1-4 March 2023

Yeravan, Armenia

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Book of Abstracts

1st International Conference

APRICOT 2023

“Magnetic nanomaterials in biomedicine: synthesis and functionalization”

APRICOT 2023

This conference focused on magnetic nanohybrids in various biomedical areas such as bioseparations, hyperthermia treatment, drug delivery and toxin removal, medical diagnostics, and sensing devices. Aiming to start a series, it will show the convergence of material science and biological sciences, bring together the scientific community of Physicists, Chemists, and Biologists to discuss the latest developments in the fabrication and characterization of nanomaterials and their biomedical applications.

APRICOT 2023 also includes the 3rd MaNaCa summer school, funded by European Union in the framework of Twinning/Horizon 2020 programme.

TOPICS

- Synthesis, characterization, and properties of magnetic nanomaterials
- Novel processing and manufacturing technologies of magnetic nanomaterials
- Investigating methods for characterization magnetic nanoparticles
- Interaction of magnetic nanoparticles with electromagnetic waves
- Biomedical applications, e.g. therapy, diagnosis, cell separation
- Functional magnetic nanomaterials and their applications

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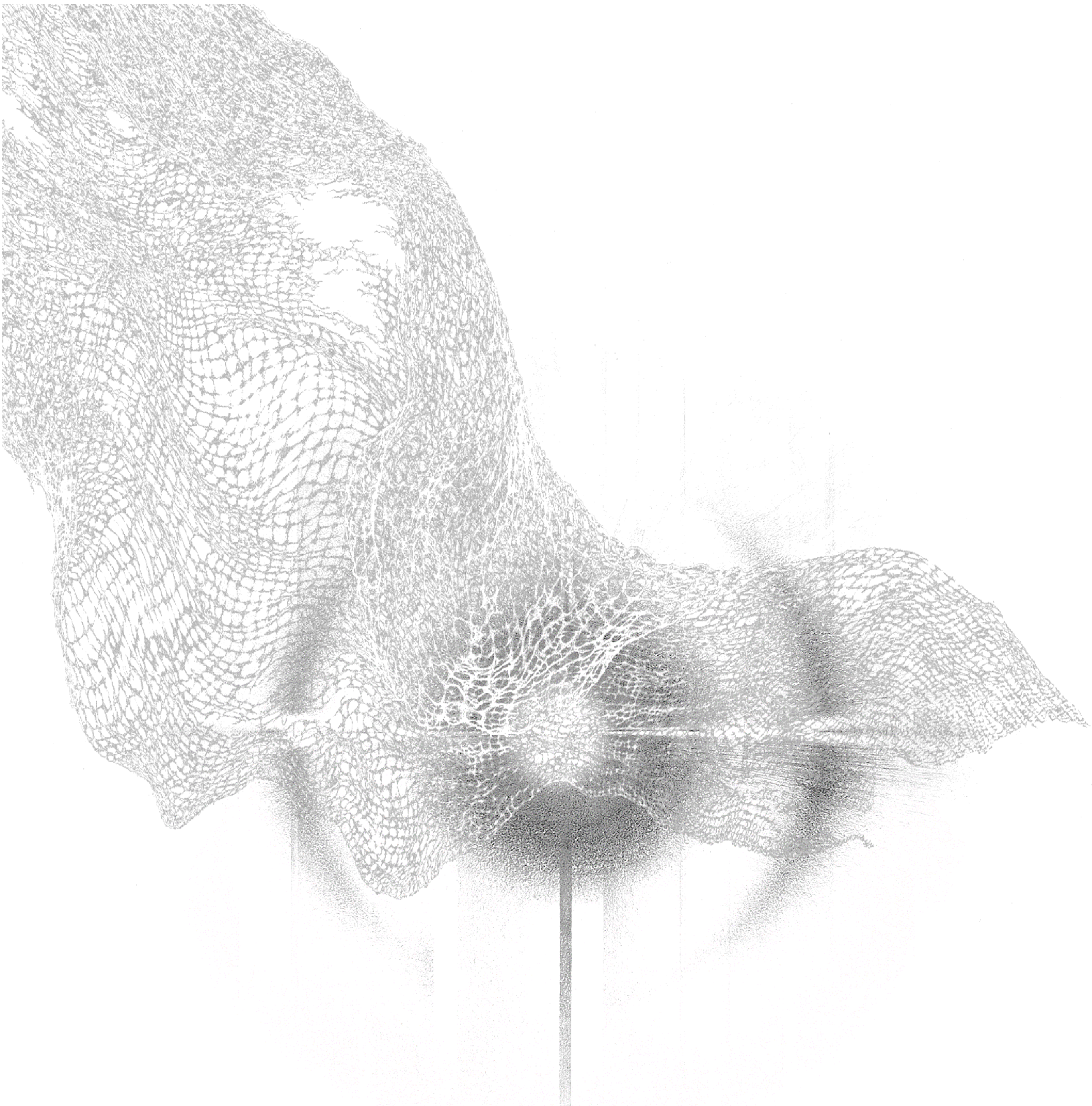


Plenary Speakers

Makis Angelakeris

Prof. Dr. Makis Angelakeris (**M**) is a professor at the School of Physics at the Aristotle University of Thessaloniki. His main scientific interest stems from the synthesis of magnetic thin films, multilayers and nanoparticles. Under this research scheme, he also works also works on structural, magnetic, electric, magneto-optic characterization of magnetic nanostructures. Within the last 10 years he is also involved in Biomagnetism applicability focusing on Magnetic Particle Hyperthermia and Magneto Mechanical Stress. He has 136 publications in peer review International Journals, 126 abstracts in International Conference Proceedings and 98 abstracts in Local Conference Proceedings. He has delivered 22 invited presentations and has 3544 Citations by 2552 documents (excluding self-citations out of 2488 citations, h-index: 33, scopus:21/04/2022). He serves as regular referee in 10 International peer-review scientific journals (12-20 manuscripts annually). His work is highlighted by two monographs: a review article on Magnetic nanoparticles: A multifunctional vehicle for modern theranostics, M. Angelakeris, Review Article (in Biochim Biophys Acta Gen Subj. 2017 Jun;1861(6):1642-1651) and a Book chapter on Magnetic Particle hyperthermia, in Vol. 8 of 21st Century Nanoscience, A handbook, (10 volumes), Taylor & Francis, in press (2020). He acted as Supervisor in 6 PhD theses (4 underway), in 17 MSc (2 underway) and 22 BSc theses (2 underway). He participated in 11 international or regional research projects. (Webpage: http://users.auth.gr/agelaker). He is currently co-ordinating the MagnaCharta Group (Magnetic Nanostructure Characterization: Technology and Applications http://magnacharta.physics.auth.gr). The MagnaCharta group focuses on modern magnetic nanomaterials from systematic synthesis and robust investigation of physical properties together with technological applicability of nanomagnetism on diverse aspects such as information storage, biomedicine and sustainable growth. All members of MagnaCharta group may actively participate and provide services within the current proposal.

