation atmosphere were kept identical. The atmosphere was chosen to be O_2, air or Ar. The choice of the atmosphere resulted to different δ in the samples. All samples exhibit T_N in temperature range 41 – 43 K, but lower temperature anomalies differ substantially: Sample prepared in air exhibits an increase of zero-field-cooling magnetization (ZFC) with increase of temperature at 12.7(1) K and then the decrease at $T_{lock} = 18.7(1)$ K. Sample prepared in Ar exhibits an increase of ZFC magnetization with increase of temperature at 7.5(1) K and decrease at $T_{lock} = 23.4(1)$ K. Sample prepared in O_2 exhibits only very weak anomalies at 11.6 K and $T_{lock} = 18.5$ K. The anomaly at T_{lock} is connected with bifurcation of the ZFC-FCW curves for samples prepared in Ar and air. ZFC-FCW curves bifurcate at 26(1) K for sample prepared in O_2. All these facts can be considered as an experimental proof of our hypothesis. More detailed data analysis will be presented in the contribution.

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Observation of strongly correlated electronic ground state in rhombohedral graphite

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In crystalline solids, the interactions of charge and spin can result in a variety of emergent quantum ground states, especially in partially filled, topological flat bands such as Landau levels or in "magic angle" graphene layers. Rhombohedral graphite (RG) is perhaps the simplest and structurally most perfect condensed matter system to host a flat band, which is also protected by the symmetry.

In this talk we provide detailed investigation of the flat band in RG by using low temperature Scanning Tunneling Microscopy (STM) measurements combined with electronic structure calculations [1]. We measured the flat surface band of 8,10 and 17 layers of RG at various charge densities and found correlated behavior up to a temperature of 20 K. At charge neutrality we also identified a degenerate ground state, forming a competing domain structure between a sublattice antiferromagnetic insulator and a gapless, correlated paramagnet. Our density-matrix renormalization group (DMRG) calculations explained this observation by revealing a degenerate ground state of the system and demonstrate the important role of the correlation effects. Our work establishes RG as a platform to study many-body interactions beyond the mean-field approach, where quantum fluctuations and entanglement dominate.

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Quantum dot detects Majorana modes of both chiralities

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A model of a tunneling junction between normal electrode and $1D$-topological wire, mediated by a quantum dot (QD), is investigated. The semiconducting wire, subjected to an external magnetic field, is described by a tight-binding Hamilotnian with Rashba field term and induced s-wave superconductivity. Above the critical magnetic field, the wire can be driven into topological p-wave phase with end-state Majorana zero modes (MZMs). The dot is coupled to the one of its ends and a normal electrode, forming tunneling junction. The self-energy of the dot's Green"s function coming form the wire is calculated within recursive summation Green's function method. The model is investigated for topological as well as trivial state of the wire.

The present investigations are motivated by the recent experimental findings [1] showing that an unintentional quantum dots can be formed in the tunneling junction between normal electrode and superconducting wire. This feature changes considerably the picture of possible MZM spotting, as the trivial localized QD states close to Fermi energy, can be mistakenly regarded as Majorana modes. This casts a serious doubt on the previous conductance spectroscopy measurements of MZM detection [2].

We demonstrate that the presence of a quantum dot in the tunneling junction can itself be advantageous for MZM detection. Namely, we show that for the dot strongly coupled to the wire, both the Zeeman split QD levels $\epsilon_{\downarrow}$ and $\epsilon_{\uparrow}$, when subsequently tuned to Fermi energy by gate voltage, can detect MZMs. These modes belong to the different chiral sub-bands formed in the wire while in topological state [3] and originate form the Majorana Kramers pairs, present in time-reversal invariant superconductors [4]. The detection is manifested by characteristic three-peak structures in the density of states of the dot. The satellite peaks in this structure, adjacent to the MZM "leaked" into the dot, come from hybridization of QD spin-sublevels with MZM of appropriate chirality. The direction of magnetic field determines which chiral sub-band of the wire is stronger coupled to the dot. For this chirality the satellite peaks, whose positions are proportional to QD-wire coupling, can be pushed outside the superconducting gap, and the remaining MZM resonance can be hardly distinguished from an accidental state close to Fermi energy. However, the three-peak structure is still preserved in the second chiral sub-band, due to a weaker coupling to the dot, and it can be noticed in conductance spectroscopy. This behavior is in contrast to the presence of trivial states only, for which such structures never appear in any chirality.

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Spin-orbit singlet magnetism - Induced atomic U- and Ru-moment in URu_2Si_2 and in Sr_2RuO_4

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Despite the fact that spin-orbit (s-o) interactions are well know in the atomic physics its importance in the solid-state physics was only recognized about 15 years ago with studies of $5d/4d$ oxides like Sr_2IrO_4 or Sr_2RuO_4 [1,2]. Earlier a scientific papers pointing out the fundamental importance of the s-o interactions also in more-discussed $3d$ oxides have been rejected [3,4,5,6,7] even in the most prestigious journal as PRL or PRB with arguments that they are weak interactions, not of importance compared to U and J_H parameters of the energy size of 5 and 0.5 eV, respectively. Also, that there is no needs for such interactions for explanation of known, at that time, phenomena. A "revolution" about the importance of the s-o interactions seems to start with two Phys.Rev.Lett.'s papers of Jackeli and Khaliullin in 2009 [1,2]. In the first one they interpreted INS excitations in Sr_2IrO_4 as due to s-o interactions in the Ir^{4+}-ion in the $5d^5$ configuration [1]. In the second paper they managed to convince the PRL Editor that weak s-o interactions in the $V^{4+}(3d^1)$-ion produce the nonmagnetic state of the whole Sr_2VO_4 oxide [2] in contrary to my earlier submissions from 1997-2010. This nonmagnetic state is clearly shown in Fig. 1 of Ref. [4] from 1999 with detailed examples of the V^{4+} ions in $BaVS_3$ [6,7] and in Sr_2VO_4.

In this contribution I will discuss $3d/4d/5d$ compounds/oxides underlying i) formation of the charge ionic state with the well-defined integer valency, like U^{4+} and Ru^{4+} ions, ii) the discrete quasi-atomic crystal-field+s-o spin-orbital low-energy electronic structure and iii) the preservation of this low-energy (below 1 meV) quasi-atomic $3d/4d/5d$ electronic structure also in solid crystals. As the s-o effects I will discuss the formation of the singlet nonmagnetic ground state of the $U^{4+}(5f^2)$ and $Ru^{4+}(4d^4)$ ions and their preservation in URu_2Si_2 [3] and in Sr_2RuO_4. In the presented approach, which one could call as Quantum Atomistic Solid-State Theory (QUASST), the orbital moment, as the s-o effect, will be discussed in NiO (Ni^{2+}) [5] and in $FeBr_2$ (Fe^{2+}) [8].

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Thermodynamcis of highly frustrated quantum magnets: Kagome vs. Square-Kagome

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Highly frustrated quantum spin systems are in the focus of theoretical and experimental studies due their unconventional properties such as highly entangled spin-liquid ground states and fractionalized excitations. The most prominent example is the s=1/2 kagome Heisenberg antiferromagnet (HAFM). Very recently the square-kagome HAFM has come into the focus as another promising candidate of a quantum spin-liquid material [1-3]. So far the theoretical studies of the s=1/2 kagome as well as square-kagome HAFM are focussed on ground state properties, whereas much less is known on thermodynamics. We fill this gap by large scale numerical simulations of both models using the finite-temperature Lanczos method for system sizes of $N = 18, 24, 30, 36, 42, 48$, and 54 [4-8]. We find a striking similarity of the temperature profiles of the basic thermodynamic properties of the square-kagome and the kagome HAFM down to very low temperatures T. The specific heat exhibits a low-temperature shoulder below the major maximum which can be attributed to low-lying singlet excitations filling the singlet-triplet gap, which is significantly larger than the singlet-singlet gap. This observation is further supported by the behavior of the entropy $S(T)$, where a change in curvature is present just at about $T/J = 0.2$, the same temperature where the shoulder in C sets in. For the susceptibility the low-lying singlet excitations are irrelevant, and the singlet-triplet gap leads to an exponentially activated low-temperature behavior. The maximum in $\chi(T)$ is found at a pretty low temperature $T_{\max}/J = 0.146$ compared to $T_{\max}/J = 0.935$ for the unfrustrated square-lattice HAFM signaling the crucial role of frustration also for the susceptibility. The magnetization process featuring plateaus and jumps and the field dependence of the specific heat that exhibits characteristic peculiarities attributed to the existence of a flat one-magnon band are as well discussed.

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Electron transfer and magnetism in hybrid molecular magnets based on $\{V_{12}O_{32}\}$ vanadium cage and functionalized with phtalocyaniato lanthanide moieties $(LnPc)_n$ (n=1,2)

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There are many different types of molecular magnets synthesized in the last decades in hope of practical application in quantum computing or molecular electronics. Their properties are determined by the type of magnetic ions and the molecular structure in which they are incorporated. Hybrid molecular magnets comprise at least two different types of magnetic molecules coupled with each other, which should lead to new interesting properties and applications.

In this contribution we present magnetic and electronic properties of a family of hybrids $(PcLn)_n$-$\{V_{12}O_{32}\}$ (n=1,2) consisting of a vanadium core $\{V_{12}O_{32}\}$ coupled covalently to a phtalocyaniato lanthanide moiety (LnPc). By using combined experimental (EPR, DC and AC SQUID) and theoretical (DFT, MD and model Hamiltonian approach) methods it is demonstrated that the proximity of the molecules in solid state and in concentrated solutions induces partial reduction of V^{5+} centers due to the electron transfer from Pc to $\{V_{12}O_{32}\}$. The intramolecular (through Ln) and intermolecular (through counter cations) electron transfers can coexist in different proportions dependent on Ln. As a result an unpaired electron can be found delocalized over $\{V_{12}O_{32}\}$ and/or at Pc. The research is carried out for Ln=Sm^{3+} - Er^{3+} and diamagnetic Lu^{3+} and Y^{3+}, but we focus mainly on molecules with $n = 1$ and Ln=Lu^{3+} or Ln=Dy^{3+} for which all the effects can be clearly demonstrated. The Dy^{3+} based hybrid appears to be also a field induced single molecule magnet with a slow relaxation of order 10^{-3} s. It has been also proven that there is an interaction between a radical electron and Dy^{3+}.

Our results open the way to further investigation of such hybrids, e.g. in electric field, which can pave the way to their application in molecular electronics or spintronics.

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Raman signatures of spin-liquid-like state and spin-phonon coupling in $Sr_2CuTe_{0.5}W_{0.5}O_6$

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Disorder or randomness in exchange pathways can produce uncompensated interactions in spin-lattice to induce a spin-liquid state. Sr_2CuTeO_6 and Sr_2CuWO_6 are square-lattice antiferromagnetic double perovskites ($A_2BB'O_6$) with dominant nearest-neighbor (Néel-type) and next-nearest neighbor (Columnar-type) magnetic interactions, respectively [1]. Random distribution of both these interactions in a system has been proposed to the key to spin-liquids [1].Here, we synthesize a possible spin-liquid candidate $Sr_2CuTe_{0.5}W_{0.5}O_6$ with B′-site mixing to explore the phonon properties and their correlation to the liquid-like interactions. Our measurements evidence a broad continuum in the Raman spectra instead of well-defined spin-wave excitations noted for the parent systems. Further, phonon anomalies are marked below the short-range magnetic ordering temperature. Observation of continuum feature in conjunction with the lack of long-range magnetic order strengthens the possibility of liquid-like correlations, as predicted in earlier studies. On the other hand, phonon anomalies indicate the existence of spin-phonon coupling.

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Multiferroicity with improper ferroelectricity and uniaxial ferromagnetism in $EuAl_{12}O_{19}$

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We report the discovery of a multiferroic phase in $EuAl_{12}O_{19}$ with ferroelectric ordering at T_e=50 K and a ferromagnetic ordering at T_C=1.3 K. $EuAl_{12}O_{19}$ is a quasi-two dimensional ferromagnet with magnetic ions Eu^{2+} building a planar triangular lattice. The magnetic ground state is ferromagnetic with a strong magnetic anisotropy, which may results from allowed Dzyaloshinskii–Moriya interactions. At the center of every second triangle of magnetic ions sits an electric dipoles AlO_5. The electric dipoles form also a triangular lattice, which may realize ferroelectric frustration, an analog of the famous problem of frustrated magnetism on a triangular lattice. These electric dipoles order via an improper ferroelectric phase transition at T_e=50 K leading to an unusual case of type I multiferroicity in $EuAl_{12}O_{19}$.

Topological superconductivity induced by two-dimensional nontrivial spin structures

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Nontrivial spin textures often give rise to topologically nontrivial quantum states and associated unconventional magnetic, transport, and optical phenomena. Usually, the Dzyaloshinskii-Moriya interaction is considered as the stabilization mechanism. In this work, we show how the Ruderman-Kittel-Kasuya-Yosida-type interaction can lead to the formation of similar structures. It has been demonstrated that helical spin structures in superconducting nanowires and ladders can induce topological superconductivity with Majorana edge states. We generalize this result to two-dimensional systems, i.e., we show the stability of nontrivial spin structures in two-dimensional superconducting systems, where they also can lead to topological superconductivity with Majorana edge states. Such systems are promising for use in fault-tolerant quantum computing.

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Expanding the library of $S_{eff} = 1/2$ pyrochlore antiferromagnets: Structure and magnetic properties of $NaCdCo_2F_7$ and $NaCdCu_2F_7$

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Materials with a pyrochlore lattice of magnetic ions have experienced decades of intense study due to the frequently exotic electronic properties brought about by the magnetic frustration. Previously these materials were typically rare-earth oxides, but more recently a class of 3d transition metal fluorides have garnered the attention of the condensed matter community. The greater extent of the 3*d* orbitals, compared to the rare-earth 4*f* orbitals, leads to greater magnetic exchange and stronger magnetic interaction strengths, leading to mean-field interactions of Θ_{CW} ~ -100 K in all studied members of the family. Despite the strong interactions, no magnetic transitions are observed down to < 4 K, where a spin -glass freezing occurs [1–3]. The spin-glass state is attributed to magnetic bond disorder arising from, fully random, mixed occupancy of the non-magnetic pyrochlore A-site. Theoretical models support this interpretation. The true Hamiltonian of the Co^{2+} pyrochlores is somewhat contentious: inelastic neutron scattering measurements indicate short range correlations with an XY anisotropy [4] and strongly anisotropic *g*-tensor [5], supported also by PDF analysis of magnetic correlations [6]; despite this, both low-field and high-field magnetisation data for $NaCaCo_2F_7$ measured along various crystallographic axes show no signs of anisotropy; and ESR measurements indicate a much smaller experimental *g*-factor of ~ 2, compared to that expected from the INS results. More materials and studies are needed to gain better understanding of these systems.

In this contribution, I will present the structural and magnetic properties of two new members of the family, $NaCdCo_2F_7$ and $NaCdCu_2F_7$. I will present a comparison with the previously investigated members. Notably the *A*-site Na/Cd ion size discrepancy is greater than the previously studied Na/Sr and Na/Ca analogues, leading to greater magnetic bond disorder. In the $S_{eff} = 1/2$ Co^{2+} this leads to a spin-glass transition with an enhanced spin-glass freezing temperature, as expected. The $S = 1/2$ Cu^{2+} pyrochlore appears unique in this family, with avoidance of the spin-glass freezing down to less than our lowest investigated temperatures (0.3 K), making $NaCdCu_2F_7$ a quantum-spin-liquid candidate.

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On localized magnons in the sawtooth chain with Dzyaloshinskii-Moriya interaction

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In the present talk we consider an extension of the flat-band scenario in one-dimensional frustrates $S = 1/2$ spin model, which becomes possible due to additional antisymmetric exchange (Dzyaloshinskii-Moriya interaction) in general and in its particular case, magnetoelectric coupling due to Katsura-Nagaosa-Baladsky (KNB) mechanism. Thus, in the context of KNB mechanism one can have an electric field induced flat bands. We present several classes of flat bands for general of $S = 1/2XXZ$ sawtooth chain with three couplings and three DM interactions. Electric field acting on the spin configurations due to KNB mechanism can induce a localized one-magnon states even if the parameters of symmetric exchange interaction do not satisfy the flat band condition. Tuning the magnitude and the direction of the electric field, one can obtain several flat-bands. Interestingly, if the direction of the electric field coincides with the basal line of the chain, the value of the saturation magnetic field can be reduced.

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Magnetic states in ZnO nanoparticles : The interface between organic and inorganic materials

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ZnO is a widely studied materiel due to its promising properties, as high electron mobility, chemical and thermal stability, photoelectric response, non-toxicity and low cost production. Besides it, ZnO nanoparticles (NP's) produced by sol-gel method stands out in the new technologies scenario due to the interaction with visible light performed by these NP's, which is useful for the development of new light-based dispositives, such as spin-polarized solar cells and spin light-emitting diodes (LEDs). The key point is that part of the magnetic behavior observed in ZnO NP's produced by sol-gel method after illumination by visible light (405nm) comes from an organic-inorganic interaction that occur in the NP's surface.

The energy provided by the light is not sufficient to promote an electron from the valence to the conduction band in the ZnO (bandgap 3.3 ev) but it's enough to create an pair electron-hole that will interact with organic compounds that surround the NP's in a solvation shell.

This interaction allows the creation of methyl radicals that are stable and observable in EPR. An interesting phenomenon occurs at temperatures near 30K, where the system passes by a transaction and the Curie's law for paramagnetic materials $X = C/T$ is broken.

In this work, we present a physical model supported by different characterization techniques that explains the organic-inorganic interaction in the NP's surface and the behavior of the paramagnetic states at different temperatures.

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Magnetic structure and phase diagram of the quasi-1D Ising-like antiferromagnet PbCo2V2O8

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The study of quantum phase transitions (QPTs) has become increasingly popular, as it offers valuable insights into the fundamentals of magnetism. Unlike classical phase transitions, which are driven by thermal fluctuations, QPTs occur at zero temperature when a non-thermal external parameter, such as pressure, magnetic field, or chemical doping, is adjusted. One of the classic examples of a system with a QPT is the Heisenberg-Ising model in a transverse magnetic field. Recently, experimental studies have focused on quasi-1D Heisenberg-Ising antiferromagnetic AM_2V_2 materials. I will present findings from various measurements performed on the $PbCo_2V_2O_8$ material, which is almost isostructural to $SrCo_2V_2O_8$ and $BaCo_2V_2O_8$ compounds and is considered as a quasi one-dimensional Ising-like antiferromagnet [1,2,3]. The measurements include: heat capacity, low and high field magnetization and neutron powder diffraction (NPD) conducted below the Néel temperature $T_N = 3.8$ K. The magnetic susceptibility parallel to the c-axis exhibits a broad maximum near 40 K, characteristic of a low dimensional antiferromagnet. The study also establishes the phase diagram for $H\|c$, $H\|a$, and $H\|[110]$, through magnetic and heat capacity measurements. Additionally, the magnetic structure of the material at 0 T is determined using NPD results. It has been found that the phase diagrams of $PbCo_2V_2O_8$, similar to that of $SrCo_2V_2O_8$ and $BaCo_2V_2O_8$, reveals a new magnetic phase, which has not been reported yet, most likely due to lower energy scale of the studied system.

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Magnetic properties of V_2MnGa, V_2MnAl, V_2FeGa and V_2FeAl.

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The investigated materials belong to Heusler compounds and are similar in composition to titanium-based analogs, like Ti_2MnAl, which was suspected of exhibiting Spin Gapless Semiconductor (SGS) or Weyl semimetal state in some earlier papers. The vanadium-based analogs are not well known in earlier reports. Therefore we show here our results of XRD analysis of the synthesized samples, their magnetic properties, and their resistivity measured vs. temperature. Heusler compounds can crystallize in simple or inverted structures, here we try to resolve which one is more probable in that materials and whether SGS state can exist in them.

Ultrafast Nonlinear Conversion of Magnons in an Antiferromagnet

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Propagating magnons, or spin waves, have recently attracted a lot of interest as strongly interacting potential information carriers, which do not generate Joule heating. In antiferromagnetic materials the frequencies of the magnons lie in the THz range, compared to the GHz range in ferromagnets, allowing for orders of magnitude faster information processing in antiferromagnets [1]. The first experimental demonstration of generation and detection of the coherent propagating magnons in an antiferromagnet was very recently reported [2]. The breakthrough is based on using nanoscale confinement of the laser pump pulse to excite magnons, and selective detection of them is achieved by scattering of another probe pulse. In this work we capitalise on this discovery to harness strong nonlinear coupling between magnons and realise ultrafast converter of quasi-uniform spin precession into propagating magnons with higher frequencies (energies) and wavenumbers (momenta). Our discovery enables control over the spin waves, required to make them suitable for information processing in the form of logic gates [3]. We demonstrate supressing or amplifying of THz propagating magnons, mimicking the operation of a transistor. To this end, we perform a double pump - probe experiment. The first pump pulse launches spin dynamics, which are modulated and transformed by the second pump. The dynamics are probed magneto-optically, using the detection mechanism reported in [2]. From the 2D spectrum of the dynamics, we find that the amplitude of the detected spin wave can be controlled by the delay between the pumps. This amplitude modulation is intrinsically nonlinear, as we observe the features at (f_k, f_k) frequencies (interference), and around (f_0, f_k) frequencies (nonlinear conversion), where f_k is the finite-k component of the freely propagating spin wave, and f_0 is the frequency of the uniform spin precession. Using the Lagrangian formalism for describing nonlinear spin dynamics [4], we can show that our experiment can be interpreted as conversion of the quasi-uniform spin precession to the finite-k magnon modes by a second light pulse. The converter enables ultrafast modulation of spin waves in an antiferromagnet, which is a major milestone in THz magnonics.

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New insights into intrinsic anomalous Hall effect from Fe(001) angle resolved photoemission

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The anomalous Hall effect (AHE), i.e. the occurrence of the transversal voltage when a longitudinal current flows through the ferromagnetic sample placed in the magnetic field, has been the subject of numerous experimental and theoretical studies, however, a complete picture of the AHE, which combines the roles of intrinsic and extrinsic scattering-related mechanisms has emerged only relatively recently [1]. The intrinsic contribution to AHE is described in terms of the Berry-phase curvatures and it is therefore an intrinsic quantum-mechanical property of a perfect crystal [2]. The intrinsic contribution to AHE depends therefore on the details of the electronic band structure of a ferromagnet in the vicinity of the Fermi level. It is established, that the intrinsic contribution dominates in the moderately conducting ferromagnetic samples, such as thin films [1].

In this contribution we will present results of the combined experimental and theoretical study, where we use angle-resolved photoemission spectroscopy to determine, which of the theoretical ab initio methods of describing the electronic band structure of bcc Fe is the closest to the experimentally obtained band structure. The experiments are performed on Fe(001) films deposited on Au(001) at cryogenic temperatures and the theoretical methods that we use are local density approximation (LDA) and the generalized gradient approximation (GGA) and GGA corrected with many-body perturbation theory in the GW approximation.

We find the best agreement between the experimental results and the photoemission simulation based on the initial state band structure given by the GW method. In the next step, we use the GW band structure with the experimental Fermi level position to calculate the value of the intrinsic AHE in bcc Fe, and we find a value of $\sigma_{xy} = 845$ S/cm, which is much closer to the experimentally measured value of $\sigma_{xy} \approx 1000$ S/cm [4] than previously available results based on GGA band structures. This finding improves our understanding of not only the anomalous Hall effect itself, but also of other related phenomena, such as the anomalous Nernst effect and shows that highly-precise results of these transversal transport properties require a very accurate evaluation of the electron structure beyond the conventionally used GGA to the exchange-correlation functional used in DFT.

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Generating different skyrmion types in ferromagnetic/ferrimagnetic bilayers

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Magnetic skyrmions are particle-like objects with a whirling structure in an otherwise uniform magnetic medium. They have been proposed as bit carriers for computing and memory applications due to their small size and energy efficient movement [1]. However, their implementation requires overcoming some issues, such as maintaining a stable inter-skyrmion distance. For this challenge, using two distinct solitons for encoding the information has been suggested [2]. Recently, the coexistence of two skyrmion types in a ferromagnetic/ferrimagnetic/ferromagnetic trilayer has been demonstrated at room temperature [3], providing the opportunity for real device applications. Tuning the ferromagnetic layer thickness and therefore its magnetic anisotropy results in a fine tunning of the skyrmion type in these trilayers [4]. Here we demonstrate that two skyrmion types can coexist in a simplified system, i.e. a ferromagnetic/ferrimagnetic bilayer. We show that the skyrmion type can be controlled by tuning the magnetic anisotropy of the ferrimagnetic layer. The simpler geometry of the bilayers paves the way for local control of the skyrmion type via, for example, voltage-controlled magnetic anisotropy and opens new directions for 3D devices.

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Anomalous Hall effect, weak (anti)-localization and magnetic interactions in Ge1-x-ySnxMnyTe epitaxial multiferroics

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We present the structural, magnetic and magnetotransport results of $Ge_{1-x-y}Sn_xMn_yTe$ epitaxial multiferroics with $x = 0.03$ and $y = 0.11$ over a broad range of temperature. The 150 nm thick layer maintains the rhombohedral crystal symmetry of its host lattice, GeTe. The dc susceptibility, χ(T) manifests double-maxima in the zero-field-cooled curves which might represent paramagnetic to ferromagnetic ($T = 55$ K) and ferromagnetic to an anticipated re-entrant spin-glass ($T = 25$ K) phase transition. Furthermore, a negative to positive crossover in magnetoresistance is observed at $T = 20$ K with a weak (anti)-localization effect below about 50 K that vansihes at higher temperatures. We also present a modified scaling mechansim of anomalous Hall resistivity which displays a large magnitude, $\rho_{AH} = 2.6$ $\mu\Omega$ cm at $T = 4.3$ K. The origin of scattering processes that induce such a large anomalous Hall resistivity is discussed.

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Shaping the spectrum of 2D magnonic crystal by modification of surface anisotropy

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The dynamics of spin waves in a magnetic medium can be shaped by the geometry of the system, i.e. by changing the shape and sizes of its components. This is the basic design strategy for any system that processes signals in the form of waves and it is commonly used in photonics, phononics, and plasmonics. Wave dynamics, its localization and propagation, can also be influenced by modifying the boundary conditions on the surfaces of the structure. This approach offers particular opportunities in the case of spin waves, where the freedom of the spin wave on the surface of a magnonic system can be controlled by many factors.

Generally, the exchange spin waves are unpinned on the surface of the magnetic body and their dynamics can be changed by the application of magnetic surface anisotropy, as shown in pioneering work by Rado and Weertman [1]. A further significant factor influencing the magnetisation dynamics at the surface is the so-called dipolar pinning [2,3]. The origin of dipolar pinning can be explained by the interplay between magnetic surface and volume charges [4].

In our research, we consider a perpendicularly magnetized 2D planar magnonic crystal. The magnonic crystal is composed of CoFeB square dots arranged into a square lattice. Therefore components of the magnonic crystal are coupled by dipolar interactions. We consider the forward volume configuration to not break the symmetry of the lattice, i.e. to keep the reference system where both principal directions of the lattice are equivalent. Then, we demonstrate that the introduction of surface anisotropy at the lateral faces of dots can release spin wave dynamics and compensate dipolar pinning, which noticeably affects the spin wave spectrum of the magnonic crystal. Finally, we introduce surface anisotropy only on one pair of lateral surfaces of each dot which makes two principal directions of magnonic crystals distinguishable for spin wave propagation. It is worth noticing that for both studies the geometry of the structure remains unaltered.

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Ultrafast demagnetization and electronic processes in cobalt trigerred by x-ray photons

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We investigated the role of electronic excitation, relaxation and transport processes in X-ray induced ultrafast demagnetization of magnetic multilayer systems. In what follows, we report on the results obtained with the newly developed modeling tool, XSPIN, which enables nanoscopic description of electronic processes occurring in X-ray irradiated ferromagnetic materials [1,2]. With this tool, we have studied the specific response of cobalt/platinum (Co/Pt) multilayer system irradiated by an ultrafast XUV pulse at the M-edge of Co (photon energy around 60 eV) [1]. It was previously studied experimentally at the FERMI free-electron-laser facility, using the magnetic small-angle X-ray scattering technique (mSAXS) [3]. The XSPIN simulations show that the magnetic scattering signal from cobalt decreases on the femtosecond timescales considered due to electronic excitation, relaxation and transport processes both in the cobalt and in the platinum layers. The signal decrease scales with the increasing fluence of incoming radiation, following the trend observed in the experimental data. Similar observations [2] were also made for the recent demagnetization data [4] from magnetic multilayer systems recorded at the L-edge of Co (Co/Pd multilayer system, photon energy about 778 eV), which are also briefly discussed here. Confirmation of the predominant role of electronic processes for X-ray induced demagnetization in the regime below the structural damage threshold, achieved with our theoretical study, is a step towards quantitative control and manipulation of X-ray induced magnetic processes on femtosecond timescales.

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Magnetic and transport properties of Ge1-x-ySixMnyTe crystals

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IV-VI materials doped with magnetic impurities hold potential for spintronic applications particularly by integrating the memory component within the semiconducting matrix. This works intends to investigate the carrier mediated magnetic interactions in GeTe lattice alloyed with Mn ions. We present Ge1-x-ySixMnyTe bulk crystals by altering their chemical composition in the range $0.056 \leq x \leq 0.10$ and $0.0036 \leq y \leq 0.046$. The magnetic phase transition temperature rises from TC = 25 K to about 160 K for the highest impurity level. The analysis of inverse of susceptibility with modified Curie-Weiss law finds ferromagnetic-like interaction in the alloys. The magnetically glassy samples were interpreted with frequency dependent susceptibility. This identified scaling parameter, $R = 0.2 - 0.6$ which indicate the formation of clusters in the glassy samples. Finally, the temperature and concentration dependence of anomalous Hall Effect (AHE) is interpreted in terms of extrinsic scattering mechanisms.

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Investigation of Magnetocaloric Effect in $RE_5Pd_2In_4$ (RE = Tb–Tm) Compounds

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Magnetocaloric measurements of the $RE_5Pd_2In_4$ (RE = Tb–Tm) rare earth compounds were examined with the use of the Vibrating Sample Magnetometer (VSM) option of the Physical Properties Measurement System by Quantum Design. The maximum magnetic entropy change ($-\Delta S_M^{max}$) at magnetic flux density change ($\Delta\mu_0 H$) 0–9 T was determined to be 3.3 $J{\cdot}kg^{-1}{\cdot}K^{-1}$ at 60 K for $Tb_5Pd_2In_4$, 7 $J{\cdot}kg^{-1}{\cdot}K^{-1}$ at 20 K for $Dy_5Pd_2In_4$, 12.6 $J{\cdot}kg^{-1}{\cdot}K^{-1}$ at 20 K for $Ho_5Pd_2In_4$, 12.1 $J{\cdot}kg^{-1}{\cdot}K^{-1}$ at 18 K for $Er_5Pd_2In_4$ and 11.9 $J{\cdot}kg^{-1}{\cdot}K^{-1}$ at 8 K for $Tm_5Pd_2In_4$. The temperature averaged entropy change (TEC) for each compound with a 5 K span was also calculated, leading to the values of 3.19, 6.96, 12.63, 12.16, and 11.84 $J{\cdot}kg^{-1}{\cdot}K^{-1}$ for RE = Tb–Tm, respectively. The relative cooling power (RCP) and refrigerant capacity (RC) equal respectively 258 and 215 $J{\cdot}kg^{-1}$ in $Tb_5Pd_2In_4$, 498 and 325 $J{\cdot}kg^{-1}$ in $Dy_5Pd_2In_4$, 489 and 403 $J{\cdot}kg^{-1}$ in $Ho_5Pd_2In_4$, 403 and 314 $J{\cdot}kg^{-1}$ in $Er_5Pd_2In_4$ and 234 and 184 $J{\cdot}kg^{-1}$ in $Tm_5Pd_2In_4$. The magnetocaloric performance of $RE_5Pd_2In_4$ is comparable to that of other low-temperature magnetocaloric materials, reaching the highest values in the case of RE = Ho and Er which show good magnetocaloric performance over a wide range of temperatures. Furthermore, $RE_5Pd_2In_4$ (RE = Tb–Tm) have the highest RCP and RC among other transition metal compounds $RE_5T_2In_4$ (T = Ni, Pt).

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Modelling magnetic walls in NiO

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NiO is a model antiferromagnetic of type G for its high transition temperature (T_N=523 K) and its simple rocksalt crystallographic structure. However, it has a complex magnetic structure, composed of T (favorite planes of spins) and S (favorite orientations of spin) domains. In the context of spintronic antiferromagnetic, the magnetic texture plays a key role. Magnetic transition zones such as T and S walls influence the overall behavior in spintronic devices. Understanding the transition zone between these structures are therefore critical.
Despite this criticity, a complete description at the atomic scale of the T and S wall is still missing. We fully simulate them, thanks to a Heisenberg Hamiltonian. We realized our simulations with Vampire, an atomic spin modelization software.
First, the superexchange constants were reassessed to obtain the experimental T_N. In order to obtain the type II antiferromagnetic structure, a linear relationship between atoms distance and first superexchange constants (J1) is implemented, coupled with a contraction along (111), used to simulate the magnetostriction and a set of two uniaxial anisotropy constant is used to describe S and T domain.
Second, we simulate 60°, 120° S walls and (100), (110) T walls by putting two domains side-to-side in the same simulation box.
A particular attention is given to the morphology of (100) T walls, created by the three different S domains from each side of the wall. From nine cases created by the variation of S walls from each side of the walls, three cases can be isolated. The general behavior of (100) T wall can be resumed in three steps for atomic spins.

1. A first in plane rotation from the departure direction to the shared direction between the two (111) plane of each domain T.

2. At the shared direction, the atomic spin split in two populations due to the antiferromagnetic structure of NiO.

3. These two population on goes a new in plane rotation in the other (111) plane to end at the arrival position.

The passage by the shared direction is the key to understand the magnetic behavior of NiO in magnetic transition zone. The behavior of (110) T walls are similar.
Some Nitrogen Vacancies Magnetometry (NVM) simulations were simulated for all walls.

Interplay between magnetism and topology in HgTe doped with Cr and V

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Dilute magnetic semiconductors have played a central role in the demonstrating and describing a strong and intricate influence of the sp-d exchange interactions upon effective mass states in semiconductors, paving the way for the rise of dilute ferromagnetic semiconductors [1] and magnetic topological insulators [2,3,4]. Recently the exchange splittings of magneto-optical spectra in $Cd_{1-x}Mn_xTe$ and $Hg_{1-x}Mn_xTe$ have been described [5] and it has been demonstrated that superexchange dominates in magnetic topological insulators [6]. Here we investigate the electronic and magnetic properties of the dilute magnetic semiconductors $Cd_{1-x}Cr_xTe$, $Hg_{1-x}Cr_xTe$, $Cd_{1-x}V_xTe$, $Hg_{1-x}V_xTe$ by using a density functional theory approach which goes beyond the standard functionals in order to correctly reproduce the topology and the band gap of these systems. We obtain the band structures of these systems, we study the distortions produced by the Jahn-Teller effect and the crystal field splitting of the d-levels of the dopants. We find that the crystal field strongly depends on the correlations. Then, we study the exchange couplings for all considered cases and we find that the coupling is ferromagnetic in case of doping with V, differently from the case of doping with Mn and Cr, where we find antiferromagnetic couplings. The ferromagnetic coupling among V atoms in the insulating phase of topological HgTe can produce the quantum anomalous Hall phase. We also checked the interplay between the distortions produced by Jahn-Teller effect and magnetism and we found that the distortions favor the ferromagnetism.

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Semiclassical dynamics of disordered fermions with non-local interactions

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Using the truncated Wigner approximation (TWA) we study quench dynamics of one and two-dimensional lattice systems consisting of interacting spinless or spinful fermions with potential disorder.

First, we show that TWA can become very accurate for non-local interactions, provided that the semiclassical Hamiltonian is correctly identified (it becomes asymptotically exact in the infinite-range limit) [1]. For the Hubbard model with long-range interactions, different dynamical timescales of charges and spins can be clearly distinguished. It is shown that in contrast to the short-range model, strong inhomogeneities such as domain walls in the initial state can significantly slow down thermalization dynamics, especially at weak disorder. This behavior can put additional challenges in designing cold-atom experimental protocols aimed to analyze possible many-body localization in such systems. While within this approach we cannot make any definite statements about the existence of a many-body localized phase, we see a very fast crossover as a function of disorder strength from rapidly thermalizing to a slow glassylike regime both for the short-range and long-range models.

Second, we demonstrate that the semiclassical dynamics generally relaxes faster than the full quantum dynamics [2]. We obtain this result by comparing the semiclassical dynamics with exact diagonalization and Lanczos propagation of one-dimensional chains with spinless fermions. Next, exploiting the TWA capabilities of simulating large lattices, we investigate how the relaxation rates depend on the dimensionality of the studied system. We show that strongly disordered one-dimensional and two-dimensional systems exhibit a transient, logarithmic-in-time relaxation, which was recently established for one-dimensional chains. Such relaxation corresponds to the infamous 1/f noise at strong disorder.

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Spin-wave dynamics in the magnetic heterostructures with regular stripe-domain texture

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Periodic magnetic structures, called magnonic crystals, allows the control of the spin-wave (SW) propagation. A standard way to introduce the periodicity is to artificially implement a structural modification of the magnetic material. Recently, magnetic materials based on rare-earth metals having a perpendicular magnetic anisotropy (PMA) which allows to stabilize a domain texture have been proposed as an alternative to manipulate SW propagation [1]. However, they are characterized by strong damping, making them inefficient for magnonic applications.

We present a magnetic multilayer structure consisting of 64-nm-thick NdCo layer and 10-nm-thick soft ferromagnetic layer (NiFe, Co/NiFe, NiFe/Co) separated by Al layer [2]. NdCo has a weak PMA allowing the stabilization of a regular stripe-domain texture. Due to the dipolar interaction between the layers, the domain pattern of NdCo is imprinted in the soft magnetic layer, which can serve as a conduit for the SWs. Due to different coercivity of the magnetic films, the magnetization orientation in the soft layer can be switched using a small external magnetic field of 20-30 mT without changing the domain structure of NdCo layer. Interestingly, this process is fully reversible. Brillouin light scattering (BLS) spectroscopy was used to analyse SWs propagating in the direction perpendicular to the stripe domains. SW dispersion was found to significantly differ in two configurations. BLS spectra show a few modes which exhibit strong asymmetrical behaviour. Numerical simulations indicate the source of the asymmetry in both static configuration and dynamic coupling. Moreover, they show that the BLS spectra contain fundamental soft layer mode branches coming from different Brillouin zones, a typical feature of magnonic crystals.

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Orientational anisotropy of magnetic damping in Ta/CoFeB/MgO heterostructures

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Magnetic damping, one of the key parameters of magnetic materials, can be controlled by spin current induced torques [1], electric field [2]; and by engineering electronic band structure at the Fermi level [3]. Being a tensor quantity the damping also depends on the orientation of magnetization, known as Orientational anisotropy. This Orientational anisotropy originates from the anisotropy in the spin-orbit coupling (SOC) and density of states (DOS) in the ferromagnetic layer (bulk) and at the interfaces (for heterostructures made of ultrathin films) [4]. Hence, Orientational anisotropy provides a great tool for tuning magnetic damping by changing the orientation of magnetization, which is quite appealing from the application point of view.

Here, we report orientational anisotropy of damping in Ta/CoFeB/MgO heterostructures deposited on Si/SiO_2 and $LiNbO_3$ substrates. The damping parameter in the films are extracted by performing ferromagnetic resonance (FMR) measurements based on spin pumping and inverse spin Hall effect (ISHE) technique [2]. The studied multilayers possess both: perpendicular magnetic anisotropy (PMA) with interfacial origin and in-plane magnetic anisotropy (IMA) with bulk origin. We observe that the orientational anisotropy of damping is composed of four-fold and two-fold anisotropy terms. The four-fold anisotropy originates from extrinsic two-magnon scattering (TMS), which occurs because the uniform magnons are scattered from inhomogeneities or imperfections present at Ta/CoFeB interface. The two-fold anisotropy, on the other hand, originates from the anisotropy in bulk SOC of CoFeB film and correlates with IMA of the films. We find that when IMA is very small, it has too little influence on two-fold anisotropy to be experimentally identified. However, as IMA increases, it starts to influence two-fold anisotropy in damping. These results will help to design the orientational anisotropy in damping in future spintronics devices by engineering bulk and interfacial SOC strengths.

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Thermal evolution of magnetic structures in R_2Ni_2In (R = Tb and Ho)

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Thermal evolution of magnetic structures in R_2Ni_2In (R = Tb and Ho) has been studied by powder neutron diffraction at low temperatures. The experimental data reveal that the compounds crystallize in an orthorhombic crystal structure of the Mn_2AlB_2-type. In magnetically ordered state, the localized magnetic moments have been found solely on the rare earth atoms. Both compounds show antiferromagnetic ordering at low temperatures. A collinear commensurate magnetic structure, related to the propagation vector $\mathbf{k} = [\frac{1}{2}, \frac{1}{2}, \frac{1}{2}]$, is observed in Tb_2Ni_2In. The Tb magnetic moments are parallel to the c-axis. The structure does not change with temperature. In contrary, the magnetic structure of Ho_2Ni_2In shows strong temperature dependence. Below the Néel temperature, an incommensurate sinusoidal structure ($\mathbf{k}_1 = [0.24, 1, 0.52]$) is observed. With decreasing temperature, the structure turns into incommensurate square-modulated one, described by $\mathbf{k}_2 = [0.17, \frac{5}{6}, \frac{1}{2}]$ (the component along the a-axis slightly differs from commensurate value) and its third harmonics $3\mathbf{k}_2 = [0.50, \frac{5}{2}, \frac{3}{2}]$. According to heat capacity data, the transition between the sinusoidal and square-modulated structures is of the first order type. Further decrease of temperature leads to reappearance of the sinusoidal structure and coexistence of both detected magnetic structures. The Ho magnetic moments remain parallel to the c-axis in both the sine- and square-modulated magnetic structures.