Alexander Mukasyan

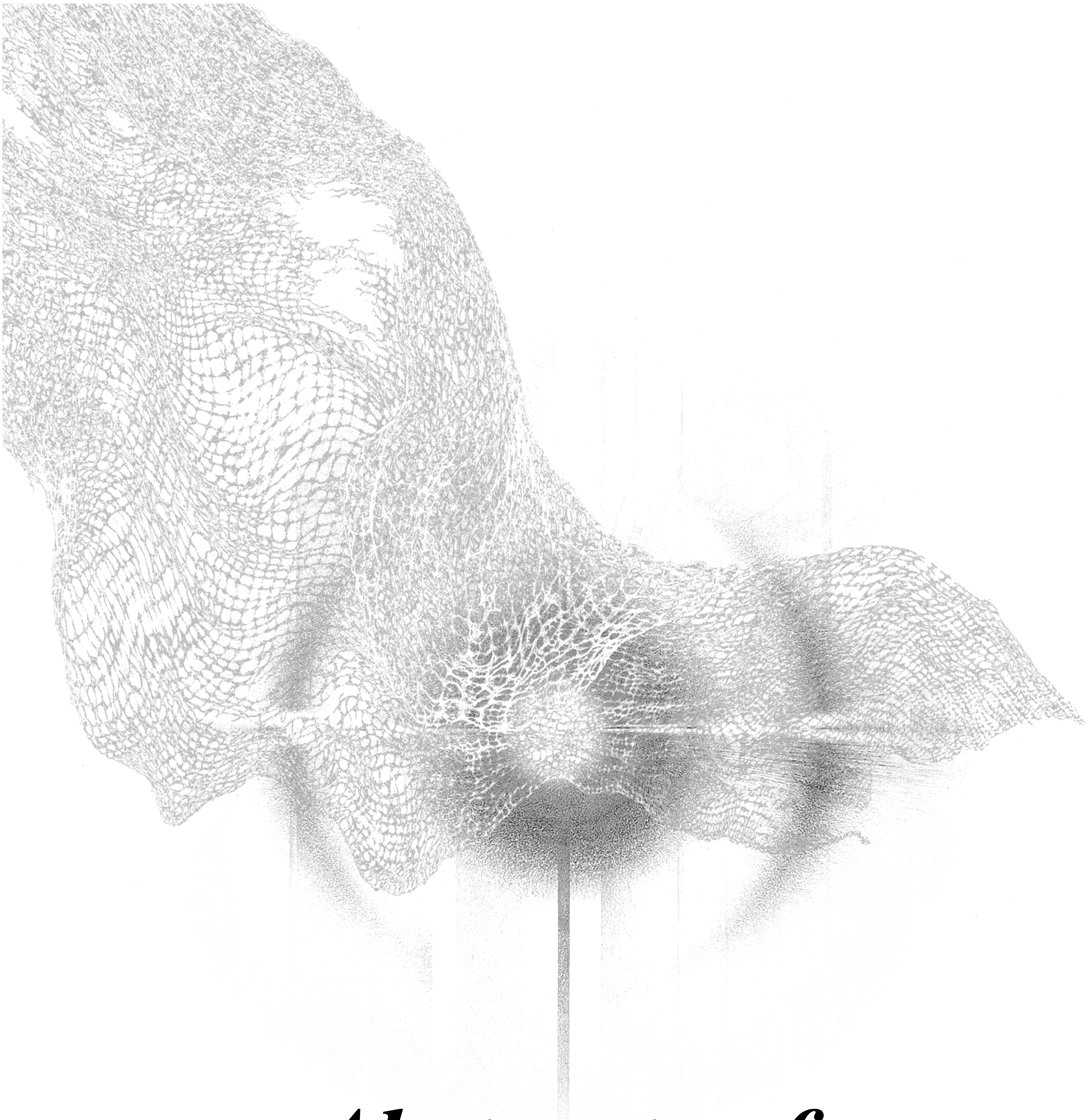
Mukasyan Alexander, Professor of Chemical and Biomolecular Engineering, University of Notre Dame, Notre Dame, IN USA since 1996. Ph.D. in physics and math (1986) Institute of Chemical Physics, Russian Academy of Sciences; Sci. Dc. (1994) Institute of Structural Macrokinetics, Russian Academy of Sciences. Academician of the International Informatization Academy (2001). Member of the Editorial boards for several International Journals; Member of International Advisory Boards of Ceramic World Academy. Medal of Exhibition of Achievements of National Economy (Moscow, 1993); Medal of Russian Academy of Sciences (2001); Medal of Kazakhstan Ministry of Science (2007). Co-author of 5 books and 1 text-book, 33 Chapters in books and invited reviews, more than 300 research publications in archive journals and 36 patents, including 14 patents in the fields of engineering of advanced materials and heterogeneous combustion (see details: https://scholar.google.com/citations?hl=en&user=b8XySnEAAAAJ). The main scientific interest relates to nanotechnology, high energy density materials, joining of refractory and dissimilar materials, as well as catalysis. The most cited publications: Combustion synthesis and nanomaterials, Current Opinion in Solid State and Materials Science 12 (3-4), 44-50, 2008; Solution combustion synthesis of nanoscale materials, Chemical Reviews 116 (23), 14493-14586, 2016; Combustion for Material Synthesis, CRC Press, Taylor and Francis, Boca Raton, London, New York, 2015, 398 p.

Karen Martirosyan

Dr. Martirosyan is Professor of Physics, Director of Advanced Nanoscience Laboratory and Associate Vice President for Research Enhancement at the University of Texas Rio Grande Valley (UTRGV). Prior to AVP position, he served as the Associate Dean for Research and Educational Innovations at the College of Sciences and worked with faculty to create new undergraduate and graduate programs in STEM fields. Dr. Martirosyan's research is focused on experimental and theoretical condensed matter physics with a wide range of solid-state phenomena to design advanced multifunctional nano-tailored materials and devices for energy, environmental and biomedical applications. The research area covers development of a broad spectrum of advanced materials for imaging, targeted drug delivery, imaging-guided brachytherapy and theranostics media, their design, fabrication, and characterization. He has been the Principal Investigator and Co-investigator for numerous federal funded research projects. His work has resulted in more than 170+ refereed papers, 20 patents, 12 book chapters and over 160 presentations at national and international conferences. He has successfully mentored undergraduate, master, doctoral students as well as postdoctoral and Fulbright fellows and international scholars exemplified by successful completion of their co-authorship in peer-reviewed publications. He was three times honored with prestigious AFRL Summer Faculty Fellowships and conducted research at the Eglin Air Force Base, Florida. Dr. Martirosyan is reviewer for the NSF and NASA projects. He has chaired several major scientific conferences, annual college symposiums, interdisciplinary colloquiums, and hosted nationally and internationally recognized scholars.

Shivaji H. Pawar

Prof. Dr. Shivaji H. Pawar, the Emeritus Scientist, CSIR, Delhi, is the Distinguished Professor and former Vice Chancellor D Y Patil University, Kolhapur. presently working as Director, Centre for Innovative and Applied Research (CIAR), Baramati, (India). He has worked as Professor and Head of Physics Department, Director, BCUD, Registrar of University, Dean of Science Faculty and Coordinator, School of Energy Studies at Shivaji University, Kolhapur. He has initiated and worked as Founder Director of three different multifaculty interdisciplinary Research Centres at TKIT, Warnanagar; Sinhgad Institutes, Solapur and Anekant Education Society, Baramati. Prof.Pawar has guided successfully 75 research scholars leading to their Ph.D. degrees, 50 in Shivaji University and 25 in D Y Patil University, Kolhapur. He has published more than 900 Research papers, contributed to 40 book chapters, edited 15 books and obtained 12 patents. He has worked as visiting Professor/Scientist at many more universities and Institutions all over the globe. His research interest includes Solid State Physics, Materials Science, Energy and Environment, Nanoscience and Nanomedicine, Nanobiotechnology, Atmospheric Nanoscience and Agricultural Nanotechnology.