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Magnetic structures and magnetoelastic effect in $R_5Pt_2In_4$ (R = Tb–Tm) investigated by neutron powder diffraction

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The $R_5Pt_2In_4$ (R = Tb–Tm) rare earth intermetallic compounds have complex and intriguing magnetic properties. The compounds crystallize in an orthorhomic crystal structure with the rare earth atoms occupying three different sublattices. Magnetic measurements indicate either ferri- or antiferromagnetic order below the critical temperatures between 4.1 K (R = Tm) and 108 K (R = Tb) [1]. Our recent neutron diffraction data reveal that the rare earth magnetic moments in two sublattices order at the critical temperature of magnetic ordering while the moments in the third sublattice order at lower temperatures. Such a sequence of magnetic transitions effects strongly temperature dependences of the lattice parameters and unit cell volume. For all compounds, a distinct jump of the above mentioned parameters is observed at the respective critical temperature. The corresponding magnetovolume effects are strongly correlated with the magnitudes of rare earth magnetic moments. At lower temperatures only small anomalies, related to the magnetic ordering in the third sublattice, are visible.

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Inelastic spin wave beam scattering on localised modes for controlling beams' trajectory and frequency.

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Spin waves (SWs) show potential for being a low-energy demanding information carrier and offer easily achieved non-linear processes such as confluence and splitting processes. In our investigation, we study the non-linear interaction of an incident SW beam with a localised SW edge mode of a thin ferromagnetic film. We propose two methods of localising the edge mode: introducing a ferromagnetic strip directly over the thin layer's edge, thus creating a magnonic Gires-Tournois [1,2] interferometer and using the demagnetising field [3]. We show that the SW beam inelastic scattering process results in creation of two new SW beams with shifted frequency that are additionally laterally shifted with respect to the SW beam's incident spot. Both the later shifts of inelastically scattered beams and their amplitudes depend on localised SW edge mode's frequency which is a tunable external parameter. Thus, our findings provide new ways to control and modulate SWs by using non-linear processes. These new possibilities will be applied in the future design of magnonic circuitry for modulating the SW signal's frequency and splitting information encoded in SWs to direct it to different channels.

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Structure and magnetism of AlCoCrCuFeNi high-entropy alloy

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Multicomponent systems like AlCoCrCuFeNi are usually investigated due to their significant hardness caused by the high configurational and mixing entropies. The term High Entropy Alloys is used when at least five of the components have at least 5% molar fraction [1,2]. This work aims at investigation of magnetic and structural properties of AlCoCrCuFeNi, which is known to crystallize in a dual phase solid solution: the face-centred cubic (FCC) or the body-centred cubic (BCC). The results of neutron (NPD) and synchrotron powder diffraction (SXRD) allow to partially resolve magnetic information coming from BCC and FCC phases, which is impossible in the bulk magnetic measurements. Electron diffraction (PED) revealed that AlCoCrCuFeNi forms dendritic microstructure with the Cu-rich FCC phase and the Ni-rich BCC phase. Lattice parameters obtained from PED method are in good agreement with parameters obtained after refinement on the basis of powder X-ray diffraction measurements. The local crystal and electronic structure around Co was studied using Co-K X-ray Absorption Spectroscopy (XAS). The magnetic measurements show that AlCoCrCuFeNi reveal a ferromagnetic transition at about 330 K and displays magnetic hysteresis loop at the room temperature. Results from NPD suggest that the magnetic moment is mostly located in the BCC subsystem. The alloy shows soft magnetic properties. Saturated magnetizations (Ms), remanence ratio (Mr/Ms) and coercivity (Hc) of the cast are estimated to be 45.10 emu/g, 4.5% and 76 Oe, respectively. Finally, the BCC-FCC phase transformation up to 673 K was investigated using temperature dependent NPD, where a possible second BCC phase was identified.

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Between waves and patterns: spin wave freezing in films with Dzyaloshinskii-Moriya interaction

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The relationship between propagating waves and static pattern formation is fascinating area of magnetism. Our research focuses on the spin-wave-induced spin reorientation transition (SRT) in magnetic films with perpendicular magnetic anisotropy and the Dzyaloshinskii-Moriya (DMI) interaction [1]. Specifically, we have discovered that propagating spin waves can freeze during SRT, resulting in the emergence of periodic magnetic domains that resemble the wave amplitude distribution. This process can occur due to changes in the magnetic field, magnetic anisotropy, film thickness, and the magnitude of DMI. Interestingly, the non-reciprocity inherent to DMI leads to the emergence of flowing magnetization patterns at SRT. This suggests a spontaneous breaking of translational symmetry and the formation of magnonic space-time crystals. These phenomena are universal and can occur in a wide range of magnetic materials. Consequently, our findings are crucial for the advancement of spintronics and magnonics.

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Micromagnetic study of response of arrays of superparamagnetic nanoparticles to high-frequency field at finite temperatures

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The magnetic response of composites of magnetic nanoparticles (MNPs) embedded in dielectric matrices to high-frequency (0.1÷1.0 GHz) field is investigated with regard to their application as core materials for microconverters of power. The advantage of the nanocomposite core is reduced conductivity, thus, the suppression of the eddy-current loss. However, the idea has been developed for superferromagnetic materials [1], hopes for ultimate reduction of loos at high frequencies are accompanied by superparamagnetic cores which are composites of highly-separated MNPs, in spite of their relatively low permeability [2]. Both thermal fluctuations and magnetostatic interactions play crucial role in dynamics of superparamagnets and they have to be included into any realistic model. For small MNPs, magnetization fluctuations are huge at room temperature and driving regular oscillations of the magnetization require use of strong alternating field, beyond applicability of linear response description, which motivates numerical approach. Additionally, macrospin approximation for MNPs can be questionable at high frequencies and our micromagnetic simulations include intra-particle dynamics. Applying periodic boundary conditions, we test 3D arrays of high-magnetization MNPs of single magnetic anisotropy axis ($Fe_{65}Co_{35}$) and of cubic anisotropy (Fe), as well as MNPs of lower magnetization (Fe_3O_4) in terms of the amplitude of the magnetic response function, susceptibility and, plotting dynamical magnetization-field curves, we conclude about hysteresis and residual losses. Influence of the interparticle distance on the strength of magnetic response is discussed. Interplay between strong crystalline anisotropy (a high blocking temperature) and dipole-dipole interactions of MNPs is especially intense for arrays of Magnetite nanoparticles, making the dynamical magnetic response of the nanocomposite at room temperature very sensitive to the particle diameter.

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Shaping the spin wave spectra of planar 1D magnonic crystals by the geometrical constraints

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We present experimental and numerical studies demonstrating the influence of geometrical parameters on the fundamental spin-wave mode in planar 1D magnonic crystals. The investigated magnonic crystals consist of flat stripes separated by air gaps. The adjustment of geometrical parameters allows tailoring of the spin-wave frequencies. The width of stripes and the width of gaps between them affect spin-wave frequencies in two ways. First, directly by geometrical constraints confining the spin waves inside the stripes. Second, indirectly by spin-wave pinning, freeing the spin waves to a different extent on the edges of stripes. Experimentally, the fundamental spin-wave mode frequencies are measured using an all-optical pump-probe time-resolved magneto-optical Kerr-effect setup. Our studies address the problem of spin-wave confinement and spin-wave dipolar pinning in an array of coupled stripes. We show that the frequency of fundamental mode can be tuned to a large extent by adjusting the width of the stripes and the width of gaps between them. The study is complemented by numerical studies on the effect of spin wave pinning on the frequency of fundamental mode in a array square of planar square dots.

The main outcomes of this research can be summarized as follows. (i) The fundamental mode frequency increases with the stripes' separation. (ii) The dipolar interactions between the constituting nanoelements of magnonic planar nanostructure must be considered even if the distance between successive stripes is within a single micrometer. (iii) The TR-MOKE measurements allow for the investigation of the frequency of fundamental mode which is inaccessible for BLS measurements. (iv) The FEM computations can be used to investigate the spin-wave dynamics in the frequency domain in considered systems. However, the semi-analytical calculations (based on the formalism of magnetostatic Green functions) provide sufficiently accurate results.

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Stabilization and racetrack application of asymmetric Néel skyrmions in hybrid nanostructures

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Nontrivial magnetization textures, such as skyrmions and vortices, have become a driving force in the field of magnetism due to their enormous potential for processing and transporting information. The ability to encode information in spin textures or spin waves can lead to the development of magnonic devices that are more space-efficient than optical devices and more energy-efficient than current electronics. In this presentation, we will demonstrate that a Néel-type skyrmion confined within a nanodot placed on top of a ferromagnetic in-plane magnetized stripe provides a unique and compelling platform to investigate the dynamics of spin waves and magnetization textures in hybrid structures. In this hybrid structures skyrmion induces an imprint upon the stripe, which, in turn, asymmetrically squeezes the skyrmion in the dot, increasing their size and the range of skyrmion stability at small values of Dzyaloshinskii-Moriya interaction, as well as introducing skyrmion bi-stability. We will discuss the consequences of skyrmion stabilization and furthermore, the spin wave coupling between propagating modes in the stripe, and skyrmion excitations. Moreover, we will present a technique for the unconstrained transport of skyrmions along a hybrid racetrack [1].

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Energy Landscape for Thermally Activated Switching of Perpendicular Magnetic Nanopillars in a Transverse field

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Generating bitstreams that are truly random is a necessary requirement for many applications in stochastic computing. A promising solution to this problem is based in thermally activated switching between metastable magnetic states of the the free layer of perpendicularly magnetized circular magnetic tunnel junctions (pMTJ) in which an applied in-plane field can modify the ground state and lower the energy barrier (E_b). Estimates of thermal stability of magnetic states require the identification of configurations that are either minima or saddle configurations of the energy density functional. In this work, we identify states involved in thermally activated switching for various device diameters and applied fields. The simplest model [1] assumes a coherent magnetization reversal (macrospin) for which the transition state is uniformly magnetized parallel to the applied field. This model can be verified using overdamped micromagnetic simulations after introducing a shape dependent magnetostic correction. For large size devices, the transition state is no longer uniform but has a sigmoidal magnetization profile. We provide analytical solutions for 1D magnetization profiles involved in thermally activated magnetization reversals and compare them with numerical results using the String Method for the Study of Rare Events [2]. Our result provides a useful framework to quickly estimate the most likely transition state and energy barrier of pMTJs under transverse fields.

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Spin Wave propagation in bilayers of Vanadium dichalcogenides with Dzyaloshinskii-Moriya interaction

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We have analyzed theoretically and numerically the spectrum of spin waves (magnons) in bilayers of two-dimensional Vanadium-based transition-metal dichalcogenides (TMDs), like VX_2 with X=S, Se, Te. [1]. The Vanadium atoms within individual atomic layers are coupled ferromagnetically, while the exchange coupling between Vanadium atoms located in different planes is either ferromagnetic or antiferromagnetic - depending on the type of dichalcogenide (X) atoms. The magnon spectra are considered in bilayers of both T and H stacking. We have analyzed in detail the magnon spectra as a function of in-plane and out-of-plane magnetic anisotropy constants, external magnetic field, and strength of Dzyaloshinskii-Moriya interactions (e.g. due to the inversion symmetry breaking by an external electric field). The spin-wave dispersion relations have been derived analytically within the spin-wave theory, in terms of the Holstein-Primakoff transformation combined with the Bogolubov diagonalization scheme. They have been also simulated numerically. For numerical analysis of analytical solutions, the intra- and interlayer exchange parameters, as well as the magneto-crystalline anisotropy constants, have been computed within the method based on the density functional theory (DFT). In the case of antiferromagnetic TMD bilayers, the system undergoes a field-induced transition to the spin-flop phase, which evolves into the saturated ferromagnetic phase for sufficiently strong magnetic fields. The existence of different phases depends on the interlayer exchange coupling and anisotropy constants. We have analyzed the spin wave spectra in all these phases and showed how the spectra change at the phase transitions, and also how they evolve with increasing magnetic field. We have taken into account both intra and interlayer Dzyaloshinskii-Moriya interactions, and have shown that these interactions lead in general to nonreciprocal spin-wave propagation.

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Relaxation processes in single crystals of $Co(NCS)_2(Ligand)_2$ spin chains

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The $Co(NCS)_2L_2$ compounds, where L denotes a pyridine based ligand, have crystal structures in which spins of Co(II) ions interact through $(NCS)_2$ bridges and create ferromagnetic spin chains. The bulky ligands separate these chains, and such systems behave magnetically as quasi-one dimensional. We will present the study that starts with the description of such systems as XXZ spin chain with almost Ising anisotropy, basing on magnetic and specific heat data, THz-EPR spectroscopy, *ab initio* calculations of electron structure, and DMRG calculations for such a spin chain.
Dynamic susceptibility measurements show that in the ordered phase, these systems demonstrate magnetic relaxations that resemble Single Chain Magnet behaviour. Using micromagnetic Monte Carlo simulations we show that the relaxation signal at zero field originates from defects of the magnetic structure, while at applied suitable field the signal originate from AF/FM domain boundary. The dynamics of both processes is compared. Finally, we will present magnetic data recently obtained for monocrystal samples, where relaxation times are much longer. Close to the critical temperature, a second relaxation process is also observed. The relaxation time of this process is temperature independent, indicating a negligible energy barrier. Such phenomenon was not previously observed for any of the powder samples of $Co(NCS)_2(ligand)_2$ compounds.

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Structural and electronic properties of Ba_2TiMnO_6 studied by DFT calculations

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Magnetically ordered perovskite-like materials show semiconductor properties with their promised applications in the optoelectronic industry. In this work, we report *ab-initio* calculations of electronic structure and magnetic properties of the Ba_2TiMnO_6 double perovskite. Calculations are carried out through the Full-Potential Linear Augmented Plane-Wave method (FP-LAPW) within the framework of the Density Functional Theory (DFT) using several common approximations: Local Density (LDA) [1] and Generalized Gradient (GGA) approximations [2] by including the relativistic effects of spin-orbit coupling with the Hubbard term corrections GGA+U. However, a good agreement is obtained for Ba_2TiMnO_6 with the previously reported data by Deluque Toro *et al.* [3], there are essential differences in the case of GGA and GGA+U approaches due to reliable lattice parameters after optimization. The study of the electronic structure was based in the analysis of the density of state (DOS), and the electronic band structure (EBS), indicating that this compound evidences an effective magnetic moment of 2.56 μ_B/Mn and the distinct energy gap of about 1.23 eV. On the other hand, the magnetic moment of Mn decreases in case of the effect of the Hubbard parameter U (U=4 eV, J=1 eV) and obtains 2.28 μ_B per Mn ion and the band gap is wider achieving 1.54 eV. The obtained results indicate that Ba_2TiMnO_6 is a direct band gap semiconductor.

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Effect of strain on the electronic and magnetic properties of bilayer T-phase VS_2: a first-principles study

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We will discuss the electronic and magnetic properties of the bi-layer of Vanadium disulfide (VS_2) in an octahedral (1T) phase. Using the Density Functional Theory (DFT), we have found that the ground state of VS_2 bilayer structure is antiferromagnetic (AFM) without taking Hubbard correction $U = 0$, however it becomes ferromagnetic with $U = 2$ eV. This shows a high sensitivity of this structure to the on-site Coulomb interaction. Moreover, subsequent spin-resolved band structures in the presence of U and spin-orbit coupling (SOC) show a metallic behavior for the pure structure.

We will also discuss the calculated exchange parameters (J_{ij}) that are crucial for understanding the magnetic behavior of the T-phase VS_2. In addition, we used the calculated exchange parameters to calculate the Curie temperature (within the mean-field approximation as well as random phase approximation) and magnon band structures.

As the calculated magnon band structure is also affected by the spin-orbit coupling (SOC), we have also calculated the Dzyaloshinski-Moriya parameters and the Magnetic Anisotropy Energy (MAE) of the bilayer structure. Our results show that the MAE is equal to -0.0610 meV, indicating an in-plane easy axis of magnetization.

Finally, we will discuss also the impact of bi-axial strain (ranging from -10% to $+10\%$) on the magnetic and electronic properties of the T-phase VS_2. Our results show that the magnetic and electronic properties of T-phase VS_2 are highly sensitive to the strain, with significant changes observed in the band gap, magnetic moment, J_{ij} parameters, Curie temperature, and magnon band structure. The ability to tune the magnetic and electronic properties of the T-phase VS_2 by strain engineering makes it a promising candidate for various applications, including magnetic memory devices, spintronics, and magnetic sensors [1-3].

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System-reservoir entanglement during Markovian relaxation of a quantum dot

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Nanoelectronic systems (e.g., quantum dots) weakly coupled to the reservoirs can be effectively described by means of a Markovian (i.e., memoryless) master equation for the charge states populations. It has been sometimes asserted that the validity of such description precludes the presence of the system-reservoir entanglement, as its derivation assumes the system and the environment to be uncorrelated. Here we question this assertion by investigating the entanglement dynamics during relaxation of a charge state of a spinful quantum dot. It is shown that a transient entanglement can be observed even in the weak coupling regime, when the reduced dynamics of the system can be well described by a Markovian master equation. This entanglement vanishes at long times, but is preserved at timescales comparable to the relaxation time. Its magnitude only weakly depends on the system-reservoir coupling, but instead strongly on the purity of the initial state of the system. We relate the presence of such transient entanglement to the quantum coherent character of the microscopic system-reservoir dynamics underlying the effectively classical reduced Markovian description.

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Highly tunable spin Hall magnetoresistance in room-temperature magnetoelectric multiferroic, $Sr_3Co_2Fe_{24}O_{41}$|Pt hybrids

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In this study, we investigate the spin transport properties of a room-temperature magnetoelectric multiferroic polycrystalline $Sr_3Co_2Fe_{24}O_{41}$|Pt heterostructure with a highly tunable transverse conical magnetic phase that results in static and dynamic magnetoelectric coupling[1,2]. By measuring the angular dependence of spin Hall magnetoresistance (SMR) at constant magnetic fields (H) ranging from 50 to 100 kOe, we observe negative SMR below a critical field of H $\approx$ 2.5 kOe, with a negative gradient in the H-evolution of normalized SMR ($\frac{\Delta R}{R} \times 100\%$). As the field is increased, a positive slope of $\frac{\Delta R}{R} \times 100\%$ vs. H is observed, and at higher fields around 14 kOe, a crossover from negative to positive SMR is observed. We employ a simple model to estimate the equilibrium magnetic configuration and compute the SMR modulation at various values of H. We propose that the tilting of the cone is dominant and responsible for the observed nature of SMR below 2.5 kOe, while the closing of the cone-angle is pronounced at higher fields and causes a reversal in the sign of the SMR from negative to positive. Importantly, our SMR experiments reveal that a change in the helicity with a reversal of the magnetic field has no influence on the observed SMR. We also measure a longitudinal spin Seebeck effect (LSSE) signal of $\approx$ 500 nV at 280 K under the application of a thermal gradient (ΔT = 23 K) and a field of 60 kOe. The observed LSSE signal, which originates from pure magnon spin current, exhibits an H-dependent behavior similar to that of the magnetization of $Sr_3Co_2Fe_{24}O_{41}$. Our detailed spin transport studies on the polycrystalline $Sr_3Co_2Fe_{24}O_{41}$|Pt heterostructure demonstrate the high tunability of the amplitude and sign of the SMR, highlighting its potential for novel spintronic devices, such as SMR-based spin valves[3] and voltage-controlled spin transport devices.

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Control of transport in semiconducting MnTe by magnetic order

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Transport properties of semiconductors depend sensitively on several factors and here, Fermi level position is the most prominent one. In magnetically ordered systems, direction of the magnetic moments (and also the degree of their disorder) is another such factor. In the present work, we investigate both theoretically and experimentally their interplay in a model system of p-type antiferromagnetic MnTe.

We first discuss the location of Fermi surface within Brillouin zone; it has recently been argued that valence band maxima can occur not only close to the A-point but, for some values of lattice parameters, also in the vicinity of Γ even if under circumstances (bulk, room temperature) the former should prevail [1]. Next, we use the effective 6×6 model $H_{kp}+H_{so}$ from this article to locate the Fermi surface (for experimentally determined carrier concentrations) and find that it is slightly displaced from A. Earlier measurements [2] detected crystalline anisotropic magnetoresistance [3] and we use the effective model to calculate this DC transport quantity; conceptual differences in this approach to the case of dilute magnetic semiconductors such as (Ga,Mn)As will be highlighted. We also show how this model can be used to calculate spin currents (which occur even in the absence of the spin-orbit interaction [4]) and finally, we turn our attention to transport measurements at non-zero frequencies.

To this end, motivated by the recent measurements of the anomalous Hall effect in MnTe [5], we measure polar Kerr spectra in optical range and discuss their microscopic origin. We find similarities with ab initio calculations [6] and show, using the effective model, how they depend on Fermi level. Non-zero signal (σ_{xy} at zero magnetic field) requires unequal population of time-reversal-linked antiferromagnetic domains (e.g. $\uparrow\downarrow$ and $\downarrow\uparrow$) and we outline a mechanism that could drive the system into this state.

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Peculiar magnetic phase in antiferromagnetic MnTe

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Antiferromagnets get increasing attention nowadays as their magnetic state is coupled to its resistance state and importantly, it may be influenced by electric current [1,2]. A new puzzling chapter has opened with the developments of topology- in particular, some antiferromagnets have been predicted to exhibit exceptional properties, induced just by the crystal symmetry induced by the crystal symmetry and not by relativistic effects [3], e.g. existence of anomalous Hall effect (even in a magnetically-compensated system). Recently, experimental evidence was made for RuO_2 [4] and thin MnTe films [5].

Hexagonal MnTe is a semiconductor with a moderate bandgap (about 1.3 eV), room temperature resistivity of about a few Ω·cm and the Néel temperature T_N of 308 K. We performed structural, transport and magnetic studies of state-of-the-art bulk samples in wide temperature and magnetic field range. Interesingly, on top of a classical signal indicating predominant p-type conductivity, the Hall resistivity ρ_{xy} shows strong temperature dependent features, including a clear hysteresis loop seen exclusively below T_N. However, the loop is flipped with respect to the one observed in epitaxial MnTe [5]. The presence of hysteresis in the Hall resistivity coincides with a weak ferromagnetic signal, resolved in SQUID magnetometry. A discussion about the origin of the observed phenomena will be provided.

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Effect of electron irradiation on the magnetotransport properties of half-Heusler topological semimetal GdPtBi

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Several half-Heusler compounds have been proposed as topological materials more than a decade ago [1], yet interest in this group of materials continues to grow. Among the most intensively studied half-Heusler topological materials is GdPtBi that is the first example of a topological Weyl semimetal in which Weyl nodes are induced by external magnetic field [2]. The observation of negative longitudinal magnetoresistance and anomalous Hall effect is the main evidence for the existence of Weyl states in this material [2, 3].

In this work, we employed high-energy electron irradiation technique to tune the Fermi level in GdPtBi and thus modify its electrical transport properties. Single crystals of GdPtBi were irradiated with several doses from the range between 1.5 and 7 C/cm^2, and then electrical resistivity, magnetoresistance and Hall effect of the irradiated samples were studied. Analysis of the Hall effect data showed that the concentration of carriers changes with increasing the dose, confirming the Fermi level shift. Interestingly, for each sample we observed the anomalous Hall effect, the magnitude of which was found to depend on the irradiation dose. In addition, we noticed that the values of transverse and longitudinal magnetoresistance (which is negative) decrease when the irradiation dose increases. All these features concomitantly point to a diminishing role of the chiral magnetic anomaly in the magnetotransport properties in GdPtBi as the position of the Fermi level is shifted.

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Generation of femtosecond spin-current pulses at Fe/MgO interface by quasi-static voltage

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The generation of short spin-current pulses is essential for fast spintronic devices. So far, spin current pulses are generated by femtosecond lasers which drive spins from a ferromagnetic metal layer. This transient spin current may be used to emit terahertz electromagnetic pulse through inverse spin-Hall effect [1]. However, the need for miniaturization, simplicity and energy efficiency favours electric field control of spintronic devices over optic control. We demonstrate theoretically that the voltage-driven instability of the electronic structure at the Fe/MgO interface results in the generation of the femtosecond spin-current pulse. We show by numeric simulations that spin-dependent screening at dielectric-ferromagnetic metal interface contributes to the spin-polarized current generation in the system subjected to the ac voltage [2]. Then, we show that spin current driven by spin-dependent screening may be used to modulate spin-wave amplitude in bilayer ferromagnetic system [3]. Finally, we combine ab initio calculations of electronic density of states at MgO/Fe interface with continuous model for charge transport. We show that the voltage-driven electron charge accumulation at MgO/Fe interface leads to the Stoner instability because of the electronic interface resonant states. This instability manifests itself in the spin-current and spin accumulation femtosecond pulses which are present because of the contribution of the dynamic spin-dependent potential to the spin-polarized current.

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Topological features in the magnetotransport of $EuIn_2As_2$

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Since a decade, topological crystalline insulators (TCIs) have been in focus due to various intriguing quantum phenomena, such as those related to axion electrodynamics or topological magnetoelectric effect [1-2]. Recently, a few TCIs have been identified amidst Eu-based materials, e.g., $EuIn_2As_2$, and $EuSn_2P_2$ [3, 4].

In this work, we comprehensively studied the magnetotransport properties of (hexagonal, P63/mmc), which orders antiferromagnetically at low temperatures, and has been recognized in the literature as an axion insulator [3].The magnetoresistance and Hall resistivity data, collected on high-quality single crystals, revealed pronounced hysteresis effects, which likely arise due to spin-momentum-locked states coupled to the in-plane ferromagnetic order.

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Putative topological states in antiferromagnetic semimetal EuSnP

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The compound EuSnP crystallizes in a layered tetragonal unit cell (s.g. $P4/nmm$, NbCrN-type) and orders antiferromagnetically at $T_N = 21$ K [1-4]. The crystal structure is very robust against high pressure, and the Néel temperature strongly increases under pressure reaching a value of 100 K at 8 GPa, which is a record-high T_N for materials based on europium [3,4]. In a recent angle-resolved photoemission spectroscopy experiment, an intriguing electronic structure has been revealed, which suggests that EuSnP can be a nodal-line Dirac semimetal or topological crystalline semimetal [5]. In the present work, we re-examined the thermodynamic properties (magnetic susceptibility, magnetization, heat capacity) of high-quality single crystals of EuSnP, and studied in depth their electrical transport behavior (electrical resistivity, magnetoresistance, Hall effect) over a wide range of temperatures and magnetic fields. We observed an unusual linear variation of the electrical resistivity in the paramagnetic state, similar to that known for strange metals. Interestingly, the Hall conductivity measured at 2 K turned out to be very high, reaching a value of about 2 kS/m in a magnetic field of about 2 T. Combined with a strongly enhanced electrical conductivity, the Hall angle in the crystals investigated was estimated to be as large as about 20%. It still remains to be verified whether the observed extraordinary magnetotransport properties of EuSnP may be due to the alleged topologically nontrivial electronic structure of this material.

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Spin-Current-Induced Magnetization Dynamics in Multiferroic Pt/Co/BTO/LSMO Tunnel Junctions

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The data stored in Magneto-Tunnel Junction (MTJ) as the magnetization orientation of a ferromagnetic electrode, results in a different tunneling current detected by the other ferromagnetic electrode of a fixed magnetization. Nowadays, MTJs serve as a basic memory cell of the magnetic random access memory - MRAM. With ongoing development, it has become possible to replace the magnetic field (originally used for the writing of the magnetization orientation) with a spin polarized current flowing through the junction (STT-MRAM), and then with the current flowing only through the high spin-orbit coupling material neighboring one of the electrodes (SOT-MRAM). We studied the static, dynamic and temperature dependent magneto-transport properties of the Pt/Co/BTO/LSMO mutliferroic tunnel junction (MFTJ) with BTO as a ferroelectric barrier. The multilayer structure was grown on a high quality crystalline STO substrate by means of pulsed laser deposition, which enables epitaxial layer-by-layer growth. The MFTJ was patterned into micrometer-size devices using the ion-etching-free lithography process. The measured static properties indicate that the MFTJ has multiferroic properties with the tunneling magnetoresistance (TMR) present below 260 K and tunneling electro-resistance (TER) reaching four orders of magnitude at T = 10 K. In such a structure, exhibiting both TMR and TER, we were able to induce the magnetization dynamics of Co by the spin Hall effect in Pt top layer by an in-plane RF current application. The room temperature SOT-FMR measurements revealed only the peak from the Co layer, as expected in the two-point in-plane measurement configuration. Surprisingly, at temperatures below 260 K, the second peak is also present, although the RA product of the BTO tunnel barrier prevents any charge currents from tunneling [1]. Both the linewidth and the resonance peak evolution with the magnetic field is in the agreement with the LSMO dynamics. The LSMO magnetization process is induced by the RF Oersted field and the signal is picked up by the inverse spin Hall effect in the Pt/Co bilayer. This observation of the dynamics of both ferromagnetic electrodes of the MFTJ together with a coexistence of the magneto- and electro-resistance proves multifunctionality of the developed multilayer system.

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Electron-phonon interaction and electronic correlations in transport through electrostatically and tunnel coupled quantum dots

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We investigate two equivalent capacitively and tunnel coupled quantum dots, each coupled to its own pair of leads. Local Holstein type electron-phonon coupling at the dots is assumed. We eliminate the linear e-ph coupling terms employing Lang-Firsov transformation. To study many-body effects we use the finite-U mean-field slave boson approach. For vanishing interdot interaction, weak e-ph coupling and finite tunneling, molecular orbital spin Kondo effects occur for single electron or single hole occupations. Strong e-ph interaction suppresses tunneling between the dots and degenerate states of single dot Kondo resonances emerge in this range at low temperatures. Similarly, for double occupancy and strong e-ph coupling two impurity Kondo (2K) becomes the ground state, while for weaker coupling local spin singlet (LSS) is formed and for still smaller coupling orbital spin singlet (OSS) appears. When dots are additionally capacitively coupled spin-orbital SU(4) Kondo state can occur for strong e-ph interaction. For the attractive effective intradot interaction charge Kondo effects appear in which charge fluctuations occur between even-occupied states.

Single spin dynamics control and spin readout in single atoms by electrical means with spin-polarized STM

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Our aim is find a theoretical description to evaluate the conditions and results of modern experiments directed to electrical control of single spin dynamics in presence of noncollinear magnetic electrodes or spin-polarized STM in quantum dot (QD) and single atoms on surface. Despite the fast-growing number of experimental works in this field, the fundamental principles remain unclear. In the such system we can observe the nonequilibrium accumulated spin on the QD (or atom), and virtual spin-dependent exchange processes between the QD and the ferromagnetic electrodes resulting in an effective exchange field [1, 3], that can be controlled by the gate and bias voltages. Using the real time diagrammatic technique and the Lindblad equation approach we define effective Lindblad jump operators for noncolinear systems and find a general Bloch equation [2, 3], which describe the complex spin dynamics in the presence of spin polarized current, and its solutions for various useful and important limits both in the sequential and the cotunneling regime. We derive effective relations describing the effect of the spin accumulation on the dc current flowing in the analyzed systems. We demonstrate that the dc current is related to distinct projections of the induced spin that allows for a single spin read-out locally by means of the electric transport measurements. Thus, the ferromagnetic electrodes can act effectively as spin detectors, that translate a spin information into a charge signal, while the readout direction can be controlled electrically. These findings allow us to explain the tunnel magnetoresistance characteristics from the recent experiment [4], where the nonequilibrium spin transport in the canted quantum dot spin valve was studied and signatures of out of equilibrium spin precession, that are electrically tunable, were observed. We also predict a new type of the zero-bias anomaly that is related to both the switching of the spin detection direction at the zero bias and to the spin dynamics due to the exchange field. Moreover, using our model with a compact equations we can explain analytically experimental results [5,6] related to recent breakthroughs in spin-polarized STM that makes it possible to probe and control the spin dynamics of individual atoms. We also propose further experiments in the analyzed systems.

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Interplay of magnetism and Majorana quasiparticles in artificial molecules

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Although experimental realization of Majorana fermions remains a challenging and unsolved problem in condensed matter physics, it is a topic of high importance due to its invaluable potential within quantum computing. One of the most promising systems to host these exotic quasiparticles, which are characterized by the equivalence of creation and annihilation operators describing them, are the topological one-dimensional superconducting nanowires, where Majorana bound states can be found at its ends. The presence of Majorana zero modes on such a nanowire can manifest itself through the zero-bias conductance peak. To measure electronic transport properties of such a system, quantum dots can serve as non-invasive spectroscopic probes, whose properties are well studied and understood. At low temperatures, strong electron correlations in such a zero-dimensional system lead to the Kondo effect. As magnetism is a non-negligible ingredient to induce Majorana modes in the topological nanowire, we are looking at the Majorana-Kondo competition in the spin-dependent transport through the double quantum dot system, where the ferromagnetic leads serve as the source of electrons. In our studies, we combine Kondo-correlated double quantum dot system with one-dimensional superconducting nanowires, focusing on the electronic and thermoelectric transport properties of such hybrid nanostructures in the presence of external magnetic field. The low temperature spectral functions as well as conductance are studied with the aid of numerical renormalization group technique, which is a well established tool of great accuracy in terms of analysing various complex quantum impurity systems. We show that introducing the spin dependency greatly modifies the two-stage Kondo effect for spin-up and spin-down channels, suppressing the transport through the quantum dot. When the topological superconductor is coupled to the second quantum dot, the low-temperature transport is lifted up to e^2/h.

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Magnetoresistance vs. electronic structure in Cu doped single crystalline Bi_2Se_3 topological insulator

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Bismuth selenide (Bi_2Se_3) is one of the 3D topological insulators (TI) that can be characterized as materials of a semiconducting volume and a conductive surface. The surface states are protected by time-reversal symmetry, which leads to a lack of backscattering of massless fermions on impurities. It results in a high efficiency of spin pumping as well as in an anomalous magnetotransport, which are both very promising from application point of view (e.g., in modern electronic devices). Unfortunately, the band gap for the volume electronic states in Bi_2Se_3 is narrow (220 meV). Thus, even a small amount of crystallographic defects leads to a shift of the Fermi level to the conduction band so that the volume is no longer semiconducting and such TIs are useless for practical applications. Moreover, the Bi_2Se_3 TI is expected to own superconducting property by Cu intercalation [1]. The aim of this work is to verify whether superconductivity can be achieved by doping, i.e., substitution of Bi with Cu (with no intercalation) and how it is related to the position of the Fermi level.

We present a magnetoresitance study that includes Shubnikov-de-Haas (SdH) oscillations, scanning tunneling spectroscopy (STS) and angle-resolved photoelectron spectroscopy (ARPES) of $Bi_{2-x}Cu_xSe_3$ (x=0, 0.05, 0.12 and 0.18) single crystals. On the basis of electronic transport measurements, we can conclude that all the tested samples reveal SdH oscillations of single frequency, which proves a good quality of the investigated single crystals as well as a high carriers mobility. The measured frequency of quantum oscillations increases with increasing content of Cu, which means that the cross section of the extremal Fermi surface increases (which is similar to the effect of Fe magnetic dopant [2]). The STS and ARPES studies confirm an occurrence of nontrivial topological surface states (forming the so-called Dirac cone) in all the tested samples. Despite obtaining good quality samples and having preserved the Dirac cone, no superconductivity is found in any of the tested samples down to the temperature of 70 mK. The results obtained from STS and SdH reveals that with Cu doping, the Fermi level is shifted towards higher energies in the conduction band reaching its final energy at around x = 0.15.

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Experimental evidence of nonlinear Hall effect in $Pb_{1-x}Sn_xTe$ topological crystalline insulators

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The linear Hall conductivity occurs in the systems, which have broken time-reversal symmetry either by the intrinsic or external magnetic field. However, recently predicted nonlinear Hall effect (NLHE) preserves time-reversal symmetry but it breaks inversion symmetry [1]. NLHE appears from the anomalous velocity of the Bloch electrons due to Berry curvature. Therefore, topological crystalline insulators and the Weyl semimetals are the potential candidates for NLHE due to a Berry curvature dipole [1-3]. The surface of topological crystalline insulators hosts massless Dirac fermions protected by mirror symmetries [2]. At low temperatures, ferroelectric transition caused one of the mirror symmetries to be broken. In the case of thin film, the small mismatch of the lattice parameter can also break the mirror symmetry. The present study reports a NLHE in the $Pb_{1-x}Sn_xTe$ topological crystalline insulator thin films with varying Sn composition. The thin film samples of $Pb_{1-x}Sn_xTe$ with compositions x=0.35 and x=0.42 were grown by molecular beam epitaxy (MBE) on (100) oriented CdTe (4 µm) // GaAs substrates. The nonlinear Hall signal appeared only when the AC excitation was applied along the mirror axis i.e. [110] in our case. The measurements of a nonlinear Hall voltage follows the same geometry as used in ordinary Hall effect, but the transverse voltage is measured at double-frequency, $V_2\omega$ and zero-frequency (DC) V_0 by using lock-in amplifiers. Both voltages quadratically depend on the perpendicular driving current and decrease when reaching transition from topological to trivial band ordering with rising temperature. The observed phenomenon opens the possibility of exploring topological phase transition as a function of temperature, composition and hydrostatic pressure in topological crystalline insulators.

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Evolution of half-metallic ferromagnetism in (111)-oriented manganite superlattices

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Oxide heterostructures can host exotic phenomena – such as flat bands [1], magnetic anisotropy [2], exchange bias [3] and spin-glass [4,5], only latent in bulk – and interesting phase competition in thin films and superlattices, because of symmetry breaking and quantum confinement. Research in these topics can reveal the potential of oxides for future applications. The (001)-oriented superlattice of two anti-ferromagnetic insulators $LaMnO_3$ and $SrMnO_3$ is found to be a half-metallic ferromagnet with short periodicity and an antiferromagnetic insulator with 2 or more unit cells [6,7,8]. Our *ab-initio* work predicts a (111)-oriented $LaMnO_3|SrMnO_3$ superlattice is a half-metallic ferromagnet in spite of its large thickness due to strain and charge transfer across the interface [9]. Magnetism and half-metallicity are bulk-like phenomena rather than due to local interfacial effects [9] – unlike in (001)-oriented superlattices [6,7,8]. We compare the two ground state space groups of bulk $LaMnO_3$ ($R\bar{3}c$) and bulk $La_{2/3}Sr_{1/3}MnO_3$ ($Pnma$), finding that their competition is tuned by in-plane strain and superlattice thickness. The $R\bar{3}c$ supports breathing distortions coupled to charge/spin oscillations, similarly to Hund's metals and high-T_C superconductors. The space group competition plays also a role in the Mn magnetic coupling, as $Pnma$ promotes A-type antiferromagnetism. Computed within the Heisenberg formalism via the magnetic force theorem, it stays strongly ferromagnetic in the La region but progressively shifts towards antiferromagnetic in the Sr region as thickness grows, suggesting mixed magnetic orders. Finally, we estimate the Curie temperature via atomistic spin dynamics.

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Comparative studies of graphene and phosphorene zigzag edge nanoribbons with antidots

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Recent studies on various graphene-like nanoribbons show that magnetic moments can appear on external zigzag edges. These magnetic moments critically influence physical properties of the nanoribbons. The effect strongly depends on relative magnetization directions of the two opposite ribbon's edges [1, 2]. Here, it is shown that magnetic moments can also appear in the nanopores (antidots). Notably, these extra internal magnetic moments can strongly influence both electronic and magnetic properties of the nanoribbons. Phosphorene and graphene nanoribbons with antidots are compared with each other. The former has got large external as well as internal magnetic moments, and seems to be very promising for future spintronic applications due to its half-metallic properties [3] for all considered antidot sizes.

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Magnetic vortex string gyrotropic dynamics in thick cylindrical nanodots

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There is a longstanding interest in the topological spin textures in small ferromagnetic particles and thin films, such as magnetic vortices, skyrmions, and hopfions. The magnetic vortex is one of the simplest topologically nontrivial and stable spin textures in condensed matter physics. Since the vortex state of magnetization was discovered as the ground state of patterned soft magnetic dots, the dynamics of magnetic vortices attract considerable attention.

The nonuniform magnetic vortex gyrotropic oscillations along the cylindrical nanodot thickness were calculated [1]. A generalized Thiele equation was used for describing the vortex core motion including magnetostatic and exchange forces. The magnetostatic interaction was accounted for in a local form. This allowed reducing the Thiele equation of motion of the vortex core to the Schrödinger differential equation and analytically determining the spin eigenmode spatial profiles and eigenfrequencies using the Liouville–Green method for the high-frequency modes. The mapping of the Schrödinger equation to the Mathieu equation was used for description of the low-frequency gyrotropic mode. The lowest-frequency gyrotropic mode is transformed to the dot faces localized mode increasing the dot thickness. The vortex gyrotropic modes are described for a wide range of the dot thicknesses according to the concept of the turning points in the magnetostatic potential. This approach allows treating the vortex localized modes (turning points) and nonlocalized excitation modes within a unified picture [1].

The vortex gyrotropic modes calculated in Ref. [1] for thick circular cylinders are not specific to this nanodot shape. Similar magnetic vortex excitations should exist also for other nanodot shapes such as a dome shape or square/rectangular shape. The point is that the dot thickness should be large enough to allow 3D magnetization texture excitations. The inhomogeneous gyrotropic oscillations of the vortex core string can be considered as a step towards understanding the magnetic topological soliton dynamics increasing the system dimensionality from 2D to 3D.