Abstracts of plenary reports

Plenary report

Tuning Nanomagnetism for Biomedical Applications

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In this talk, I will discuss ways to promote the magnetic material- field interaction which is the driving force for modern biomagnetic applications. The diversity of magnetically driven applicability schemes urges not only for handling to diagnostic and therapeutic probes but for their combinatory exploitation as well. Moreover, effectiveness of a biomedical modality also puts additional constraints based on physiochemical interactions will living matter, typically hindering effective in-vivo performance.

I will start with materials currently used in biomedical applications focusing on their nanoscopic features. Namely, magnetic nanoparticles of tunable sizes, morphologies, stoichiometries and consequently magnetic features, will be evaluated in conjunction with prompt delivery of their adequate “cargo” at specific sites. I will discuss ways to circumvent biomedical issues such toxicity, biocompatibility, and sustainability within biological environments.

The second part of the talk will focus on field conditions required to provide an effective scheme. Again, issues imposed by field amplitude, frequency, and modes (DC, AC, Pulsed) will be discussed with respect to Brezovich-Atkinson criterion and potential side-effects.

Finally, certain applicable case studies of magnetic field-material combinations for handling, diagnosis and therapy studies and combinatory theranostic schemes will be proposed.

Plenary report

Combustion Synthesis of Advanced Materials

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The term "*combustion synthesis* (CS) of materials" means to fabricate a variety of different solid substances by using exothermic *self-sustained* non-catalytic chemical reactions [1]. The reaction systems may involve only solid reagents. In this case, the term "*solid flame*" is used [2]. The reaction mixture can also be a liquid solution, i.e., *solution combustion synthesis* (SCS) [3]. CS can occur in two modes: *self-propagating high-temperature synthesis* (SHS) and *volume combustion synthesis* (VCS). The characteristic feature of the SHS mode is, after initiation *locally*, the self-sustained reaction wave propagates through the mixture of reactants. During VCS, the entire sample is heated uniformly in a controlled manner until the reaction occurs simultaneously throughout the reactive volume. The number of products synthesized by CS increased rapidly starting from the 1970s and currently exceeds thousands of different compounds. Specifically, these materials include carbides (TiC, ZrC, SiC, B_4C, etc.), borides (TiB_2, ZrB_2, MoB_2, etc.), silicides (Ti_5Si_3, TiSi, MoSi, etc.), nitrides (TiN, ZrN, Si_3N_4, BN, AIN), and intermetallics (NiA1, Ni, Al, TiNi, TiA1, CoAl, etc.). Examples of the bulk materials and net-shape articles produced by CS are shown in the Figure.

The goal of this lecture is to present the fundamental basis of CS, which is critical to control the material's microstructure and, thus, properties. It will also be demonstrated how the uniqueness of CS conditions, i.e., extremely high temperatures (up to 4000 K), high preheating rate (up to 105 K/s), and short process duration (10-3-10 s), may lead to the unique properties of the fabricated materials. Special attention is paid to CS of nanomaterials, suitable for a variety of applications, including biomedicine.

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Plenary report

Recent Progress in the Development of Nanotheranostics for Cancer Diagnosis and Therapy

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Theranostics is a novel and innovative field of nanomedicine that combines both targeted specific therapy and imaging. The theranostics approach uses multifunctional nanostructured media specifically designed on a single delivery platform enabled by nanotechnology. This talk will expose the present status of research in the development of nano theranostics media and systems for cancer diagnosis and therapy. These nanoplatforms can perform multiple functions, such as tracking and imaging the diseased cells and delivering drug very precisely at the cellular level and can perform various therapeutic procedures using photothermal therapy, precision radiation brachytherapy and magnetic field–based hyperthermia. The fabrication of magnetic ferrite nanoparticles supported by biocompatible shells for the MRI contrast agents and hyperthermia treatment will be presented. Key factors that affected to the theranostics media (size, shape, magnetization, relaxation time, and other) will be discussed in detail. Development of these emerging technologies warrants a multifaceted approach to advance nanomedicine, which includes interdisciplinary collaboration, and partnerships among science, engineering, and medicine.

Plenary report

Applications of Magnetic Nanoparticles in Hyperthermia Therapy: A Painless Curing of Cancer

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As per the WHO report, the cancer is still the second highest leading cause of death all over the world. Despite the intensive advances in clinical technology,the treatment of cancer has been considered the most challenging health issue.Cancer is known to develop cell signaling and apoptosis, making it a highly complex and incompressible disease . The principal types of cancer therapies include radiation therapy, chemotherapy, and surgery. Although chemotherapy is often a first-line therapeutic approach for the treatment of a variety of cancer types, it may damage healthy tissues, leading to irreversible side effects. For example, the highly effective anti-cancer drug doxorubicin (Dox) can cause long-term and potentially lethal cardiovascular toxicity, which may occur many years after chemotherapy. Additionally, to avoid undesirable side effects, chemotherapy dosages are limited, which can ultimately lead to insufficient destruction of cancer. In recent years, however, an additional treatment modality like hyperthermia has been evolved which involves heating the tumor region with significant damage to normal cells. Hyperthermia treatment is divided into three main types: whole-body hyperthermia, regional hyperthermia, and local hyperthermia. In whole-body hyperthermia, the whole body is exposed to heat by an external heat source, such as radiofrequency waves, microwaves, or ultrasound waves. This treatment method can lead to bad side effects due to non-selective heating. Regional hyperthermia is an advanced method of hyperthermia treatment, which heats a selected large area of cells, such as an organ or limb or body cavity. Regional hyperthermia requires external applicators or thermal perfusions during therapy. Local hyperthermia is more often used to kill cancer cells in a selected small area, with greater selectivity by introducing heat carriers like magnetic nanoparticals into the body, such as Fe, Co, and Ni metallic nanoparticles and their oxides, which act as a heat source. Given the above-mentioned challenges with hyperthermia treatment, a novel method with improved effectiveness must be developed to treat cancer. In this regard, scientific research is directed towards the application of magnetic nanoparticles (MNPs) as a source of heat, called magnetic hyperthermia.

Magnetic iron oxide nanoparticles (IONPs) are one of the most extensively studied materials for theranostic applications. IONPs can be used for magnetic resonance imaging (MRI), delivery of therapeutics, and hyperthermia treatment. Silk is a biocompatible material and can be used for biomedical applications. Previously, we produced spheres made of bioengineered silk that specifically carried a drug to the cancer cells. To confer biocompatibility and targeting properties to IONPs, we blended these particles with bioengineered silk fibroin. The blending of silks (silk / Iron oxide) composite spheres. enabled the generation of cancer-targeting spheres with a high affinity for iron oxide nanoparticles, which has been used for anti-cancer hyperthermia therapy. Silk fibroin bionanocomposites being biocompatible, biodegradable, targetable, non cytotoxic and with high hyperthermia SAR values have become suitable and potential drug for painless curing of cancer.

Abstracts of invited reports

Invited report

Magnetic Nanoparticles in Biomedicine: Current Applications and Future Perspectives

M.A. Abakumov[1,2], N.A. Nikitin[1,2], A.G. Savchenko[2], V.P. Chekhonin[1]

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Nowadays magnetic nanoparticles bring a lot of attention as a theranostic platform by combining unique MRI contrast properties, ability to delivery drugs to tumors by magnetic field, ability to generate heat, being irradiated by high frequency alternating magnetic field and many others. However, each of the applications requires special design of nanoparticle shape, size, structure and surface chemistry.

This work is devoted to a brief introduction of what are the requirements for magnetic nanoparticles if one wants to use them in listed above fields, based on results previously obtained in our group.

We have shown that serum albumin coating is one of the best coating strategies for combination of drug delivery and MRI imaging, allowing to visualize tumor by MRI and delivery anticancer drugs, such as doxorubicin [1]. Moreover it was shown that combination of MRI imaging modality and photosensitizer molecules can provide a new tool for real time monitoring and therapy scheduling for deeply located tumors [2]. On the other hand such nanoparticles are not capable to provide any sufficient heating under influence of high frequency alternating magnetic field, whereas 8-12 nm cobalt ferrite nanoparticles are one of the best candidates for magnetic hyperthermia treatment allowing not only heat tumor locally, but also control the temperature for precise tumor therapy [3].

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Invited report

Experimental and Theoretical Study of Magnetic Carbon Nano- and Microspheres

L.A. Avakyan[1], A.S. Manukyan[2], D.B. Tolchina[1], A.T. Kozakov[3], A.V. Nikolskiy[3], A.V. Emelyanov[4], N.S. Sysakyan[2], H. Gyulasaryan[2], L.A. Bugaev[1]

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Ferromagnetism of compounds containing only p- and s-electrons is a very rapidly developing branch of science [1]. Recently, many experimental and theoretical works have appeared, indicating that the features of the electronic structure of carbon can lead to the appearance of ferromagnetic correlations, persisting up to high temperatures [2]. It was shown in [3] that if some carbon atoms in a graphene sheet are replaced by trivalent atoms (for example, B, N, Al) then a sufficiently large magnetic moment can occur in such a systems. According to [4], the magnetic moment can also be formed in a pure carbon structure if sp^2- and sp^3-hybridized carbon atoms are presented as the atoms of different valency.

In this work, we study the magnetic characteristics of three nitrogen-containing carbon samples at room temperature (RT), which were obtained by solid-phase pyrolysis of phthalonitrile PN = $C_6H_4(CN)_2$ at a temperature of 700°C, a duration of 30 min, and various pressures (p) in an autoclave. With the aim to vary the nitrogen atomic states in the synthesized samples, different pressures were considered: 0.01 bar, 0.5 bar, 1 bar, 3 bar, etc. TEM study of samples showed the presence of nanographene clusters in carbon nano- and micro-spheres. Analysis of X-ray photoelectron spectra (XPS) of the samples showed the variation of concentration of nitrogen in the samples. The decomposition of the C 1s-XPS spectra into the components of different carbon fractions enabled to determine the dependence of sp^2/sp^3 ratio (planar/spatial) of carbon bonds [4] in the samples upon the conditions of their synthesis.

The local atomic structure of carbon and nitrogen atoms was probed using C and N K-edge NEXAFS spectra. Panel (a) of Figure 1 shows the experimental N K-edge NEXAFS of the sample, while panel (b) presents the theoretical spectra, obtained using simple atomic models, based on a few atoms clusters, with some of them shown on the right figure part. The comparison of experimental and theoretical spectra shows that features A and B are originated from pyridinic and pyrrolic nitrogen atoms. The feature C emerges only when oxygen atoms are introduced in the vicinity of nitrogen.

The consideration of C K-edge NEXAFS shows the presence of both sp^2 and sp^3 hybridized carbon atoms. This allows it conclude that RT ferromagnetism in the studied samples arises as a result of the coexistence of two mechanisms associated both with the presence of trivalent N ions and with the presence of variously hybridized carbon atoms.

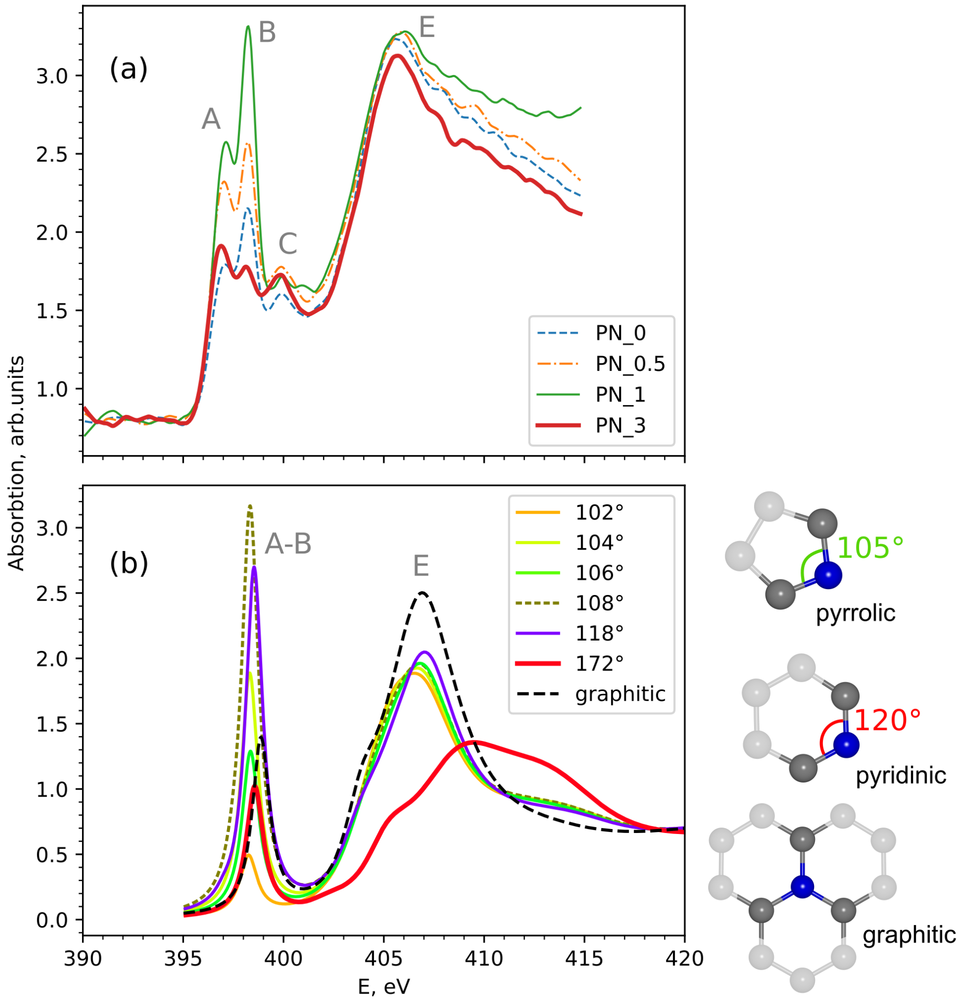

Figure 1. (a) Experimental N K-NEXAFS spectra of the samples obtained at different pressures (0.01 – 3 bar); (b) theoretical N K-NEXAFS spectra.

Acknowledgement: This work was supported by the project of RFBR and RA Science Committee in the frames of the joint research project RFBR 0-52-05011 Arm_a and SCS 20RF-166 accordingly.