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Proximity effects in graphene/1T-TaS_2 heterostructure triggered by charge density wave and controlled with electric field

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Van der Waals heterostructures of graphene with transition metal dichalcogenides constitute highly promising systems for studies of proximity effects in graphene and their further applications in spintronics [1]. These effects include, in particular, the possibility to boost spin-orbit coupling (SOC) in graphene. In heterostructure systems, any additional degree of freedom enabling the control of proximity-induced effects is highly desirable. Such a tuning knob can be provided by charge density wave (CDW) ordering which emerges at low temperatures in selected transition metal dichalcogenides. In particular, 1T-TaS_2 develops such CDW ordering and, in addition, is predicted to acquire magnetic polarization.

In the paper, we discuss the van der Waals heterostructure composed of monolayer graphene and monolayer 1T-TaS_2 [2]. We present first-principles Density Functional Theory (DFT) calculations of its electronic structure both in the normal phase and in the CDW phase in TaS_2. Focusing on the graphene electronic structure close to the K/K' points, we predict the emergence of significant proximity effects. In order to interpret them we construct a symmetry-based tight-binding model Hamiltonian and determine its parameters by fitting the DFT data. We predict the appearence of proximity-induced Rasba and intrinsic SOC as well as exchange coupling when magnetism emerges in TaS_2 monolayer.

We find that the presence of CDW in TaS_2 profoundly influences the proximity-induced SOC in graphene, especially the Rashba SOC, modifying both its energy and Rashba angle. In this way, the CDW degree of freedom, reversibly controllable with factors such as temperature or laser light, is able to play the role analogous to the variable twist angle between the heterostructure layers, paving the way to the realization of twistronic functionalities without physically modifying a twist angle.

To add yet another tuning knob, we study the effect of the electric field normal to the heterostructure, finding the additional possibility of controlling the proximity effects.

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Magnetization reversal in Fe(001) films grown on MgO(001) by magnetic field assisted molecular beam epitaxy

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Molecular beam epitaxy (MBE) is a powerful tool in modern thin film technologies, including electronic, optoelectronic, spintronic or sensoric application. In the traditional MBE film growth is controlled by substrate temperature, deposition rate and partial pressure of reactive gases. Applying the magnetic fields (MF), although uncommon for ultra-high vacuum (UHV) MBE growth, should not be ignored in the synthesis, processing of thin films, especially in ferroic systems [1]. Whereas post-deposition annealing under MF at high temperatures is known as a method of shaping desired magnetic anisotropy, engineering of magnetic properties using MF-assisted MBE was unexplored. Recently, we have developed a method of growing epitaxial films under external MF [2], and showed how this MF affects both in-plane and out-of-plane magnetization reversal for epitaxial magnetite films. In the present contribution we apply this method to epitaxial Fe(001) films on MgO(001).

Fe(001) films, 10 nm thick, were grown on MgO(001) substrates in a multi-chamber UHV system (base pressure $3*10^{-10}$ mbar), including MBE facility and standard surface characterization techniques. Combination of flag-style and PTS-style sample holders [3] (the latter including permanent magnets for generation of MF) and a sophisticated two-station 4-axis manipulator allowed us an easy transfer of the substrate between the stations proper of a given preparation step (cleaning, deposition, annealing). For the *ex situ* measurements the films were protected with 3 nm of MgO.

The role of the external magnetic field for the magnetization reversal process was revealed by measuring the full in-plane angular dependence of the hysteresis loops for MF applied during deposition along the Fe easy [100] and hard [110] in plane axes, using a sample deposited without MF as a reference. The MOKE loops were further interpreted by magnetic domain imaging.

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Efficient cooling with hot magnons

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The advent of nanotechnology allowed for investigation of behaviour of particles and quasi-particles in the smallest possible scale. In particular, systems in which different type of particles interact have been a subject of extensive studies. It was shown that such hybrid systems exhibit novel phenomena due to the interplay between different statistics governing the behaviour of the particles [1,2]. What is more, investigation of nanoscale hybrid systems proved to be worthwhile due to their potential for application. Number of heat engines, spin current converters, refrigerators and other devices have been already proposed [3-6].

We present a nanoscale refrigerator composed of two ferromagnetic metals and a magnetic insulator coupled to a quantum dot. By applying temperature gradient to the metals an imbalance in the occupations of the electronic states is created. This leads to the flow of electrons from hot to cold terminal. However with the energy input from outside it is possible to force the net current of electrons from above of Fermi level (hot electrons) to flow in the opposite direction with electrons from below Fermi level (cold electrons) still flowing in the direction of the temperature gradient. This leads to the cooling of the electrons in the cold lead - phenomenon called *cooling by heating* [7]. In the system under study one of the metals is cooled by the help of the outside source of the energy delivered by magnons coming from the magnetic insulator. The inclusion of quantum dot allows the transport to take place through discrete level which has a beneficial influence on the efficiency of the cooling. We investigate the flow of heat in the system and calculate coefficient of performance of such a device for various system's parameters.

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Heusler alloy thin films on graphene-based substrates

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Spin transport in lateral spin valve (LSV) devices depends on the state of LSVs building blocks: spin injectors/detectors (ferromagnetic electrodes) and a nonmagnetic spin transport channel. Since the basic operation in spintronic devices is switching bistable nanomagnets [1] – the ferromagnetic electrodes – deployed for injection or detection of a spin-polarized current, their spin polarization at the Fermi level is crucial. The ideal candidates for spin injection/detection are half-metallic ferromagnets which exhibit 100% spin polarization of conduction electrons. Examples are some Heusler alloys: NiMnSb, Co_2FeSi, and Co_2MnSi, among others [2]. The suitable spin transport channel should allow for a long spin lifetime and long-distance spin propagation. The experimental studies of spin transport measurements identified graphene as the most favorable material for spin transport channels in spin-logic devices [3].

The properties of CVD-grown graphene on the surface of magnetron sputtered $Co_2FeGe_{0.5}Ga_{0.5}$(001) half-metallic Heusler alloy thin film was studied by Li et al. [4]. They suggest that the electronic properties of the Heusler alloy were preserved at the interface with graphene. Yamaguchi et al. demonstrated the dry transfer of a multilayer graphene flake on the Co_2FeSi spin valve electrodes [5]. The performance of their device – large nonlocal magnetoresistance signal – was significantly large compared with previously reported values. Recently, Li et al. reported epitaxial growth of Co_2MnSi film on Ge(111) substrate via a graphene interlayer [6].

Herein, we present the influence of the properties of a graphene substrate on the growth of Heusler alloy thin films. The sputter deposited thin films of Co_2MnSn and Co_2MnAl Heusler alloys on HOPG (highly oriented pyrolytic graphite – whose surface is similar to graphene) have a polycrystalline structure. However, Co_2FeSi films grown on the same substrate have (001) texture. In the case of MBE (molecular beam epitaxy) growth of Co_2FeSi thin films on the epitaxial graphene on SiC and transferred graphene on Si/SiO_2, the morphology of the film is an island-type with (022) texture.

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Chains of nanoparticles with cubic magnetic anisotropy: a Monte Carlo simulation

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We use Monte Carlo techniques to simulate magnetic properties of chains of identical, spherical, single-domain, ferromagnetic nanoparticles with cubic magnetocrystalline anisotropy. Hysteresis curves as well as zero field cooled (ZFC) and field cooled (FC) experiments are simulated for chains of different lengths, i.e. differing in both: the number of particles and interparticle distances. Strongly anisotropic dipole-dipole interparticle interactions lead to significant differences in system's response to the external magnetic fields oriented parallel and perpendicular to the chain, and further, to the occurrence of wasp-waisted hysteresis loops. To get the idea about the quantitative scale of the discussed phenomena we assume values of magnetocrystalline anisotropy consatants as known for fcc-Co.

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Time of Majorana mode leakage into the region of quantum dots

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Hybrids comprising quantum dots and topological chains are considered as scalable platforms for topological quantum computation. To determine how fast such devices can perform dynamic operations, it is important to evaluate time required for the transfer of quantum state between subsystems. In presentation, the dynamics of electron transfer in the system comprising quantum dots deposited on a s-wave superconductor and tunnel coupled to one end of the topological chain will be analyzed. In particular it will be shown how long it takes for the Majorana zero mode to be induced in the region of quantum dot and how charge transfer properties change over time under abrupt change of model parameters e.g. the gate voltage. The relevant time and energy scales characterizing such dynamics will also be discussed.

Detection of persistent current correlation in cavity-QED

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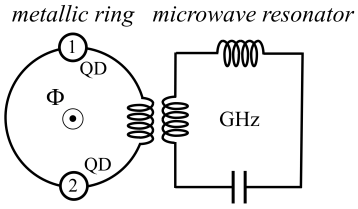
Recent technological developments in circuit quantum electrodynamics (cQED) offers superconducting microwave resonators operating in the range of GHz. This technique has been applied to studies charge, spin and current dynamics in various nanodevices: single spins in doped crystals, quantum dot systems, superconducting qubits, nanomechanical oscillators or magnonic nanostructures [1].



Scheme of the considered model: the metallic ring with two quantum dots (QD) inductively coupled to the microwave resonator.

Here, we want to show how cQED can be applied to measure correlations of the persistent current in the metallic ring (shown in the figure). We simulated the radiative response of the cavity quantum electrodynamics (QED) inductively coupled to the ring pierced by magnetic flux and analyzed its spectral dependence to get insight into persistent current dynamics. Current fluctuations in the ring induce changes in the microwave resonator: shifting the resonant frequency and changing its damping. We use the linear response theory and calculate the current response function by means of the Green function technique. Our model contains two quantum dots which divide the ring into two branches with different electron transfers. There are two opposite (symmetric and asymmetric) components of the persistent current, which interplay can be observed the response functions. We observe a nonmonotonic dependence of the local current response function on the Aharovov-Bohm phase ϕ. Its shape depends on transmission asymmetry between the left and the right branch. The resonator reflectance shows characteristic shifts in the dispersive regime and avoided crossings at the resonance points. The competition of two opposite persistent currents is also quite pronounced. In the region around $\phi = \pi$ the asymmetric component of the persistent current is dominant which leads to a negative resonant frequency shift, a negative damping ratio and signal amplification. Outside this region fluctuations of the symmetric persistent current component are relevant.

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Atomistic simulations and magnetic properties of Co/Tb-Co bilayers

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Ferrimagnetic RE-TM films (RE-rare earth, TM-transition metal) are experiencing renewed interest for applications such as spintronics and all-optical switching. It has previously been demonstrated that ion bombardment (IB) can be used to modify the properties of ferrimagnetic RE/TM multilayers primarily due to preferential oxidation of RE after bombardment [1,2]. In this work we show that the addition of a Co underlayer can also be used to tailor magnetic properties of Tb-Co alloy films. Several Co/Tb-Co bilayer systems deposited by magnetron co-sputtering in which the Tb-Co alloy layer was prepared with mutually perpendicular gradients of Tb concentration ($16 \leq c_{Tb} \leq 59$ at. %) and thickness ($3 \leq t_{alloy} \leq 10$ nm) as detailed in Ref. [3]. The thickness of the Co underlayer (t_{Co}) was kept uniform ($t_{Co} = 0.5$, 1.0, 2.0, 4.0 nm). The magnetic characterization of the samples was performed using PMOKE magnetometry.

This allowed us to determine which combinations of layer thicknesses and RE concentration allow simultaneous magnetization reversal of both layers, maintain perpendicular magnetic anisotropy, and show that the addition of the Co underlayer shifts the compensation point towards higher c_{Tb}. At a specific composition ($c_{Tb} \gtrapprox 40$ at. %), a second compensation point was observed where the sublattice domination changes from Tb to Co. At this composition, the Tb-Co layer is expected to be paramagnetic at room temperature [4].

Atomistic simulations using the Vampire package [5] were used to provide an understanding of the mechanisms responsible for the observed features. An atomistic approach is ideal for ferrimagnetic systems because it allows for the consideration of the individual sublattices. In particular, cross-sectional profiles of the magnetization of the system for varying temperature indicate that a small part region of the paramagnetic Tb-Co layer exhibits spontaneous magnetization close to the Co/Tb-Co interface. The simulations reveal that, close to the interface between the two layers, a small part of the paramagnetic alloy layer exhibits spontaneous magnetization, causing the system to behave as a ferrimagnet with Co domination due to a proximity-induced spin polarization.

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Towards controlled chirality in disordered systems: Bi on 2Ni/Co multilayers

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Ultrathin magnetic metal films in contact to heavy metal (HM) layers are well known to develop robust spin-orbit (SO) derived properties ultimately leading to stabilization of chiral objects. At the basis of these phenomena are local interface Dzyaloshinskii-Moriya interactions (DMIs) that can be manipulated through different designs. The magnitude and sign of the DMI can be tuned by interface engineering, which allows to stabilize chiral or non-chiral Néel and Bloch domain walls in a given magnetic system, opening technological opportunities to handle information in electronic devices without the need of magnetic fields. The main drawback of the approach is the lack of descriptors easing prediction of the best conditions to enhance the DMI and gain control on the chirality sign. This confers additional interest to explore different systems and conditions that make possible the identification of trends.

Here we investigate a special system that adds new ingredients to previously explored metal/HM heterostructures: epitaxial [2Ni/Co] stacks on Cu(111) modified by Bi. Spin Polarized Low Energy Electron Microscopy (SPLEEM) measurements demonstrate that Bi influences the spin texture of the system, with magnetic domain walls evolving from non-chiral Bloch to homo-chiral Néel configurations when Bi is added. Eventhough the surfactant properties of Bi render a disordered distribution, the system preserves constant homochirality both at low and room temperatures. Here we will focus on understanding the origin of this behavior based on ab initio calculations within the density functional theory, exploring the balance of magnetic energy terms (exchange and SO-derived) under different geometries. Bi contributes with singular properties: it has a large size, that introduces incomplete interface layer coverage; and it is a p valence band metal, weakly polarizable. Also the 2Ni/Co stacks confer an inherent asymmetry that conditions interface additive effects, further supported by the different chiral response of Ni and Co. Our results evidence 2Co/Ni heterostructures combined with Bi as unique systems to tune and control stable homochiral structures where the DMI can even be made the dominant energy scale.

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Nonreciprocal spin wave dynamics in uniformly and nonuniformly magnetized symmetric Pt/Co/Pt multilayers

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In modern times, magnetic multilayers are considered as a building block of various magnetic memory applications such as magneto-resistive heads, magneto-optical recording devices [1]. Magnetic excitations of multilayers contain intriguing physics related to exchange interactions and spin configurations. A symmetric multilayer of Pt/Co/Pt was deposited, on an oxidized silicon substrate, by dc magnetron sputtering with a nominal structure of Ti(4)/Pt(29.3)/$[Pt(0.7)/Co(2.2)]_{24}$/Pt(3) (all thicknesses are given in nm). The sample was characterized by: (i) vibrating sample magnetometry, (ii) magneto-optical Kerr effect magnetometry and microscopy, and (iii) magnetic force microscopy. The following hybrid magnetization structure was deduced: (i) large with size in sub micrometer scale domains with in-plane "core magnetization", these domains are responsible for magnetization hysteresis driven by in-plane applied magnetic field H, and (ii) small – in nanometer scale "weak stripe domains" with opposite out-of-plane magnetization component, realizing demagnetized remanent state. Optical Brillouin light scattering (BLS) spectroscopy was used to observe the multimode dispersion characteristics in the in-plane magnetic saturation state as well as in the remanent state, in the presence of a stripe domain structure [2]. In both cases, some excitations were characterized by strong non-reciprocity (difference between the frequencies of the Stokes f_{St} and anti-Stokes f_{aSt} peaks, $\Delta f = f_{aSt}\text{-}f_{St}$, increased with the increase of the wave vector) in comparison to other frequency modes with $\Delta f = 0$. Magnetization dynamics have also been studied using cavity based X-band (9.5 GHz) ferromagnetic resonance (FMR) and broadband Vector Network Analyzer (VNA) VNA-FMR spectroscopies as a function of magnetic field. The hysteresis of the dynamical responses measured by both FMR is related to the switching in sign of core in-plane magnetization. Experimental investigations of multimodal spectra were also supported by micromagnetic simulations, which gave us an insight into their origin. Our findings of observed spin-wave modes in both in-plane and out-of-plane magnetization states are intriguing and provide information about the spin-wave band structure in multilayer magnonic structures.

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Thermoelectric properties of a hybrid quantum dot containing topological superconductor

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Thermoelectric properties of hybrid systems based on a single-level quantum dot coupled to normal-metal/half-metallic lead and attached to topological superconductor wire are investigated. Topological superconductor wire is modelled by spinless p-wave superconductor which hosts both Majorana bound state and over-barrier quasiparticle excitations. As topological superconductor couples only electrons of one spin orientation the transport through the system is fully spin-polarized. The main interest of the paper is studying the interplay of sub-gap and quasi-particle tunneling and its contribution to thermoelectric response of the considered system. The over-barrier tunneling driven by temperature gradient is responsible for relatively large thermopower, whereas sub-gap processes, due to zero energy Majorana state, only indirectly can influence thermoelectric response. The thermoelectric coefficients, including electric conductance, Seebeck coefficient, heat conductance, and the corresponding figure of merit, are calculated by means of nonequilibrium Green's function technique. The temperature dependence of superconducting gap is considered within the BCS theory. We also study the system out of equilibrium working as heat engine. The output power and the corresponding efficiency are presented.

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Mott transition in the Hubbard model on anisotropic honeycomb lattice with implications for strained graphene

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Modification of interatomic distances due to high pressure leads to exotic phenomena, including metallicity, superconductivity and magnetism, observed in materials not showing such properties in normal conditions. In two-dimensional crystals, such as graphene, atomic bond lengths can be modified by more that 10 percent by applying in-plane strain, i.e., without generating high pressure in the bulk. In this work, we study the strain-induced Mott transition on a honeycomb lattice by using computationally inexpensive techniques, including Gutzwiller Wave Function (GWF) and different variants of Gutzwiller Approximation (GA), obtaining the lower and upper bounds for critical Hubbard repulsion (U) of electrons. For uniaxial strain in the armchair direction the band gap is absent, and electron correlations play a dominant role. A significant reduction of the critical Hubbard U is predicted. Model considerations are mapped onto tight-binding Hamiltonian for monolayer graphene by the auxiliary Su-Schrieffer-Heeger model [1,2] for acoustic phonons, assuming zero stress in the direction perpendicular to the strain applied. Our results suggest that graphene, although staying in semimetallic phase even for extremely high uniaxial strains, may show some measurable signatures of electron correlations.

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Ex-situ versus in-situ synthesis of NZFO/f-MWCNTs nanocomposites

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Nowadays, spinel ferrites magnetic nanoparticles (SF-MNPs) incorporated into 1D or/and 2D carbon-based matrix are intensively studied due to their outstanding promising application properties e.g. drug delivery systems for magnetic hyperthermia or microwave-absorbing materials [1-3]. A lot of attention has been recently paid to Ni-Zn-based ferrites with non–collinear spin structure [4] and microstructure which can be controlled by applying various synthesis methods. Our research is focused on the synthesis and complex characterization of $Ni_{0.5}Zn_{0.5}Fe_2O_4$ nanoparticles with 5 wt.% of (NZFO) incorporated into functionalized carbon nanotubes (f-MWCNTs). The synthesis of NZFO/f-MWCNTs nanocomposites was carried out by so-called *in-situ* and *ex-situ* approaches followed by the calcination. The XRD patterns and TEM images confirm the successful formation of nanocomposites. The crystallite size of NZFO particles significantly depends on the synthesis route, as evidenced by multi-technique characterization. The comparison of photoemission XPS spectra of studied nanohybrids reveals the domination of f-MWCNTs contribution as expected. The iron redistribution/separation confirmed by variation within deconvoluted Fe2p spectra is dependent on synthesis routes and the calcination process. The XAS and ReSPES study confirms the evident difference in *in-situ* and *ex-situ italic text*synthesis. The magnetic properties are slightly affected by Fe-based catalyst residuals as evidenced for f-MWCNTs, but the magnetic state originating from NZFO is dependent on nanoparticles size.

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A magnetic C36 Laves phase in Co-Fe-Ta system

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The computational tools at hand allow for an unprecedented prediction of new structures with desired physical properties. Yet, in many cases, no recipes are provided to synthesize them. In the case of a binary compound, we show a route to bring a theoretically predicted structure to a real material. In particular, we demonstrated the possibility to synthesize a C36 Laves phase ($hP24$ structure) with improved intrinsic magnetic properties in the Co-Fe-Ta system. Computational studies predict superior intrinsic magnetic properties for an experimentally not observed Fe_2Ta C36 Laves phase. This phase, however, occur in the Co-Ta system, which suggests the possibility of the existence of a stable compound along the $(Co_{1-x}Fe_x)_2Ta$ path. Following this route, we computationally predict a stable C36 Laves phase with improved intrinsic magnetic properties for large Fe content, and successfully synthesize it experimentally. This approach is general and can be applied to identify a synthesis path for a predicted material with desired properties.

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Magnetic properties of FeB and MnB doped with 3d, 4d and 5d transition metal elements

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The increasing use of magnetically hard materials in industry, together with the unstable prices of rare earths observed over the past several years, is mobilizing the search for new materials that could, albeit in specific applications, replace rare earth-containing magnets. Of the Mn- and Fe-rich compounds under consideration, the notable ones, in our opinion, are MnB and FeB monoborides and their alloys. In this paper, using first-principles calculation methods, we systematically study MnB and FeB alloys with 3d, 4d and 5d transition metals (TM) [1-2]. We consider compositions with the general chemical formula of $Mn_{11}(TM)_1B_{12}$ and $Fe_{11}(TM)_1B_{12}$. In our calculation magnetocrystalline anisotropy energy (MAE), magnetic moments, and magnetic hardness are determined for all compositions considered. Moreover, the calculated dependence of MAE on the spin magnetic moment made it possible to predict the upper limits of the MAE. We have also shown within the virtual crystal approximation that the magnetic moments on magnetic atoms strongly depend on the electron occupancy, which is modified by both the substitution and the strong interaction between the (Mn/Fe) – 3d and B – 2p orbitals. This interaction leads to a shift in the Bethe-Slater curve, showing the dependence of transition metal exchange energy on d-band occupation. This mixing of p – d orbitals, resulting from the redistribution of band occupancy, also leads to strain-induced MAE changes. We have also selected few materials with potential of becoming rare-earth free permanent magnets such as $Fe_{11}TiB_{12}$ for which we have obtained value of MAE equal 0.86 MJ m^{-3} and magnetic hardness equal 1.15.

Calculations were performed using the full-potential local-orbital electronic structure code FPLO18 [3], whose unique fully relativistic implementation of the fixed spin moment method allowed the calculation of the MAE dependence of the magnetic moment.

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Magnetic domain structures in amorphous microwires with distributed magnetic anisotropy

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We studied the magnetic properties of glass covered amorphous microwire that was stress-annealed at temperatures distributed along the microwire length. The Sixtus-Tonks, Kerr effect microscopy and magnetic impedance techniques have been applied. There was a transformation of the magnetic structure across the zones subjected to annealing at different temperatures. The annealing temperature distribution induces the graded magnetic anisotropy in the studied sample. The variety of the surface domain structures depending on the longitudinal location has been discovered. The spiral, circular, curved, elliptic and longitudinal domain structures coexist and replace each other in the process of magnetization reversal. The analysis of the obtained results was carried out based on the calculations of the magnetic structure, assuming the distribution of internal stresses.

The Effect of Copper Ion Substitution on the Magnetic Microstructure and Magnetic Characteristics of Nickel Ferrite

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Ferrites with a spinel structure attract considerable attention from researchers due to their good magnetic properties and the possibility to change their characteristics in a wide range, using different methods and conditions of synthesis and selective replacement of them with magnetic or non-magnetic elements [1]. Among the spinel ferrites, nickel ($NiFe_2O_4$) and copper ($CuFe_2O_4$) ferrites are particularly interesting due to their high magnetocrystalline anisotropy, high saturation magnetization, and electrical resistance [2]. In the inverted spinel structure, Ni and Cu ions occupy the octahedral (B) sublattice, however, when nickel ferrite is replaced by copper ions, the latter can be localized both in octa- and tetra-sublattices, displacing iron ions from there. Thus, preconditions are created for changing the magnetic parameters with the corresponding variation in the concentration of the substituting element and the synthesis conditions.

Nanosized copper-substituted nickel ferrite was synthesized by a single-step, energy-saving, and environmentally friendly sol-gel autocombustion method. To determine the effect of substitution on the structure and magnetic characteristics, the obtained samples were studied by several methods, including X-ray diffraction (XRD), vibrating-sample magnetometry (VSM), and ^{57}Fe Mössbauer spectroscopy.

The results of the research showed that with an increase of copper ions in the content. Also, we observed a non-monotonically decrease in saturation magnetization values and other parameters (remanent magnetization, coercive force, and magnetocrystalline anisotropy coefficient). These changes have related to the presence of copper ions in both the octa- and tetra-sublattices. The Mössbauer spectra show that the influence of the dopant is manifested in the fact that a paramagnetic doublet appears and grows, which is a result of the effect of non-magnetic ions near Fe nuclei.

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Temperature driven spin switching and exchange bias in $ErFeO_3$ compensated ferrimagnet

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In single crystals of $R\mathrm{FeO_3}$ (R = Nd, Sm, Er) the weak ferromagnetic (FM) moment results from the canted antiferromagnetic (AFM) ordering of Fe spins below $T_N \approx 700$ K due to the Dzyaloshinskii-Moriya interactions, while the opposite compensating paramagnetic moment of R spins appears owing to a strong AFM coupling between $4f$ and $3d$ ions within the unit cell. Due to this mechanism, the Er, Nd, and Sm orthoferrites exhibit a specific T_{comp} at which the two opposite moments cancel each other, so the net magnetization vanishes, and below T_{comp} the FM moment is aligned oppositely to the moderate applied magnetic field, demonstrating a negative magnetization. It was found that the magnetization hysteresis loops of these ferrimagnets are analogously exchange biased around their compensation temperatures T_{comp} [1]. Interestingly, in spite of very different R-Fe interactions, T_{comp} values, and spin-reorientation temperatures, the EB field similarly emerges and diverges upon approaching T_{comp} and changes sign with crossing it.

$ErFeO_3$ exhibits additionally specific phenomenon: temperature driven spin switching and exchange bias [2]. The EB manifests itself as the temperature shift of the hysteresis loops M vs T, which occurs upon successive cooling and heating in a weak magnetic field. The $M(T)$ loops, limiting the region of coexistence of negative and positive magnetization, are shifted towards lower or higher temperatures, depending on the sign of the applied magnetic field, which causes the unidirectional EB anisotropy. The EB anisotropy energy, which contributes to the energy barrier for switching spins to an equilibrium state, determines the shift in the switching temperature T_{sw}.

A model of nonequilibrium thermodynamics of $ErFeO_3$ was proposed. The quantum-mechanical effects in arbitrary magnetic fields related both to the direction of a general quantization axis and an influence of anisotropic exchange interactions on the magnetic structure, spin-reorientation phase transition, spin reversals, and hysteresis were considered. Based on recent experimental data on temperature-induced spin switching, a possible mechanism for the exchange bias of magnetic hysteresis loops is proposed [3].

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DFT analysis of magnetic properties of $L1_0$ $(Fe_{1-x}Co_x)Pt$ alloys for heat assisted magnetic recording

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Constantly developing technology increases the demand for data carriers with increasingly high recording densities. This leads to the problem of maintaining the thermal stability of the recorded information, good signal-to-noise ratio, and recording fields small enough to be within the technologically available range. One way to circumvent this problem is to use materials with high perpendicular magnetic anisotropy together with the use of heat-assisted magnetic recording (HAMR) [1].

$L1_0$ FePt and CoPt phases are often considered in this context [2]. We showed previously that fine-tuning magnetic parameters of the $L1_0$ FePt should be achievable [3]. In presented work, we investigate possible tailoring of magnetic properties of $L1_0$ FePt by alloying with Co in the $(Fe_{1-x}Co_x)Pt$ $L1_0$ phase in a lookout for any intermediate systems with better properties than the pure $L1_0$ FePt and CoPt.

The calculations were performed using different density functional theory (DFT) codes: full-potential local-orbital (FPLO) and spin-polarized Korringa-Kohn-Rostoker (SPR-KKR) schemes. We compare several different implementations of the chemical disorder consideration, namely virtual crystal approximation (VCA) and coherent potential approximation (CPA) effective medium methods, supported by a direct Fe/Co full configuration space analysis in a $2\times2\times2$ supercell. Due to the specificity of the utilized codes, we used the VCA and supercell methods in the FPLO code and the CPA method in the SPR-KKR code.

We present Co content dependencies of structural (unit cell volume, lattice constants ratio) and magnetic (magnetic moments, magnetocrystalline anisotropy energy (MAE)) properties of the system, as well as the MAE dependency on magnetic moment in the fixed spin moment (FSM) approach. We further evaluate changes in magnetic hardness and magnetostriction coefficient with Co concentration. In the disordered local moment (DLM) approximation, we calculate Curie temperatures in the SPR-KKR/CPA. The mixing enthalpy calculations for the full configuration space allows us to evaluate the overall stability of the system.

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How can a magnetic field influence the evaporation of water?

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A static magnetic field should not be expected to have any appreciable influence on the evaporation rate of water because the magnetic energy per mole $(1/2\mu_0)c_{mol}B_2$ in 1 T is seven orders of magnitude less than the energy of the hydrogen bonds. Nevertheless when evaporation from half-filled beakers ia compared in a field of 0,5 T and no field. the evaporation rate in-field is 12 ± 7 greater. However, in-field evaporation from 6M urea or 1M NaCl solutions is about 20% slower than no field evaporation [1]. The critical feature is whether or not the water is evaporating into its own vapour. The field effect is up to an order of magnitude greater when the evaporation from a water droplet at the centre of a microchannel is measured [2]. The explanation is related to an influence of magnetic field on the symmetry of the wave function of water vapour. There are two nuclear isomers, *ortho* water vapour with parallel spins of the hydrogen protons forming a triplet state and *para* water vapour where the spins are antiparallel. In thermodynamic equilibrium the *ortho* /*para* ratio is 3:1 but the two isomers behave as quasi-independent gasses and equilibrium takes weeks to establish. Analysis of the field and time-dependence of the evaporation rate of deionized water indicates that the isomeric ratio in fresh water vapour is 39:61 rather than 75:25. The field effect is due to dephasing of the nuclear Larmour precessions of the two protons in a water molecule, which tends to equalize their populations.

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Magnetic Particle Based MRI Thermometry at 0.2 T and 3 T

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This study provides insight into the advantages and disadvantages of using ferrite particles embedded in agar gel phantoms as Magnetic Resonance Imaging (MRI) temperature indicators for low-magnetic field scanners. The advantages of high-field MRI, like lower purchase and operation costs and the reduction of certain artifacts are well known. Nevertheless, the more open designs for the low-field scanners are better suited for MRI-guided interventional procedures and reduces claustrophobic issues for patients. In order to circumvent issues of toxicity and develop more biocompatible agents, in this study we use mixed magnesium-zinc $(Mg_{1-x}Zn_x)_yFe_{3-y}O_4$ ferrite particles as temperature contrast agents. In a recent work, we have shown that these mixed MgZn ferrites possess promising magnetic properties and, in moderate concentrations under 240 $\mu g/mL$, are much less toxic than other previously studied materials [1]. We compare the temperature-dependent intensity of MR images at low-field (0.2 T) to those at high-field (3.0 T). Due to a shorter T_1 relaxation time at low-fields, MRI scanners operating at 0.2 T can use shorter repetition times and achieve a significant T_2^* weighting, resulting in strong temperature-dependent changes of MR image brightness in short acquisition times. Although the signal-to-noise ratio for MR images at 0.2 T MR is much lower than at 3.0 T, it is sufficient to achieve a temperature measurement uncertainty of about $\pm 1.0^oC$ at 37^oC for a 90 $\mu g/mL$ concentration of magnetic particles [2]. In addition to the advantages listed above, we discovered a surprising benefit when using low-field scanners. The percentage changes of the temperature-dependent image intensities are larger for low-field scanners compared to high-field scanners. As a consequence, there are two potential advantages of conducting MRI thermometry at 0.2 T compared to 3.0 T. First, the temperature measurement itself can be more accurate, and second, the acquisition time can be shorter.

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Halbach Arrays in Magnetomechanics: A Promising Technology for Biomedical Applications

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This paper explores the potential of a novel device consisting of circular Halbach arrays for harnessing magneto-mechanical phenomena. Aiming to adopt the setup for biomedical applications, this work analyzes the magnetic properties and establishes its convergence with the model it was based on. Specifically, the device was modelled with the Multiphysics computational program COMSOL v. 3.5a. The first step towards this goal is to register the different operational modes of the apparatus to demonstrate its flexibility and versatility. Subsequently, fundamental quantities that are directly related to diseases, such as magnetic field strength, gradient and force are studied to determine the device's effectiveness in treating various conditions. The numerical analysis results are then validated experimentally via magnetic field measurements to evaluate potential deviations from the computational model. The results corroborate the potential of the device in a wide range of biomedical applications, especially targeted drug delivery and tissue engineering. Additionally, the demonstrated versatility of the magnet arrangements suggests possible utility in various settings and scenarios. Overall, this study offers valuable insights into the application of magneto-mechanical phenomena in biomedical engineering and provides a promising direction for further research. As the biomedical field continues to evolve, it is important to pursue innovative solutions that can potentially revolutionize the angle of approach for Theranostics. The apparatus presented in this paper paves a promising avenue leading to this aim. In conclusion, the results of this study suggest that the proposed device is a valuable tool in biomedical applications, the full potential of which remains to be identified in future research.

The influence of the magnetic field on the entry of nanodrugs into cells

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Magnetic nanoparticles are very interesting materials in various fields. In medicine they can be used as contrast in diagnostic imaging, drug carriers and in magnetic hyperthermia. Their advantage is the possibility of attaching various drugs to the surface. These can be for example chemotherapeutics or antioxidants. Both of them play a big role in medical therapy. Antioxidants, as free radicals scavengers, are very important because most diseases, including cancer, are associated with uncontrolled radical processes taking place in the body. However, there is always the question of whether and how nanoparticles enter cells. A method which can be used to study both the properties of functionalized magnetic nanoparticles and their interactions with cells is electron spin resonance (ESR). As a result two sources of information are given: about the core and the surface. The second signal informs about the interaction with the external environment, for example cells. Several factors are believed to affect the permeability of the cell membrane, such as electric, magnetic fields and ultrasounds. In this work it will be shown how the magnetic field in various configurations can affect the process of entering nanodrugs based on magnetic nanoparticles into cells.

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POSTER CONTRIBUTIONS

ABSTRACT CATEGORIES

1. Strongly Correlated Electrons and High Temperature Superconductivity

Heavy fermions and Kondo systems; Charge, orbital, and multipole orderings and excitations; Quantum phase transitions; Metal-insulator transitions; Highly correlated metals and insulators; Itinerant electron magnetism; Organic conductors; Low dimensional conductors, Correlation effects in mesoscopic systems; Multiferroics

2. Quantum and Classical Spin Systems

Low dimensional quantum magnets; Frustrated magnets and spin liquids; Quantum phase transitions; Lattice effects and spin Peierls systems; Solitons and nonlinear effects; Statistical mechanics of quantum and classical systems; Molecular magnetism; Quantum tunnelling and coherence; Quantum information; Organic and organo-metallic materials

3. Magnetic Structure and Dynamics

Crystal field and anisotropy; Magnetic structure and spin waves; Dynamic phenomena; Electronic structure; Magnetic interactions; Rare-earth and actinide magnetism; Transition metal alloys and compounds; Spin glasses; Random magnets; Magnonic crystals

4. Spin Electronics and Magneto-Transport

Magnetoresistance effects; Current induced magnetization reversal; Spin injection and accumulation; Spin Hall effect, Magnetic Semiconductors; Optical properties; Quantum computation

5. Nano-structure, Surfaces, and Interfaces

Surfaces and interfaces; Films, multilayers and superlattices; Exchange interaction and anisotropy; Spin dynamics, Patterned films; Nanoparticles; Nanowires and dots

6. Soft and Hard Magnetic Materials

Amorphous and nanocrystalline materials; Granular materials; Ferrites, garnets and microwave materials; Permanent magnets; Magnetization processes; Magneto-elastic and magnetostrictive materials; Modeling and simulations

7. Applications

Magnetic sensors; Ferromagnetic shape-memory materials; Actuators and magnetic drives; Magnetic refrigeration; Magnetic fluids; Magnetic separation and levitation

8. Other Topics

Biomagnetics; Magnetism in medicine; Measuring techniques and instruments; Magnetic recording and memories

Localized-Itinerant Ferromagnetism of the Two-Dimensional Van der Waals Metallic Fe5-xGeTe2 Single Crystal

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Two-dimensional van der Waals ferromagnet Fe5-xGeTe2 material has drawn increasing attention due to its near-room Curie temperature (Tc) and wide spectrum of physical characteristics. However, the magnetism of quenched Fe5-xGeTe2 single crystals has been found to be complex due to its dependency on thermal history. On the other hand, very few studies on electrical transport properties have been conducted. Here, we report the thermal history-dependent physical properties of a quenched Fe5-xGeTe2 single crystal with x = 0.16 by employing the temperature-dependent magnetization, isotherm magnetization, electrical resistivity, Seebeck coefficient, thermal conductivity, and specific heat measurements. The results represent the local ferromagnetic moment at Curie temperature, Tc = 310 K, and the helimagnetic phase transition, Th = 273 K. Our observations shed new light on the origin of and interplay between the thermal history-dependent magnetic and electrical properties of van der Waals ferromagnets.

Polaronic effects in thin films of metal-insulator nickelates

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Rare-earth nickelates is a rare family of oxides showing metallic conductivity. A first member of the family $LaNiO_3$ having practically ideal perovskite structure is metallic in the whole temperature range. Substituting the rare-earth element by smaller ions (Pr, Nd or Sm) distorts the lattice orthorhombically initiating a sharp metal-to-insulator transition (MIT) at cooling. Rich physics and promising application potential of the MIT maintain intensive research of the nickelates. Due to extreme synthesis conditions, there is still no a sizable single crystal of $NdNiO_3$ and $SmNiO_3$ having the MIT at 200 and 400 K, respectively. Therefore, thin epitaxial films present the best current approach to study its intriguing physical properties including strong electron-lattice coupling [1].

We have firstly analysed dc electrical resistivity of epitaxial thin films of the rare-earth nickelates in a wide temperature interval up to 800 K. A noticeable deviation of the metallic resistivity of $NdNiO_3$ films from the classical linear relation $\rho \propto T$ is observed. This deviation is ascribed to an additional conductivity channel with a thermally activated hopping mobility: small polaron is suggested as a plausible charge carrier. The high-temperature conductivity of our $SmNiO_3$ films is of hopping nature: $\sigma T \propto \exp(-E_a/k_BT)$ with similar activation energy $E_a \approx 80$ meV [2]. Emerging hopping conductivity is related to a Jahn–Teller distortion of the perovskite structure with decreasing radius of the rare-earth ion.

The hopping conductivity prevails in the low-temperature insulator phase of the nickelates. This emphasizes an importance of the electron-phonon coupling and suggests a formation of small polaron quasi-particles in the nickelates films. Their hopping activity observed in the high-temperature metallic phase should remain from a cooperative breathing distortion of the nickelate lattice, which drives the MIT. This finding should also shed light on other electro-magnetic anomalies in the nickelates: for instance, opposite signs of the Hall and the Seebeck coefficients. In particular, we also demonstrate that anomalous behaviour of the Hall resistance is defined by the hopping conductivity component, whereas the Seebeck thermal force mostly reflects the metallic conductivity.

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Properties of bound pairs in layered Hubbard model

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Hubbard model has been applied to explain the properties of surprisingly many types of materials: insulators, conductors, ferromagnets, antiferromagnets, high-temperature superconductors or heavy-fermion superconductors. It is formally simple but exhibits very rich behavior requiring sophisticated and usually approximate methods. The exact results are thus very valuable but few and concern mostly one-dimensional (1D) lattice. I present exact solution of two-electron case on 2D square lattice with extension to few such 2D layers leading eventually to 3D case. I calculate effective masses of pairs of different symmetries and discuss their relevance to possible superconducting many-body state.

Reentrance behaviour of superfluidity in magnetic fields (part 2/2)

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We study quantum phase transitions in a system of bosons where the effects of single and pair tunnelling coexist. The pair condensation in the model stems from density induced tunnelling. The model is mapped onto the solvable quantum generalisation of the spherical model, improving accuracy over mean-field approximations. Lattice dependence and external magnetic fields are introduced via density of states functions. We show that the pair term has a dissipative effect on single particle superfluidity, however sufficiently large density induced tunnelling leads to the revival of the single superfluid. The impact of orbital magnetic field effects cannot be anticipated from typical assumptions.

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Thermoelectric Response of a Quantum Dot coupled to Ferromagnetic Electrode and Unconventional Superconductor Lead

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The BCS theory of conventional (*s wave*) superconductors present the Cooper pair as a net spin zero particle. In turn, unconventional superconductors[1] of triplet type like *p wave* superconductors form Cooper pair with S=1 spin. These have been theoretically modelled and seen experimentally[2] though origin of interaction is not identified singularly precisely.

Here, we investigate spin-dependent thermoelectric response of a quantum dot hybrid structure coupled to triplet superconductor and ferromagnetic lead. We present the local and non-local transport coefficients like electrical and thermal conductances, thermopower and its spin counterparts. These quantities are calculated with the help of non-equilibrium Green's function approach. Moreover, we also investigate non-equilibrium case, in which the system can work as heat engine or refrigerator. To characterize the effectiveness of such device we calculate the efficiency at maximum power or the coefficient of performance (COP) depending on the way the system works. Apart from that, the triplet superconductor might also exhibit the breaking of both time and inversion symmetry, and thus, we also analyse the influence of this phenomena on transport properties of the considered system.