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Invited report

The Rising Cost of Novel Therapies: Implications for Economically Challenged Populations

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The rising cost of cancer care is a major concern in global health today [1]. Novel cancer therapies are constantly being developed and are driving up healthcare costs worldwide [2]. However, only a small proportion of innovative new therapies find their way to the world population at large [1]. While most high-income countries have universal health care programs and ensure their populations have access to novel drugs, the majority of low- and middle-income countries (LMICs) suffer from major health disparities [3]. Moreover, certain novel technologies in cancer therapy are not even affordable for the health systems of high-income countries with universal health care [4]. This calls for global efforts to reduce the cost of new cancer therapies. Many factors influence these high costs, including the cost of the preclinical R&D efforts that go into the development of these therapies, the large costs of running clinical trials, and the costs of manufacturing [5, 6]. To ensure adequate access to emerging therapies, LMICs can collaborate with pharmaceutical companies to drive down the cost of running clinical trials by facilitating the recruitment of patients who have exhausted the treatment options they have access to. If handled with ethical due diligence, this can ensure that these patients receive treatment under optimal conditions and have firsthand access to potentially effective novel therapies. Another method of managing the costs of cancer care is investing in health technology assessment which would ensure that the limited resources of LMICs are spent as efficiently as possible. This is especially important when considering that new therapies do not necessarily achieve added clinical benefits that are equivalent to their added costs [7]. While neither of these solutions has the power to close the health equity gap that we have today, they can complement the efforts of the WHO and other global stakeholders to reduce the real-world impact of health disparities.

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Invited report

Shedding the Light on the Properties of the Nanomaterials with Scanning and Transmission Electron Microscopy

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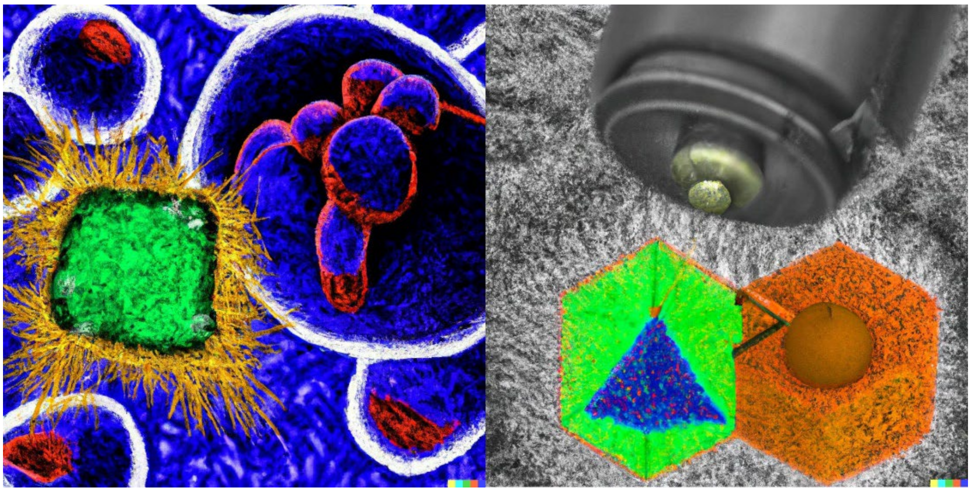
Since its invention in the beginning of the 20th century electron microscopy became an indispensable tool for material characterization, both for hard and soft matter. There are two types of electron microscopes – scanning (SEM) and transmission (TEM). Both are using electrons as the source of illumination which makes it possible to obtain key information about the sample on a local scale.

In conventional SEM the images are produced by secondary electrons emitted from the sample surface, and TEM images are formed by electron transmitted through a thin sample. Initially, electron microscopes were used to obtain information about surface morphology (SEM) or reveal crystal structure of the material (TEM). Further, several techniques utilizing signals resulting from interaction of incident electrons with sample's atoms, were developed. These techniques – Energy Dispersive X-ray Spectroscopy (EDXS) and Electron Energy-Loss Spectroscopy (EELS) - allowed to supplement structural data with information about sample chemical composition and state.

In my talk I will demonstrate how electron microscopy data leads to a better understanding of nanomaterials properties and help to optimize them to achieve desired functionality. I will give a brief introduction into microscopy basics and established techniques, as well as modern advanced methods - Electron Back-Scattered Diffraction (EBSD), precession diffraction, 3D tomography and in-situ microscopy. I will also touch on some important practical aspects such as dose management and using machine learning for data processing.



“Shedding the light on nanomaterials with Transmission Electron Microscopy”, images were generated with the assistance of AI DALL·E 2 (https://openai.com/dall-e-2/)

Invited report

Ferromagnetic Resonance: A Versatile Tool to Determine Magnetic Properties

M. Farle

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In this tutorial, I will introduce the technique of microwave spectroscopy and its different technical options to analyse static and dynamic properties of magnetic particle systems and single particles. Examples on how to extract information on intrinsic magnetic damping as well as magnetic anisotropy and high frequency susceptibility will be given for different types of materials ranging from ferro- to paramagnetic as well as from metallic to oxidic materials.

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Invited report

MPI and MFH: A Theranostic Pair Not Quite Made in Heaven

U. G. Hofmann

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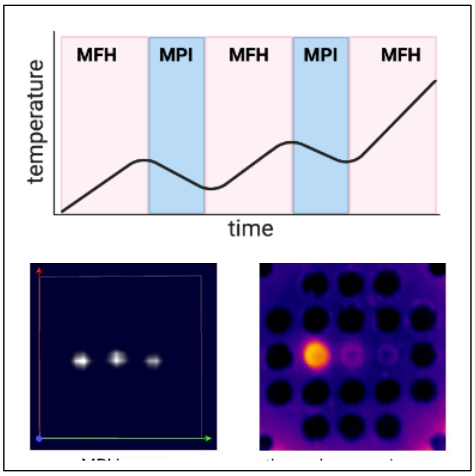
Magnetic Fluid Hyperthermia (MFH) is the sought after treatment for difficult tumors by over-heating them via magnetic nanoparticles in alternating magnetic fields. Magnetic nanoparticles can nowadays be used to produce density pictures in Magnetic Particle Imaging (MPI) systems rapidly revealing interesting, anatomy related features. What lies closer than combining the therapeutic MFH with the diagnostic MPI into one single device?



We succeeded in a fruitful cooperative project in integrating a 600W magnetic heating coil into a commercial pre-clinical MPI imager targeting phantom structures with less than 1mm diameter [1]. Consecutive heating and imaging phases demonstrated a clear increase in SPIO's temperature and their location with multi-color image reconstruction deep inside the carrier.

Since our ultimate goal is to treat glioblastoma, we aimed at locally heating the brain parenchyma up to 42°C to open the blood brain barrier of rodent models [3] allowing an effective chemotherapeutic treatment. Although a temperature increase by MFH was measurable by MPI itself [2], the cooling properties of blood flow through capillaries were not overcome resulting from insufficient SAR values of the iv injected nanoparticles. The BBB still awaits non-invasive opening by future generations of nanoparticles.

We conclude, that we are on the right path to the Theranostic Olymp, but are clearly not on the summit with acceptable nanomaterials.

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Invited report

Nanocomposites and Nanostructures for Biomedicine: Structure and Properties

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These report is devoted to the magnetic structure, phase composition of Graphene-Ferrite (GF), nanostructures (NS) as spinel-ferrites MFe_2O_4, $M_xFe_{3-x}O_4$ (M= metalls) and nanocomposites (NC) of the Core/Shell (CS) type. Interest in these materials is determined by their using in biomedicine. The method used for research was Mössbauer spectroscopy MS with a highly sensitivity for studying the phase states and magnetic structure of both complex composites and individual components. MS gives possibility to obtain information that is inaccessible to other methods.