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Thermodynamic properties of superconducting $CuBa_2Ca_3Cu_4O_{11+\delta}$ (Cu1234) system

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The well-known high-T_c superconductors such as La-, Y-, Bi-, Tl- and Hg-systems are not good enough to satisfy the necessary condition in irreversible field of the order of 30 T at 77 K for high field superconducting magnetic energy storage (SMES), mainly because of their too low superconducting state transition temperature or too high anisotropy of superconducting state properties. Superconducting state properties of the $CuBa_2Ca_3Cu_4O_{11+\delta}$ (Cu1234) system, with transition temperature as high as 118 K, has been investigated in the current work. AC susceptibility measurements confirmed very sharp transition to superconducting state. The upper critical field, H_{c2}, as high as 46.5 T at 95 K has been determined in dc SQUID magnetization measurements. However, critical current density, j_c, determined from magnetic hysteresis loop, is very low. It is supposed that the weak intergrain connections of studied material are the cause of small j_c values.

Effect of oxygen content on magnetic properties of $La_{1-x}Ag_xMnO_3$ magnetic nanoparticles

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In our paper we study the effect of oxygen content on magnetic properties of $La_{0.80}Ag_{0.15}MnO_{3+\delta}$ and $La_{0.70}Ag_{0.25}MnO_{3+\delta}$ systems of nanoparticles which were prepared by glycine – nitrate method and annealed at 800°C for 48 hours in different atmosphere (air, O_2 and Ar). The annealed samples crystallize in rhombohedral crystal structure ($R\overline{3}c$ space group). The contribution is extension of our study devoted to magnetic properties and magnetocaloric effect of $La_{0.70}Ag_{0.25}MnO_{3+\delta}$ nanoparticles [1] and in generally is related to preparation of nanoparticles for hyperthermia. We supposed that the heat treatment in Ar does not change the content of oxygen in the sample, only the crystal structure changes from orthorhombic to rhombohedral. The heat treatment in the oxidative atmosphere increases the content of oxygen and T_C increased from 235.8 K (Ar) to 321 K (air) and 322 K (O_2, the volume of the elementary cell decreased and simultaneously the bonding angle Mn–O–Mn increased which both lead to the rise of T_C [1]. The increase of oxygen content results in enhancement of double exchange interaction due to the population of Mn^{4+} ions. In this paper we present a comparative analysis of thermogravimetric (TG), X-ray powder diffraction, magnetization and AC susceptibility measurements which allows us to obtain correlation among oxygen content, volume of elementary cell and magnetic properties. TG measurements performed on $La_{0.70}Ag_{0.25}MnO_{3+\delta}$ samples show a small gaining of mass at about 720°C and subsequent drop of the mass for all samples up to about 800°C for the first heating cycle; the largest one for sample treated in O_2 and smallest one for Ar sample. Another drop of mass represented by an increase of volume of unit cell and decrease of T_C takes place at about 1000°C for sample fabricated in oxidative atmosphere. All these processes are taken part at higher temperatures in the case of $La_{0.80}Ag_{0.15}MnO_{3+\delta}$. Heat treatment up to 1400 °C during TG measurement of $La_{0.80}Ag_{0.15}MnO_{3+\delta}$ treated in O_2 leads to huge drop of mass resulting in nearly the same elementary cell volume 353.082 Å^3 at room temperature and $T_C = 239$ K which are comparable with sample fabricated in Ar. All drops of mass in TG we associate with reduction of oxygen content and the temperature range in vicinity of the first drop represents region with maximal gaining of oxygen in the process of sample preparation which affects T_C. Our study confirmed that the volume of elementary cell increases with decreasing oxygen content and simultaneously T_C decreases.

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Electronic structure of $YbFe_4Al_8$ antiferromagnet: A combined X-ray photoelectron spectroscopy and first-principles study

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Depending on their chemical composition, Yb compounds often exhibit different valence states. Here we investigate the valence state of $YbFe_4Al_8$ using X-ray photoelectron spectroscopy (XPS) and first-principles calculations. The XPS valence band of $YbFe_4Al_8$ consists of two contributions coming from divalent (Yb^{2+}) and trivalent (Yb^{3+}) configurations. The determined value of the valence at room temperature is 2.81. Divalent and trivalent contributions are also observed for core-level Yb $4d$ XPS spectra. We study several collinear antiferromagnetic models of $YbFe_4Al_8$ from the first-principles and for comparison we also consider $LuFe_4Al_8$ with a fully filled $4f$ shell. We predict that only Fe sublattices of $YbFe_4Al_8$ carry significant magnetic moments and that the most stable magnetic configuration is AFM-C with antiparallel columns of magnetic moments. We also present a Mullliken electronic population analysis describing charge transfer both within and between atoms. In addition, we also study the effect of intra-atomic Coulomb U repulsion term applied for $4f$ orbitals on Yb valence and Fe magnetic moments. The results presented were published in Ref. [1].

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Many-body phases in optical-lattice systems with alkaline-earth-like atoms. Dynamical Mean Field approach.

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We study finite-temperature properties of ultracold mixtures of alkaline-earth-like atoms in state-dependent quasi-two-dimensional optical lattices that can be effectively described by the two-band Hubbard model. We use the Dynamical Mean Field approach (DMFT) with Local Density Approximation (LDA) to include the effects of a (harmonic) trap, which is inevitably present in all experiments with ultracold gases on the lattices, and to obtain the real-space distributions of the density of particles, local order parameters and other local physical observables relevant for the experiments. In certain ranges of densities, we investigate the stability of different possible strongly correlated phases of the atomic system. We estimate the critical temperature below which these phases occur. In order to account for the proximity effects that are usually present at the boundaries between phases in strongly-correlated systems, we extend our analysis using the real-space generalization of DMFT.

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Selected Molecular Systems and Their Properties from Exact Diagonalization Ab Initio Solution

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This abstract highlights our research on unraveling the intricate nature of molecular bonding by determining many-particle covalency and ionicity factors. We employ microscopic single-particle and interaction parameters within our method to calculate these factors, while also discussing their limitations. To overcome these limitations, we introduce the concept of partial atomicity, which offers a new perspective on the bonding phenomenon.

Our study addresses the challenge of accurately characterizing molecular properties and bonding behavior. By incorporating partial atomicity, we bring atomic ingredients into the collective electron states, effectively eliminating spurious behavior of covalency with increasing interatomic distance. Furthermore, this concept offers a fresh interpretation of bonding, providing a deeper understanding of the underlying physics.

The implications of our research extend to various scientific disciplines, including chemistry, materials science, and physics. By shedding light on the interplay between covalency and ionicity in molecular systems, we contribute to the development of advanced models for molecular analysis, paving the way for more accurate predictions and improved design strategies.

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Study of low-dimensional magnetism in zeolitic imidazolate frameworks

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Zeolitic imidazolate frameworks (ZIFs) are a class of porous metal-organic frameworks composed of tetrahedrally-coordinated transition metal ions connected via imidazolate linkers. This work is devoted to the study of $[\{Zn(mIm)_2 \cdot 2H_2O\}_\infty]$ known as ZIF-8 and $[\{Cu(mIm)_2 \cdot 2H_2O\}_\infty]$, abbreviated as Cu-ZIF-8 (HmIm = 2-methylimidazole). Cu-ZIF-8 can be considered as a structural analog of ZIF-8, since it was found that partial replacement of the Zn(II) ion for Cu(II) did not modify the crystal structure. The heat capacity of powdered samples was measured from 0.4 to 300 K in magnetic fields up to 9 T. Both ZIF-8 and Cu-ZIF-8 data sets are nearly identical, suggesting that the lattice dynamics is not sensitive to the Cu-Zn substitution. At low temperatures, in B = 0 the heat capacity of the nonmagnetic ZIF-8 drops to zero, while the Cu-ZIF-8 data form a round maximum at about 0.4 K. The application of nonzero fields leads to the significant reduction of the maximum and its shift towards higher temperatures. The temperature dependence of the magnetic susceptibility of polycrystalline samples was measured in constant magnetic fields of 10 mT and 1 T at temperatures from 2 to 300 K in field cooling (FC) and zero field cooling (ZFC) regimes. The ZFC susceptibilities of Cu-ZIF-8 and ZIF-8 are characterized by a sharp maximum at about 50 K which shifts towards lower temperatures in the FC data. The origin of the sharp maximum is most likely related to the atmospheric oxygen present in the pores of our compounds. At higher temperatures, FC and ZFC data of Cu-ZIF-8 are identical and are characterized by a broad maximum at about 130 K which can be described within the model of Heisenberg antiferromagnetic chain with spin 1/2, intrachain coupling $J/k_B \sim 217K$ and g=2. Such strong coupling preserved observation of the corresponding magnetic contribution with the maximal value $C_{max} \sim 3J/Kmol$ at about 100 K in the experimental specific heat which is dominated by lattice contribution. The origin of the low-temperature magnetic specific heat is discussed.

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A genuine tripartite entanglement of a Heisenberg mixed spin-(1/2,1,1) trimer in a magnetic field

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A genuine tripartite entanglement is rigorously analyzed in a quantum mixed spin-(1/2,1,1) Heisenberg trimer with a geometric structure of an elementary triangular plaquette in presence of an external magnetic field. Two different strengths of the Heisenberg interaction J_1 (for identical spins) and J (for various spins) are taken into account. A genuine tripartite entanglement is quantified according to the negativity, utilizing the one of the generally accepted definition in which, the tripartite entanglement is a geometric mean of three various negativities between a single spin and a couple of remaining two spins. It turns out that the model under the investigation is always *fully inseparable* (entangled) if $J_1/J \leq 1$ until the increasing magnetic field favors the fully polarized separable state. In contrast, the tripartite entanglement cannot emerge for $J_1/J > 1$ due to a full separability of the spin-1/2 entity from the spin-1 dimer. Moreover, it was demonstrated that the tripartite thermal entanglement can be detected also at non-zero temperatures, even in a $J_1/J > 1$ limit, where the tripartite quantum entanglement is not possible. Unexpectedly, the maximum of negativity magnitude is detected at relatively high magnetic field as a consequence of competition between thermal fluctuations and exchange interactions.

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Magnetic properties of $Cu[C_6H_2(COO)_4][H_3N\text{-}(CH_2)_2\text{-}NH_3]\cdot 3H_2O$ - a quasi-two-dimensional $S = 1/2$ antiferromagnet on rectangular lattice

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The analysis of specific heat, magnetic susceptibility and magnetization identified the studied compound $Cu[C_6H_2(COO)_4][H_3N\text{-}(CH_2)_2(\text{-}NH_3]\cdot 3H_2O$ as a quasi-two-dimensional $S = 1/2$ Heisenberg antiferromagnet on the rectangular lattice. A phase transition to a magnetically ordered state was observed in zero magnetic field at $T_N = 1.28$ K. The best agreement with experimental data was observed for the rectangular lattice model with antiferromagnetic intrachain coupling $J_1/k_B \approx 7.39$ K and ratio $R \approx 0.44$. The analysis of magnetic specific heat in non-zero magnetic fields revealed features characteristic for the field-induced Berezinskii-Kosterlitz-Thouless (BKT) phase transition theoretically predicted for ideal two-dimensional magnets. It was found that the transition temperatures of $Cu[C_6H_2(COO)_4][H_3N\text{-}(CH_2)_2(\text{-}NH_3]\cdot 3H_2O$ are higher than the BKT temperatures from theoretical predictions. This difference was ascribed to the effect of interlayer interactions. The electron paramagnetic resonance studies of $Cu[C_6H_2(COO)_4][H_3N\text{-}(CH_2)_2(\text{-}NH_3]\cdot 3H_2O$ revealed the increase of g_x and g_y and decrease of g_z below 25 K due to the presence of dipolar coupling and the exchange anisotropy. The upturn of linewidth appearing below 30 K can be ascribed to the development of intralayer magnetic correlations. In the future, the band-structure calculation will be performed to evaluate individual exchange couplings to confirm present results.

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Magnetization processes and magnetocaloric effect of the Ising model on the octahedral lattice

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The magnetocaloric effect and magnetization processes of the extended Ising model on the 3-dimensional octahedral lattice are studied by the classical Monte Carlo method with Metropolis algorithm. It is shown that different combinations of antiferromagnetic and ferromagnetic nearest-neighbor interactions J_1 and J_2 (in particular $J_1 = -1$, $J_2 = 1$ and $J_1 = -1$, $J_2 = -1$) lead to the fundamentally different magnetic behaviors at nonzero temperatures, despite the fact that zero-temperature magnetization curves have exactly the same form. The reason is that the spin configurations forming zero-temperature magnetization plateaus for both $J_2 = -1$ and $J_2 = 1$ are different, and different are also their temperature evolutions (controlled by calculations of in-plane and inter-plane sublattice magnetizations), which lead to different results for the magnetic entropy change (the magnetocaloric effect). Due to this fact a much higher positive entropy change is observed for the ferro-antiferromagnetic system compared to the pure antiferromagnetic system.

Magnetization process and ordering of the $S = 1/2$ pyrochlore Heisenberg antiferromagnet in a magnetic field

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We study the $S = 1/2$ pyrochlore Heisenberg antiferromagnet in a magnetic field. Using large scale density-matrix renormalization group calculations for clusters with up to 128 spins, we find indications for a finite triplet gap, causing a threshold field to nonzero magnetization in the magnetization curve. We obtain a robust saturation field consistent with a magnon crystal, although the corresponding 5/6 magnetization plateau is very slim and possibly unstable. Most remarkably, there is a pronounced and apparently robust 1/2 magnetization plateau where the ground state breaks the rotational symmetry of the lattice, exhibiting *oppositely polarized* spins on alternating kagomé and triangular planes. Reminiscent of the kagomé ice plateau of the pyrochlore Ising antiferromagnet known as spin ice, it arises via a much more subtle 'quantum order-by-disorder' mechanism. [1]

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Magnetic properties of quantum spin liquid candidate $PrMgAl_{11}O_{19}$

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The frustrated magnets have caused an abiding fascination in recent decades due to the large variety of competing ground states. While some of these states are magnetically ordered, magnetically disordered states of different natures have also been predicted and reported, such as quantum spin liquid (QSL). Among them, the QSL states attract much attention due to the occurrence of quantum entanglement of spins without any long-range magnetic order down to zero temperature. In this work, we focus on one of the simplest case of geometrical magnetic frustration: the triangular lattice antiferromagnet (TLAF). It is a quasi-two dimensional magnet with magnetic ions forming a triangular lattice and antiferromagnetic interactions along the three sides of triangles. Recently the realization of a quantum spin liquid has been proposed in the TLAF $PrZnAl_{11}O_{19}$ based on specific heat, neutron scattering and muon spectroscopy on polycrystalline samples [1]. We succeeded to grow single crystals of the similar compound $PrMgAl_{11}O_{19}$ [2] by the floating zone method. We are characterizing the magnetic properties of single crystal $PrMgAl_{11}O_{19}$ by magnetization, and specific heat measurements.

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On magnetic models in wavefunction ensembles

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We recasted thermodynamics in terms of spin-wavefunction ensembles, rather than classical particle configurations or "found" values of Copenaghen Quantum Mechanics. This asks a completely new mathematical treatment. In these ensembles, magnetic phase transitions are possible if and only if we consider indistinguishable particles together with a macroscopoc non-linearity which blocks macroscopic dispersion (i.e. macroscopic superpositions) by energy conservation (preserving norm and energy). This mechanism is negligible at atomic scale but becomes very large for large N, and hence is of possible interest for the Classical-Quantum boundary.

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Simulations of molecular nanomagnets with various metallic cores and topologies

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We present the results of simulations of a class of molecular nanomagnets with ring, centered ring and dimer topologies. We demonstrate [1,2] that anisotropic Heisenberg model describes quantitatively magnetic properties of a family of the doped Cr_8 molecular rings revealed by the variety of experimental techniques. Interestingly, the nearest neighbor coupling parameters between the localized spins are all transferable across its members. We show that the broken symmetry approach within density functional theory, based on suitable functionals, provides a reliable tool [2,3] to extract magnetic exchange coupling parameters in all rings considered.

The molecular complex containing the bimetallic core Ni_6Cr [3], representing the centered ring geometry as well as its analogue geometrically frustrated are also simulated using the phenomenological and DFT approach. Consequently, the magnetic properties observed are quantitatively explained. In the isotropic limit of the model and the spin frustration switched on, the sequence of the ground states determined by the total spin S is obtained in agreement with the fundamental Lieb-Mattis theorem. Curiously enough, the temperature dependence of the susceptibility product χT with characteristic minimum and maximum is revealed not only as a signature of competition between the ferro- and antiferro-magnetic interaction but also as a symptom of the spin frustration phenomenon.

We have pioneered the application of the Heisenberg-type model to rare-earth dimers [4]. To that end, a new family of 3d-4f coordination polymers has been synthesized in search for new single-molecule magnet materials containing highly anisotropic lanthanides. Their magnetic properties have been explained quantitatively by comprehensive phenomenological modeling.

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Experimental study of Cu(*en*)$(H_2O)_2SO_4$ embedded into mesoporous silica matrix SBA-15 with the hexagonal arrangement of pores

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In this work, we performed the experimental study of the complex Cu(*en*)$(H_2O)_2SO_4$ embedded into the pores of mesoporous silica SBA-15 with hexagonal pore symmetry. The highest pore-filling degree represents up to 60 percent of the total internal pore volume for the silica, which was synthesized for 72 hours in a saturated solution of Cu(*en*)$(H_2O)_2SO_4$. The magnetic properties of the given complex were carried out by the measurements of EPR spectra and magnetic susceptibility on the powder sample. They were further compared with experimental data obtained from previous studies on the bulk Cu(*en*)$(H_2O)_2SO_4$. The EPR experimental data were analyzed within the EasySpin software package, with a simple model including the anisotropic g-factors, hyperfine interactions, and EPR linewidth. The best agreement with experimental data measured at temperature 2.1 K was achieved for parameters g_z =2.33, $g_y = 2.10$, $g_x = 2.01$, $A_x = 125$ MHz, $A_z = 315$ MHz, $A_y = 100$ MHz, and $\Delta B = 7$ mT. Temperature dependence of the magnetic susceptibility for the synthesized complex shows the typical paramagnetic behavior at temperatures ranging from 0.4K to 1.8 K. A phase transition to a magnetically ordered state for the bulk crystals of Cu(*en*)$(H_2O)_2SO_4$ is located at $T_N = (0.91 \pm 0.02)$ K in zero magnetic field. However, for encapsulated complex into pores of SBA-15, no signs associated with the magnetic phase transition have been seen down to 0.4 K.

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Magnetic field-induced phase transitions in Cu(en)$_2$SO$_4$ – dimerized S = 1/2 quantum antiferromagnet

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The studies of the magnetic properties of single crystals of Cu(en)$_2$SO$_4$ (en = ethylenediamine - $C_2H_8N_2$) in magnetic fields applied along the b - axis showed that this structure consists of an array of coupled magnetic dimers on the square lattice connected by interdimer interactions. This was confirmed by the study of magneto-structural correlations. The analysis of susceptibility, magnetization, and specific heat within a simple model of the Heisenberg antiferromagnetic dimer with spin 1/2 showed that the intradimer interaction is J/k_B = -5.52, corresponding energy gap is $\Delta/k_B \approx 11$ K and a critical field $B_c^b \approx 7.8$ T [1]. The strength of effective interdimer interactions was estimated from the mean field approximation, J'/k_B = -0.3 K. Previous studies of Cu(en)$_2$SO$_4$were carried out in the singlet phase of the dimerized quantum system, which is characterized by the nonmagnetic ground state S = 0.
This work is devoted to the response of the heat capacity of powder and single-crystal samples on the application of magnetic field applied along the a, b, and c axes. The heat capacity was measured in magnetic fields from 0 to 9 T at temperatures down to 0.4 K. At low temperatures, in magnetic fields above 7 T, sharp λ-like anomalies are observed. Based on the obtained results, magnetic phase diagrams were constructed in all field orientations and compared with the results of powder sample. From the obtained phase diagrams, the average value of critical field was estimated B_c = 6.5 ± 0.5 T and saturation field B_{sat} = 11.0 ± 0.5 T. Below B_c, the singlet nonmagnetic phase is stable while in higher fields up to B_{sat} a magnetically ordered phase is induced. Further studies at lower temperatures and higher fields are required to refine the boundaries of the ordered phase as well as to determine the character of the corresponding quantum phase transitions.

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Topological dynamical quantum phase transition in a quantum skyrmion phase

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The quantum skyrmionic phase is modeled in a two-dimensional helical spin lattice. This topological skyrmionic phase retains its nature in a large parameter space before moving to a ferromagnetic phase. Next-nearest-neighbor interaction improves the stability and it also causes a shift of the topological phase in the parameter space. Nonanalytic behavior of the rate function observed, when the system which is initially in a quantum skyrmion phase is quenched to a trivial quantum ferromagnetic phase, indicates a dynamical quantum phase transition. Dynamical quantum phase transition is absent when the system initially in a skyrmion phase is quenched to a helical phase.

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Exceptional point-based correlative nonreciprocal light propagation in nonlinear media

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The non-Hermitian Hamiltonian of an open (nonconservative) system can exhibit some spectral singularities as topological defects, called Exceptional Points (EPs), which results in a simultaneous coalescence of coupled eigenvalues and the corresponding eigenvectors. Recently, gain-loss engineering in different open systems has revealed EPs as nontrivial tools to control light-matter interactions [1]. In this context, a concept of conjugate EPs has recently been drawn [2] based on the complex parameter dependence of a non-Hermitian Hamiltonian. For a certain Hamiltonian $H(\delta)$, the presence of EPs can be realized via modulating a complex parameter $\delta = u + iv$, where two scenarios based on $v < 0$ and $v > 0$ analytically define two correlative time $(\mathcal{T})$-symmetric variants of $H(\delta)$ [provided that $\mathcal{T} : \{x, t, i\} \to \{x, -t, -i\}$]. Such two $\mathcal{T}$-symmetric variants exhibit two conjugate EPs at two complex conjugate critical points: $\delta_c = u_c + iv_c$ and $\delta_c^* = u_c - iv_c$.

Here, we exploit such a concept of conjugate EPs in exploring a correlative nonreciprocal light guidance in two $\mathcal{T}$-symmetric nonlinear mediums. Nonreciprocity is achieved based on a controlled Kerr-type local nonlinearity in a planar gain-loss assisted waveguide with two $\mathcal{T}$-symmetric variants hosting two conjugate EPs. We establish that the dynamic gain-loss variations around two conjugate EPs (in their respective parameter spaces) allow the asymmetric transfer of two different modes through two waveguide variants, while considering the light propagation in the same direction (while no transmission in the opposite direction). Moreover, the explicit dependence of the nonlinearity-level is investigated in maximizing the nonreciprocal ratio (NR), where two $\mathcal{T}$-symmetric variants achieve their maximum NR at the same nonlinearity-level. The proposed mechanism to achieve such a correlative nonreciprocity can be implemented in microwave and optical domains. Our findings would enrich the platform to develop indispensable nonreciprocal components like isolators and circulators for a wide range of magnetic and photonic systems, including superconducting quantum circuits with microwave resonators.

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Quantum and classical aspects of a low-temperature (∼500 mK) magnetic phase transition in aluminoborates

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Specific heat, C_B, of $R\mathrm{Al_3(BO_3)_4}$ single crystals with R = Tb, Dy, Gd was studied for 50 mK $< T <$ 300 K, with emphasis on the $T < 1$ K range, where a phase transition was found. For the Tb compound, which will be analyzed further as an example, the transition appears at $T_c = 0.68$ K. Nuclear, non-phonon, and lattice contributions to C_B were separated. Based on C_B and magnetization, M, studies, we established that the phase transition shifts to lower temperatures with increase in magnetic field $\mathbf{B}_{||}$, parallel to the easy magnetization axis. We found that the critical, i.e., related to the transition, contribution to the specific heat, C_{cr}, shows an unusual $C_{\mathrm{cr}} \sim T^{y_0}$ dependence on T, and that the Grüneisen ratio, Γ, defined as:

$$\Gamma = -\frac{1}{T}\frac{(\partial S/\partial B)_T}{(\partial S/\partial T)_B} = -\frac{(\partial M/\partial T)_B}{C_B\,(T)} = \frac{1}{T}\left(\frac{\partial T}{\partial B}\right)_S, \tag{2}$$

where S is entropy, diverges as a function of $B_{||}$ for $B_{||}$ approaching a critical value of 0.6 T. The behaviors of both C_{cr} and Γ as a function of T (especially scaling of Γ for $B_{||} \geq 0.30$ T), and dependence of Γ on $B_{||}$ are characteristic of systems, in which the classical phase transition line is influenced by quantum fluctuations, QF, and ends at quantum critical point. Using the determined y_0 and Γ values, we assessed the dynamical critical exponent z to be $0.82 \leq z \leq 0.96$. Based on these results, we suppose that QF dominate the behavior of the system and destroy the long range order, i.e., we suppose the transition found to have a quantum character. Its physical nature is not clear. The interpretation that this is the transition to the ferromagnetic ordering of Tb^{3+} magnetic moments is the most natural and supported by the M studies. However, such a classical transition should be smeared and shifted to higher T by $B_{||}$, while we observe the opposite effect. It was observed, e.g., in systems, in which exchange and magnetic dipolar interactions were of similar strength [1]. Also the possibility, that the transition is related to any other ordering , e.g., multipolar, and the ordering of the Tb^{3+} moments is a "side effect" only can not be ruled out.

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Anisotropic hyperfine coupling and internal field in the van der Waals antiferromagnet of FePS3

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We report a 31P nuclear magnetic resonance (NMR) study of two-dimensional (2D) van der Waals antiferromagnet of FePS3. To explore the anisotropic magnetic coupling, we have carried out the temperature-dependent Knight shift measurement on the single crystalline FePS3 with the external field perpendicular and parallel to the magnetic c* axis. The observations exhibit a distinctive difference with the crystalline orientation and the transferred hyperfine coupling constant for each oriented direction has been resolved. In the antiferromagnetic state, we have observed the splitting of the 31P NMR resonance line with the external field perpendicular to the c* axis while no such a splitting feature as the field parallel along the c* axis. It reveals the existence of the ordered static internal field at the phosphorous site and the direction of the internal field is parallel to its ab plane. Furthermore, the temperature evolution of the internal field obeys the 2D critical behavior, giving evidence for the Ising-type character in FePS3.

Ho_2IrSi_3: A new geometrically frustrated antiferromagnetic compound with large crystalline electric field splitting

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Geometrically frustrated magnets are considered of great interest as they provide a plentiful opportunity for discovering complex spin textures. The recent discovery of magnetic skyrmion in the frustrated centrosymmetric triangular antiferromagnet Gd_2PdSi_3 [1] have drawn a lot of interest in R_2TX_3 (R=rare earth, T=transition element, X=p block element) series which are known to show diverse novel magnetic ground states.

In this work, we have synthesized a new intermetallic polycrystalline material Ho_2IrSi_3 in single phase forming in edge sharing triangular lattice geometry (space group: *$P6_3/mmc$, No. 194*). The dc magnetic measurements, together with heat capacity data suggest the system to order antiferromagnetically at ∼3.4 K. A rather high value of negative Weiss temperature estimated from the dc magnetic susceptibility data in comparison to its Neel temperature suggest presence of a large fraction of magnetically frustrated spins (frustration parameter, $f = \mid \theta_p \mid / T_N \sim 5$). As expected for an antiferromagnet (AFM), the isothermal magnetisation, $M(H)$, exhibit linear behavior in low field region and no hysteresis. However, $M(H)$ at low temperatures tends to saturate at high field, with a value of 7.1 μ_B/Ho-ion at T=2 K and H=70 kOe. This is rather large value for a simple AFM system, indicating the additional contributions from the frustrated spins under the influence of high field. As the system form in triangular lattice geometry, one may expect a competing ferromagnetic (FM) and AFM interaction, where the FM components tends to overwhelm with increasing strength of applied magnetic field [2]. The long range nature of magnetic ordering is reflected in the lambda-like peak in heat capacity data, although the magnetic entropy at T_N is only 20% of Rln17, expected for Ho-ion. The value is even lower than that expected from a doublet ground state, suggesting a large fraction of Ho-spins are indeed remain frustrated. The magnetic ordering also appears to be quite fragile, as a relatively weak external field of 10 kOe is sufficient to suppress the magnetic ordering below 2 K. One of the major finding of this work is very large splitting of crystalline electric field parameters, as reflected in unusually prominent broad peak in the heat capacity data.

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The influence of the demagnetizing field on the concentration of spin wave energy in two-dimensional magnonic crystals

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We use the Plane Wave Method [1] to theoretically study thin-film magnonic crystals (MCs) composed of two very common magnetic materials, namely cobalt and permalloy, in both cases: Co inclusions in the Py matrix and Py inclusions in the Co matrix. The external magnetic field applied in the plane of such structure causes the appearance of a demagnetizing field at the interface of inclusions and matrix. It has already been shown that this field strongly influences the spectrum of spin waves, e.g. the position and width of bandgaps [2-3]. In this work, we use the in-plane squeezing of the MC structure to enhance the demagnetizing field, resulting in the transfer of the energy distribution (i.e. the spin-wave profile) of low-frequency spin waves from Py to Co. The change of the concentration of spin-wave profiles leads to some peculiarities in the spin-wave frequency spectrum, such as modes repulsion caused by their hybridization and resulting in their reordering in the spectrum.

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Nonrelaxational FMR peak broadening in martensitic films

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Potential applications of magnetic shape memory alloys (MSMAs) are ranging from magnetic nanoelectronics to magnetic refrigeration and magnetic actuators [1,2]. Most of these applications require extensive knowledge about the magnetic properties of these materials and the relation of their magnetic and magnetodynamic parameters with structural and electronic ones.

Here we combined the statistical model of the spatially inhomogeneous martensitic state of a thin film with the well-elaborated Landau theory of cubic-tetragonal MTs observed in the widely studied Ni-Mn-Ga alloys. Although in real martensitic films, the symmetry of the martensitic phase can be lower (orthorhombic for instance) the theoretical results, reported here, provide a satisfactory description of the observed temperature dependence of FMR peak width.

It has been shown that spatial inhomogeneity of real MSMAs leading to a difference of "local" MT temperatures can result in "local" variation of magnetic anisotropy constants. Such differences in anisotropy constants can increase or decrease with the temperature decrease depending on the influence of inhomogeneities on MT parameters. The proposed theoretical model allowed describing dramatic broadening of the FMR line with the temperature decreasing in epitaxial films of MSMAs. It is worth to be noted that such inhomogeneity can result in nontrivial temperature behavior of the net anisotropy of these compounds. Although the consideration here is mainly focused on the analysis of FMR linewidth but obtained results can be easily adapted for the analysis of magnetometry data (magnetic susceptibility, hysteresis loops, etc.) which are widely used for the investigation and characterization of MSMAs.

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Structural and magnetic properties of multi-frustrated $La_{0.5}R_{0.5}MgCo_2Ni_2$ (R = Y, Ce, Tb) compounds

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Over the past decades, a lot of efforts have been directed to study different Mg-based compounds for hydrogen storage applications and as negative electrodes in a Ni/MH batteries. In this work, we investigate structural and magnetic properties of complex compounds showing structural disorder over magnetic lattice.

The samples were obtained in two steps. At first, the $La_{0.5}R_{0.5}Co_2Ni_2$ alloy was synthesized by arc-melting. Secondly, the precursors were finely ground in agate mortar. The obtained powder was then mixed with magnesium and sintered. Samples were characterised by X-ray diffraction, scanning electron microscopy with energy dispersive X-ray spectroscopy, vibrating sample magnetometry in the 2-300 K temperature range, and neutron diffraction.

X-ray diffraction showed that in the $La_{0.5}R_{0.5}MgCo_2Ni_2$ system, the pyrochlore lattice built from transition metals (Co/Ni) can be found. The second magnetic lattice is face centered one involving the rare earth magnetic atoms. The long-range magnetic order (LRMO) was observed for Tb-based compound, while for the Ce-based one it was absent, basing on magnetometric and neutron diffraction studies. Two of the investigated samples: $La_{0.5}Y_{0.5}MgCo_2Ni_2$ and $La_{0.5}Ce_{0.5}MgCo_2Ni_2$ show signs of spin glass like state from the 1.5 K up to the 350 K. However, the Y-based specimen shows significantly broader departure between FC (field cooled) and ZFC (zero-field cooled) curves. For the Ce-based sample below roughly 100 K the dispersion between FC and ZFC starts to rise. This behavior resembles blocking of superparamagnetic particles. The $La_{0.5}Tb_{0.5}MgCo_2Ni_2$ sample shows magnetic ordering below 35 K. Above that temperature, the system transforms into the cluster spin glass like other compounds. At the 1.5 K the magnetic structure of Tb sublattice is simple ferromagnetic, while the Ni/Co pyrochlore sublattice exhibits antiferromagnetic behavior. For all investigated specimens even in the vicinity of 350 K no Curie-Weiss behavior was noticed.

Investigation of Spin Wave Dynamics in Si/Ti/Au/CoFeB/Au Multilayers with PMA

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Magnonics is an emerging research and technological field, focused on study of spin waves (SWs), which can transfer a spin for large distance without charge transfer, what minimizes the energy cost of logic operations. This is an experimental investigation of interaction between SWs, based on ferromagnetic/heavy metal multilayers with Perpendicular Magnetic Anisotropy (PMA). Here we employed Brillouin Light Scattering (BLS) method to quantify energy of magnons in thin-film samples composed of magnetic and non-magnetic layers deposited on Si substrate. This composition exhibits small pumping effect (hence low damping) together with PMA effect, will promising for future applications in magnonics. Measurements were taken in 180 degree backscattering geometry. At appropriate angle of incidence, it permits the observation of Brillouin spectra of magnons. Magnetostatic configuration applied here is Damon- Eshbach. We observed Dzyaloshinskii-Moriya Interaction (DMI) and characterized the strength of interfacial DMI in these perpendicularly magnetized thin films. This synergy of PMA and DMI can be considered as interesting thing here due to their necessities to make chiralities which change the whole magnetic properties. Moreover, here we emphasis field dependent studies by FMR and BLS as well. Spin wave dispersion relations were extracted and studied the nonlinear effect as well as system behaviour. Opposed to the conventional dispersion relations of magnetic multilayers, it shows anomalous characteristics[1-3]

Keywords: Perpendicular Magnetic Anisotropy, Brillouin Light Scattering, Dzyaloshinskii-Moriya Interaction, Backscattering geometry, Damon-Eshbach.

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Spin Dynamics, Loop Formation and Cooperative Reversal in Artificial Quasicrystals with Tailored Exchange Coupling

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Aperiodicity and un-conventional rotational symmetries allow quasicrystalline structures to exhibit unprecedented physical and functional properties [1,2]. In magnetism, artificial ferromagnetic quasicrystals exhibited knee anomalies suggesting reprogrammable magnetic properties via non-stochastic switching [3,4]. However, the decisive roles of short-range exchange and long-range dipolar interactions have not yet been clarified for optimized reconfigurable functionality. We report broadband spin-wave spectroscopy and X-ray photoemission electron microscopy on different quasicrystal lattices consisting of ferromagnetic Ni81Fe19 nanobars arranged on aperiodic Penrose and Ammann tilings with different exchange and dipolar interactions. We imaged the magnetic states of partially reversed quasicrystals and analyzed their configurations in terms of the charge model, geometrical frustration and the formation of flux-closure loops. Only the exchange-coupled lattices are found to show aperiodicity-specific collective phenomena and non-stochastic switching. Both, exchange and dipolarly coupled quasicrystals show magnonic excitations with narrow linewidths in minor loop measurements. Thereby reconfigurable functionalities in spintronics and magnonics become realistic.

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Spin wave dynamics in double CoFeB/Au layers

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Magnonics is a research field which concentrate on the study of spin wave dynamics and their applications. In a few kind of magnetic materials, perpendicular magnetic anisotropy can exist. This area of research has attracted a significant amount of interest because, possibility of implication for the new generation magnetic recording devices. One of the materials which possess PMA effect is CoFeB thin films. Such effect is observable for thin layers of CofeB. Here, the experimental studies of PMA in CoFeB thin films will be presented. Also, the existence of nontrivial magnonic band structure will be shown. For the thin films, the magnetic properties strongly depends on the thickness of the film. Increasing the thickness of studied magnetic material, results disappearance of PMA effect. In presented results, we employed Brillouin Light Scattering (BLS) method to quantify energy of magnons in thin film samples composed of magnetic (CoFeB) and non-magnetic (Au) layers deposited on Si substrate. Spin wave dispersion relations were extracted and studied the nonlinear effect as well as system behaviour as the function of thickness of magnetic film. The dispersion relations show anomalous characteristics.

Keywords: Perpendicular Magnetic Anisotropy, Brillouin Light Scattering,

Spin wave analysis on magnetic multilayers of Cobalt/Nickel

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Magnon-spintronics is an emerging field of modern magnetism, to illustrate the behaviour of spin waves (SWs) in nanostructure elements, and is considered to be the requirement of future signal processing devices. The magnonic systems can have the possibility to fill the gap between ultra-fast photonic and extremely miniaturized electronic systems, ie; to design energetically efficient devices miniaturized down to 100 nm and operating at relatively high frequencies in the range from a few to tens of GHz. This study reports the spin wave dynamics on the composition consisting of Ti/Au/Co/Ni. Here we examine the quantitative analysis of spin wave energy under a range of wave vectors. To extract the dispersion relations of the magnon and phonon system we used the Brillouin Light Scattering (BLS) method. These measurements were shown to lead to a visible difference in the positions of the modes on the right and left sides of the Brillouin spectrum. This indicates an accurate determination of the existence of Dzyaloshinskii-Moriya Interaction (DMI) in this system. A detailed comparison of phonon analysis is made through COMSOL simulations. The effect of the magnetic field was investigated by means of BLS and Ferromagnetic resonance (FMR) as well.

Keywords: Brillouin Light Scattering, Dzyaloshinskii-Moriya Interaction, Ferromagnetic Resonace.

Spin wave dynamics in CoFeB/Au/Co/Au layers

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The dynamics of spin waves in differentiated thin magnetic structures makes it possible to determine the suitability of a given structure for application purposes. The relationship between the spin wave vector and the direction of the external magnetic field determines the different effects in the same layered structure, especially when the direction of magnetization of the two magnetic layers is different. In the tested case, the thin layer of CoFeB shows PMA, while the Co layer shows in-plane magnetization. Separating these ferromagnetic layers with a gold wedge allows us to study the interrelationships in the dynamics of spin waves in this structure. The Brillouin spectroscopy method (in two measurement geometries: Damon-Eshbach and Backward Volume) and MOKE were used in the research. Spin wave dispersion relations were extracted and studied the nonlinear effect as well as system behaviour as the function of thickness of nonmagnetic film. The dispersion relations between the effective CoFeB-Co magnetic layer and the independent separated magnetic layers was performed. It was found that the presence of single gold layers causes a significant reduction of the effective layer, which results in a strong change in the observed Brillouin shift. A layer of gold with a thickness of more than 1.1 nm causes that we observe a spin wave propagating in the CoFeB layer. The fluctuations of the Brillouin shift in successive points of the wedge structure indicate that there is an interphase interaction of the RKKY type.

Keywords: Thin magnetic layers, wedge of gold, Brillouin Light Scattering,

Interpreting FMR experiments: Tradition vs. Machine Learning

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The phenomenon of ferromagnetic resonance (FMR) is still widely used to determine the spatial distribution of magnetic free energy, and thus to determine the magnetocrystalline anisotropy constants of magnetic materials. There exist at least three methods of analyzing experimental data: fitting them to the Kittel equation [Phys. Rev. 73, 155 (1948)], fitting them to the Smith-Beljers equation [Philips Res. Rep. 10, 113 (1955)], and the latest method - using machine learning techniques [Phys. Rev. **B** 98, 144415 (2018)].

We compare the results of applying these three methods to the analysis of an old FMR experiment carried out for magnetite [Phys. Rev, 78, 449 (1950)] and a newer one for epitaxial layers of magnetic semiconductor (Ga, Mn)As on (113) GaAs [Phys. Rev. **B** 81, 155203 (2010), Phys.Rev. **B** 91, 184403 (2018)].

The results of our analysis show that the use of machine learning has a significant advantage over older methods. This approach allows us to unambiguously determine the spatial distribution of free energy (and thus magnetocrystalline energy).

This applies in particular when the FMR measurements were carried out in different crystallographic planes and the directions crystallographic axes of the sample do not coincide with the directions of the shape anisotropy. Then the use of machine learning techniques is necessary.

Temperature Dependence of Spin Pumping in Y3Fe5O12/Pt, Ni81Fe19/Pt and SnTe/Ni81Fe19 Thin Films

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Magnons (quanta of spin waves) are collective excitations in magnetic material and allow information processing without transferring charge [1]. Such no-charge-based devices are in great demand owing to information transfer without Joule heat loss. One of the crucial components of a magnonic device is the detection of a magnon signal by transferring it to an electrical signal. One prominent way to accomplish the goal of electric detection of magnon spin current is via a method called spin pumping [2] using inverse spin hall effect (ISHE) phenomena. When the heavy metal (e.g. Pt) or topological material is interfaced with the magnetic materials (FM), the spin current can be injected into the HM from FM via spin pumping. Precessing magnetic material transfer angular momentum from the FM to the FM/HM interface via coupling of the local magnetic moments of the FM with the conduction electrons of the HM. Recently, it has been reported via ferromagnetic resonance experiments that induced spin currents can be amplified instead of suppresses by adding a strong spin-orbit coupled spin sink layers in a superconductor/ferromagnet hybrid structure [3] and is key for superconducting spintronics. Therefore, it is essential to study the low-temperature spin pumping in Pt and topological materials, such as SnTe. We report broadband spin-wave spectroscopy and spin pumping experiments on $Y_3Fe_5O_{12}$/Pt, $Ni_{81}Fe_{19}$ (with Pt thickness varied from 7 nm to 75 nm), and SnTe/ $Ni_{81}Fe_{19}$ bilayer thin films for temperatures ranging from 300 K to 4 K. We observed a systematic shift in ferromagnetic resonance fields, amplitude, and linewidths as a function of frequency and temperature. For the in-plane and out-of-plane directions of the magnetic field, we observed distinct modes at lower temperatures. The spin mixing conductance, spin current density, and spin hall angle values showed strong temperature dependence. Our findings are key for the usage of Pt and SnTe as spin sink layers for the superconducting spintronics applications.