The CS particles consist of a core, with high magnetic moment (for example, iron or others), which is covered with a magnetic sheath with good biocompatibility. GF NC consist of graphene and spinel ferrites, for ex. as Fe_3O_4, $CoFe_2O_4$. Main advantage of such materials is their versatility, as well as the ability to optimize the physical and chemical properties of the material.

As shown by Mössbauer studies the magnetic GF contain phases identified as spinels, iron carbides and iron-depleted carbon clusters that were not detected by X-ray diffraction. Those GF structures were able to retain the functional groups of graphene oxide. The efficacy of the magnetic GF systems for killing of cancerous cells is studied in vitro using HeLa cells in the presence of an Alternating Current magnetic field.

MNPs for biomedicine are used to create magnetic nanofluids or ferrofluids (FF). FF is colloidal suspension of a dispersed phase of MNPs 5–20 nm in size in a suitable liquid. It is necessary to develop methods for the synthesis of MNPs with a well-controlled size, a narrow particle size distribution, and stable properties in ferrofluids. The report describes the creation of MNPs by using MFe_2O_4, $M_xFe_{3-x}O_4$ (M=metalls) ferrites for FF.

In the case of the CS structures, f.a. as of $Fe_3O_4/\alpha\text{-}Fe_2O_3$, it was established that they consist of a magnetite (Fe_3O_4) core and a maghemite ($\gamma\text{-}Fe_2O_3$) shell. On the surface of the shell is formed a layer, in which the spin magnetic moments are canted relative to the moments in-side the shell. Between the core and the shell is formed an intermediate layer in the spin-glass state. So, for the first time was shown that CS systems have complicated magnetic structure and we must account it at the creation such particles for biomedicine.

As a result of this research, the dependence of the properties of GF NC and CS NS on the synthesis technology and particle size was shown, the interaction of the components and their influence on each other, as well as the phase state and magnetic structure, which significantly affect the properties of this NC, CS and NS materials.

Invited report

Nanocomposites and Functionalized Nanostructures for Biomedicine: Mössbauer Studies

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Progress in techniques for fabrication of magnetic nanoparticles (MNPs) has enabled the development of methods for synthesis of new types of MNPs, as core/shell (C/S), Bi-phase (BP) particles. MNP of C/S type consists of an inner core which made of a one material coated with another material as an external shell. So, in the case of CS MNP it is possible to combine materials with a high magnetic moment as core (for ex. Iron or others) and a shell with good biocompatibility (for ex. iron oxide or others). BP MNP consists of two magnetic materials with opposite magnetic properties, for ex. hard (spinels ferrites, hexaferrites) and soft (manganites) magnets, magnetic materials (with high magnetic parameters) and biocompatible (for ex. Hydroxyapatite or other) magnetic and ferroelectric materials.

A large fraction of atoms in the MNPs is located on the surface and the exchange interactions of these atoms are broken. This can lead to a change in the spin structure of only surface layer but do not change of volume structure of nanoparticle.

The main attention in the study of such particles is given to studying the dependence of their properties on the synthesis technology and particle size, while the phase state and magnetic structure significantly affect the properties of CS and BP MNP. It is very important to understand the magnetic structure of MNPs used for biomedicine, since such knowledge allows one to control the properties of particles during their creation.

One of extensively utilized for the analysis of properties of iron containing MNP is Mossbauer spectroscopy (MS) - a unique technique, which gives information about the valence state, stoichiometry, coordination type, magnetic structure, phase states. By using MS we can obtain information that is not available to other methods.

The review shows that Mössbauer spectroscopy is an unique and important technique for extracting unique information about relationships between the structure and magnetic properties of materials and providing evidence for changes caused by substitution effects in magnetic materials.

Invited report

Composites of Gold and CFO-Nanoparticles as an Instrument for Photothermal Therapy

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Nanocomposites are multiphase solid materials, which combine various structural and physical characteristics. Such combination of different characteristics makes it possible to produce multifunctional nanomaterials for biomedical applications. In current research we propose nanocomposites (Fig. 1, A) which consist a gold core (gold nanoparticles, (Fig. 1, yellow)) surrounded with cobalt ferrite nanoparticles (coated with dihydrocaffeic acid, (Fig. 1, purple)). Additionally, nanocomposites were covered with arginine. Biocompatibility tests performed on Huh7 and Jurkat cell lines and also peripheral blood mononuclear cells demonstrate dose doze-dependent cytotoxic effect (at concentrations 10, 50 and 100 μg/ml, data no shown). Huh7 human cancer cells were incubated in standard conditions (37 °C, 5% CO_2). For experiments Huh7 cells were treated with nutrient medium solution supplemented with nanocomposites for 24h. After incubation cells were placed to the chamber for photothermal therapy.

Experiments showed an increase of cell death rate to 42% ($p < 0.0001$) after complex treatment via nanoparticles and laser irradiation (Fig. 1, B, 100L). Additionally, the cytotoxic effect of composites was measured in the same conditions (without laser irradiation) for correct data analysis. Also, photothermal treatment inhibited cell viability for 22% ($p < 0.01$) more than singular nanocomposite's treatment (Fig. 1, B, 100).

This work was supported by the Russian Science Foundation (RSF, project number 21-72-20158).

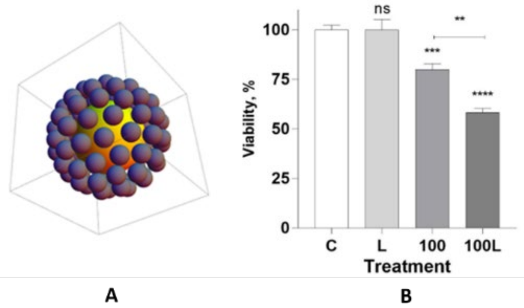

Figure 1. Nanocomposites (schematic model marked with letter A) inhibit viability of cancer cells (Huh7) after photothermal treatment (B).

Invited report

Microwave-Assisted Synthesis of Uniform Magnetic Nanoparticles

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The search for more efficient, scalable, reproducible and standardized synthesis methods able to control particle size and crystallinity is still a challenge in nanotechnology. The microwave-assisted process is an interesting alternative for the production of well-defined magnetic nanoparticles that are highly uniform and crystalline with diameters between 5 and 50 nm. Tuning of the size, chemical composition, and interstitial occupation of the ferrite structure offer a wide set of parameters to adjust the magnetic properties of the particles to the specific requirements for biomedical applications [1, 2]. The advantages of the microwave heating are mainly found in the improved product yields, shorter reaction times and reproducibility. Microwave irradiation provides a uniform rise in temperature over the whole reaction volume by coupling microwave energy to the molecules inside the reaction mixture. These particles found application in many different areas, from water remediation to NMR imaging [2].