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Cavity-mediated coupling of terahertz magnons and vibrational modes of molecules

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In the regime of strong light-matter coupling, polariton modes are formed that are hybrid light-matter excitations sharing properties of both, an electrodynamic cavity mode and a matter mode. In the recent decade, magnon-polaritons were intensively researched using ferromagnetic materials in the microwave range, with potential applications for quantum technology and sensors. Exploring antiferromagnetic resonance (AFMR) rises magnon-polariton frequencies into the terahertz (THz) range [1]. In this range there are many dielectric excitations like phonons, vibrational modes of molecules, plasmons in two-dimensional electron gas, etc, which are characterized with higher light-matter coupling rates than those of magnetic excitations because of their high dipole moments. Recently, we reported cavity-mediated coupling of magnons in two distant slabs of antiferromagnets [2]. Here, we are investigating AFMR in yttrium ferrite (YFO) owing to its low spin damping and temperature-dependent frequency above room temperature. We report on coupling of its quasi-antiferromagnetic mode to a vibrational mode of α-lactose. Our experimental setup consists of parallel-plane slabs of both materials, placed next to each other at a well controlled gap, forming a tunable Fabry-Perot type cavity. Frequency of AFMR was controlled by temperature of a YFO crystal. We used time-domain spectrometer to measure reflection spectra, collected as a function of YFO temperature and distance between the slabs. Frequencies of cavity modes are controlled by changing the gap between the crystals. Thus, as a function of distance, we observed narrow avoided crossings of cavity modes with AFMR and much broader avoided crossings with the vibrational mode of lactose at 0.53 GHz. At some distances between the slabs and YFO temperatures, we observed such polariton modes that are simultaneously coupled to the vibrational mode of lactose and the AFMR in the YFO crystal. Such states are hybridized magnon-vibrational modes that share properties of both matter excitations.

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In-depth study of dynamics in coupled magnonic waveguides

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Magnonic waveguides are fundamental building blocks in the logic devices based on spin waves [1,2]. In general, they are of multimodal character. However, while going to sizes of tens of nanometers, their single-mode regime range can reach a few GHz. In the past, fabrication of such waveguides was almost impossible, but current techniques are giving wide range of possibilities including structures with complex geometries [3]. We investigate numerically the spin-wave dynamics in the system of two dipolar-coupled magnonic waveguides. In an in-depth study, we analyse the effect of plenty of physical and geometrical parameters. In terms of coupling strength, waveguides aligned in the form of a planar structure, the most common type of alignment studied experimentally, seems to be a worse choice than the vertically-stacked waveguides, i.e., one placed over another. From the side of fabrication, vertical stacking enables small separation between the waveguides, giving the possibility for strong coupling. One of the interesting features of the vertically-stacked waveguides is a no-gap mode crossing at which frequency the wave transmission between the waveguides in prohibited. This frequency can be controlled by the external magnetic field. Making a mismatch by shifting one of the waveguides in plane, one can control the interaction between the spin-wave modes. In a right geometry, it is possible to reach almost constant transmission length between the waveguides in a wide range of frequencies allowing the possibility to transfer wide wave packets from one conduit to another.

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Hybridizations between edge and bulk modes in an antidot lattice with perpendiculat anisotropy

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Magnonic crystals (MCs) have demonstrated a lot of potential as a way to control the propagation of spin waves (SWs). Having the ability to create and control SWs could lead to the creation of magnonic devices that are more space efficient than optical devices and more energy efficient than current electronics. In this research, we study a MC created in a thin film made up of 8 repetitions of Co (0.75nm) and Pd (0.9nm) bilayers for a total thickness of 13.2 nm [1]. This particular combination of a ferromagnetic layer and a heavy metal layer results in a strong perpendicular magnetic anisotropy (PMA) which is interesting as it makes the SW dispersion isotropic. Periodically throughout this thin-plane film, nanodots were etched out using a 10nm wide focused ion beam producing a pattern of antidots. This process not only removed some material, but also damaged the area around each antidot, creating a ring around the antidots where the magnetic properties, notably the PMA have been modified. Due to this, the magnetization at the antidot's edges is almost in-plane. The ground state of a circular antidot is magnetized in its edge ring in a vortex-like configuration. Through micromagnetic simulations, we analyse the dynamic coupling between edge localised and bulk modes in the film. At first, we limit our analysis to non-propagating SWs and we modify the exciting field as well as the strength of the global external static magnetic field which is oriented out-of-plane and we analyze the SW modes that exist in the rim or in the bulk. Next we compare the spin-wave modes when excited with a global antenna oriented out-of-plane, in-plane and with a more complex excitation meant to equally excite all modes. Lastly, we show the dynamic coupling between rims and bulk, demonstrating collective behavior on the lattice and promising magnonic applications.

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Competing Interactions, and magnetization dynamics in Doped Rare-Earth Manganites nano-particles

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The Structural, magnetic and transport behavior of $La_{1-x}Ca_xMnO_{3+\delta}$ (x=0.48, 0.50, 0.52 and 0.55 and δ=0.015) compositions close to charge ordering, was studied through XRD, resistivity, DC magnetization and AC susceptibility measurements. With time and thermal cycling (T<300 K) there is an irreversible transformation of the low-temperature phase from a partially ferromagnetic and metallic to one that is less ferromagnetic and highly resistive. For instance, an increase of resistivity can be observed by thermal cycling, where no effect is obtained for lower Ca concentration. The time changes in the magnetization are logarithmic in general and activation energies are consistent with those expected for electron transfer between Mn ions. The data suggest that oxygen non-stoichiometry results in mechanical strains in this two-phase system, leading to the development of irreversible metastable states, which relax towards the more stable charge-ordered and antiferromagnetic microdomains at the nano-meter size. This behavior is interpreted in terms of strains induced charge localization at the interface between FM/AFM domains in the antiferromagnetic matrix. Charge, orbital ordering and phase separation play a prominent role in the appearance of such properties, since they can be modified in a spectacular manner by external factor, making the different physical properties metastable. Here we describe two factors that deeply modify those properties, viz. the doping concentration and the thermal cycling. The metastable state is recovered by the high temperature annealing. We also measure the magnetic relaxation in the metastable state and also the revival of the metastable state (in a relaxed sample) due to high temperature (800) thermal treatment.

Brillouin light scattering study of Co_2FeGe Heusler thin films

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Full-Heusler alloys are interesting due to their unique physical properties and potential applications in different science areas and technology. In addition, due to the possibility of demonstrating half-metallic ferromagnetic properties They can be useful spintronics and magnonics applications. Recently a lot of investigations were focused on Co_2FeGe which is half-metallic ferromagnet with relatively high magnetization and high Curie temperature. It has been shown [1] that regulation of the technological conditions of film preparation alows change the structural, magnetic and magnetdynamical properties of polycrystalline films of Co_2FeGe.

X-ray studies (Rigaku SmartLab diffractometer) confirmed epitaxial growth [110]CFG // [100]MgO. The films prepared at RT are tensile stressed in the film plane. The atomically ordered phase L21 was fair for the annealed samples and the samples deposited at elevated temperatures. The main difference from polycrystalline films studied earlier [1] is that the elevated temperature deposition does not improve the magnetic characteristics of the films.

All BLS measurements presented in this abstract were performed using a diode pumped, frequency doubled Nd : YVO4 laser with a wavelength of 532 nm as a light source. The spin-waves behavior all of groups samples have been presented. There were two investigation parts. The first one is the dependence of BLS frequencies on different propagating wave vectors. The second is the dependence of BLS frequencies on the external magnetic field. Using this method, it was possible to find such important parameters as Ms, Aex, g which agrees with FMR analisys.

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Study of magnetic properties of the rare-earth ion doped phosphate glass $Dy(PO_3)_3$

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An experimental study was conducted to investigate the magnetic properties of dysprosium-doped phosphate glasses. Low-temperature (LT) measurements of the specific heat of $Dy(PO_3)_3$ were performed in the range of 0.4 – 300 K in the magnetic fields up to 9 T. The LT specific heat of amorphous materials is characterized by the presence of a broad maximum named Boson peak (BP). The LT specific heat of the Dy-doped sample is dominated by the magnetic contribution, which overlaps the BP. Due to that reason, the specific heat of equivalent non-magnetic glasses was also measured at the same temperature range, revealing the BP at 12 – 15 K, depending on sample compositions. The magnetic susceptibility was measured from 1.8 K up to room temperature, yielding the effective magnetic moment 10.65 μ_B, which is close to the theoretical prediction for Dy3+. Magnetization curves were measured up to B = 5 T with temperatures ranging from 2 to 50 K. X-band Electron-paramagnetic resonance spectra were measured from 0 to 1 T, revealing a maximum at 100 mT. The line achieves maximal intensity at temperatures around 12 – 14 K, which coincides with the appearance of BP in specific heat. The coincidence suggests a possible correlation between lattice and magnetic properties. The experimental results and data analysis will be discussed.

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Investigation on the magnetocaloric effect in the rhombohedral ternary ordered variant of the cubic Laves phase of Pr_2Rh_3Ge

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The subject of this research is the ternary compound Pr_2Rh_3Ge obtained in the polycrystalline form, belonging to rhombohedral Laves phases (space group $R\bar{3}m$) [1]. The compound is known to be a ferromagnet with magnetic ordering temperature $T_C = 8.5$ K [2]. Nevertheless, the general picture of the physical properties of the ground state in this case seems to be quite intriguing, not to say intricate. The reason for this is the observed moderate heavy fermion behaviour of itinerant charge carriers at low temperatures ($\gamma = 315$ mJ/Pr-mol·K^2), with no sign of the spin Kondo effect [2]. In this situation, the mechanism responsible for mass enhancement leading to the heavy electron ground state is probably related with the dynamic low-lying crystal-field excitations. This assumption is based on the theory of excitonic mass enhancement proposed by White and Fulde [3] to explain the electron mass improvement in Pr ions and subsequently extended to rare-earth systems [4]. Driven by curiosity and a wish to expand the scope of existing knowledge about the physical properties of Pr_2Rh_3Ge, we present research on the magnetocaloric effect basis of the well-known thermodynamic approaches. The magnetocaloric properties were established in terms of the isothermal magnetic entropy change ΔS_M and the adiabatic temperature change ΔT_{ad} using the specific heat data and magnetization measurements.

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Control of magnetic damping by introducing ultrathin nonmagnetic layer with varying spin-orbit coupling strength at CoFeB/MgO interface

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The performance of many spintronics devices are controlled by magnetic damping, one of the key parameters of magnetic materials. Hence, it is quite important to understand the origin of damping and to control the damping parameter in magnetic materials, especially in magnetic thin film heterostructures. The intrinsic component of damping can be optimized by engineering electronic band structure at the Fermi level [1]. Interestingly, the interfaces in magnetic heterostructures also has a significant contribution in magnetic damping [2]. Previously it was reported that the perpendicular magnetic anisotropy in CoFeB/MgO heterostructures can be enhanced by introducing an ultrathin nonmagnetic (NM) layer at CoFeB/MgO interface [3]. Therefore, it is quite possible that the damping constant can also be tuned by adopting the same strategy. However, no study have been reported to address this issue so far.

In the current study, we adopt Ta(10)/CoFeB(2)/MgO(10)/Al_2O_3(10) heterostructures deposited on Si/SiO_2 substrates as our model system. Five set of samples were prepared by introducing an ultrathin NM layer at CoFeB/MgO interface with varying spin-orbit coupling (SOC) strength: Ta(10)/CoFeB(2)/NM(0.12)/MgO(10), where NM = no layer, Ru, Ta, Pt and W. According to the literatures, the SOC strength varies as Ru<Ta<Pt<W. The damping parameters are characterized by measuring frequency dependent ferromagnetic resonance linewidth by a set up based on vector network analyser. In absence of ultrathin NM layer, the damping parameter comes out to be 0.0128. Surprisingly, the damping parameter significantly reduces to 0.0103 when Ru or Ta are introduced. In contrast, the damping parameter remains almost unchanged for Pt layer, and significantly increased to 0.0142 for W layer. We infer that the SOC strength of NM layer significantly influences the spin relaxation at CoFeB/MgO interface resulting in the reduction or enhancement of intrinsic damping parameter. Our results pave the way to tune the damping parameter in ultrathin ferromagnetic films by interfacial engineering, which will be very demanding from application point of view.

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Magnetic relaxations in $La_{0.80}Ag_{0.15}MnO_{3+\delta}$ nanoparticles

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Hole doped manganites systems have attracted significant scientific interest in the last few decades due to the variety of observed relaxation phenomena that resemble the behaviour of spin glasses. The origin of glassy dynamics was found in the frustration of the magnetic ground state, although the nature of frustration remains controversial. First it arises from the competition of super exchange (SE) Mn^{3+}–Mn^{3+} interaction, leading to antiferromagnetic (AFM) ordering and double exchange (DE) Mn^{3+}–Mn^{4+} mechanism which leads to ferromagnetic (FM) ordering. On the other hand, frustration is attributed to the formation of a phase-separated state. Phase separation implies the appearance of spatially confined magnetic clusters with magnetic coupling different from the surrounding FM background. Competing exchange interactions among clusters lead to additional frustration, which results in the appearance of spin glass like dynamics at low temperatures [1]. In our paper we present the results of a systematic study of nonequilibrium dynamics in $La_{0.80}Ag_{0.15}MnO_{3+\delta}$ magnetic nanoparticles system by ac susceptibility measurements using Cole–Cole analysis and by magnetization versus time measurements after zero field cooling (ZFC) and field cooling (FC) regimes in various fields and at various temperature. Nanoparticles were prepared by glycine – nitrate method and annealed at 800°C for 48 hours in different atmosphere (O_2 and Ar). The annealed samples crystallize in rhombohedral crystal structure ($R\overline{3}c$ space group). Sample prepared in O_2 has the volume of elementary cell 349.07 Å^3, the Curie temperature T_C = 320.5 K and the magnetic phase transition is sharp. Preparation in Ar results in smaller content of oxygen in sample, volume of elementary cell is 353.88 Å^3, T_C = 242.5 K, small maximum appears at T_1 - 41 K in magnetization and imaginary part of susceptibility χ", which we associate with AFM ordering due to SE interaction. The preparation of samples in different atmosphere enable us to perform comparative study of magnetic relaxation on systems with different content of Mn^{3+} and Mn^{4+} ions as well with different degree of magnetic phase separation.

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Effects of Biodegradation on Electronic Properties of Common Lithium Manganese Oxides

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The looming era of electric cars and increased production of lithium-ion batteries opens up new questions about long term usage, disposal and chemical stability of materials used for their production. $LiMn_2O_4$ and L_2MnO_3 are one of the most common compounds used for cathodes in batteries sold on the consumer market. This work focuses on structural and electronic changes induced in both materials after 3-months degradation in an open air environment in an abiotic (sand) and biotic (compost) environment. The starting materials were structurally characterized using x-ray (XRD) and neutron (NPD) powder diffraction and found to crystallize in the nominal $Fd\text{-}3m$ and $C2/m$ space groups, respectively. The chemical composition was verified using x-ray photoelectron spectroscopy (XPS) and neutron prompt gamma activation analysis. The effects of degradation were studied by reinvestigating the samples using XRD and XPS, where the main expected effect was a possible leaching out of lithium. The studies did not reveal any statistically significant degradation of the materials both in their structure and composition. At the end a local structure was studied using x-ray absorption on the Mn K edge XANES and the results will be presented at the conference.

Resonances In Metallic Structures

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The concept of ferromagnetic anti-resonance (FMRA) frequency is simple: it's the frequency where the real part of complex permeability $Re(\mu) = 0$ resulting in a high microwave transmission while for ferromagnetic resonance (FMR) the complex permeability μ shows a pole, which corresponds to the condition of resonantly enhanced FMR absorption. Although the phenomenon of ferromagnetic anti-resonance has been known for a long time, its application to ferromagnetic films/foils is limited to the thickness of several micrometers (of the range of skin depth) using a transmission waveguide equipment. Our aim is to show the usefulness of a vector network analyzer combined with a strip line for analysis both FMR and FMRA for parallel and perpendicular configurations in ferromagnetic ribbons based on ferromagnetic amorphous and nanocrystalline alloys. A problem of FMRA in thin films of several nm in thickness will be also discussed in connection with previous measurements [1].

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Statistical Control of Vortex Chirality in Ferromagnetic Rings with Nanoelements

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Chirality control in ferromagnetic nanorings (NR) typically requires breaking the ring symmetry [1], which affects domain wall motion under an external magnetic field. Our approach instead uses a single-domain ferromagnetic nanoelement (NE) with strong shape anisotropy inside the nanoring to control vortex chirality via its magnetization state. In our study we use MuMax3 [2]. Using magnetic parameters of Fe from [3], we added 20 nm magnetic grains in the NR via Voronoi tessellation to show that our results are robust even for imperfect materials. Grain's are obtained from a normal distribution of M_s with mean 1600 kA/m and standard deviation σ of 5% = 32 kA/m. In our study, we ran 600 simulations for a single NR, 51.8% resulted in a Clockwise (CW) state and 48.2% resulted in a Counterclockwise (CCW) state. With NE, we have almost complete control over VS chirality at remanence based on NE magnetization orientation. For parallel magnetization of NE with B_{ext}, 99.0% of simulations show CCW configuration, and for opposite magnetization, 98.5% show CW configuration.

In summary, we have shown that adding a small FEN inside a FER can systematically control the vortex chirality. By altering the magnetization orientation in FEN, the symmetry of HTH DWs can be changed during remagnetization and determine the ring's magnetization chirality. This approach has potential applications in magnetic memories and spin wave control for stochastic computing in ring-based systems

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The transmission of spin wave affected by the location of an antidot defect within a waveguide

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In the past few decades, the field of nanomagnetism has made significant progress through extensive research into the magnetization dynamics in nanostructures. This has resulted in the discovery of new effects, the development of various applications, and the identification of promising new directions such as magnonics, which focuses on studying the dynamics of spin waves and their potential applications.

To investigate how the size and placement of a circular defect in a waveguide affect propagating spin waves and their transmission, we conducted micromagnetic simulations of a waveguide-defect system. Simulations were performed on a 768 nm wide Py waveguide with a defect diameter between 50 and 400 nm and a vertical displacement from the center of the waveguide every 50 nm towards the edge. To excite all frequencies, a broadband source was used.

According to our results, displacement and size changes have different effects on spin wave transmission in the waveguide. Using the transmission spectrum for the waveguide with varying sizes and displacements of the antidot defect, we distinguished three main areas. (i) In the low-frequency range up to 5 GHz, corresponding to the FMR frequency, we observe a change in the maximum frequency of the transmitted wave with a change in the diameter of the antidot defect. As the defect moves toward the edge, the transmittance of spin waves at low frequencies increases. These relationships can be used as a spin wave filtering at low frequency part of the spectra. (ii) In the range from 5 to 12 GHz, the resonance effects with multiple transmission maximums and minimums are observed which can be controlled by the defect placement. This interesting relationship shows the ability of using the system for controlling transmission channels. (iii) As the size and displacement from the center of the defect increase, the transmission amplitude decreases monotonously in high-frequency ranges above 12 GHz.

Our findings suggest that creating a defect in a waveguide is a viable method of controlling spin wave propagation, making it a promising technique for various applications, as a filters or demultiplexers.

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Exciting skyrmion dynamics through higher-order spin-wave modes

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The interaction of propagating spin waves with spin textures, particularly with skyrmions, is an interesting research topic in magnetism, particularly in magnonics. It also provides the opportunity for control spin-wave propagation and brain-inspired computing systems.

A three-layered hybrid system with zero magnetic field was investigated using micromagnetic simulations. It combines a permalloy waveguide with a thin circular nanodot with a stable Néel-type skyrmion made of material with perpendicular magnetic anisotropy and Dzyaloshinskii-Moriya interactions, as well as a layer of nonmagnetic separation. Throughout this study, we examined (i) the static coupling between the nanodot and waveguide, [1] (ii) whether propagating spin waves could be used to induce skyrmion dynamics, (iii) the effects of a skyrmion in nanodot on spin-wave transmission through a waveguide [2]. Shape anisotropy maintains magnetic saturation along the waveguide's long axis. Magnetic interactions between a nanodot and a waveguide result in a skyrmion imprint below the nanodot. Through this mutual interaction, the skyrmion in the nanodot loses its circular symmetry and becomes deformed. Long spin-wave propagation is enabled by our system, which combines a waveguide and a nanoresonator. The presence of skyrmion in nanodot and imprint in waveguide affect spin-wave flow.

Using broadband excitation, we studied spin-wave transmission over a wide range of frequencies. A skyrmion and its imprint affect the transmission spectrum differently. Imprint at low frequencies exhibit significant amplitude, meanwhile, skyrmion excitations become dominant around 10 GHz. Excitation of the skyrmion leads to appearing of azimuthal modes at the edge and standing waves in the skyrmion core. Moreover, the skyrmion stimulates very low-frequency modes by coupling with higher-frequency modes, which origin is still under debate. Due to coupling with the nanodot, these excitations are also visible in the imprint spectrum.

In order to control spin waves, we have found that coupling them to the resonant modes of the skyrmion-imprint hybrid system is a viable approach, making it a promising technique for various applications.

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On the stability of low-symmetry phases in Zr_2CoSi

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Several proposed Zr_2-based Heusler compounds have attracted interest due to their promising half-metallic properties in inverse cubic Heusler structure. Since ideal full Heusler alloys can crystallize in two different well-ordered cubic structures (Hg_2CuTi-type and Cu_2MnAl-type), this implies diverse behavior of the magnetic moments on the transition metal atoms and also a difference in electronic structure. Therefore, it is important to determine which of the possible structures is energetically more favorable from a finite number of possible candidate structures in the new proposed materials.

Here, with the full potential local orbital (FPLO) minimum basis method and the Vienna ab-initio simulation package (VASP), we present a predictive study of the structural and magnetic properties of Zr_2CoSi. The spin-polarized calculations of the electronic structure of Zr_2CoSi involved both above-mentioned cubic Heusler structures. In our calculations, Zr_2CoSi in the Hg_2CuTi structure has a higher total energy of about 1.4 eV/f.u. than that in the Cu_2MnAl one (or $L2_1$). Additionally, it seems that the negative value of formation energy may indicate the possibility of crystallization of the Zr_2CoSi compound in the $L2_1$ cubic structure. Unfortunately, the density of states (DOS) do not support the half-metallic state of Zr_2CoSi. Van Hove singularity involving partially occupied Co 3d e_g states occurs in minority states of the Zr_2CoSi at the Fermi level. The studied compound satisfies the preconditions to exhibit a cubic-to-tetragonal instability according to a band-Jahn-Teller mechanism. On the other hand, the calculated elastic constants of Zr_2CoSi in the $L2_1$ structure for both exchange-correlation functionals used in the calculations: generalized gradient approximations (GGA) and local density approximations (LDA), shows that the system exhibits mechanical instability due to negative value of the tetragonal shear modulus C'. Our analysis of the total energy landscapes of the system shows that there are two tetragonal and one orthorhombic distorted phases of Zr_2CoSi that are energetically favored over the undistorted cubic $L2_1$ structure. However, only one tetragonal phase of Zr_2 CoSi with $c/a = 1.22$ fulfills necessary and sufficient elastic stability conditions in both GGA and LDA calculation. The calculated values of elastic constants of Zr_2CoSi in the second tetragonal phase (with $c/a < 1.0$) and orthorhombic one (with parameter $\delta = 0.89$) have not satisfied the Born inequalities. The calculations show that the lowering of the symmetry and the increase of the tetragonal distortion parameter is responsible for the decrease in the magnetic moment. In the tetragonal phase ($c/a = 1.22$) the total magnetic moment of Zr_2CoSi falls to 1.268 μ_B.

Jacobi Elliptic Functions describe a large class of 1D domain walls in thin infinite slabs.

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The understanding of energy minimizing magnetization configurations is of essential importance for many technological applications of magnetism because systems will spend most of their time in the vicinity of energy minima. Therefore, device designers must be able to predict and identify these configurations. Micromagnetic software has become an invaluable tool for this purpose.

However, the problem is usually not amenable to an analytical solution and the ubiquitousness of advanced computational tools in micromagnetism leads investigators directly into numerics. Hence, it has become common practice to dismiss the question of whether analytical solutions exist to any given problem and many studies stop at the simulator's output. This is unfortunate since analytical results provide further points of access to investigate magnetic systems.

In this work we will describe how Jacobi Elliptic Functions can be used to describe a large class of 1D-dimensional magnetization profiles. To illustrate their use, we will investigate ferromagnetic ribbons with perpendicular anisotropy (PMA). Ribbons are infinitely long and extremely thin structures with moderate width (as compared to the ferromagnetic exchange length). This type of device is important because they can easily be manufactured using a variety of techniques, such as lateral modification of magnetic properties by ion bombardment.

We will show how the number of micromagnetic stable states available to ribbons increases with width in discrete steps. Limiting cases of the Jacobi-Elliptic function include the known profiles of Neel walls for very wide ribbons. A finite interfacial Dzyaloshinskii-Moriya effect causes an energy decrease of non-uniform profiles and forces a magnetization tilt at the ribbon's edge. These effects can readily be understood using Jacobi elliptic functions to describe magnetic textures.

Our hope is that this work illustrates the potential of these functions in a non intimidating way so that they become more widely exploited by the magnetism community.

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Identification of magnetic anisotropy axes by means of the thermomagnetic Nernst effect

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The research focuses on the study of the thermomagnetic Nernst effect in selected soft magnetic materials. The Nernst effect links the electric field with the thermal gradient in conductors under the presence of an external magnetic field or spontaneous magnetization. Therefore, research activity is predominantly focused on thermoelectric generators exploiting ordinary or anomalous Nernst effect [1,2]. Other works reveal possible application as a spin-caloritronic devices [3,4], heat-flux meters or next generation energy harvesters [5,6]. An increased value of the Nernst coefficient due to presence a magnetic order of the sample has been presented in the papers [7,8].

The presented experimental research discusses and shows results of the influence of magnetic anisotropy of soft magnetic structures on the thermomagnetic Nernst effect. Contrary to existing works in this field, our approach concerns the application of the Nernst effect to identify and study the magnetic properties of the substrate in which this effect is observed. The effect was investigated in several samples made of high magnetic permeability Fe-containing alloys. The samples with 20x4x0.2mm were tested in a transverse arrangement, i.e. in which the magnetic field vector was applied transversely to the temperature gradient. The studies were performed for several values of temperature ranging from 293K to 320K.

The experimental results reveal a significant impact of structural and micromagnetic order on electric field potential caused by the presence of the Nernst effect. The linear relationship of the Nernst coefficient in the applied temperature range shows the feasibility of the effect as a tool for the identification of magnetic anisotropy axes using alternative, nonmagnetic techniques.

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Magnetic properties of the topologically non-trivial compound $CaMnSb_2$

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$CaMnSb_2$ is a layered transition-metal pnictide, which crystalizes in the orthorhombic structure, space group *Pnma* [1]. Previous magnetic measurements [2] provided evidence of distinct anisotropy with magnetic easy direction along the *a* axis and antiferromagnetic (AFM) order below $T_N = 302$ K. It was also suggested that $CaMnSb_2$ hosts nearly massless Dirac fermions, which give rise to nonzero Berry phase, high carrier mobility, and very small cyclotron masses derived from de Haas–van Alphen (dHvA) oscillations. In the present study, we extended magnetic characterization of single-crystalline $CaMnSb_2$ up to 750 K. The results clearly indicated that the AFM ordering sets in much above the room temperature. At $T = 2$ K, we observed dHvA effect that corroborated the previous findings. Moreover, we performed angle- dependent magnetic torque measurements, which provided new insight into interplay of magneto-crystalline anisotropy and the AFM exchange interactions.

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Laser pulse and photon energy tuning for increased all-optical magnetization switching efficiency

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Magnetization manipulation on ever shorter time scales has been an indispensable tool and remains important for application development as well as basic research [1]. So far, optical laser pulses provide the fastest means to trigger magnetization dynamics. The ultrafast magnetization processes speed is determined by the energy transfer from the electron system to the spins. From the application point of view, granular FePt has gained special interest as media for heat-assisted magnetic recording with high coercivity and switching fields above 6 T [2]. In our approach, we use femtosecond laser pulses of two opposite helicities to directly manipulate the magnetization state and thus write information to the FePt grains, a technique, that has been applied to several magnetic materials. In our current understanding, after the ultrafast excitation and heating, the influence of magnetic dichroism together with the presence of the inverse Faraday effect jointly interact and work as forces, causing magnetization reversal. The switching rates are calculated for individual FePt nanoparticles by obtaining the optical effects (inverse Faraday effect and magnetic dichroism induced heating) from ab-initio calculations in the first step, and in the second step including those into thermal modelling of magnetization dynamics in the Landau-Lifshitz-Bloch model. This provides the switching rates for the ensembles. We can trace the different processes from the beginning of the laser pulse impact [3]. This theoretical description allows us to optimize the required number of shots to reverse the magnetization of FePt nanoparticles and pinpoints how to optimize the all-optical writing by tuning the laser fluence and wavelengths. For further understanding of the interplay between the involved processes, additional investigations are providing answers to the open questions and extending the possibilities of all-optical writing as a general mechanism. Experiments tuning the laser wavelengths, while simulatneously adjusting the fluence and pulse duration provide and insight in the behavior caused by an increase photon absorbtion and changed asymmetry for the inverse Faraday effect induces by the opposite helicities. The switching efficiency behaves in a nontrivial way, as slightly changing the experimental parameters does not automatically lead to better magnetization results.

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Magnetic adatoms on two-dimensional $NbSe_2$

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In the last decade, much research has been focused on quasi-two-dimensional magnetism in monolayers or buried interfaces [1]. Two-dimensional transition metal dichalcogenides are very interesting from a fundamental point of view, as magnetism and charge-density waves compete with each other. Magnetic impurities may modify a charge-density wave, by altering its energetic stability as well as its local patterns. The charge density wave in turn affects how magnetic impurities can interact with each other, modulating the exchange coupling. Therefore, inducing magnetism with external chemical species has the potential to be an effective way to engineer new electronic and magnetic phases in perspective of technological applications. In this poster, we present our study on the extrinsic magnetism arising from adsorbed transition metals on two-dimensional $NbSe_2$ [2,3]. We demonstate that each investigated adatom (Cr, Mn, Fe, and Co) can be located in various metastable positions on the monolayer, inducing substantial modifications in the local patterns of the charge densities [2]. The coupling between magnetic impurities is then investigated by means of the magnetic force theorem [3]. Our results show that the exchange coupling has an oscillatory nature accompanied by an exponential decay, typical of a damped RKKY interaction [4]. The oscillatory behavior can be traced back to a single nesting vector in the Fermi surface, which is not affected by small changes on the height of the impurity, making magnetism robust against external perturbations.

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Doppler effect for spin waves: micromagnetic studies

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The Doppler (and Cherenkov) effect is the physical phenomenon existing for any kind of waves. To observe it one needs to move uniformly the source of the wave with a velocity comparable to (or larger than) the velocity of propagating waves. In 2013, Ming Yan et al [1] demonstrated (using micromagnetic simulations) the Doppler and Cherenkov effects for spin waves excited by the moving pulse of the magnetic field. The authors also found that for 2D and 3D ferromagnetic systems a bending of the wavefront forming a Mach cone can be observed.

In our work, we reproduced the results obtained by M. Yang, using the micromagnetic solver MuMax3. Our studies were supplemented by the case of pair of linearly oriented sources (generating plane waves), keeping the same distance from each other (i.e. moving with the same velocity). For the appropriately selected distance and the speed of the sources, we observed the destructive interference of the spin waves in the front (or in the back of moving sources). Such a system works as a unidirectional spin wave antenna, generating spin waves of different frequencies only in the forward (or only in the backward) direction.

One of the main problems in the experimental observation of Doppler for spin waves is the realization of a moving source that travels with the required velocity, i.e. in the range of single km/s. We are going to discuss such possibilities. One feasible realization is to use the stray field of superconducting vortices [2] (or Abrikosov lattices of such vortices), which can travel in the superconducting layer, placed above the ferromagnetic layer, with the velocity reaching single km/s.

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Ultra-thin high-quality magnetic insulator films

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Due to fundamental limitations, the miniaturization of CMOS devices becomes very difficult, and alternative concepts that allow for higher storage density at low power are required [1]. Spin waves, the elementary low-energy excitations in magnetic systems, exist in the high-frequency regime and are considered a potential technology that can complement the CMOS devices. However, the common magnetic materials, such as Nickel, iron, cobalt, and their alloys used in devices are not ideal for spin-wave propagation due to their high magnetic losses, which translated into shorter propagation lengths. The solution lies in using materials with ultralow damping, such as yttrium iron garnet (YIG) [2-4]. Typically, YIG films are prepared by liquid phase epitaxy (LPE) with a thickness range of tens of microns which is not ideal for applications. Here, we prepared ultra-thin yig films with a thickness down to 30 nm by the pulsed laser deposition technique. We study the static and dynamic properties of these films using a broadband ferromagnetic resonance (FMR) technique where we investigate the effect of the laser energy and the oxygen pressure on the saturation magnetization and the Gilbert damping in these films. We found that a better quality of the films is achieved at higher deposition energy of the laser and under high oxygen pressure. We report ultra-low damping ($\alpha = 2\text{x}10^{-4}$) and Ms = 0.2 T which approaches the recorded values of the bulk YIG films.

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Monodomain magnetization state at remanence in antidot lattices with inhomogenous perpendicular magnetic anisotropy

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Antidot-type lattice (ADL) magnonic crystals have been gaining interest due to its technological potential in high density data storage and signal processing [1]. Previous investigation of spin-wave (SW) dynamics in circular ADLs with perpendicular magnetic anisotropy (PMA) and the rims of reduced PMA around the holes, discovered strong interaction between bulk modes of the ADL and the rim localized modes [2-3]. This shows the potential of circular ADL as an SW waveguide. However, squircle-shaped ADLs (a superposition of a square and a circle) as an alternative geometry have not been explored.

Here, we run multiple simulations using MuMax3 micromagnetic solver to find the ground state of ADL based on Co/Pd multilayer with squircle antidots. We follow a scenario used in standard hysteresis loop measurements, i.e., we set the initial magnetization distribution to be at full saturation with strong external magnetic field ($\mu_0 H_{ext} = 1$ T) parallel to the PMA axis and reduce the external field strength in a stepwise manner to remanence. The material parameters are set following the Co/Pd multilayer [3], but we vary some parameters such as thickness of the thin film d, uniaxial anisotropy constant K_{u1}, and the lattice constant a. The simulations are then categorized into two-types of domain structures, monodomain (perpendicular magnetization component, $m_z > 0.99$ outside the rim) or multidomain ($m_z < 0.99$ outside the rim). The phase diagram is created from simulations varying the parameters mentioned, either with $a = 500$ nm or fixed thin film thickness of $d = 13.2$ nm. Our results show that there is no apparent dependence of the type of domain structure to the area of region with full PMA, i.e., a. On the other hand, we observed some dependence to the thickness of the thin film. This study provides guidance on the selection of material and geometric parameters for ADLs with a regular domain structure in remanence, and thus serves as a first step prior to simulating the SW dynamics in such systems.

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Magnon transport in bilayer $CrCl_3$

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Recently it has been shown that the monolayer and bilayer of two-dimensional van der Waals material $CrCl_3$ are ideal systems to test and explore different magnetic phases in low-dimensional magnetic materials [1].

A finite-size Berezinskii-Kosterlitz-Thouless phase transition has been observed in the monolayer of this material [2]. In addition, it has been shown that the magnetic ground state and spin-spin interactions in its bilayer can be tuned by strain and electric fields [3]. The system shows a transition from ferro- to anti-ferromagnetism under proper strain fields. It was also shown that both the sign and amplitude of the magnetic anisotropy and Dzyaloshinskii–Moriya interactions may also be tuned by applied strain fields [3].

In the present work, we study magnon dynamics and magnon transport in bilayer $CrCl_3$ under different strains using large-scale atomistic spin dynamics simulations. First, we compute the magnon dispersion in the presence and absence of tensile and compressive strain fields. Second, we investigate the nonthermal spin transport using a non-local geometry [4][5] and explore how different strain fields change the characteristics of the magnon transport in this system.

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Effect of magnon-magnon interaction on the ferromagnetism in hexagonal manganese pnictide monolayers

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The low dimensional magnetism has a key role in developing the novel nano-scale spintronics devices and understanding quantum magnetism. According to the Mermin–Wagner–Hohenberg theorem, the long-range magnetic order is thermally unstable for the 1D and 2D isotropic spins at a finite temperature [1]. However, recent successful synthesis of two-dimensional magnets has shown that magnetic anisotropy can repress the thermal fluctuations and stabilize log-range magnetic order at finite temperature [2]. Accordingly, 2D magnetization opens up many novel, vast and interesting questions and challenges that are not clear until now. The physics of high temperature is affected by magnon-magnon interaction and the presence of this interaction plays an essential role when studying excited states at finite temperatures close to phase transitions. In our study, the second-order of Holstein-Primakoff transformations are used to describe interacting magnons in hexagonal MnX (X = N, P, As, Sb) monolayers with an out-of-plane or in-plane easy axis. We map the DFT results into an effective anisotropic Heisenberg Hamiltonian. Our studies indicate that the magnon-magnon interaction slightly softens the magnetic excitation energy and significantly reduces the magnon energy gap which is crucial for finite temperature long-range magnetic order in 2D [3].

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Electronic structure of $CeCu_4In$ from band structure calculations and X-ray photoelectron spectroscopy

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We present a combined new experimental and theoretical study of the electronic structure for the heavy fermion $CeCu_4In$ based on X-ray photoelectron spectroscopy (XPS) data and $ab-initio$ band structure calculations. The compound crystallizes in the orthorhombic $CeCu_{4.38}In_{1.62}$ type of structure (space group $Pnnm$). Below the Fermi energy the total density of states contains mainly the $3d$ states of Cu atoms that hybridize with the Ce $4f$ electronic states. The Ce core-level XPS spectra point to a stable trivalent configuration of Ce atoms in $CeCu_4In$, consistently with the magnetic susceptibility data.

For more detailed information about electronic states the fully relativistic band structure was calculated within the density functional theory (DFT) for the first time. Based on these calculations we present calculated photoemission spectra, which very well reproduce the experimental ones. The Fermi level is located at a deep decrease in the density of electron states and reaches a value of 3.69 states/(eV f.u.), which corresponds to a Sommerfeld coefficient in the electron specific heat of 8.69 mJ/(mol K). This value is much smaller than that obtained experimentally, which indicates the importance of many-body effects, which are not properly taken into account in ab-initio calculations. The valence band is formed mainly by Cu($3d$) electrons with a small contribution of Ce($4f$) electrons in the immediate vicinity of the Fermi level.

Superconductivity in Monolayer FeTe on Bi_2Te_3

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The temperature and magnetic field dependence of electric transport indicates a superconducting (SC) ground state in monolayer (ML) thin FeTe on Bi_2Te_3, while respective $FeSe/Bi_2Se_3$ samples remain in a normal state at temperatures $T \geq 1$ K. Strong indications for superconductivity presence were previously observed by scanning tunneling spectroscopy [1,2]. The samples were grown in UHV by molecular beam epitaxy and were characterized by X-ray and UV photoemission spectroscopy as described in Ref.[3]. A protective amorphous silicon layer was added for subsequent *ex-situ* transport measurements. Zero-field transport data reveals characteristic drops in resistance at critical temperatures T_c, which depend on the magnetic field and FeTe coverage on Bi_2Te_3. For ~ 1 ML FeTe, the zero-field transition appears at $T_c \sim 2.8$ K and increases to $T_c \sim 5.8$ K for ~ 2 ML. Out-of-plane critical fields are extracted to be $\mu_0 H_{C2} \approx 0.3$ T and 2.2 T, respectively. The observed temperature dependence of the critical fields is discussed in terms of the presence of 60° rotated FeTe island domains on Bi_2Te_3 of varying width in the range of (50 ± 30) nm. For larger islands, we show that critical fields are dominated by orbital pair breaking.

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Magnetoresistance study of Fe doped $TlInTe_2$ crystal

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In this study, the influence of spin dependent scattering effect on magnetoresistance (MR) in Fe doped $TlInTe_2$ magnetic semiconductor with chain structure has been investigated for normal (B⊥c) and parallel (B∥c) orientation of B vector relative to sample plane and c-axes. The single crystal of Fe doped $TlInTe_2$ which crystallizes in a tetragonal structure with I4/mcm space group was prepared by using the directed crystallization Bridgman method. Temperature dependence of resistance in cooling/heating regimes and magnetoresistance in heating regime have been measured in the range of 200 - 300 K and magnetic fields with induction B≤ 14T. For both orientations of magnetic field vector to the sample surface, the MR(B) curves shows remarkable hysteresis loops of different shape, exhibiting negative, positive and anisotropic magnetoresistive effect. We concluded that magnetotransport properties are determined by trivalent iron atoms which most probably substitute into In^{3+} ion sites located at the center of ($In^{3+}Te_4^{2-}$) structural units in the chain structure of $TlInTe_2$ crystal. The shape of hysteresis MR(B) loops is strongly different for configurations (B⊥c) and (B∥c) (current vector I is always parallel to b-axes). In particular, we observe sharp increase of initial (virgin) part of MR(B) curve up to maximal value of ∼1-1,2 % at B∼6 T for (B⊥c) orientation. At the same time for B∥c orientation, small negative MR effect of ∼2 % at B ∼ 14 T is observed for virgin curve. After first magnetization MR(B) loop for B⊥c orientation has double peak shape shifted on app. 2,5 T when B changes its sign. For B∥c configuration, MR(B) loop has only one peak shape where peaks are shifted on app. 1,5 – 1.7 T relative to each other. It is possible to explain such behavior of MR(B) loops by rotation of spins in Fe^{3+} ions, distributed in In-chains, if we make the following guess: spins in neighboring Fe ions, directed in In chains along c-axes, are antiparallel (AFM configuration) and are directed along a-axes. In such a case, for B⊥c configuration at B < 6 T spin rotates on 180° (through intermediate state at 90°) while for B∥c configuration spin rotates only on 90° at B ∼ 14 T. Such diffrent behavior of spins in magnetic field results in different character of electron scattering that fully determine MR(B) loops behavior.

Keywords: Magnetic semiconductors; magnetoresistance; spin-dependent scattering, antiferromagnetic structure.

Carrier transport in heavily Sb-doped Si layers near the Mott transition

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We studied spin-resolved components of resistivity tensor ρ_{xx}(T,B) and ρ_{xy}(T,B) and magnetization M(T,B) on temperature T and magnetic field B in thin epitaxial Si layers heavily doped with Sb which were initiated by spins arised on paramagnetic "dangling bonds" at the Si<Sb> layers surface when epitaxial growing process. The Si<Sb> 10-12 nm thick layers were epitaxially grown on the p-Si(001) 12 Ω×cm substrate covered with 100 nm thick lightly-doped buffer and capping Si layers [1]. Studies have shown the following 3 features of ρ_{xx}(T,B) and ρ_{xy}(T,B) dependences in Si<Sb> layers: (1) ρ_{xx}(T,B) and ρ_{xy}(T,B) dependences in samples without capping Si layer includes 2 contributions: (1) from Sb impurity in Si<Sb> layer bulk and (2) from "dangling bonds" on Si<Sb> layer surface. As a result, the Hall resistance component is described by the relation $\rho_{xy}(\mathrm{T,B}) = R_o\mathrm{B} + R_a\mathrm{M}$, where R_o and R_a are the ordinary (OHE) and anomalous (AHE) Hall effect constants, respectively, M is the magnetic moment of paramagnetic centers and $\rho_{xx}(\mathrm{T,B}) \sim B^2$. (2) Below 10-15 K, our measurements have shown a linear change of σ_{xx} with L_n(T) that is typical for weakly disordered two-dimensional (2D) semiconductors and metals and is described by the interference quantum corrections (QC) to the Drude conductivity in weakly-localized systems [3]. The QC contribution to low-T ρ_{xx}(T,B) is also confirmed by its suppressing at low values of B ∼ 0.1 T. (3) The estimation of the appropriate Thouless lengths L_{TH} from fitting of σ_{xx}(T,B) dependences has shown a power-like function $L_{Th} \sim T^{-p/2}$, where p is constant depending on the scattering mechanism of carriers [2]. The best agreement with the experimental data was achieved with p values close to 1 that corresponds to the 2D quantum corrections theory [3].

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Signature of Quantum Transport in ferromagnet $SrRuO_3$(111)

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Weyl semimetals are attractive candidates for a variety of applications in electronics, spintronics, and quantum computing because they have unique electrical characteristics such the linear dispersion relation, chiral anomaly, and Fermi arcs. The presence of $SrRuO_3$ (SRO) films on (111) surfaces has been predicted to exhibit emergent phases, such as the **Haldane quantum Hall state[1,2], Weyl semi-metallic state**[3], etc. Our research aims to find such signs of quantum transport, particularly weyl fermionic transport in the case of expitaxial $SrRuO_3$. High-quality epitaxial SRO thin films was grown on atomically terminated $SrTiO_3$ (111) substrates through RHEED-assisted PLD. The characterization of the films was carried out using a combination of magnetic, XRD, and magnetoresistance/Hall transport techniques.

The findings of our work demonstrate that the growth conditions have a significant effect on the Residual Resistivity Ratio (RRR) values, which are indicative of ruthenium vacancies in the films. Although changes in RRR have minimal effects on magnetic properties, they significantly impact the transport regime. There seems to be clear relation between RRR and its corresponding transport data. Notably, thin (111)-oriented SRO films exhibits remarkably **high positive as well as linear MR and consistent Hall transport behaviour**, which makes them a very strong candidate for further research as a Weyl semimetal.[4].

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Electron scattering by magnetic quantum dots in topological insulators: a path to electron optics with spin-momentum locking

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One of the challenges in modern spintronics is the ability to manipulate electron charge and spin motion with magnetic fields. Although methods of conventional optics based on electron waves are used to achieve this goal, advanced electron optics should include electron spin to control both coupled spin and charge dynamics.

In our work, we consider formation of coupled spin and charge densities resulting from electron scattering by magnetic quantum dots producing a position-dependent Zeeman field in the presence of spin-momentum locking typical for topological insulators.

Using analytical and numerical methods, we study scattering by a single magnetic quantum dot and by a diffraction grating made of such dots. The spin-momentum locking produces strong differences with respect to the spin-diagonal coupling and leads to the scattering asymmetry with nonzero mean scattering angle as determined by only two parameters characterizing the system. These results can be applied for designing magnetic topological insulators-based nanostructures producing required distributions of charge and spin densities.

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Magnetic phase diagram of topological $Sn_{1-x}Mn_xTe$ layers

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$Sn_{1-x}Mn_xTe$ is a IV-VI semimagnetic (diluted magnetic) semiconductor known to exhibit both the properties of topological crystalline insulators and carrier-induced ferromagnetism. We carried out an extensive technological program of molecular beam epitaxial growth of $Sn_{1-x}Mn_xTe$ layers and summarize our findings in the form of magnetic phase diagram for ferromagnetic transition temperature and magnetic anisotropy constants for layers grown under different MBE conditions. The $Sn_{1-x}Mn_xTe$ were grown under varying stoichiometry regimes on various substrates: BaF_2, with either (111) or (001) orientation, and GaAs/CdTe (001). Magnetization measurements were carried out with a superconducting quantum interference device (SQUID). For magnetic anisotropy studies we applied ferromagnetic resonance (FMR) technique. We found that most of $Sn_{1-x}Mn_xTe$ layers studied with concentration of conducting holes ($p \leq 3x10^{20} cm^{-3}$) undergo a ferromagnetic transition with T_C below 10 K. In particular, by growing the $Sn_{1-x}Mn_xTe$ layer with nominal concentration 4.5 at.% under various Te flux, we demonstrated the control between paramagnetic and ferromagnetic properties. The magnetic anisotropy observed directly in magnetization measurements as well as in the angular dependence of the FMR resonance field confirmed the easy magnetization axis in the plane of the layer as expected for ferromagnetic layers with dominant shape (dipolar) anisotropy and smaller crystal direction dependent contributions of single ion anisotropy. The largest magnetic anisotropy field of the order of 1 kOe is observed for (001) oriented layers with factor of two reduction for (111)- oriented layers on BaF_2.

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Tunnel magnetoresistance and cross-correlations in double quantum dot-Majorana wire system

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We theoretically investigate the spin and charge transport properties of double quantum dot system attached to distinct edges of the topological nanowire hosting Majorana zero-modes and weakly coupled to external ferromagnetic leads. The focus is put on the analysis of the current and tunnel magnetoresistance in a wide parameter space, while we specifically inspect the influence of spin canting angle characterizing the wavefunctions of the edge states.

Moreover, two protocols of dots' gate voltage detuning are examined. In the case of symmetric detuning, a noticeable current is present only in the narrow range of the parameters and flows in an uncorrelated manner between the drains. However, for the antisymmetric gate detuning there is an extensive regime where currents are considerable, while revealing strong, positive cross-correlations between two arms of the device associated with a highly correlated transport. The predicted transport features can be considered as further fingerprints of Majorana physics present in the system.

Unusual angle-dependent magnetoresistance of $EuCd_2As_2$

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In pursuit of non-trivial topological properties of Europium bearing Zintl phases the physical properties of $EuCd_2As_2$ have been intensively explored. There are numerous reports on its magnetization and magnetotransport, but the angular dependence of its magnetoresistance was not studied yet.

Several papers reported $EuCd_2As_2$ as a semimetal with single pair of Weyl nodes induced by spin fluctuations [1] and/or magnetic exchange interaction [2]. On the other hand, a very recent preprint argues that the compound is a magnetic semiconductor with a gap of 0.77 eV [3]. That came as no surprise, regarding extreme tunability of the electronic structure of this compound by pressure and chemical substitution [4,5]. In this work we revisit the magnetic properties and present novel angular dependence of the magnetoresistance, measured on good quality single crystals. Behavior of the anisotropic magnetoresistance is unconventional, and indicates topologically non-trivial state, most likely of Weyl nodes character.

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Anisotropic Magnetotransport Properties of Magnetic Shape Memory Heusler Alloy $Ni_{50}Mn_{25}Ga_{20}Fe_5$

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Heusler alloys of Ni_2MnGa, and its off-stoichimetry or substituted derivatives, show multiferroic properties including the magnetic shape memory effect (MSM) [1-2]. This property has received significant attention due to its application potential in micropumps, actuators, and sensors [3]. The magneto-crystalline anisotropy of the martensite states is a key requirement allowing magnetic-field induced reorientation (MIR) of twin domains that defines the magnetic shape memory effect.

Magnetotransport properties of Ni_2MnGa has gained far less attention than its magnetoelastic investigation. Difficulties in maintaining a single variant state, as well as complications in maintain electrical contacts during the up to 12 % magnetic-field induced strains has hindered electrical transport investigations. Here we will present results of extensive magnetotransport measurements (resistivity, magnetoresistance, and Hall effect) of single crystalline $Ni_{50}Mn_{25}Ga_{20}Fe_5$. The material undergoes martensitic transformation into the 10M MIR-active phase on cooling below $T_{mart} = 309$ K, as well as further inter-martensitic transformations into the 14M and non-modulated (NM) phases on further cooling.

To maintain a single-variant state in 10M martensite, a custom-built in-situ compression device was used. Despite maintaining a unique short-axis, the inter-martensitic transformations to 14M and NM phases inevitably result in multi-variant states. We will present both the device, and the results of the anisotropic magnetotransport measurements across these phase transitions in this intriguing multiferroic material.

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Topological Hall effect due to skyrmion in canted antiferromagnets

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We study theoretically the topological Hall effect (THE) due to skyrmions in a two-dimensional (2D) noncollinear antiferromagnet (AFM). It is well known that THE in ferromagnetic materials is described by the Berry phase [1] acquired by the wavefunction when an electron spin follows adiabatically the local magnetic texture. In this picture the influence of skyrmions is characterized by an emergent magnetic field which leads to the spin-dependent force acting on the itinerant electrons.
Such an adiabatic approximation fails in collinear (and thus also in noncollinear) AFM materials, since an electron cannot adjust its spin momentum to the spin texture of AFM due to alternating magnetic moments of the two sublattices. In this work we use the approach that allows for a description of the quasi-adiabatic dynamics of electron spin in canted AFMs with slowly varying component of the spin texture due to antiferromagnetic skyrmions. To do this, we first diagonalize the Hamiltonian of the canted AFM and derive the eigenvalues and eigenstates of the system. The magnetization due to canting of the sublattice moments is shown to give rise to a splitting of the conduction and valance electron bands. Then, we calculate the contribution of each sublattice to the emerging magnetic field, and obtain the total effective emergent magnetic field. As in ferromagnets, the effective emergent magnetic field gives rise to the spin-dependent force which leads to an adiabatic contribution to the electron spin dynamics. Considering such a picture of quasi-adiabaticity and using the semi-classical Boltzmann approach, we obtain the diffusion equation for spin accumulation in the presence of spin-flip scattering [5]. Effective emergent magnetic field acts as a source for spin accumulation and spin-flip scattering. The latter, however, originates mainly from extrinsic spin-dependent scatterings. As a result, we find the corresponding THE conductivity/resistivity and analyze in detail its dependence on total magnetization, spin-flip scattering, and skyrmion size.

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Evidence of variable range hopping in the Zintl phase $EuIn_2P_2$

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We report a comprehensive characterization of the magnetic, electrical transport, and thermal properties of single-crystalline Zintl-type material $EuIn_2P_2$. The compound crystalizes with a hexagonal unit cell (space group $P6_3/mmc$) and orders magnetically at $T_C = 24$ K with the Eu magnetic moments aligned ferromagnetically within the *ab* plane but tilted alternately along the *c* direction. The effective and saturation magnetic moments are in good agreement with the theoretical values expected for the Eu^{2+} ion. Above T_C, the transport behavior of $EuIn_2P_2$ is dominated by short-range magnetic interactions, similar to other Zintl phases based on Eu^{2+}, such as $EuIn_2As_2$ [1-3]. The temperature dependence of the electrical resistivity has been modelled in terms of variable-range hopping, inherent in the double-exchange mechanism [4]. Another indication of the latter scenario seems to be the observation for $EuIn_2P_2$ of a quadratic dependence of the negative magnetoresistance on the magnetic field strength and on the scaled magnetization, reported also for $EuIn_2As_2$ [5].

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Nonlinear planar Hall effect in topological insulators: contribution from scattering on magnetic impurities

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We will present results of our theoretical study of a new type of nonlinear Hall effects, that appears in non-magnetic layers with strong spin-orbit coupling (SOC) [1,2]. Assuming the low-energy electronic states on the surface of a 3D topological insulator in terms of Dirac model, and applying the semiclassical Boltzmann formalism, we derive the planar Hall conductivity within the generalized relaxation time approximation. We show that the planar Hall conductivity consist of the linear and nonlinear terms with respect to the external electric field. The linear term scales quadratically with an external magnetic field and presents the conventional planar Hall conductivity, whereas the nonlinear term scales linearly with both the charge current density and in-plane magnetic field. Thus, the latter term reveals the bilinear behavior.

The nonlinear Hall effect in this description is a consequence of electron scattering on spin-momentum locking inhomogeneities [3] in the presence of current-induced spin polarization and external magnetic field. The main objective of the presentation is a detailed analysis of the influence of electron scattering on magnetic impurities in the system on the nonliinear planar Hall effect. Generally, magnetic impurities contribute to scalar scattering (on impurity electrostatic potential) and magnetic scattering (via exchange coupling of electron spin to impurity magnetic momentum). Assuming that magnetic moments of the impurities in the system follow the external magnetic field orientation [4], we show that the nonlinear Hall conductivity becomes remarkably modified by scattering on magnetic impurities. The most pronounced effect of such a scattering is an additional periodicity (in comparison to scattering on scalar impurities) in the dependence of the Hall conductivity on the angle between charge current direction and magnetic field orientation.

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Effects of symmetry reduction on transport through strongly correlated triple quantum dot

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We consider transport through three capacitively coupled quantum dots, each of which is connected to a separate pair of electrodes. To study many-body effects we use finite-U mean-field slave boson approach. High symmetry case of equal dot energies, Coulomb interactions and dot-lead couplings exhibits SU(6) Kondo effect with the same role played by spin and three dimensional (flavor) dot isospin. The role of different transport channels can be changed by introducing magnetic field, polarization of some electrodes or by tuning the on-site dot potentials. New highly symmetric states can occur (SU(5), SU(4), SU(3), SU(2)) for the selected modifications. This is achieved for very large (infinite) separation of former degenerate levels or by attaching fully polarized electrodes to some of the dots. Apart from gate dependencies of conductances we also present occupations, spin magnetic moments at the dots, their corresponding fluctuations, spin polarizations of conductance, Casimir operators and temperature dependencies of entropies for the examined symmetries. We also study effects of symmetry breaking on conductance and we show the methods of restoring symmetry.

Study of Spin-Orbit Interactions and Multilevel Switching in Co/Pt/Co trilayer

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Spin-orbit torque induced current magnetization switching (SOT-CIMS) provides an energy-efficient way of manipulating the magnetization in the ferromagnetic layers. We present a detailed study of Dzyaloshinskii–Moriya and spin-orbit interactions in the Ti(2)/Co(1)/Pt(0-4)/Co(1)/MgO(2)/Ti(2) (thicknesses in nanometers) patterned into micrometer-sized Hall-bar device. Here, the Pt is used as a source of the spin current, and as a nonmagnetic spacer whose variable thickness enables the magnitude of the ferromagnetic interlayer exchange coupling (IEC) to be effectively tuned [1]. From anomalous Hall effect (AHE), anisotropic magnetoresistance (AMR) and spin Hall magnetoresistance (SMR) measurements, we found that the increase in Pt thickness (t_{Pt}) leads to the reorientation of Co-magnetizations from the in-plane to the perpendicular direction at $t_{Pt} \approx 1.3$ nm. Further increase in Pt thickness, over 3 nm, reduces the ferromagnetic coupling and consequently, two weakly coupled Co layers become magnetized orthogonally to each other. From analysis of the Stokes and anti-Stokes peaks spectra measured by the Brillouin light scattering (BLS), the value of effective DMI constant (D_{eff}) was determined as a function of Pt spacer thickness. These quantities reach their highest value for Pt thicknesses of around 2 nm, where the perpendicular anisotropy is the largest [1]. Magnetic domain images obtained by the polar-magnetooptical Kerr microscopy (P-MOKE) demonstrated the skyrmion bubble domains in the region of strong coupling, which disappears with decreasing ferromagnetic coupling. The asymmetric expansion of the bubble domain indicates the counterclockwise (CCW) chirality of the Néel-type DWs. The results obtained for the trilayer were compared with the Pt(4)/Co(1)/MgO bilayer system. Finally, we investigated SOT-CIMS in both systems and analyse the switching mechanism using Landau-Lifshitz-Gilbert-Slonczewski equation.

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Influence of spatially random magnetization on the conduction of surface electrons in a topological insulator

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The influence of correlated fluctuations of magnetization on the transport properties of surface 2D electrons in topological insulators was studied by using the Green's function method. Both scattering from magnetization fluctuations and scattering from nonmagnetic impurities were taken into account on equal footing in the calculations of the relaxation time and the vertex function. The conductivity is remarkably reduced by scattering from magnetization fluctuations in comparison to that in the absence of such fluctuations—especially at higher Fermi energies, where scattering from impurities plays a dominant role. The temperature dependence of the conductivity follows not only from the Fermi distribution function but also from the temperature dependence of the correlation length of magnetization fluctuations. This can result, for a specific range of parameters, in an increase of the longitudinal conductivity with temperature.

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Nonlinear effects in 2DEG with cubic form of Rashba spin-orbit interaction

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Nonlinear transport phenomena are focusing recenty enormous attention due to the unidirectional character of the current response that may be easily applied in spin-logic devices [1] or the current rectification in THz technology [2]. Moreover, the nonlinear Hall effect is sensitive to breaking the crystal symmetries and does not undergo the limits of optical methods. Therefore, it became a prominent tool for material characterisation in spatial-symmetry-related physics and probing the topological phase transitions [3].

Here, we consider theoretically 2DEG with a spin-orbit coupling of k-cubed Rashba type in the presence of an external magnetic field. We derived the intrinsic nonlinear Hall effect induced by the Berry curvature dipole [4]. We discuss, among others, the nonlinear transverse response that can be tuned by an in-plane magnetic field. Furthermore, using Green's function formalism, we provide the analytical results for the bilinear magnetoresistance as well as the planar Hall effect originating in non-equilibrium spin polarisation in the system [5].

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Spin-resolved transport properties of a quantum dot-Majorana nanowire system

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The resurgence of Majorana fermions in theoretical physics as a potential foundation for topological quantum computing [1], led in the last decade to a rapid rise of developments in the condensed matter systems [2], such as topological superconducting nanowires, which host Majorana quasiparticles at the ends [3].

The presence of Majorana modes can be probed by attaching quantum dots to the wires, which can then exhibit some non-trivial and unique transport properties. In this work we thus theoretically study a leakage of Majorana zero mode from the edge state of topological superconducting nanowire into a single quantum dot weakly coupled to two ferromagnetic leads. Such system is expected to indicate the presence of Majorana quasiparticles through spin-resolved transport characteristics.

Using the real-time diagrammatic technique [4] in the first order of the perturbation theory, we determine the charge current and associated differential conductance in the linear and non-linear response regimes.

Two protocols of how the bias voltage is applied to the system are considered. The first one is a fork geometry, where the current flows between the grounded nanowire and two ferromagnetic leads with equal electrochemical potentials. In the second geometry, topological superconductor remains grounded, while the bias voltage is applied symmetrically between the left and right electrodes.

Moreover, we consider two magnetic alignments of the ferromagnetic electrodes, parallel and antiparallel one, allowing us to determine the tunnel magnetoresistance of the system. By calculating the transport properties for various parameters we identify unique spin-resolved features associated with the presence of Majorana zero-energy modes.

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Temperature and Frequency Dependent Spin Pumping in NbN/Ni81Fe19 Bilayer Thin Films

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A flow of spin angular momentum with no net charge current, called pure spin current, is a key to fabrication of energy efficient spintronic devices. Such no-charge-based devices are in great demand owing to information transfer without Joule heat loss. One way to generate pure spin current is via ferromagnetic resonance spin pumping [1,2] using the dynamic transfer of spin angular momentum from a precessing ferromagnet into an adjacent nonmagnet. The spin current can be detected electrically using the inverse spin hall effect (ISHE) phenomena. Recent spin pumping studies in superconducting spintronics [3,4] have shown that superconductors could be used towards future low-energy computing technologies. It has been reported via ferromagnetic resonance experiments that induced spin currents can be amplified by adding a strong spin-orbit coupled spin sink layers in a superconductor/ferromagnet hybrid structure and will be key for superconducting spintronics. Therefore, this makes essential to study the spin pumping in other superconductor/ferromagnet hybrid structure, where superconductor exhibit higher superconducting transition temperature (T_C), and investigate magnetodynamic properties below and above the (T_C).

We report broadband ferromagnetic resonance spin pumping experiments, for temperatures ranging from 300 K - 4 K and frequencies from 2 GHz - 12 GHz, on NbN/$Ni_{81}Fe_{19}$ hybrid structures. The NbN thickness was varied from 40 nm - 140 nm, whereas $Ni_{81}Fe_{19}$ was kept at 15 nm. We observed a systematic shift in ferromagnetic resonance fields, amplitude, and linewidths as a function of frequency and temperature. We observed disappearance of the ISHE voltage below the T_C of NbN thin films, indicating the suppression of spin current below the T_C. The spin mixing conductance, spin current density, and estimated spin hall angle values showed strong temperature dependence.

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Electronic and Topological Properties of a Topological Insulator Thin Film Sandwiched between Ferromagnetic Insulators

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We consider a thin film of a topological insulator (TI) sandwiched between two ferromagnetic (FM) layers under external gate voltage. The surface electron states are magnetized due to the magnetic proximity effect to the ferromagnetic layers. The magnetization of ferromagnetic layers can be changed by applying an external magnetic field or varying thickness of the topological insulator (due to the interlayer exchange coupling). The change of magnetic configuration in the system affects the transport properties of surface electronic states.

Using the Green function formalism, we calculated spin polarization, anomalous Hall effect and magnetoresistance of the system. We will show, among others, that by tuning gate voltage and magnetizations of the top and bottom FM layers, one can observe the topological transition to the anomalous quantum Hall state.

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Bilinear magnetoresistance and planar Hall effect in topological insulators: Interplay of scattering on spin-orbital impurities and non-equilibrium spin polarization

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Bilinear magnetoresistance (BMR) and nonlinear planar Hall effect (NPHE) appear in nonmagnetic materials as a consequence of strong spin-orbit interaction. These effects behave linearly with respect to both external electric and in-plane magnetic fields. As far, several microscopic mechanisms have been proposed such as Berry Curvature dipole, the inhomogeneity of spin-momentum locking, as well as the hexagonal warping of the Dirac cones [1-3].

Using Green functions formalism and diagrammatic techniques, we have performed a consistent theoretical study of the nonlinear terms in the diagonal and transverse conductivity, taking into account the renormalized velocity vertex function and the side-jump diagrams. These terms appear due to the current-induced spin polarization and spin-orbital component of the impurities scattering potential. We will present detailed characteristics of BMR and NPHE, and compare our new results with those obtained recently without impurity vertex correction [4].

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Topoligically induced Hall effects in graphene-based EX-SO-TIC van-der-Waals heterostructures

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Two-dimensional Van-der-Waals materials focus enormous attention due to a variety of electronic and magnetic properties that might be controlled by external fields. A special group of van-der-Waals materials are so-called *EX-SO-TIC* structures where one can turn the time-reversal symmetry on and off on demand by electric gating. This leads to the swap between an exchange (EX) and spin-orbit (SO) coupling. An example of such an ex-so-tic structure is bilayer graphene (GG) sandwiched by a 2D ferromagnet Cr2Ge2Te6 (CGT) and a monolayer of transition metal dichalcogenides, e.g., WS2. Swapping between the exchange and spin-orbit coupling in CGT/GG/WS2 is possible due to the interplay of gate-dependent layer polarization in bilayer graphene and short-range spin-orbit and exchange proximity effects affecting only the layer of graphene in contact with the sandwiching materials

We will present a theoretical study of topological transport properties of CGT/GG/WS2 based on an effective Hamiltonian derived from symmetry considerations and DFT study [1]. Within Green's function formalism we have derived numerical and analytical characteristics describing intrinsic (topological) anomalous, valley and spin Hall effects. Among others, we will expose the influence of certain parameters and external gate voltage on the changes in the band structure and, consequently, on the Hall effects (topological properties described by the Berry curvature). We will also present a potential Hall effects-based device grounded on this heterostructure.

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Impact of intra- and inter-orbital BCS pairing on electrical transport through carbon nanotube quantum dot

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A carbon nanotube quantum dot (CNTQD) with spin-orbit interaction, strongly hybridized with a side-attached superconducting lead and weakly coupled with normal electrodes, is considered. We focus on electrical transport properties of the CNTQD in an external magnetic field, using a two-orbital Anderson model. In the case an effective Hamiltonian describing a proximized CNTQD takes a form of the BCS type. Two cases are studied, where Cooper pairs on the CNTQD are formed between electrons from the same or different orbitals. We calculated the total conductance and its components: normal electron tunneling (ET), direct (DAR) and cross (CAR) Andreev reflections in the limit of low bias voltage. The total as well as the partial conductances were analyzed as functions of the gate voltage applied to CNTQD coupled to superconductor, in presence of external magnetic field and in the regimes of weak and strong Coulomb interactions, *i.e.* with and without Kondo correlations.

Amplifying Dzyaloshinskii-Moriya Interaction in Pt/Co/Pt with Dy Dusting

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Spintronic technology exploits both the spin and charge characteristics of electrons to design electronic devices that are characterized by rapid response times and low energy consumption. By analyzing magnetic materials and manipulating micromagnetic parameters, such as anisotropy and exchange stiffness, scientists have succeeded in creating small, energy-efficient spintronic devices that exhibit high magnetic stability. One area of interest in research has been the use of perpendicular magnetic anisotropy (PMA) in ultra-thin layers of ferromagnetic and heavy metals. The Pt/Co/Pt sandwich structure is a well-studied HM/FM structure that exhibits strong PMA at room temperature. Despite this, spintronics is a constantly evolving field of research that requires different phenomena besides PMA to operate effectively. To investigate the physical mechanism governing the interfacial Dzyaloshinskii-Moriya Interaction (iDMI), which stabilizes noncollinear chiral magnetic structures such as domain walls and skyrmions, a comprehensive understanding is needed in order to be able to control it precisely. Pt/Co/Pt trilayers would be ideal for iDMI research. However, the lack of inversion symmetry breaking prevents iDMI even if they have a high spin-orbit coupling (SOC).

In this present research, we explored the impact of Dy layer dusting on PMA, iDMI, and exchange energy in Pt/Co/Pt structure, utilizing experiments and first-principles calculations. By depositing 0.25 monolayer of Dy on the top Co/Pt interface, we were able to substantially enhance DMI while maintaining PMA. Additionally, we could adjust the exchange energy of the system. Our study is anticipated to provide a logical framework for controlling the strength of iDMI, PMA, and exchange energy, as well as inspiring future research on the effects of rare-earth element dusting on magnetic properties.

Out of plane antiferromagnetic spins induced by reorientation transition in NiO(111)/Co bilayers

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While the engineering of magnetic anisotropy (MA) in ferromagnets (FM) has been intensively studied, the control of antiferromagnets (AFM) is now in focus of the magnetism community. The aim of AFM spintronics is to complement or replace ferromagnets in the active components of spintronic devices. NiO(111) is of particular interest as the high Neel temperature and easiness of controlling reorientation of in-plane [1] antiferromagnetic spins via coupling with a ferromagnet make it a potential candidate for practical applications. We used X-ray magnetic linear and circular dichroism (XMLD and XMCD) spectroscopy at Solaris PIRX end-station to study polar spin reorientation transition (SRT) in NiO(111)/Co epitaxial bilayer. XMCD spectra of Co epitaxially grown on Au(111)/W(110) directly proved an in-plane to out-of-plane SRT [2] induced by decreasing Co thickness. Accordingly, XMLD spectra at the L2 absorption edge of NiO proved that with decreasing Co thickness the antiferromagnetic NiO moments switch to out-of-plane orientation below the critical SRT thickness dCo = 15 Å. The observed polar SRT in antiferromagnet results from AFM/FM proximity effect due to strong interfacial exchange coupling [3].

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Electric field modulation of magnetic state in ferromagnet/antiferromagnet bilayers grown on PMN-PT(001) piezosubstrate

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Antiferromagnetic materials (AFMs) are robust against external magnetic fields, generate large magnetotransport effects, and exhibit terahertz spin dynamics. These features make them excellent candidates for the future spintronic applications [1]. To date, the manipulation of magnetic state in AFM has been carried out by four groups of methods: magnetic, optical, electrical and strain manipulation [2]. Recently, the piezoelectric strains induced by electric field were demonstrated to modify AFM spin structure in AFM/piezoelectric heterostructures. A major advantage of this approach is low power consumption which is crucial for spintronic devices [3]. In this study we use piezoelectric strain to modulate the magnetic state of ferromagnetic/AFM bilayers grown on PMN-PT(001) piezoelectric substrate. We used Magneto-Optic Kerr Effect (MOKE) technique to investigate the magnetic properties of Fe(5nm)/CoO(10nm)/PMN-PT(001) system as a function of the applied electric field. The MOKE measurements obtained at 80 K showed an increase (decrease) in Fe coercive field after applying negative (positive) voltage across the substrate (Fig.1). Moreover, the states of the Fe coercivity at +300 V and -300 V were stable after the removal of the voltage, which proves non-volatility of the observed phenomenon. Once the system was heated up to 330 K, which is above the Néel temperature of bulk CoO (T_N = 293 K), the dependence of coercive field on applied voltage disappeared. This suggests that the observed voltage-induced changes in coercivity in Fe/CoO are related to the piezoelectric strain-induced modification of magnetic state in AFM.

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Fingerprints of super spin-glass state in magnetic iron oxide nanoparticles deposited on the polymer surface

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The potential formation of super spin-glass (SSG) state in Fe_3O_4 nanoparticles modified by adding 10% citric acid and deposited on the polymer surface using grafting technique was studied. The Fe_3O_4 nanoparticles of the nominal size 7 nm create agglomerates with sizes ranging from nominally 20 nm to 80 nm. The phase diagram glassy temperature vs. magnetic field indicating the onset of the SSG state, as a static and disordered magnetic state, was studied using Almeida-Thouless model [1]. More specifically, the analysis of zero-field cooled, and field-cooled static susceptibility data obtained at various magnetic fields yielded the value of the glassy temperature $T_g = 82$ K. In addition, the relative shift in the maxima in real susceptibility with changing the excitation frequency $\Gamma = 0.015$ and the value $z\nu = 10.2$ obtained from critical slowing down analysis of the relaxation time revealed good agreement with theoretical predictions and reported experimental results for the magnetically three-dimensional (3D) systems in which SSG behaviour was confirmed [2,3]. However, dynamic scaling with the values $T_g = 82$ K, $z\nu = 10.2$ and $\beta = 0.7$ showed no collapse. Pronounced renormalization of these parameters necessary to obtain the collapse in dynamic scaling may indicate deviation towards anticipated 2D magnetic behaviour. The observed memory and aging effects represent other features supporting the presence of SSG in the studied system. The obtained results suggest the presence of SSG state in 2D nanoscopic system with dominant dipolar coupling. The manufactured assembly may represent a potential step towards 2D matrix of thermal memory cells and may find its applications in data storage technology.

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SAS and SAR studies of nanosized $Ga_xFe_{3-x}O_4$ coated with chitosan

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The variety of properties of magnetic nanoparticles, which are still being explored, makes the range of their possible applications grow. The best recognized nanosystems are based on pure and doped magnetite [1]. The most important condition for the use of nanoparticles in medicine is the fact that they must be non-toxic and biocompatible. It was discovered that in order to improve their applicability, it is possible to cover nanoparticles with functionalizing substances, e.g. frequently used chitosan [2]. An example of the use of such nanoparticles in medicine is an alternative oncology therapy - magnetic fluid hyperthermia (MFH). MFH therapy requires a high heat capacity of biocompatible nanoparticles. In this respect, gallium ferrites are an interesting class of bioactive materials. Two series of nanoparticles were obtained using the Massart method: $Ga_xFe_{3-x}O_4$ pure and coated with chitosan ($x =< 0; 1.5 >$) [3]. The nanoparticles were studied by small-angle neutron scattering (SANS) and small-angle X-ray scattering (SAXS). The data obtained from the SANS measurements were described by the Guinier-Porod function. SAXS studies have shown that the nanoparticles are mass fractals. An important parameter from the point of view of MFH is SAR (Specific Absorption Rate). SAR was measured for ferrifluids of various concentrations and configurations of alternating magnetic field parameters (frequency and magnetic field strength). The heating time was 700 s. Systems for $x =< 0.53; 0.66 >$, regardless of whether they were coated by chitosan or not, gave similar results. The most promising was the system with $x = 0.73$ without chitosan at the lowest concentration of 2.8 mg/mL ($f = 532\ kHz$, $H = 15.2\ kA/m$), giving SAR = $(83.4 \pm 2.2)\ W/g$.

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$L1_0$ FeNi and $L1_0$ FePt ultra-thin films with in-plane and tilted magnetic anisotropy: density functional theory calculations

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The increasing miniaturization of electronic devices, evident in today's processors, and the growth of recording density in memories are directing researchers' attention to structures on the order of nanometers in size, whose properties can differ significantly from those of bulk macroscopic materials. Also, the growth of demand for hard magnetic materials without rare-earth elements was observed. In connection with the mentioned issues, many systems are considered, such as $Fe_{1-x}Co_x$ alloys, iron-based $L1_0$ phases: FePt and FeNi, or $L1_0$ CoPt [1,2].

$L1_0$ FePt phase, especially thin films, is considered for applications in heat-assisted magnetic recording, which allows reducing of switching magnetic fields without decreasing its stability after the recording process [3]. An experiment has shown that a tilted magnetization direction characterizes $L1_0$ FeNi slabs. Tilted magnetization direction allows such films to reduce the necessary switching magnetic field while maintaining the temperature stability of the systems' magnetic properties [4]. Considering the above, we decided to research further slabs of $L1_0$ phases: FePt and FeNi, with (010) and (111) surfaces.

For this purpose, we performed quantum calculations based on the full-potential local-orbital (FPLO) method using the density functional theory (DFT) implemented in the FPLO18 code. Our research allowed us to determine the preferred direction of the easy magnetization axis and changes in this direction as a function of film thickness in the considered systems. It confirmed the experimentally observed tilt of the easy magnetization axis from the out-of-plane direction in the case of both viewed materials, with it being greater for FeNi $L1_0$. In addition, we determined changes in magnetic moments and magnetic anisotropy energy of systems with magnetization consistent with particular crystallographic directions as a function of layer thickness.

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Influence of CoFeB layer thickness on elastic parameters in CoFeB/MgO heterostructures

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Surface acoustic waves (SAWs), i.e. phonons (quasiparticles of SAWs) are elastic waves propagating along the surface of an elastic material with decreasing amplitude with the depth of the material [1]. SAW-based devices has become an integral part of our daily lives [2]. They may also have potential applications in future spintronic devices if coupled with other waves (e.g. spin waves (SWs)) and/or quasiparticles. So, it is quite important to understand the coupling of phonons with other quasiparticles and enhance the coupling efficiency, especially in magnetic thin film heterostructures such as CoFeB/MgO, one of the most promising materials for future spintronics applications [3]. As a first step it is important to understand how elastic parameters of magnetic heterostructures and properties of acoustic phonons evolve with the CoFeB layer thickness.

Here, we have investigated SAWs in CoFeB/MgO multilayers by probing thermally generated acoustic phonons by Brillouin light scattering (BLS) spectroscopy to find out effective elastic parameters of the multilayers with varying CoFeB thickness. The multilayer structures: Ta(10)/$Co_{20}Fe_{60}B_{20}$(t=1 to 20)/MgO(2)/Al_2O_3(10) are deposited on Si[001]/SiO_2(700) substrates (the numbers in parentheses are the nominal thicknesses of layers in nm). We observe that the group velocity of Rayleigh-type SAWs decreases with increasing CoFeB layer thickness and the phase velocity of Rayleigh waves is lower in studied multilayers as compared to Si/SiO_2 substrate. The experimental results are corroborated with Finite element method (FEM) based simulations, which helped us to estimate the elastic parameter of the individual CoFeB layer. Additionally, we estimate the effective elastic parameters (elastic tensors, Young's modulous, Poisson's ratio) of the whole stacks for varying CoFeB thickness. Interestingly, the simulated dispersion characters of SAWs with both types of parameters show very good agreement with the experimental results. These estimated elastic parameter will be quite useful to investigate magnon-phonon interaction in CoFeB/MgO heterostructures.

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The influence of underlayer on surface acoustic waves velocity in underlayer/CoFeB/MgO heterostructures

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Surface acoustic waves (SAWs) are confined near the surface in an elastic material. The quasiparticle associated with SAWs are known as phonons, analogous to photons for light waves. The SAW-based devices find applications in our daily life due to their high sensitivity and broad operational frequency. They also have potential to be used in future spintronics devices if coupled with, e.g. spin waves (SWs). Because of such importance, a detailed study on the properties of SAWs is required, especially, in magnetic thin film heterostructures such as CoFeB/MgO, a promising candidate for future spintronics applicatons [1-4].

Hence, we adapted Si/SiO_2(substrate)/X/$Co_{20}Fe_{60}B_{20}$(1.4)/MgO(2)/Al_2O_3(10) heterostructures to investigate the evolution of SAWs properties and elastic parameters with the underlayer (X). We chose Ta(10), W(10), Pt(10), Ta(5)/Ru(20)/Ta(5) as underlayer to systematically vary the material density and mass loading. The Brillouin light scattering (BLS) spectroscopy was employed to probe thermally generated acoustic phonons in those multilayers. From the measured dispersion relations, we observe that the group velocities of SAWs decrease with increasing density of the underlayer material (Ta < W < Pt) and increasing total mass (for Ta/Ru/Ta). Moreover, the Rayleigh-type SAW velocity in the multilayers is lower than that of Si substrate. We also performed simulation based on finite element method (FEM), which further supports our experimental results. We find that the varying density of underlayer materials efficiently changes the effective elastic properties of composite layer and thus the properties of phonons. We estimate the effective elastic parameters of multilayers with varying underlayer. This study is our first step towards the investigation of coupling of SAWs with SWs in CoFeB/MgO heterostructures.

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Structure and Magnetic Properties of Hydrothermally Synthesized $CuFe_2O_4$/Reduced Graphene Oxide Nanocomposites

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Spinel ferrites are a class of materials with a general formula of MFe_2O_4, where M is a divalent cation such as Zn^{2+}, Ni^{2+}, Mn^{2+}, or Cu^{2+}. These materials have gained increasing attention in recent years due to their beneficial combination of magnetic, electrical, and optical properties, suitable for a variety of applications - from data storage (high anisotropy and coercivity magnetic nanoparticles), biomedical (drug delivery, magnetic resonance imaging, hyperthermia), energy storage (chemically stable redox electrode for batteries and supercapacitors). Spinel nanoparticles have shown great potential for environmental applications such as water treatment agents (heavy metals removal or the catalytic destruction of organic pollutants). Copper ferrites $CuFe_2O_4$ is an attractive catalyst for both organic synthesis (oxidation of alcohols, the Knoevenagel condensation reaction, synthesis of heterocyclic compounds) and environmental applications (photodegradation of organic pollutants such as dyes and pesticides in contaminated water while the magnetic properties allow its easy separation). The catalytic activity of $CuFe_2O_4$ nanoparticles can be improved by finding the conditions of thermal treatment that lead to the optimal balance between surface area and crystallinity. The use of $CuFe_2O_4$ / rGO (reduced graphene oxide) composites allows for enhancing catalytic properties due to the synergistic effect, resulting from the interfacial interaction between ferrite and rGO in the composite. This work aims to establish the effect of various calcination temperatures on the magnetic and structural properties of $CuFe_2O_4$ / rGO composites.