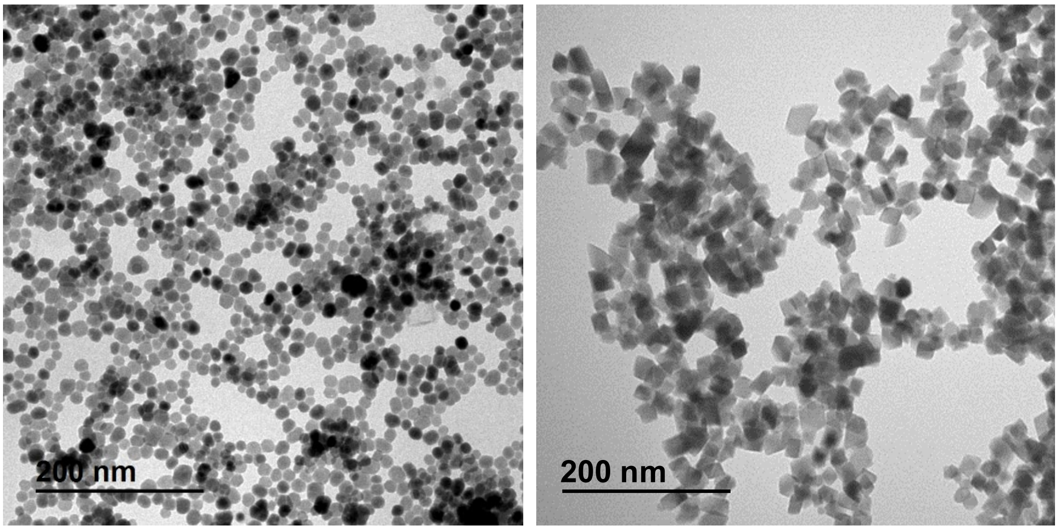

Figure 1. Magnetic iron oxide nanoparticles synthesized by microwave-assisted method in polyol (a) and in water media (b).

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Invited report

Scaling Down of the co-precipitation Synthesis to Tune Magnetic Properties of MXene-Based Nanocomposites

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Magnetic nanocomposites, which consist of a magnetic component (e.g., magnetic nanoparticles, MNPs) and two-dimensional MXenes, attracted a lot of attention as a prominent candidate for water remediation. Such materials can be used as nanoadsorbents with a high sorption capacity for heavy metal ions, cationic dyes and other contaminants, due to the extremely high surface proportion of the MXenes, and due to the magnetic component, such a nanoadsorbents can be easily removed from the polluted solvent by means of a magnetic field [1]. In this work we used the modified co-precipitation method for the fabrication of magnetic MNPs/MXene nanocomposites. It was shown that the application of ultrasonic stirring makes it possible to obtain iron oxide MNPs with high values of saturation magnetization. The achieved saturation magnetization values at room temperature (up to 79±4 Am^2/kg) are comparable to those obtained by other methods but requiring the use of toxic solvents and high temperatures. The influence of the concentration of iron cations in the initial solution on the structural and magnetic properties of the produced MNPs and nanocomposites was also investigated.

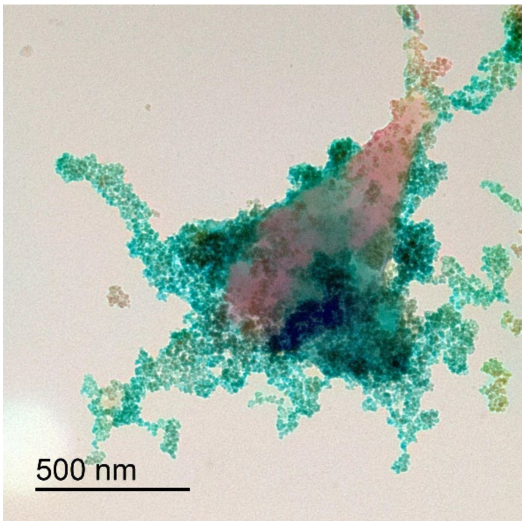

Figure 1. AI driven colored TEM image of MNPs(blue)/MXenes(reddish) nanocomposite.

This work was supported by the Russian Science Foundation under grant no 22-12-20036.

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Invited report

Design of Magnetic Nanoarchitecture for Theranostic

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Magnetic Nanoparticles (MNPs) are unique complex objects whose physical properties differ greatly from their parent massive materials. In fact, the magnetic properties are particularly sensitive to the particle size, being determined by finite size effects on the core properties, related to the reduced number of spins cooperatively linked within the particle, and by surface effects, becoming more important as the particle size decreases. [1–3] MNPs play an important role in nature, as they are commonly found in soils, sediments and rocks and may store information on the past Earth's magnetic field as well as environmental conditions at the time of sediment deposition. In addition, magnetic nanoparticles have generated much interest because of their possible applications in high density data storage, ferrofluid technology, catalysis and biomedicine (drug delivery, contrast enhanced MRI). Design of magnetic nano-architecture (MNA) for specific applications means to control the matter at the nanoscale, correlating magnetic properties, micro- and meso-structure and molecular coating. These MNA are typically of core-shell morphology, with a magnetic core and a shell that may be composed of polymers surfactants or mesoporous silica, which typically serve for embedding the therapeutic agents within their framework. Selectivity of the treatment is ensured through employing magnetic field responsive homing of the nanocarriers to the therapeutic area, along with possibilities for alternating magnetic field hyperthermia-resulted treatment of the ill tissues. The induced hyperthermia may be therapeutically active through causing denaturation of biomolecules in the treatment area, or/and through mediating release of the cargo therapeutic agents. Taking into account all of these points, this communication will focus on the design MNA for application in biomedicine discussing some recent results synthesis and functionalization of magnetic nanomaterials[4–6].

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Invited report

Magnetic and Magneto-optical Nanocomposites for the Benefit of Health

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A start of the start fabrication, characterization and application of superparamagnetic iron oxide nanoparticles (SPIONs) along with their applications in bio-separation and cancer Theranostics. Iron oxide nanoparticles (IONPs) have played a pivotal role in the development of nanomedicine owing to their versatile functions at the nanoscale, that facilitates targeted delivery, high contrast imaging, and on-demand therapy. Some biomedical inadequacies of IONPs on its' own, such as poor resolution of IONP-based Magnetic Resonance Imaging (MRI), can be overcome by co-incorporating optical probes onto them, which can be either molecule-based or nanoparticulate. Optical probe-incorporated IONPs, together with two prominent non-ionizing radiation sources (i.e. magnetic field and light), enables a myriad of biomedical applications from early detection to targeted treatment of various diseases. However, selecting right optically active photosensitizer is the key for nanomaterials' function. For example, UV sensitive dye methylene blue has been studied extensively, however, due to the limitation of UV light penetration depth in tissues limit it's use as a photosensitizer. Therefore, we found an alternate photosensitizer, Indocyanine Green (ICG) in connection with Royal Blackburn Teaching Hospital who has been using routinely for Liver cancer surgery due to it's affinity towards Liver tumour and visualisation using Near Infrared (NIR) light. In our hypothesis, ICG incorporated magnetic nanoparticles can be administered and monitored via NIR imaging (diagnosis) before applying the combination of AMF+NIR light for localized heating (therapy).

In my talk, I will cover the latest research1-10 in this topic from the University of Central Lancashire.

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Invited report

Career Prospect in Nanotechnology: Applications in Food, Water, Pharmaceutical and Medical Sectors

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An overview of group's research on magnetic nanomaterials and their applications in the separation of nucleic acids (DNA and RNA) from the biological cells, Water purification and cancer treatment will be covered in this talk. The following figure provides an overview of Nano-biomaterials research at the University of Central Lancashire, United Kingdom. The talk will also provide the recent trends on Nanotechnology especially dealing with Covid-pandemic.