All samples were calcinated at 300, 400, and 500^0C in argon flow. The average particle size values were 19 nm for initial $CuFe_2O_4$ and 17, 16, and 13 nm after calcination at 300, 400, and 500^0C. Mossbauer spectra measured for these materials consist of a central doublet and broadened two sextets that correspond to the presence of both ferromagnetic and superparamagnetic ferrite particles. The increase in the annealing temperature causes the crystallization of both tetrahedral and cubic phases of $CuFe_2O_4$ as a part of composite materials. The Mossbauer spectra of the $CuFe_2O_4$ / rGO sample annealed at 400^0C indicate its transition state between superparamagnetic and ferromagnetic state. The suggested approach allows obtaining the thermally stable $CuFe_2O_4$/rGO composite with controllable structural and magnetic properties.

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Magnetic Properties of Ir/Co/Pt Films Tuned by Ga^+ Ion Bombardment

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Magnetic properties of layered films are determined not only by the materials of the particular layers and their thicknesses but also by the structure of their interfaces. In particular, this applies to magnetic anisotropy and Dzyaloshinskii-Moriya interaction. The morphology of interfaces can be modified as a post-deposition treatment. One of the most frequently used methods of modification is ion bombardment (IB).

The study aimed to investigate the effect of Ga^+ IB on the magnetic properties of Ti(4nm)/Au(30nm)/Ir(30nm)/Co(0.8nm)/Pt(5nm) films. The changes of magnetic properties were determined from hysteresis loops measured using the magneto-optical Kerr effect in polar geometry (P-MOKE) in an as-deposited state and after each step of IB. The evolution of hysteresis loops caused by the IB process indicates that with increasing ion energy ($5 \leq E_{ion} \leq 30$ keV) and ion dose ($10^{12} \leq D \leq 10^{15}$ Ga^+/cm^2) a gradual transformation from loops characteristic for perpendicular magnetic anisotropy to loops characteristic for easy-plane anisotropy take place. These changes are well described by the dependence of the coercive field (H_C) on E_{ion} and D.

A previous study performed by C.T. Rettner [1] for Co/Pt multilayers modified by IB with He^+ and Ar^+ ions indicates that the value of D should be greater to obtain the same changes in H_C for E_{ion}=2 MV as for E_{ion}=20 keV. In our case, the same changes of H_C for the higher value of E_{ion} are obtained for a smaller value of D.

To explain this difference, we performed Monte-Carlo simulations using the SRIM code to investigate the so-called stopping power of Ar^+, He^+, and Ga^+ ions in a Co layer. This parameter can be separated into the ion-atom nucleus (S_n) and ion-electron (S_e) interactions. The simulations revealed that Ga^+ ions with E_{ion} of 5, 8, and 30 keV have $S_n > S_e$, which leads to elastic collisions and requires a higher D to observe the same effect with decreasing E_{ion}. On the other hand, E_{ion}=2 MeV for He^+ and Ar^+ ions have $S_n < S_e$, resulting in less efficient atom displacement and requiring a higher D than E_{ion}=20 keV to observe the same effect.

This study emphasizes that careful parameter selection during IB is crucial for precise modification of the magnetic properties and structure of thin-film systems.

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Faraday rotation enhancement for colloidal Au and Ag spherical nanoparticles and their mixtures

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Ag-metallic nanoparticles (AgNPs) along with AuNPs are intensively researched nanomaterials.The magnetooptical (MO) properties of AgNPs have been described mainly by magnetic circular dichroism (MCD) spectroscopy for a very wide range of dimensions from 7.5 nm to 200 nm [1]. Compared to AuNPs, AgNPs plasmonic extinction spectra are shifted to the low-wavelengths part of the spectrum by about 100 nm, and MCD spectra have a symmetrical shape in contrast to asymmetric one of AuNPs, also the magnitude of MCD is higher for AgNPs. It may be noticed that Ag and Au are also prepared as core-shell hybrid nanostructures showing an enhancement of MO properties [2]. In the presented work, we test the enhancement of Faraday rotation (FR) in a mixture of colloidal solutions of both NPs with different concentrations. The Au and Ag spherical NPs of similar dimensions were synthesised independently as colloids in aqueous solution and then mixtures of different proportions were prepared. The FR of single NPs are consistent with available data [1,3]. For the mixtures, weak enhancement of FR is observed owing to the additivity of the contribution of plasmonic modes. The obtained FR spectra have been converted to MCD one using Kramers-Kroning relations and simultaneus deconvolution of absorption and MCD spectra were discused.

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Magnetic anisotropy and structural phase transition in ultrathin Fe (111) films: first-principles study

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Experimental research proves, that the phase transition from Fe-fcc (c/a 1.4) to bcc (c/a 1.0) system was accomplished by depositing iron by molecular beam epitaxy onto a Cu_3Au (001) substrate. This phase transition is observed with layer thicknesses somewhere between 4 - 12 monolayers of iron [1]. In our research we consider Fe layers with a triangular lattice surface, which are known to form an fcc structure and are stable for thicknesses of a few monolayers. In the limit of large thicknesses, the bcc structure is stable. We show at what thickness the structural transition from fcc to bcc should be expected. In the presented calculations, the Perdew-Burk-Erzerhof (PBE) potential was used. Our calculations show the anisotropy characteristics of magnetocrystalline energy and magnetic spin moments for the considered thickness ranges of an iron layer suspended in vacuum, which does not take into account substrate-related effects. Through calculations, we show that the studied layers have stable magnetic configurations. The studied set is consistent with experimental results [3].

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Synthesis, structural magnetic and electric properties of Mn–Zn ferrite spinel nanoparticles

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Manganese–zinc ferrites were prepared by hydrothermal method. Bulk material was pressed into pellets and sintering at different temperature. The single-phase nature of the prepared nanoceramic samples was confirmed by X-ray diffraction analysis. X-ray diffraction and scanning electron microscopy were utilized to investigate structural parameters. Impedance spectroscopy (IS) and magnetic measurements were carried out in order to study the effect of synthesis on the characteristic properties of Mn-Zn ferrites. The electric parameters (Z', Z", σ) of the samples were measured using impedance analyzer at temperature range 20-600 °C in frequency range 0.1 Hz – 2 MHz.

Keywords: Nanoferrites MFe_2O_4; Zn^{2+} and Mn^{2+} ions; Magnetic and Electric properties

Edge disorder and valley filtering in strained graphene nanostructures

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Valleytronics aims to use the control over the valley degree of freedom, i.e. the index of the minimum of the conduction band in semiconductor, in order to process or store the information. Graphene – and other 2D materials of the same symmetry – with the distinctive valleys (Dirac cones) located at non-equivalent corners of the 2D Brillouin zone and weak inter-valley scattering is well suited to be the base material for valleytronic devices. The necessary condition for realizing these is the creation of the efficient valley-polarizers. One possible way to achieve this is to introduce strain, which enters the effective Dirac-Weyl Hamiltonian as pseudo magnetic gauge field. Importantly the sign of the field depends on the valley index, opening the way to use in order to separate carriers from different valleys. In the present contribution we discuss the results of theoretical calculations of the transport properties of the strained graphene nanostructures designed to facilitate valley-filtering. The particular focus here is the effect of the edge disorder invariably present in the structures obtained using contemporary lithographic processes.

Transfer of magnetic anisotropy through an antiferromagnet in Co/NiO/Fe multilayer structure

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Recently we showed that ferromagnetic layer with strong uniaxial magnetic anisotropy determines the spin orientation of neighbouring antiferromagnetic layer in NiO/Fe [1, 2]. In this contribution we further extend the research to trilayer structure. With a use of the X-ray linear and circular dichroism (XMLD and XMCD) we investigated the magnetic properties of Fe/NiO(4nm)/Co(1nm) trilayer epitaxially grown on W(110) substrate. Fe/W(110) is a prototypical system for which together with a decrease of Fe thickness spontaneous magnetization switches from [001] to [1-10] direction [3]. We showed that Fe thickness-driven spin reorientation transition in Co/NiO/Fe/W(110) is transferred not only to NiO layer but to ferromagnetic Co layer as well. Thus, a considerable exchange coupling occurs at both NiO/Fe and Co/NiO interfaces. Our studies reveal that modulation of the magnetic state and anisotropy of Co layer can be triggered not only by changing Fe thickness but also by applying a small magnetic field or changing the temperature.

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Magnetic properties of Pt/Co/Pt trilayers with W insert layer

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Ultrathin ferromagnetic films with asymmetric neighboring layers of heavy and/or transition metals attract much interest due to their potential applications as new type of magnetic memories [1, 2]. Here we report the epitaxial symmetric magnetic trilayers Pt/Co/Pt modified by inserting W layer at the bottom or top interfaces in wide the ranges of Co, W layers thicknesses. It is an extension of the analysis reported in [3]. The exemplary double wedge geometry sample consists of Co magnetic layer (continuous wedge with thickness ranged d_{Co}=0÷3 nm) and orthogonal nonmagnetic overlayer (underlayer) of W (steps with thicknesses d_W=0, 0.1, 0.2,. . . , 0.7, and 3.0 nm) resulting in 2D matrix-like W/Co/Pt (Pt/Co/W) stacks with corresponding (d_{Co}, d_W) thicknesses. The influence of (d_{Co}, d_W) on magnetization parameters using static (magnetooptical Kerr effect) and dynamical (Brillouin light scattering) methods were studied. Double wedge stacks with wider range of W thickness (until 10nm) were also studied. The thickness of magnetic dead layer d0 depends on d_W and quickly saturates at d_W 0.5 nm for both sample sets. Then for Pt/Co/W its value becomes constant for d_W>1 nm, while for W/Co/Pt saturation occurs at d_W ∼3 nm and further monotonic increase is observed. For W/Co/Pt stacks the strong reduction of coercivity field and transition to in-plane magnetization is observed with d_W increase, while for Pt/Co/W sample we found increase in coercivity with small influence on spin reorientation thickness. Surface magnetic anisotropy decreases and volume anisotropy increases with d_W for both stacks. Dynamical characteristics measured by Brillouin light scattering (BLS) in Damon-Eshbach mode determine the strength of interfacial Dzyaloshinskii-Moriya interaction (iDMI) and spin wave (SW) damping for selected d_{Co} thicknesses as a function of d_W. Characteristic d_W thickness for iDMI appearance is about 0.1 nm for both samples. A sufficiently large value of iDMI is determined for the range d_W=1.5÷3 nm in W/Co/Pt (1.7 pJ/m) samples. Our findings demonstrate the efficiency of thin W interlayer on modification of magnetic parameters in Pt/Co/Pt trilayer. Knowledge about W thickness driving ultrathin Co magnetic parameters is important for next steps studies of interlayer coupling and nanostructures designing, e.g. synthetic antiferromagnetic racetracks.

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Localized states at the Rashba spin-orbit domain wall in a magnetized graphene: interplay of the Rashba and magnetic domain walls

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It is well known that electronic states in a graphene with uniform Rashba spin-orbit interaction and also uniformly magnetized due to exchange coupling to a magnetic substrate display an energy gap in the Dirac K and K' points. When the magnetization of graphene is nonuniform and forms a magnetic domain wall, electronic states localized at the wall exist in the energy gap. In this paper we show that similar localized electronic states appear in the gap in the case of a uniformly magnetized graphene, but with the domain wall in the Rashba spin-orbit interaction (i.e. opposite signs of the Rashba parameter on both sides of the wall). These electronic states propagate along the wall and are localized exponentially at the Rashba domain wall. They form narrow and nearly parabolic bands, with relatively large effective electron mass. However, contrary to the magnetic domain wall, these states do not close the energy gap. We also consider the situation when the magnetic domain wall is associated with the Rashba one and both are localized at the same position.

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First-Principles Investigation of the Electronic, Magnetic, and Transport Properties of $MnBi_2Te_4$

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$MnBi_2Te_4$ is a material with unique electronic, magnetic, and transport properties that make it promising material for quantum computing and spintronics applications. We used the density functional theory to investigate its bulk and surface electronic states, and found that it is a topological insulator with a significant bandgap and a Dirac cone-like dispersion. The magnetic properties of this material arise from coupling between the magnetic moments of Mn atoms and non-magnetic Bi_2Te_4 layers, resulting in a high magnetic anisotropy with the easy-axis along the c-axis. We showed that an electric field can induce a splitting of the bandgap in the electronic structure, which could be useful for application in spin-based devices. However, the growth of high-quality $MnBi_2Te_4$ thin films remains a challenge, and further research is needed to uncover all their properties. [1-5]

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Effect of temperature on the structural and microstructural evolution of core-shell type nanocomposites based on $MFe_2O_4@SiO_2$ (M= Ni, Co)

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Our study focuses on the structural, microstructural and magnetic characterization of core-shell-type composite particles based on $MFe_2O_4@SiO_2$ [1]. These particles were obtained by a microemulsion process and come in the form of several nanoparticles of spinel ferrite MFe_2O_4 (M = Ni, Co) a few nanometers in diameter coated in a porous silica ball 40 to 80 nm in diameter. On a fundamental level, we seek to understand the influence of thermal stimulation and the environment on the structural and magnetic properties of isolated nanometric objects. Technologically, these $MFe_2O_4@SiO_2$ composites are potential candidates in the field of data storage or health, where this kind of nanostructures based on nanoparticles are used as a contrast agent in medical imaging (MRI) or as a vector of molecules active in the field of oncology. Our contribution concerns a comparative study between two nanocomposites $NiFe_2O_4@SiO_2$and $CoFe_2O_4@SiO_2$, where we present the results of the evolution of their structure and microstructure as a function of the annealing temperature. These results were obtained by X-ray diffraction, transmission electron microscopy and Mössbauer spectrometry of $^{5}7$ Fe.

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Influence of interface mixed layer on non-collinear exchange coupling in V/Fe multilayers

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The interlayer exchange coupling (IEC) through non-magnetic spacers plays an important role in the potential application of magnetic systems. However, the type and strength of the IEC dependence on the thickness of non-magnetic spacer have not been completely explained. The objective of this work is to determine the mechanisms leading to non-collinear exchange coupling in V/Fe multilayers (MLs). The samples were deposited onto naturally oxidised Si(100) substrates at room temperature (RT) by UHV magnetron sputtering.The mixed layer thicknesses near the Fe-V interfaces of the studied multilayers were determined in-situ using X-ray photoelectron spectroscopy (XPS). Ex-situ studies using standard X-ray diffraction confirmed the strong (110) texture of the multilayers. The results of systematic in-situ XPS studies of the integral intensity of the Fe-2p peak as a function of the nominal thickness of the Fe sublayer deposited on vanadium allowed us to estimate the thickness of the pure iron layer that forms the mixed layer at about 0.4 nm. Assuming the same thickness of the vanadium layer that forms the mixed layer, the total thickness of the mixed layer in the Fe-V interface region was about 0.8 nm. Magnetic characterization of the V/Fe MLs with constant thicknesses of the Fe sublayers equal to 0.6 nm (about three (110) atomic layers) confirmed the oscillatory nature of the IEC with a period of 0.6-0.8 nm of the vanadium layer. At a temperature of 300 K, four energy minima are visible confirming local maxima of the antiferromagnetic coupling for V thickness of about 1.2-1.4, 1.8-2, 2.6-2.8, and 3.2-3.4 nm. The experimentally determined thickness dependence of the coupling energy was sufficiently consistent with results obtained from the ab-initio calculations for (110) Fe-V-Fe trilayers with ideal interfaces without mixed layers. It should be emphasized that in the case of the experimentally studied V/Fe MLs, there is practically no layer of pure iron, but only an alloy with variable concentration in the direction perpendicular to the substrate.The antiferromagnetic coupling of the V/Fe MLs was also confirmed in magnetoresistance studies. So far, in the analysis of the interlayer exchange coupling based on the fit of the Stoner-Wohlfarth model to the experimental hysteresis loops have been limited to two terms: bilinear and biquadratic. In the case of the 1.6 nm - V/0.6 nm - Fe ML the measured hysteresis loops could not be satisfactorily fitted to the model considering only these two terms. Therefore, the hysteresis loop analysis additionally takes into account the contribution from the cubic constant of the IEC. Furthermore, using the IEC modification by hydrogen absorption in the V spacer, possible mechanisms responsible for biquadratic and cubic coupling are given. The modification of the coupling using hydrogen absorption is fully reversible. After desorption of hydrogen in air at RT, the sample returned to the original state.

Experimental investigation of the correlation between particle surface smoothing and soft magnetic compact's properties

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The study provides insight into the potential of particle surface smoothing for the development and optimization of the production of soft magnetic composites, which could lead to further innovations in the field. The fabrication of magnetic materials using specialized techniques has been employed for decades, allowing the production of more precise magnetic and electrical circuits with improved energy efficiency. Despite existing knowledge, there remain unexplored areas within this domain.

This research sought to explore the properties of soft magnetic composites composed of iron particles with smooth and non-smooth surfaces. Commercial 1 mm-2 mm iron granulates with a purity of 99.98% were milled to the desired powder fractions (63 µm-125 µm and 200 µm-400 µm) and thermally processed, then divided into two groups; the first mechanically smoothed, and the second served as the reference. Using hot isostatic method, the powders were pressed into toroidal ring-shaped compacts and annealed.

In both compacts (smaller and larger powder sizes based), smoothing results in increased porosity; by 0.3% and 1.2%, respectively. The peak value of the real part of complex relative permeability rose by 13 - to 86 when 63 µm-125 µm powder fractions were used and remained around 188 for those created from 200 µm–400 µm. The peak value of the imaginary part of complex relative permeability increased by 4 (to 29) and 60 (to 170) for the two experimental scenarios. The relaxation frequency decreased by 140 Hz (to 990 Hz) for the first compacts group and went up by 15 Hz (to 130 Hz) for the second; the coercivity dropped by 180 A/m (to 1080 A/m) and 20 A/m (to 324 A/m). AC loss measurements in a 0.5 T field showed a drop of 5.6% and 3.8% (smaller and larger powder based) at 950 Hz; and by 8% and 5.7% on average over all measuring frequencies (0 Hz–950 Hz). In the 1 T field, losses decreased by 5.2% and 6.2% at 950 Hz; and by 10.7% and 5% on average over all measuring frequencies.

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The effect of substitution of Mn by Pd on the structure and thermomagnetic properties of the $Mn_{1-x}Pd_xCoGe$ alloys

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The aim of the present work is to study the influence of a partial substitution of Mn by Pd in MnCoGe alloys. The X–ray diffraction (XRD) studies revealed a coexistence of the orthorhombic TiNiSi–type and hexagonal Ni_2In–type phases. The Rietveld analysis showed that the changes in lattice constants and content of recognized phases depended on the Pd addition. The occurrence of structural transformation was detected. This transformation was confirmed by analysis of the temperature dependence of exponent n given in the relation $\Delta S_M = C \cdot (B_{MAX})^n$. A decrease of the Curie temperature with an increase of the Pd content in the alloy composition was detected. The magnetic entropy changes were determined for $Mn_{0.97}Pd_{0.03}CoGe$, $Mn_{0.95}Pd_{0.05}CoGe$, $Mn_{0.93}Pd_{0.07}CoGe$, and $Mn_{0.9}Pd_{0.1}CoGe$.

The influence of changes in medium range ordering on evolution of the crtical exponents in the $Fe_{76}Mo_{10}Cu_1B_{13}$ alloy

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The main goal of this work is to study the critical behavior in the as-quenched and annealed NANOPERM $Fe_{76}Mo_{10}Cu_1B_{13}$ alloy in the vicinity of the critical temperature T_C. The second order phase transition from ferro- to paramagnetic state was confirmed by the positive slope of Arrott plots. The critical exponents (β, γ, and δ) have been revealed using the Kouvel-Fisher method. Moreover, the Kouvel-Fisher analysis revealed the detailed Curie temperature for all investigated samples.

Influence of annealing temperature on magnetism and defects in $Mn_{2.4}Fe_{0.8}Al_{0.8}$ alloys

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Manganese-based alloys with the composition Mn_2FeZ, Z = Si, Al, have been widely investigated in recent years due to their potential applications in spintronics. Mn_2FeSi alloy already prepared in the form of ingots, thin films, powders or ribbons exhibits a cubic full-Heusler ($L2_1$) or inverse-Heusler (XA) structure or combination of both [1]. Contrary, the Mn_2FeAl alloy has so far only been prepared in the form of an ingot and owns a primitive cubic (β-Mn type) structure [2]. Present investigations are devoted to the $Mn_{2.4}Fe_{0.8}Al_{0.8}$ ingots prepared by induction melting technique and additionally annealed for 5 days at 773 K and 1073 K in the argon protective atmosphere. Their microstructural, defect, and magnetic properties are studied in dependence on annealing temperature and compared to the Mn_2FeAl alloys. The scanning electron microscopy completed by the energy dispersive X-ray spectroscopy confirmed single phase alloys with compositions slightly different from the nominal one (about 57.5 at.% Mn, 20.5 at.% Fe, and 22.0 at.% Al). The X-ray diffraction analysis revealed the origin of β-Mn structure with the lattice parameter of 0.636(1) nm well comparable with the value of 0.637(3) nm obtained for Mn_2FeAl ingot [2]. Results of positron annihilation spectroscopy showed that vacancy concentration in both Mn_2FeAl and $Mn_{2.4}Fe_{0.8}Al_{0.8}$ ingots is very low and almost all positrons are annihilated in the free state. Coincidence Doppler broadening measurements indicated that the alloys with increased amount of Mn have higher contribution of positrons annihilating near Mn. Magnetic properties of Mn_2FeAl alloys showed an antiferromagnetic-paramagnetic transition with the Néel temperature about 36-37 K without essential impact of annealing temperature. Similar magnetic characteristics are observed for $Mn_{2.4}Fe_{0.8}Al_{0.8}$ ingots in as-cast state and after annealing at 773 K. Contrary, the sample annealed at 1073 K exhibited a weak ferromagnetic contribution at room temperature and its influence increased during cooling down to 5 K.

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Influence of different milling parameters on structural and soft magnetic properties of Fe/SiO_2 composites

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Soft magnetic composites (SMCs) are an important type of soft magnetic materials with incredible magnetic properties compared to conventional materials of the same class. Those days SMCs find extensive use in various electromagnetic applications and it's important to provide the best possible magnetic properties with little waste and financial expense. This paper presents structural and magnetic properties of soft magnetic composites made of highly pure iron with SiO_2 coating. The composites were prepared by milling iron granules in a planetary ball mill with different ball to powder ratio (BPR) and innovative surface treatment technic, insulation of prepared ferromagnetic powder into SiO_2 coat and then compacting into ring-shaped samples. The samples made by implying higher BPR showed better coercivity values even with using the same powder fraction. The best coercivity values were shown by sample made with the BPR value 9:1 and an innovative surface treatment technic. The microstructure was studied using scanning electron microscopy (SEM) and X-ray diffraction (XRD), while the magnetic properties were characterized using systems for measuring coercivity and hysteresis such as Koerzimat and Hysterezigraph. The aim of this work is to demonstrate the dependency of the final magnetic properties of the compacted composites on their inner structure and preparation technics. These results could provide valuable information about the optimization of SMCs for various applications.

Effects of Ni doping on structural and magnetic properties of copper ferrite

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The aim of this work was to obtain more information about the influence of small quantities of Ni^{2+} ion on the structural and magnetic properties of the tetragonally distorted of $Cu_{1-x}Ni_xFe_2O_4$. A series of ferrite samples of the chemical composition $Cu_{1-x}Ni_xFe_2O_4$ (with x = 0.0; 0.05; 0.1 and 0.15) prepared by the combustion method using citrate-nitrate precursors. The samples underwent a successive thermal treatment in air 300, 600, and 900^{o}C for 4 hours. After heating, the preparations were either cooled slowly to the room temperature. Structural analysis results for tetragonal copper ferrite indicated that above 360^{o}C a part of copper ions moves into the tetrahedral sites and structural tetragonal *($I4_1amd$)* $\rightarrow$ cubic *($Fd\bar{3}m$)* phase transition appears. Substitution with small quantities of nickel ions clearly decreases the temperature of structural transformation for $Cu_{1-x}Ni_xFe_2O_4$ system. The obtained result indicates that the distribution of cations has a great influence on the structural and magnetic properties of the modified copper ferrites.

Magnetic anisotropy in Fe-Nb-B-RE amorphous alloys

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The presented work refers to the magnetic anisotropy properties of Fe-Nb-B-RE (RE = Tb, Nd, Tb/Y) amorphous alloys. The samples (i.e. $(Fe_{80}Nb_6B_{14})_{1-x}RE_x$, $0.04 < x < 0.12$) were prepared by a typical melt-spinning technique. The occurrence of the amorphous state was confirmed by XRD and thermomagnetic measurements. Some selected magnetic properties and domain structure were determined from hysteresis loops (measured at different temperatures) and Kerr effect (MOKE) observations. The Fe-Nb-B family of amorphous alloys is widely known as an excellent soft magnetic material (e.g. the so-called NANOPERM type of alloys) with extremely low power losses and coercivity [1]. Despite the lack of crystal structure such alloys reveal ferromagnetic ordering of Fe magnetic moments. On the other hand, some rare earth elements can introduce magnetic anisotropy into many Fe-RE structurally ordered compounds as a consequence of strong spin-orbit coupling [2,3]. It is interesting to see whether the RE alloying additions can cause magnetic anisotropy in the case of amorphous Fe-based magnets and how they influence the magnetic structure as well as the interactions between magnetic atoms. It was shown that the applied RE additions has an effect on magnetic properties such as coercivity, the Curie temperature and domain structure. Surprisingly, the small addition of localized magnetism, introduced by the RE elements, significantly changed the magnetic exchange interactions between the Fe atoms, which is widely discussed based on the numerical analysis utilizing the mean field theory (MFT) approach.

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Magnetocaloric properties of polycrystalline compound $PrCrGe_3$

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Magnetic materials can be used in refrigerators based on the magnetocaloric effect. In this work, we studied the magnetocaloric properties of polycrystalline germanide $PrCrGe_3$. The compound crystallizes in the hexagonal $BaNiO_3$-type structure (space group of $P6_3/mmc$, No. 194), confirmed by powder X-ray diffraction. $PrCrGe_3$ is a metal and it exhibits two subsequent magnetic phase transitions of ferromagnetic character, one at $T = 95(1)$ K and another one at ∼16 K, both evidenced as distinct anomalies in the temperature dependencies of the specific heat and the magnetization. For all recorded magnetic transitions, the normal magnetocaloric effect was observed. The specific heat data yielded the maximum value of the magnetic entropy change ΔS_m = -0.8(1) J kg^{-1} K^{-1} at $T = 94(1)$ K and ΔS_m = -0.6(1) J kg^{-1} K^{-1} at T = 16(1) K, for the magnetic field change $\mu_0 \Delta H = 1$ T. The adiabatic temperature change was estimated to be $\Delta T_{ad} = 0.31(1)$ K at $T = 94(1)$ K and $\Delta T_{ad} = 0.27(1)$ K at $T = 16(1)$ K, for $\mu_0 \Delta H = 1$ T. The magnetocaloric parameters determined from the magnetization data are very close to the values derived from the specific heat.

Effect of oxygen point defects on electronic and magnetic properties of copper pyrophosphate material.

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Based on density functional theory (DFT), we investigate the oxygen point defects (V-vacancy, V_I- interstitials) impact on the electronic and magnetic properties of copper pyrophosphate dihydrate (CuPPD) material. Calculations were performed with the generalized gradient approximation (GGA) of the exchange-correlation functional (E_{xc}) supplemented by strong Coulomb interaction via Hubbard-like Hamiltonian (U). The GGA+U method was applied for Cu-3d and O-2p states. The results show that oxygen atom vacancy defect induced the decrease of a magnetic moment from U=8.66 to 7.02 and 7.84 μB/cell for vacancy and interstitials defect, respectively. The magnetic moment mainly comes from the Cu atom d orbitals. Furthermore, our calculations reveal that oxygen vacancies strongly modified the electronic structure of CuPPD by inducing non-zero density of states (from Cu-3d and O-2p state) near the Fermi level. As a result, a significant reduction in the electronic band gap of our material can be noticed. The findings of this study provide insight into modified by defects electronic properties of semiconductor-like CuPPD crystal. This issue is of interest to nanoelectronics and the production of nanomaterials, including quantum dots [1].

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Magnetic Anisotropy of FeCo Thin Films with B, C and N

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Modern science has reached the ultimate level of monoatomic layers in the race for miniaturization of electronic devices, and the limit of about twenty atomic monolayers for magnetic tunnel junctions with perpendicular magnetic anisotropy [1, 2]. Layered systems are particularly interesting for their ability to tune effective material parameters such as the magnetic anisotropy energy (MAE). Among such systems, iron-based layered systems are of considerable interest. An intriguing and important topic from the point of view of applications is the influence of the crystallographic structure of Fe, its thickness, and the presence of other layers above and below the Fe layer on magnetic parameters such as the MAE of the studied system.

Here we present a theoretical investigation of the magnetic anisotropy of FeCo thin films with B, C and N dopants located in octahedral interstitial positions. The theoretical study is based on calculations using the full-potential local-orbital electronic structure code FPLO [3] and the generalized gradient approximation. The chemical disorder in FeCo layers was modeled using the virtual crystal approximation. The layer structures were subjected to geometry optimization of interlayer distances and vicinity region of the dopant sites. We determined the local magnetic moments and excess charge at each position in the films. We identified the effect of dopant atoms on the magnetic properties of the FeCo films such as magnetization and magnetic anisotropy.

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Mössbauer Spectrometry as a Tool for Probing Universality Classes in Magnetocaloric Compound $(Pr,Sm)_2Fe_{17}$

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Gadolinium is known for its strong magnetocaloric effect near room temperature, but its limitations such as rapid corrosion, high cost, and limited global resources hinder its competitiveness with conventional refrigeration systems. In this study, our goal is to synthesize new materials that exhibit interesting magnetocaloric effects at room temperature, while being chemically stable and cost-effective compared to Gd. We focus on iron-rich Pr_2Fe_{17} compounds, which show a relatively large magnetic entropy change maximum around room temperature with a broad full width at half-maximum, indicating a reversible magnetocaloric effect. This makes Pr_2Fe_{17} a promising candidate for Gd-based magnetic materials. However, its Curie temperature, which is the working temperature for cooling applications, is below room temperature. To achieve a Curie temperature equivalent to room temperature, we explore the substitution of Pr atoms with Sm atoms.

For a deeper understanding of the magnetic phase transition. Traditional techniques that rely on pure magnetic measurements, such as the Kouvel-Fisher plot, Modified Arrott plot, and Critical Isotherm technique, are typically used to estimate critical exponents. However, in this research, a local approach utilizing Mössbauer spectrometry is incorporated in addition to the conventional macroscopic approach based on direct magnetic measurements.

The findings of this study indicate that for $Pr_{1.64}Sm_{0.36}Fe_{17}$ RCP is found to be around $167.4\,\mathrm{J.kg^{-1}}$ under a magnetic field change of T which is around 80% of that observed in pure Gd and makes our compound a potential candidate for magnetic refrigeration around the room temperature. the critical exponents of Pr_2Fe_{17} and $(Pr,Sm)_2Fe_{17}$ closely approximate those of the 3D-Ising model, as confirmed by the scaling analysis of our critical exponents. Moreover, we observed that isotherms collapse into two distinct and independent universal branches above and below the Curie temperature when utilizing the critical exponents we obtained. This phenomenon can be described by the single scaling equation $m = f_{\pm}(h)$, where m and h denote the renormalized magnetization and magnetic field, respectively. Our results indicate that the exponents determined using both conventional methods and Mössbauer spectrometry closely match those of the 3D-Ising model for spins coupled in three dimensions ($d = 3$, $n = 1$) with attractive interactions between spins at the boundary of short-range and long-range decay as $J(r) = r^{-(3+\sigma)}$ with $\sigma = 1.95$.

Magnetocaloric effect in iron-rich $PrFe_{11}Ti$ intermetallic alloy: A Comprehensive Investigation using Experimental and DFT calculation.

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In this study, we present a comprehensive investigation of the structural, magnetic, and magneto-caloric properties in iron-rich $PrFe_{11}Ti$ intermetallic alloy with $ThMn_{12}$ type structure using a combination of experimental and theoretical techniques. The structural characterization was performed using X-ray diffraction coupled with Rietveld refinement, which provided valuable information about the crystal structure and lattice parameters. Magnetic properties were studied through intrinsic magnetic measurements and magneto-caloric effect analysis, which gave insight into the magnetic ordering and response of the material to an external magnetic field. Mössbauer spectroscopy was employed to probe the local magnetic environment and to further characterize the magnetic properties of the material. The experimental results were complemented by theoretical calculations based on density functional theory (DFT), which allowed for the prediction and interpretation of the magnetic and electronic properties of the material.

Overall, our results provide a deeper understanding of the structural and magnetic properties of the material under study and demonstrate the effectiveness of the combined experimental and theoretical approach in the investigation of complex materials. The insights gained from this study could have implications for the development of advanced magnetic materials with enhanced properties for potential magnetic applications.

Formation of structural disorder in FeNi-based alloys – semi-empirical approach

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Alloys based on FeNi are known to commonly crystallize in bcc or fcc structures, depending on their chemical composition. Additionally, in slowly cooled objects (like meteorites) ordered tetragonal $L1_0$ phase was observed [1]. It shows promising hard magnetic properties, because of its hard uniaxial magnetocrystalline anisotropy. Still, the synthesis of this phase in industrial amount has not been possible yet, mainly because of sluggish diffusion and low ordering temperature [2]. In this work results of the calculations of formation enthalpies for solid solution and amorphous phase in Fe-Ni system were analyzed. Additionally, substitution with Co and Cu was taken into account. These calculations confirm poor glass forming ability of FeNi system and indicate limited influence of Co-substitution. On the other hand, negative heat of mixing of Cu can be treated as a decisive feature for chemical segregation and therefore is a promising candidate when aiming destabilization of the fcc FeNi structure. The latest is critical for the L10 FeNi phase formation.

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Influence of Nd substitution on the phase constitution in (Zr,Ce)$Fe_{10}Si_2$ alloys with the $ThMn_{12}$ structure

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Iron-based alloys with a tetragonal $ThMn_{12}$-type structure have the potential to bridge the performance gap between ferrite and 2:14:1-type magnetic materials. Calcualtions based on the semi-empirical Miedema's model were performed for the (Zr, Nd, Ce)-Fe-Si system with emphasis on Fe-rich compositions. The stability range and stabilization routes of the amorphous phase, solid solutions and intermetallic compounds were compared and discussed. Afterwards, $Zr_{0.4-x}Nd_xCe_{0.6}Fe_{10}Si_2$ alloys were synthesized. It was already known that in $Zr_{0.4}Ce_{0.6}Fe_{10}Si_2$ $ThMn_{12}$-type structure could be stabilized in almost 100% of the volume fraction [1]. The substitution of Zr by Nd was thought to improve the hard magnetic properties of these alloys. To confirm the phase constitution in the obtained alloys, X-ray diffraction experiments were performed and followed by ^{57}Fe Mössbauer spectrometry. The presence of a $ThMn_{12}$-type structure in the arc-melted samples was confirmed over almost the whole composition range. The substitution Nd by Zr led to the destabilization of the $ThMn_{12}$-type structure and facilitated the formation of a bcc-Fe type structure. It is related to the expansion of the lattice parameter and the destabilization of $ThMn_{12}$-type structure. Additionally, it was confirmed that isothermal annealing at 1373 K led to the stabilization of the $ThMn_{12}$-type structure in an even wider compositional range.

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Magnetism and magnetocaloric effect in structurally disordered $Ce(Fe_{0.9}Co_{0.1})_2$ metamagnet

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Electronic structure, as well as magnetic and magnetocaloric properties of $Ce(Fe_{0.9}Co_{0.1})_2$ alloy with C15 Laves phase are presented. Metamagnetic behavior, well-known for ordered form of this compound, was also observed for melt-spun sample, where quenched-in structural disorder was reported, as in the case of YCo_2 [1]. Following, as-quenched ribbons were plastically deformed to induce further microstructural modifications. Their impact on the magnetic and magnetocaloric properties was analyzed with the emphasis put on the metamagnetic transition and the presence of antiferromagnetic phase. Cubic $Ce(Fe_{0.9}Co_{0.1})_2$ is known to distort into rhombohedral symmetry at 90 K in zero magnetic field. As the temperature decreases, a magnetic phase transition from ferromagnetic to antiferromagnetic state occurs. However, a significant volume fraction of the deformed sample retains its ferromagnetic properties due to structural disorder. The remaining antiferromagnetic phase undergoes expected metamagnetic transition to ferromagnetic state with an applied magnetic field. The decrease in volume of the antiferromagnetic phase is also reflected in a significant reduction of magnetic entropy change for the inverse magnetocaloric effect in the vicinity of antiferro-ferro transition. The ΔS_m value decreased from 1.45 J/kg K ($\Delta\mu_0 H = 2T$) for melt-spun ribbon to about 0.15 J/kg K for plastically deformed sample. Moreover, we discuss the electronic structure of the alloy with antiferromagnetic and ferromagnetic ordering in the framework of the Density Functional Theory.

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Chemically synthesized carbon coated NiFe-based nanoparticles

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Magnetic materials are nowadays broadly investigated due to growth novel green energy sources. One of the materials, which is considered as magnetically hard and destined for future applications, is NiFe-based alloy crystallizing in the $L1_0$ structure. There are various ways to obtain the $L1_0$ structure, including physical and chemical methods, for example rapid quenching or reduction and isothermal annealing. NiFe-based and CoFe-based core-shell nanoparticles with carbon were prepared by use of precipitation method followed by isothermal annealing of prussian blue analogue (PBA) at 320°C. The XRD analysis of the NiFe annealed for 7 days, showed two types of NiFe nanoparticles with possible presence of tetrataenite ($L1_0$ structure) and Fe_3O_4 (due to high amounts of oxygen). Mostly α-Fe crystals are visible for CoFe-based nanoparticles. One broad exothermic peak was visible on calorimetric curves for both analyzed alloys and is related to the release of residual water and additional at higher temperatures both compounds decompose. Crystallization of the α-Fe phase results in high saturation magnetization of above 160 emu/g for CoFe nanoparticles.

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Magnetocaloric effect in amorphous $Fe_{11}Ni_{70}Zr_7B_{12}$

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The magnetocaloric effect (MCE) occurs in all magnetic materials with variations of applied magnetic field $\mu_0 H$ and is related to changes of magnetic entropy ΔS_m. MCE manifests itself in heating or cooling of the material (adiabatic temperature change, ΔT_{ad}) and is used in magnetic refrigeration, which nowadays is becoming an alternative to conventional cooling cycles.

Our investigation is focused on the MCE in structurally metastable $Fe_{11}Ni_{70}Zr_7B_{12}$ alloy with quenched-in topological disorder. The sample was prepared by melt-spinning under Ar atmosphere on a rotating copper wheel.

Our measurements are summarized as follows: X-ray diffraction confirmed the presence of a fully amorphous structure; the Curie temperature T_C of the investigated sample equals 275 K; the maximum value of magnetic entropy changes ΔS_{mpk} is 0.68 J/kgK (determined for $\mu_0 H = 7$ T); a rather high value of δT_{FWHM} was obtained which we associate with topological disorder. A relatively low saturation magnetization $M = 35$ Am^{2}kg^{-1} is a consequence of significant content of Ni, which has a weaker ferromagnetism than Fe or Co, common elements in well-known amorphous or nanocrystalline soft magnetic materials.

Liquid marbles manipulated via magnetic fields

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In biotechnology and biomedicine, one of the crucial issues is the efficient storage and transportation of active species such as drugs and enzymes. When encapsulated within the droplets, the active substances can be delivered and released in the site of interest. Recently, the enhanced reaction rate was shown, e.g., for particle-stabilized droplets with magnetotactic bacteria, i.e., the microorganisms that possess the intracellular chains of the magnetic nanoparticles (so-called magnetosomes). When exposed to the rotating magnetic field, such bacteria acted as nano-stirring bars [1].

The alternating magnetic fields with a frequency of hundreds of kHz can be used to prepare colloidal capsules from particle-stabilized emulsions with the rigidified shell to protect the inner substance better [2]. However, not only the droplets immersed in another liquid can be potential precursors for capsules. The droplets covered by solid particles have been shown to exist also in the air as the so-called liquid marbles. A facile rolling of the droplet in a powder bed results in the formation of droplets coated by particles. In our work, liquid marbles consisted of a water-based magnetic fluid core with either magnetosomes or pristine spherical nanoparticles entrapped within a polymer shell from modified polystyrene microparticles. Such magnetic liquid marbles were exposed to the static and alternating magnetic fields and showed magnetoresponsiveness. Due to relaxation and hysteresis losses, the temperature increased when liquid marbles were exposed to the alternating magnetic field. Depending on the concentration and the sort of magnetic agent in the liquid core, the partial fusion of the polymer shell was observed [3].

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Systematic studies of the magnetocaloric properties for the $La_{0.65}(BaCa)_{0.25}X_{0.1}MnO_3$ series (X = alkali metal and alkaline earth metals)

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We present results of systematic studies of magnetocaloric effect (MCE) in a series of manganites $La_{1-x}Ca_xMnO_3$ with Ca substituted by alkali metal (X = Li, Na, K, Rb, Cs) and alkaline earth metals (Mg, Ca, Sr, Ba). We found that the $La_{0.65}Ca_{0.35}MnO_3$ compound was the best starting composition for further fine-tuning the MCE properties by substitution for Ca with X. For each of the $La_{0.65}Ca_{0.25}X_{0.1}MnO_3$ samples an extensive characterization of the physical properties was carried out, including: structural analysis, magnetic susceptibility and magnetization vs applied magnetic field measurements, magnetic phase transition identification by Arrott plots, and finally determination of the isothermal magnetic entropy change $-\Delta S_M$. The obtained results indicate a path for searching a compromise composition, i.e. a material exhibiting a reasonable MCE performance at temperatures close to room temperature.

Influence of thermal and magnetic couplings on magnetocaloric effect in multiphase stacked sample made of LaFeMnSi$_{13}$-H$_x$ alloys

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The work concerns the study of the magnetocaloric effect for applications in magnetic cooling technology. One of the known problems of the technology is the narrow temperature range near Curie Temperature T_{Curie} [1], where entropy changes are sufficient to initiate heat transfer in the thermomagnetic cycle. The range can be increased by combining single magnetocaloric components with different T_{Curie} temperatures into multiphase structures [2]. However, the influence of inactive magnetocaloric components on the transient thermal response of the structure is adverse. Peak temperatures of operating components caused by entropy changes are dumped by inactive components due to their thermal coupling [3].

The presented findings show the magnetocaloric effect in the composite structure made of LaFeMnSi$_{13}$-H$_x$ samples with magnetic phase transitions at 298K, 303K, 308K [4,5]. The composite structure was made of stacked rectangular plates 30x30x0.5mm and assembled with active thermal and magnetic spacers. The influence of thermal and magnetic couplings was investigated by the direct measurement of the magnetocaloric effect under magnetic field excitation (0.5-1.5T).

On the basis of experimental data a simplified model of thermal response of the multiphase magnetocaloric system was formulated and validated. The model allows one to estimate the thermal behavior of the magnetic regenerator containing a given number of field and temperature-dependent interacting magnetocaloric components. Details of experimental studies and the formulated model of the thermomagnetic couplings in magnetocaloric structures will be discussed in the presentation.

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Magnetorheological characterization of oil-in-oil magnetic Pickering emulsions

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A magnetic Pickering emulsion is a type of emulsion stabilized by magnetic nanoparticles that accumulate at the droplet interface. This makes the emulsion easy to control using an external magnetic field, which, in turn, makes it useful in many different applications. Research and development in this field are ongoing, and regardless of the application, the control of the formation process is necessary. Rheological measurements are one of the most important techniques for evaluating the internal structure and stability of emulsions. The main focus of the presented study is investigating the magnetorheological effect of the rarely tested oil-in-oil magnetic Pickering emulsions and comparing them with better-characterised oil-based magnetic fluids. The magnetoviscous effect typically occurs when magnetic nanoparticles or magnetic Pickering emulsions align with the magnetic field, and this effect depends mainly on the internal structure, such as size and shape.

The experimental results indicate that the magnetic emulsion treated by an electric field exhibits a higher dynamic yield stress as a function of the magnetic field compared to the partially covered droplets. This suggests that the stable emulsion becomes a more rigid system and more resistant to deformation when a magnetic field is applied. In addition, the magnetoviscous effect of the magnetic emulsions was lower compared to that of magnetic suspensions with the same mass fraction of magnetic nanoparticles.

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Effect of the sheet-straightening process on magnetic properties and texture evolution of high-strength Fe-Si alloys.

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Fe-Si alloy sheets, called also non-oriented (NO) electrical steels, have excellent magnetic properties such as magnetic permeability, high frequency, low iron loss, and almost zero magnetostriction. This type of steel has good application prospects in high-speed high-frequency motors, transformers, and other equipment [1]. Their good soft magnetic characteristics strongly rely on the ability to control the grain size, texture, and chemistry of the final steel sheets products. The most appropriate texture for NO steels is the "rotating cube" texture, which provides isotropic magnetic properties in all plane directions of non-oriented steels [2]. In the present work, we have used a fairly innovative technological approach applicable to fully-finished high–strength NO electrical steel before punching the laminations. It is based on a specific mechanical treatment by means of the sheet-straightening process in combination with subsequent annealing under dynamic heating conditions. It has been revealed that the proposed unconventional treatment clearly led to effective improvement of the steel magnetic properties thanks to its beneficial effects involving additional grain growth with appropriate crystallographic orientation and residual stress relief. The main idea behind the improvement of soft magnetic properties relies on the formation of huge grains with the desired orientation. The coarse-grained microstructure with the pronounced intensity of cube and Goss texture components was achieved by using deformation-induced growth of ferrite grains during annealing at dynamic conditions. The magnetic measurements of fully finished samples in AC magnetic field conditions have clearly indicated that the evolved microstructures and textures of the strips, obtained by the application of a straightening mechanism and heat treatment using two different procedures, are directly responsible for their final magnetic characteristics. The power loss data have clearly shown that the investigated steel treated according to our innovative approach exhibited a more than 16% decrease in power losses at 400Hz in comparison with the material treated by conventional stress relief heat treatment without activation of grain growth.

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Magnetocaloric effect in thin films of the Laves phases $TbCo_2$ and $DyCo_2$ grown on SiO_x substrate

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In the present study, we show the preparation process and magnetocaloric properties of polycrystalline thin films of intermetallic compounds $TbCo_2$ and $DyCo_2$. These compounds belong to the Laves phases [1], which are promising magnetocaloric materials in the low temperature range [2]. The samples were fabricated using the Pulsed Laser Deposition technique. The layers were deposited onto naturally oxidized silicon (100) and Al_2O_3 $(11\bar{2}0)$ [3] substrates to investigate the influence of the substrate on the quality of the grown materials. The crystal structure of the prepared materials was verified by X-ray diffraction method. The studies indicated the presence of a texturized cubic $MgCu_2$-type phase (space group $Fd\bar{3}m$, No 227) for thin films deposited on both substrates. Measurements of magnetization as a function of temperature revealed anomalies for thin film samples around the Curie temperatures denoted for bulk materials at $T_C = 230$ K for $TbCo_2$ and at $T_C = 135$ K for $DyCo_2$ [4,5]. The determined magnetocaloric parameters, magnetic entropy change ΔS_M and relative cooling power RCP, for a change of magnetic field of 5 T, are equal to $-\Delta S_M = 4.3$ J kg^{-1} K^{-1} and $RCP = 121$ J kg^{-1} at $T = 217$ K for $TbCo_2$, while $-\Delta S_M = 4.4$ J kg^{-1} K^{-1} and $RCP = 23$ J kg^{-1} at $T = 127$ K for $DyCo_2$.

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Analysis of the resolution of the passive magnetic method on the example of nondestructive testing of steel wire ropes

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Early identification of micro defects in steel wire ropes significantly impacts structures' in-service reliability and safety. The analysis of the possibility of using the passive magnetic technique in diagnosing steel wire ropes is the subject of ongoing research [1], [2]. The self-magnetic flux leakage (SMFL) method is a passive variant of the magnetic flux leakage (MFL) method [3]. The main difference is that the SMFL method relies on the self-magnetization of ferromagnetic material in a geomagnetic field, while the MFL method requires an externally formatted excitation source [4]. Some authors [5] emphasize that a significant threat to this method is the influence of the magnetic force of the neighbouring elements of the tested object, which can effectively suppress the diagnostic signal. Magnetic signal inspection based on the self-magnetic flux leakage (SMFL) effect can effectively identify the location of defects. However, current research on the magnetic signal of defects under the influence of various factors needs to be more comprehensive. In [6], the authors proved that the damage depth depends on the diagnostic signal's amplitude. This method is the subject of intense research. However, no paper was found that compared different distances between discontinuities and their magnetic signatures. This work aims to analyze the resolution of the passive magnetic method on the example of defect tests of steel wire ropes. The research was conducted with sensors using the following phenomena: magnetoimpedance (MI), tunnelling magnetoresistance (TMR), and optically pumped magnetometers (OPM). The article aims to indicate the most appropriate sensor that best shows the modelled failure description as a beginning for further calculation diagnostics algorithms.

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The Exhausting Experimental Search for Alternative MSM-active Heusler Alloys

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The magnetic shape memory effect is a near-unique multiferroic property of the Ni_2MnGa Heusler alloy family (and it's off-stoichiometry or substituted derivatives). The effect relies on the synergistic combination of high magneto-crystalline anisotropy, high magnetic moment, and low energy required to move twin domain boundaries, known as the twinning stress [1]. Despite extensive searching, no alternatives to the Ni-Mn-Ga alloys have been found to have the required combination of properties. With the increasing libraries of computationally investigated materials, identification of promising alterative candidates, through appropriate property filtering should become easier.

We chose to use the results of several ab intio calculation papers, predicting the ground-state structure and resulting magnetic properties of a large list of potential Heusler alloys, to help shortlist and target our experimental efforts to identify alternatives to Ni-Mn-Ga [2,3]. The shortlisting used filters such as ground-state structure, effective moment, magneto-crystalline anisotropy, and tetragonality ratio, to predict the most likely candidate Heusler alloys. Synthesis of the potential candidates was then attempted using arc-melting, followed by compositional characterisation by SEM-EDX, and homogenisation heat-treatments. The most promising (phase pure) candidates were then investigated by magnetometry and structural analysis [4-6].

Despite the targeting using ab intio calculations, many of the predicted properties from the calculations were not realised in the experimentally prepared alloys, if a single-phase alloy could even be prepared. No promising alternatives to Ni-Mn-Ga have so far been identified. In this presentation we will summarise this exhausting search, highlighting the filtering parameters, preparation successes, and so-far identified magnetic properties of the prepared alloys.

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CoFe and NiFe-based Planar Hall Effect sensors

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Magnetic sensors based on the Planar Hall Effect (PHE) have gained in popularity in recent years thanks to a number of advantages, such as their ease of fabrication, high sensitivity, and remarkable thermal stability, which make them one of the most promising technologies on the market today. As a result of these advantages, PHE sensors are being introduced as candidates in a wide range of modern applications, such as lab-on-a-chip devices and nano-tesla magnetometers. The ferromagnetic material in a PHE sensor ideally has a very low coercive field and a high magnetization saturation. The most commonly used ferromagnetic material is permalloy (NiFe), owing to its magnetic softness and high AMR ratio. Although other materials, such as CoFe, show great promise due to their high magnetization saturation, they have extremely high coercive fields, which are unsuitable for use in the detection of small magnetic fields. The magnetic properties of the ferromagnetic layer can be dramatically altered by using different buffer layers, and therefore, a number of different combinations, geometries, and materials are being investigated as promising candidates for their use in Planar Hall effect sensors. The aim of our study was to design and fabricate trilayers using different ferromagnetic materials, as well as capping and buffer layers so as to optimize the performance of PHE sensors. The films were grown by magnetron sputtering at UHV conditions using CoFe, CoFeB, and NiFe as ferromagnetic materials, as well as Ta and W as capping and buffer layers. Various geometrical Hall crosses have been microfabricated on the stacks by Direct Laser Lithography combined with Ion Milling to investigate the Planar Hall Effect. The magnetic and electrical properties of the different devices were measured at room temperature. We found that, although the CoFeB and NiFe structures have different magnetic and electric properties, the geometry of the Hall crosses was the main delimiting factor in the voltage response of every single structure. For every cross, the sensor's sensitivity is limited to values close to 10 mV/T.

Magnetic composite based on ABS polymer and iron powder for 3D printing

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Additive manufacturing (AM) is a modern technology that allows to fabricate complex products from various materials and has many advantages compared to traditional production methods. Magnetic materials are related to many essential applications. They are key components of motors, generators, transformers, magnetic-coolers, and many others. In this work, we present research on a magnetic composite designed for AM. The composite material with magnetic properties was prepared from acrylonitrile butadiene styrene (ABS) and iron (Fe). The components in various ratios (Fe powder from 50% to 75%) were mixed mechanically and thermally compounded through a single-screw extruder. The physical properties of composites were investigated by X-ray diffraction, density, electron microscopy, magnetization, specific heat, and mechanical properties measurements. Structural measurements showed that Fe particles do not agglomerate or oxidize during the composite synthesis process. Soft ferromagnetic properties for all prepared samples were confirmed by magnetic studies. The results were compared with those obtained for a commercially available polylactide-based (PLA) material. Finally, 1.75 mm diameter filament was fabricated and the electromagnet components were printed using the fused deposition modeling (FDM) technique.

The kinetics of aggregation of the Aβ_{1-40} peptide monitored by magnetooptical methods

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Protein misfolding leads to the formation of amyloid fibrils and causes many serious diseases affecting millions of people worldwide [1]. In the presented study we used magnetooptical (MO) methods such as Faraday and Cotton-Mouton [2] effects (FE and CME respectively) to monitor the aggregation processes of one of the most studied peptides, amyloid β_{1-40} (Aβ_{1-40}) which is associated with Alzheimer's disease. Especially CME is very sensitive to the shape (through the anisotropy of optical polarizability and magnetic susceptibility) of the studied species which allows us to monitor their changes. The impact of time (up to 30 days) and storing temperature (8, 23, 36 °C) on the aggregation of Aβ_{1-40} was evaluated by calculations and modeling the measured coefficients that describe both effects. In addition, the time-dependent kinetic profile of Aβ_{1-40} amyloid aggregations has been monitored using Thioflavin T fluorescence assay and the morphology of mature Aβ_{1-40} fibrils was visualized by atomic force microscopy. As expected, CME, proved to be more suitable for monitoring protein aggregation than FE and, thus using a compact magnetopolarimeter, it could routinely be applied without any additional chemical procedure in biomedical studies. In addition, CME has been successfully used by us to demonstrate the self-assembly of phenylalanine which is considered as the most important amino acid in understanding the aggregation process of Aβ_{1-40}.

References:

[1] Chen, Gf. *et al.*, Acta Pharmacol Sin 38, 1205–1235 (2017). https://doi.org/10.1038/aps.2017.28
[2] Koralewski M. *et al.*, ACS Appl. Mater. Interfaces 10 (9), 7777-7787 (2018). https://doi.org/10.1021/acsami.7b18304

This work was supported (to KS) by research grants from the Slovak Grant Agency VEGA (No. 2/0034/22) and SAS-MOST/JRP/2021/192/AZCAI.

Faraday effect of imidazole derivatives and imidazolium halide ionic liquids

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Ionic liquids (ILs) are of great interest to researchers due to their spectacular physicochemical properties and applications [1]. A new subclass of ILs, which shows strong response to a magnetic field, was discovered in 2006. The magnetooptical (MO) properties of ILs are very rarely discussed in the literature, although our recent research has paved the way for the possible application of magnetic ILs (MILs) in photonics [2]. These facts motivated us to start with further studies on the basic compounds of most known ILs based on imidazole. In the paper, we present results of the magnetooptical rotatory dispersion (MORD), so called Faraday effect dispersion, of imidazole derivatives and commonly known imidazolium halides ILs with different alkyl chain length. We have shown that the MORD spectrum can be explained by using the model based on the Faraday B-terms according to Serber theory [2]. Additionally, using Pascal's and Lorentz-Lorenz relations, the magnetic susceptibility and the optical polarizability of the compounds were evaluated, respectively. The results obtained allow to establish the empirical relation between the Verdet constant and the alkyl chain length, as well as the optical polarizability and magnetic susceptibility. These relations will be very useful for designing new ILs/MILs and tuning their MO properties.

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Multilevel Nonlinear Transition Shift in High Density Perpendicular Magnetic Recording

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In magnetic recording, electric currents pass through the head to apply an external field that changes the polarity of magnetic grains, thus binary data is written and stored on the media. Nonlinear transition shift (NLTS) produced by the interaction between transitions is a significant source of distortions in the writing process of magnetic recording. It is defined as the shift between the ideal and the actual position when writing a transition, due to the fact that the total field not only depends on the write field of the head, but also is affected by the demagnetizing field from the previously written transitions. NLTS must be reduced to realize higher density and maintain signal quality, meeting the ever-increasing demand for data storage.

In this work, the production and the behavior of NLTS in high density perpendicular magnetic recording (PMR) were studied, and the confusion about NLTS in previous reports [1,2] was revised. Combined with the micromagnetic simulation of CoCrPt-oxide-based thin film with Voronoi grains and nonmagnetic grain boundaries, we have developed a complete theoretical model to predict NLTS in PMR.

The results show that the observed NLTS (τ_{ob}) in PMR is inversely proportional to the bit length (BL) squared, i.e. $\tau_{ob} \propto \mathrm{BL}^{-2}$. τ_{ob} can be over 30% of BL at high linear density under the given conditions. Optimizing the write field gradient can effectively reduce τ_{ob}, but only at a low write field gradient. Particularly, for multilevel NLTS, which is caused by consecutive multiple transitions previously, τ_{ob} will firstly increase and quickly approach a constant value as the number of consecutive transitions increases.

References:

[1] B. F. Valcu and M. Alex, IEEE Trans. Magn. **49**, 3648 (2013).
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This work was funded by National Natural Science Foundation of China (Grant No. 62272178).

Faraday effect of colloidal gold spherical nanoparticles with dimensions between 5 and 200 nm

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Au-metallic nanoparticles (AuNPs) are one of the most investigated nanomaterials. Despite being non-magnetic AuNPs were found to display sizable magnetooptical (MO) properties when they are confined in the nanostructure. In the last two decades, the MO properties of colloidal AuNPs have been mainly described by magnetic circular dichroism (MCD) spectroscopy. An extensive set of MCD spectra was obtained for AuNPs with dimensions (D) of 3 nm to 25 nm. Despite the fact that MCD spectra are closely connected to MORD (dispersion of Faraday effect (FE)) through Kramers-Kronig (KK) relationships, only one paper [1] was directly devoted to FE (D = 17 nm) and its theoretical modelling. The FE is widely employed in many magnetooptical devices and in recent years has been extensively researched for all-optical magnetization reversal by inverse FE (IFE). Recently, the FE and IFE of 100 nm colloidal AuNPs have been described [2]. The paper presents room-temperature FE spectra at 280-650 nm for colloidal AuNPs in aqueous citrate buffer with particle D equal to 5, 20, 40, 60, 100 and 200 nm and exhibiting the localized surface plasmon resonance (LSPR) between 520 and 575 nm. In practice the FE have low magnitude but the obtained results show systematic changes related to LSPR position and are in good relation with the results of ref. [1], but they are about 2 orders smaller than those describing FE in a static magnetic field presented in ref. [2]. In addition, the KK analysis performed for our MORD spectra allowed for further discussion and comparison with literature results. Modelling of the obtained MORD spectra for the plasmonic resonances using the Maxwell-Garnett theory will also be presented.

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Lithium phthalocyanine - radical-based molecular oxygen sensor

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Lithium phthalocyanine nanocrystals are radical-based dissolved oxygen sensors (oxygen partial pressure sensor- pO_2). The main field of their applications is the measurement of dissolved oxygen in tissues, tumors, 3D cell cultures (e.g. spheroids), or cells in biological *in-vivo* and *in-vitro* studies. Sensors are biocompatible, stable in biological conditions - unsolvable in water, which makes them an ideal system for long-period oxygen level monitoring. Molecular oxygen sensors of dissolved oxygen (pO_2) are extremely important for biological and medical *in-vivo* studies in various tissues (e.g. tumors in a mouse model). Changed oxygen levels can be a marker of general inflammatory processes, miss-build of blood vessels, poor diffusion geometry, and severe structural abnormalities in tissues (e.g. tumors). Above that medical treatment can be dependent on pO_2 levels e.g. radiological anticancer therapy. For intracellular processes, oxygen is also important inside living cells in gaining energy by the formation of adenosine triphosphate (ATP) in the mitochondria. The principle of work is based on the detection of magnetic field fluctuations caused by tumbling O_2 molecules around the spin probe. Such fluctuations cause EPR line broadening which can be calibrated and quantified for EPR *in-vivo* oximetry/mapping purposes.

We acknowledge the financial support from the Ministry of Education, Youth and Sports of the Czech Republic [grant no. LM2023053].

Direct Mechanical Evaluation of Flexoelectric Response of Free-standing Cantilever Beams by Nanoindentation Instrumentation

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Flexoelectricity and flexoelectric effects have been gathering and increasing attention in the past few years. This new enthusiasm has been boosted, at least in a big part, due to the potential exploitation of this effect in micro/nanoelectromechanical actuators and sensors without inherent piezoresponse [1]. Currently, there are a few limiting aspects to their testing. i) the dimensions and geometry required (relatively large samples, typically millimetric in size); ii), the maximum oscillation frequency of the instrument because the relationship $I=Q*f$ (between electric current (I), charge (Q) and frequency (f)) implies that higher frequencies are desirable to improve signal detection; and iii), the mechanical resilience of the nanocrystals studied. The last aspect is particularly important since single crystalline samples will normally break with amplitudes over a few microns and relatively low strain fields ($>0.3\ m^{-1}$); as a consequence, large samples are required, limiting the strain gradients accessible in experiments. Previosuly, a method for measuring flexoelectric response on free-standing cantilever beams using nanoindentation instrumentation was developed. The general advantages of the method are the use of controlled sub micrometric oscillations, small strain field and the possibility of exploiting the micro and nano capabilities of modern indenters to probe small devices in-operando conditions. Moreover, several instrumentation and error sources are discussed and considered prior measurements. Finally, the efficiency of the methodology is confirmed by testing Strontium Titanate (STO) and Hydroxyapatite (HAp) beams, with an established flexoelectric response. Further tests have allowed the evaluation of the photo flexoelectric coefficient of STO. The results confirm the applicability and accuracy of the method [2].

References:

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Study partially funded by the SONATA Project (2021/43/D/ST5/01116) NCN Poland

Insulating State in Topological Half Heusler compound TmPdSb

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Our study presents both theoretical and experimental evidence supporting the existence of a robust topological insulator state in TmPdSb, a half-Heusler compound. Typically, half-Heusler systems display topological features only in their semimetallic state and are topologically trivial in the insulating state. However, using a tight binding model to calculate the $\mathbb{Z}_2$ topological invariant, we found that TmPdSb has a (1; 000) invariant, which directly indicates it as a strong topological insulator. Furthermore, we observed the manifestation of topological features through unique surface states that extend across the entire Brillouin zone, independent of surface termination, and were confirmed in single crystal experimental results. TmPdSb exhibits insulating behavior at high temperatures, as evidenced by the temperature-dependent electrical resistivity. The transverse and longitudinal magnetoresistance behaviors display a linear in B trend at low temperatures and a quadratic B dependency at high temperatures. Despite being paramagnetic at 2 K, magnetic scattering was observed in the electrical transport, below 40 K. We also derived a large prefactor α and coherence length $L_\phi(0)$ using the Hikami-Larkin-Nagaoka model, based on the weak antilocalization behavior of conductance in weak magnetic fields. The relatively large value of $L_\phi(0)$ suggests the dominance of conducting surface states, which is typical of 2D topological sheets.

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The determination of masses of components in physical mixtures by NMR method

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Pharmaceutical medications are used in our society everyday – sometimes we started to be medicate in our prenatal life. It is often in the form of a compressed powder and is a physical mixture of a pharmacologically active ingredient and various excipients. The most important component of medicines is the active pharmaceutical ingredient (API), which causes a pharmacological action in the patient's body, i.e., restoring, improving or altering the physiological functions. The amount of active ingredient in a particular drug is crucial information in pharmacology, as it determines whether the drug will help the patient to recover their health or, in case of exceeding the safe dose, will harm the patient.

Other components of the medicine are called excipients. They do not affect the patient's condition, but make it easier to take the active substance. Knowing their amount in drug intake is not as important as knowing the amount of the active substance. What is intriguing that we can obtain this knowledge using Nuclear Magnetic Resonance Relaxometry.

The purpose of the research was to check the ability of quantitative determination of the composition of mixtures of two substances: active pharmaceutical ingredient and excipient. To do so, magnetization recovery of pure ofloxacin, pure polivinylopyrolidone and their physical mixture in various proportions was measure.

Results give promising information about abilities of Nuclear Magnetic Resonance Relaxometry.

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Study of calorimetric effect in ferrogels subjected to the high-frequency rotating magnetic field

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This study investigates the calorimetric effect observed in ferrogels containing magnetic nanoparticles (MNPs) when subjected to a high-frequency rotating magnetic field (RMF). The primary heat generation mechanisms are magnetic relaxation (Néel and Brown) and magnetic hysteresis. These findings have potential applications in magnetic hyperthermia (MH) as adjuvant therapy in conjunction with chemotherapy and radiation therapy for cancer treatment.

In vitro experiments were performed at a frequency of 200 kHz, with magnetic field amplitudes up to 7.5 kA/m, using tissue-mimicking agar ferrogels with varying weight concentrations of MNPs (5-30%). The experimental setup employs a two-phase magnetic system enclosed by an external magnetic core, as shown in [1-3]. Two pairs of magnetizing coils and parallel-connected capacitors generate spatially and phase-shifted magnetic fluxes by 90 degrees, resulting in a RMF with constant amplitude during rotation. Although the design can achieve magnetic field amplitudes of up to 20 kA/m, such intensities are unsuitable for MH applications due to potential harm to the human body.

The study involved monitoring temperature over time for various magnetic field amplitudes and ferrogel samples, with the released power being proportional to the rate of temperature change ($\mathrm{d}T/\mathrm{d}t$). This approach enabled the determination of the contributions of both heat release mechanisms as a function of MNP concentration and magnetic field strength. The heating efficiency of RMF was approximately twice as effective as an alternating magnetic field (AMF) of the same intensity. As there is no existing data on the effects of RMF on ferrogels, the research provides novel results for the potential optimization of MH treatments using RMF rather than AMF.

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[1] Andrzej Skumiel, Generation of a rotating high frequency magnetic field designed for use in magnetic hyperthermia, Journal of Magnetism and Magnetic Materials 553 (2022) 169294.
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Reentrance behaviour of superfluidity in orbital magnetic fields (part 1/2)

T. Polak, and A. Krzywicka

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We study the quantum phase transitions in a system of bosons where the effects of single and pair tunnelling coexist. We map the problem onto the solvable quantum generalisation of the spherical model, which is an improvement of the mean-field theory method. Reentrant behaviour can be observed within the system for sufficiently large density induced tunnelling. It proves both the dissipative character of the influence of the pair phase on single superfluidity and the revival of the latter. Interestingly, the impact of orbital magnetic field effects cannot be anticipated from typical assumptions.

Tuning the Neel temperature of α-$TbAlB_4$ by alteration of Fe:Tb ratio in multi-phase Al-Cu(B, Fe, Tb) alloys

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[1] *Faculty of Chemistry, University of Wrocław, Wrocław, Poland*
[2] *Division of Geological and Planetary Sciences, Caltech, Pasadena, USA*
[3] *Division of Physics, Mathematics and Astronomy, Caltech, Pasadena, USA*

One of the prospective materials for ultrafast magnetic switching memory are rare-earth–transition-metal antiferromagnetic alloys. There are only limited reports describing Al-Cu alloys with more than three alloying components that include both d- and f-electron elements. Here we investigate one such alloy family, Al–Cu with variable amounts of $TbAlB_4$ boride. The magnetic properties of analogous end member β-$YbAlB_4$ were described by Nakatsui *et al.* [1] as a heavy-fermion system that exhibits a low-temperature superconducting transition and quantum criticality.

Four Al-Cu(B, Fe, Tb) alloy compositions with Fe:Tb atomic ratios of 3:1, 1:1, 1:3 and 0:1 were considered in the current study, and were referred as S1, S2, S3 and S4, respectively. The dominant phase by volume in all studied alloys is Al_8Cu_4Tb, isostructural with $ThMn_{12}$ (space group 139), which appears to be non-magnetic. The accompanying precipitates of Al_2Cu (s.g. 69) in composition S1 and Al_3Tb (s.g. 221) in mixes S2–S4 are not expected to significantly contribute [2] to antiferromagnetic response of the samples. In the alloys S1-S3, the boride has the structure of TbB_4, isostructural with UB_4 (s.g. 127), while in S4 it is β-$TbAlB_4$.

For alloys S2, S3 and S4, the Neel temperatures T_N are 8 K, 15 K and 23-28 K, respecitvely, forming a broad maximum in FC-ZFC magnetization versus temperature in the case of S4. It may be that Cu and Fe substitute for some fraction of the boron atoms sandwiched between Al and Tb layers in β-$TbAlB_4$. If so, this would lead to unit cell expansion, affecting the exchange interactions. In VSM data measured up to 1 kHz, no frequency dependence is observed in magnetic AC susceptibility versus temperature. The alloys exhibited no magnetic DC hysteresis, showing clearly antiferromagnetic behavior.

The case of alloy S1 is more complex. A Curie-Weiss fit to inverse susceptibility versus temperature revealed T_N as high as 67.3 K, which we ascribe to the TbB_4 (s.g. 127) phase. But there is also a ferromagnetic phase present, monoclinic Fe_4Al_{13} (s.g. 12). A Curie law fit to inverse susceptibility shows that the coexisting phase has T_C of 46.2 K. No magnetic DC hysteresis is observed at $T > 75$ K, while H_c changes with decreasing temperature from very narrow at $T = 50$ K to about 4 kOe at $T = 3$ K, illustrating dominantly ferromagnetic interactions in the lowest temperature regime.

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SCIENTIFIC EXHIBITORS

18 Tesla Cryogen-Free Magnet with 50 mm / 65 mm sample

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Specifications:

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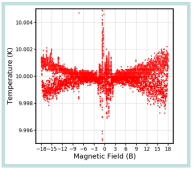

Modulus field along axis with 2.6 T central field

Compatible with:

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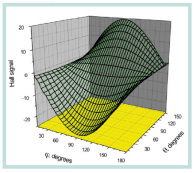
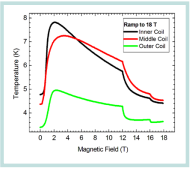


Hall Voltage as a function of polar angle in magnetic field



Ramp of magnetic field to 18 T

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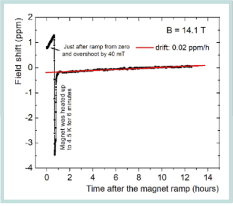
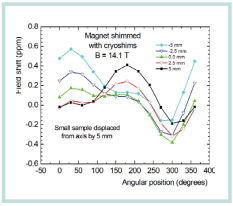
- EPR / ESR
- DNP



Magnet: Fixed and Variable field operation

Operating fields to 16.44 / 700 MHz
≤ 1 ppm fixed field central homogeneity
~ 10 ppm bare field homogeneity in 10 mm DSV
~ 1 ppm field homogeneity with cryoshims
Rapid <<0.1 ppm / hr drift in persistent mode



Sample environment

Room temperature bore: 89 mm / 54 mm
Variable sample temperatures 1.3 K to 400 K

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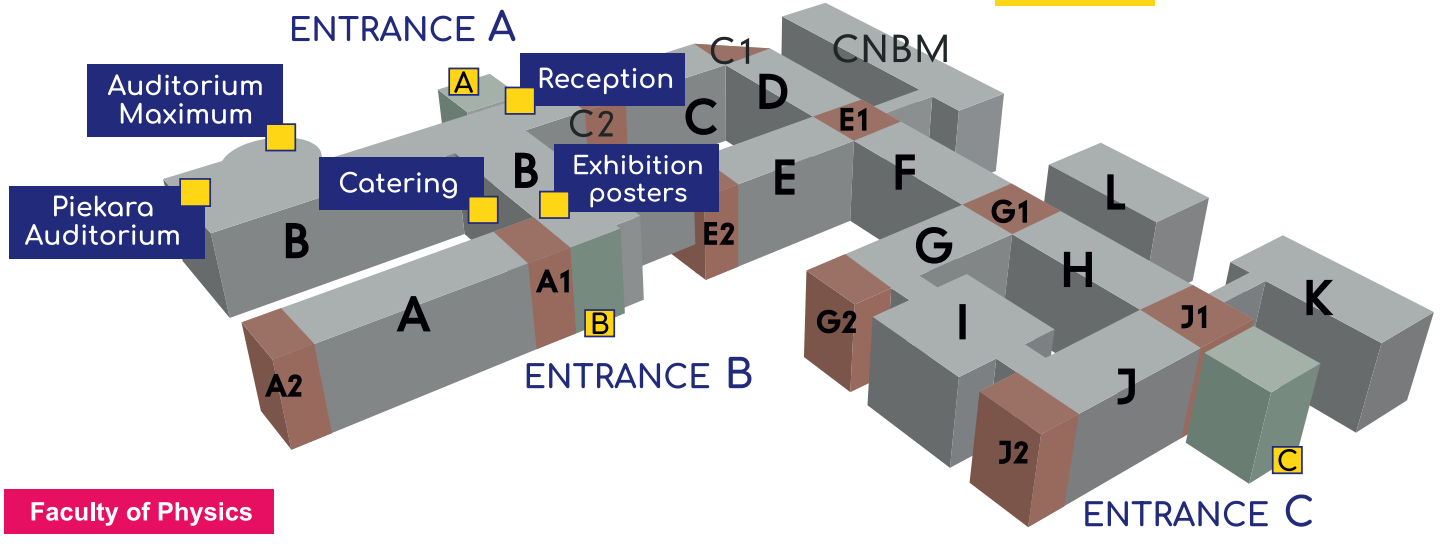

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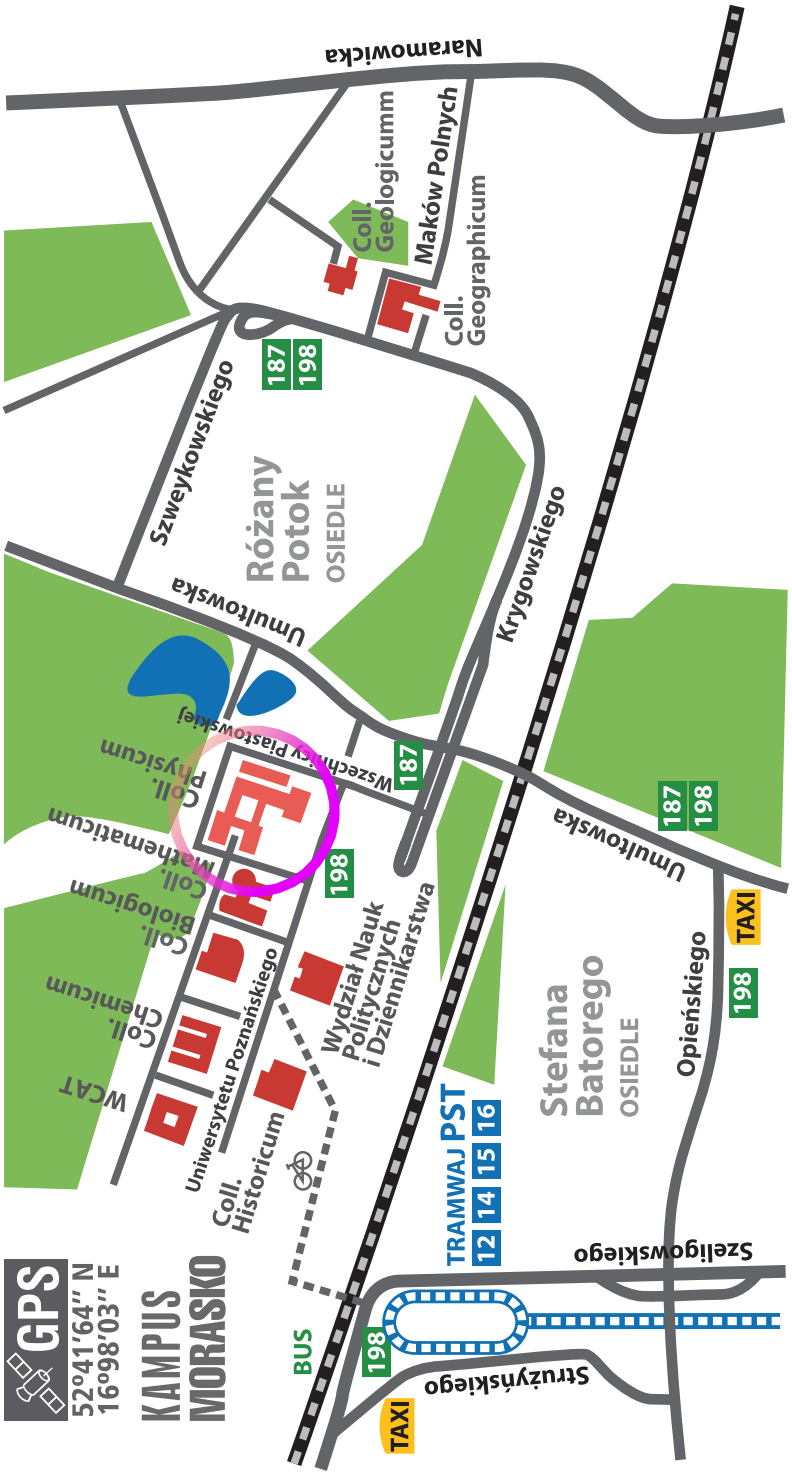
C	Entrance C


Naramowicka
Maków Polnych
Coll. Geologicumm
Coll. Geographicum
187
198
Szweykowskiego
Różany Potok
OSIEDLE
Umultowska
Krygowskiego
Wszechnicy Piastowskiej
187
Coll. Physicum
Coll. Mathematicum
Coll. Biologicum
Coll. Chemicum
WCAT
198
Uniwersytetu Poznańskiego
Coll. Historicum
Wydział Nauk Politycznych i Dziennikarstwa
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52°41'64" N
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KAMPUS MORASKO

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The European Conference PHYSICS OF MAGNETISM 2023 (PM'23)

	Monday, June 26	Tuesday, June 27	Wednesday, June 28	Thursday, June 29	Friday, June 30	
$8^{30} - 9^{00}$	***REGISTRATION*** ***$8^{30} - 10^{00}$***	**D. Grundler**	**J. Spałek**	**T. Jungwirth**	**T. Schrefl**	$8^{30} - 9^{00}$
$9^{00} - 9^{30}$		**F. Casanova**		**W. Skowroński**	**T. Domański**	$9^{00} - 9^{30}$
$9^{30} - 10^{00}$		**P. Oppeneer**	**D. Agterberg**	**R. Sobolewski**	**O. Gomonay**	$9^{30} - 10^{00}$
$10^{00} - 10^{30}$	***OPENING***	**V. Zablotskii**	**C. Panagopoulos**	**A. Stupakiewicz**	**Z. Śniadecki**	$10^{00} - 10^{30}$
$10^{30} - 11^{00}$	**J.M.D. Coey**	*coffee break*	*conference photo*	*coffee break*	*coffee break*	$10^{30} - 11^{00}$
$11^{00} - 11^{30}$	**A.J. Heinrich**	***POSTER SESSION I*** ***$11^{00} - 12^{45}$*** *categories: 1, 3, 5 + P-6-02, P-6-03*	*coffee break*	***POSTER SESSION II*** ***$11^{00} - 12^{45}$*** *categories: 2, 4, 6, 7, 8*	**J. Chaloupka**	$11^{00} - 11^{30}$
$11^{30} - 12^{00}$	**S. van Dijken**		O-3-01 O-6-01 O-3-02 O-6-02 O-3-04 O-6-04		**R. Frésard**	$11^{30} - 12^{00}$
$12^{00} - 12^{30}$	**M.C. Bañuls**		O-3-05 O-6-05 O-3-12 O-6-06 O-3-13 O-6-07		**A. Józefczak**	$12^{00} - 12^{30}$
$12^{30} - 13^{00}$	**I. Oyarzabal Epelde**	*lunch*	O-3-20 O-6-08	*lunch*	*coffee break*	$12^{30} - 13^{00}$
$13^{00} - 13^{30}$	*lunch*		*lunch*		**T. Cichorek**	$13^{00} - 13^{30}$
$13^{30} - 14^{00}$		O-7-01 O-4-03		O-1-01 O-3-06	***AWARDS, SUMMARY, CLOSING***	$13^{30} - 14^{00}$
$14^{00} - 14^{30}$	O-2-01 O-3-16	O-5-18 O-4-04	O-7-02 O-8-01	O-1-02 O-3-07	*lunch*	$14^{00} - 14^{30}$
$14^{30} - 15^{00}$	O-2-02 O-3-18 O-2-04 O-3-19	O-5-02 O-4-05 O-5-03 O-4-06	O-4-08 O-8-02 O-4-09 O-2-03	O-1-03 O-3-08 O-1-08 O-3-09		$14^{30} - 15^{00}$
$15^{00} - 15^{30}$	O-2-05 O-3-26 O-2-08 O-3-27	O-5-04 O-4-07 O-5-10 O-4-12	O-5-09 O-2-09 O-4-15 O-1-04	O-1-09 O-3-10 O-1-10 O-3-11		$15^{00} - 15^{30}$
$15^{30} - 16^{00}$	O-2-10 O-3-28 O-2-11 O-3-29	O-5-13 O-4-13 O-5-17	O-4-01 O-1-05 O-4-10 O-1-06	O-1-11 O-3-15		$15^{30} - 16^{00}$
$16^{00} - 16^{30}$	*coffee break*	O-5-01	O-4-11 O-4-02	*$15^{45} - 16^{15}$ transportation*		$16^{00} - 16^{30}$
$16^{30} - 17^{00}$	**B. Lake**	*coffee break*	*coffee break*			$16^{30} - 17^{00}$
$17^{00} - 17^{30}$	**A. Chumak**	**M. Dziurawiec**	**A. Manaparambil**			$17^{00} - 17^{30}$
$17^{30} - 18^{00}$	**A. Szewczyk**	**M. Gołębiewski**	**J. Juraszek**			$17^{30} - 18^{00}$
$18^{00} - 18^{30}$	**M. Bibes**	**A. Labh**	**A. Sinha**			$18^{00} - 18^{30}$
$18^{30} - 19^{00}$	*coffee break* O-3-17 O-5-06 O-3-14 O-5-08	**B. Niedzielski** **N. Soya** **A. Pacewicz**	*$17^{30} - 18^{15}$ transportation to the concert hall*			$18^{30} - 19^{00}$
$19^{00} - 19^{30}$	O-3-21 O-5-11 O-3-22 O-5-14					$19^{00} - 19^{30}$
$19^{30} - 20^{00}$	O-3-23 O-5-15 O-3-25 O-5-16		*19^{00} - ... concert*	*19^{00} - ... banquet*		$19^{30} - 20^{00}$
$20^{15} - \ldots$	*welcome party*					$20^{15} - \ldots$