Invited report

Interplay Between the Intrinsic Features of Magnetic Nanoparticles and their Assembly on the Heating Performance under AC Fields

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Optimising the heat released by magnetic nanoparticles (MNPs) under AC fields is critical for heat-triggered biomedical applications as hyperthermia cancer treatment or magnetogenetics, and therefore a good comprehension of the heating ingredients becomes essential. The problem is that the heat release is defined by various parameters intrinsically entwined that need to be simultaneously considered: the particle composition, shape, and size; its geometrical arrangement in relation to others; and the orientation of the AC field. The particle composition, which stands for its magnetic nature, points out as a critical parameter defining the effectiveness of the conversion of electromagnetic energy into heat, in first approximation defined by its magnetic anisotropy constant (which dictates both the maximum energy that can be absorbed, and the performance under a certain field amplitude). However, it is worthy to emphasize the fact that the most studied MNPs for biomedical applications, iron oxides, are described in terms of an effective uniaxial contribution despite being well known that their magnetocrystalline anisotropy is cubic. This is to say, it is inherently assumed that an anisotropy term coming from the shape will rapidly dominate over the magnetocrystalline one – how does such contribution modify the heating scenario? Interparticle interactions may in addition strongly modify too the corresponding local energy landscape, and therefore the heating performance. Concomitant to these is also the role of the particle size, which together with the anisotropy constant defines the height of the energy barriers and therefore the effect of the thermal fluctuations; however, size may also modify the role of the surface contribution to the anisotropy and, what may even be more relevant, the inner-particle magnetisation reversal mechanism and therefore the associated heat production. I will revise here some of the most relevant effects, as we have reported in our recent work [1], with a particular focus on the theoretical analysis.

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Invited report

Magnetic Nanomaterials in Biomedicine: Synthesis and Functionalization

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Magnetic nanoparticles (MNPs) are exploited in several biomedical applications: in diagnostics, as contrast agents for magnetic resonance imaging or tracers for magnetic particle imaging; in therapeutics, as cargos for drug delivery or heat mediators for magnetic hyperthermia. In magnetic hyperthermia treatment, the MNPs, submitted to an AC magnetic field, release heat in the tumor tissue in which they have been localized [1]. The physical mechanism at the base of heat generation, estimated by the specific loss power (SLP) value, depends on several parameters; some of these are correlated to the properties of the AC magnetic field (i.e., intensity and frequency), whereas others are strictly depending on the intrinsic properties of the magnetic particles such as composition, size, shape and surface coatings. Among the open issues preventing NDs full exploitation as therapeutic agents, reliable and reproducible methods of measuring the functional capability have to be established. In case of magnetic hyperthermia, traceability of specific absorption rate (SAR) is far to be gained. In particular, a careful characterization of the magnetic properties regarding both the fundamental properties of the studied particles (magnetization curves, hysteresis losses) and their thermal properties during hyperthermia treatments is required [2,3]. Indeed, these data are often available from different setup operating in different experimental conditions that make difficult to ensure measurements traceability. In this context, magnetic hysteresis loops areas and their role on the heat released have been studied with the aim of providing reliable and reproducible methods to measure the specific absorption rate (SAR). As a consequence, the understanding and control of magnetization process is crucial and turned out to be strongly dependent on magnetic interactions among MNP, usually neglected.

In this talk, magnetic hysteresis loops areas and their role on the heat released will be highlighted taking into account both from the material characteristics (i.e shape, composition, dimension and quantity) and experimental conditions (measuring frequency, exciting waveform, magnetic field peak intensity) with the aim of providing reliable and reproducible methods to measure the specific absorption rate (SAR) or Specific Loss Power (SLP).

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Abstracts of oral reports

Oral report

Photothermal Conversion Efficiency of Composites of Gold and CFO-Nanoparticles

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Cobalt ferrite $CoFe_2O_4$ (CFO) nanoparticles are widely used in the magnetic hyperthermia studies [1]. Low toxicity and high magnetic moment make them suitable for cancer treatment. A different way is to use strong magnetic fields to drag magnetic nanoparticles and concentrate them in the desired location within living tissues as in the magnetomechanical therapy [2]. Recent developments in the biocompatible nanoparticle studies include the combination of different properties, for example, magnetic and plasmonic, in a single nanoparticle agent. Plasmonic nanoparticles, such as gold, are used in the photothermal therapy, that utilizes infrared radiation to locally heat tissues with cancer cells [3]. CFO nanoparticles along have low ability to produce heat under an infrared radiation, however, the composite nanoparticle agent made of CFO and gold could be used in the combined therapies.

In current research nanocomposites made of a gold core surrounded with CFO nanoparticles, coated with dihydrocaffeic acid and arginine, were studied for the ability to convert light into heat. The colloidal water solutions of nanoparticles of different concentrations were examined in the controlled infrared laser exposition in a photothermal experimental setup. Laser heat induction has been measured by an infrared camera, and the light-to-heat conversion coefficient has been extracted from the temperature evolution on warming-cooling cycles. As the results of the study showed, the addition of the gold cores to the CFO at least doubles the light-to-heat conversion efficiency compared to CFO nanoparticles along, indicating the possibility of extension of the biocompatible composite nanoparticles studies.

This work has been supported by the grant of the Russian Science Foundation, RSF 21-72-20158.

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Oral report

Disk-shaped Nano- and Microstructures: A Tool for Cancer Therapy

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Spatiotemporal application and modulation of mechanical forces in biological systems are of great interest for studying a wide range of mechanotransduction processes involved in therapy, including cancer mechano-immunoengineering [1,2]. Cancer cells perceive mechanical stimuli such as tissue stiffness, shear stress, and tissue pressure from the extracellular space, which ultimately alter cancer cell migration, proliferation, and metastatic spread [3,4].

Remote manipulation of cancer cells in an external magnetic field thus could be implemented by using magnetic nanoparticles that serve as the "nanotransducers," converting the energy of a magnetic field into a mechanical force or a torque. To maximize this torque, the use of disk-shaped structures (synthetic antiferromagnetic and/or vortex) is preferred.

In this literature-based talk, I will present the latest concepts about disk-shaped nano- and microstructures as a tool for cancer therapy. This includes the manipulation performed on the outer cell membrane (e.g., via the mechanosensitive ion channels) and when the disk-shaped particles are internalized and involved in the destruction of lysosomes, leading to cancer cell apoptosis.

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Oral report

Nanothermometry of Magnetic and Photoactivated Nanoparticles for Hyperthermia Therapies Using X-rays

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Temperature is a critical parameter that exerts a major influence on biological events, metabolic rates and homeostatic processes in cells. Thermal nanotherapies are non-invasive approaches for tumor ablation, where localized heat generation is mediated by magnetic and photo-themal nanomaterials for efficient therapeutic purposes in the fight of cancer. However, the intended therapeutic application requires optimal heating efficiency in the intratumoral environment, where cellular confinement effects play an important role in the final heat-generating performance, which can preserve healthy tissues. Actually, therapeutic effects have been observed by localized nanoparticle heating without a detectable macroscopic temperature rise [1,2]. In this work, we investigate the heating efficiency of nanoparticles subjected to magneto- and photo-thermal effects in combination with other therapeutic approaches methods [3,4]. Moreover, we also present the use of the extended X-ray absorption fine structure (EXAFS) analysis as a direct and *in situ* nanothermometric probe to determine the local temperature at the nanoscale of photothermal nanoparticles upon laser photo-excitation, revealing significant nanothermal gradients [5].

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Oral report

Magnetic and Hyperthermia Properties of Carbon Coated Fe-Fe_3C Nanoparticles Synthesized by Ferrocene Compound

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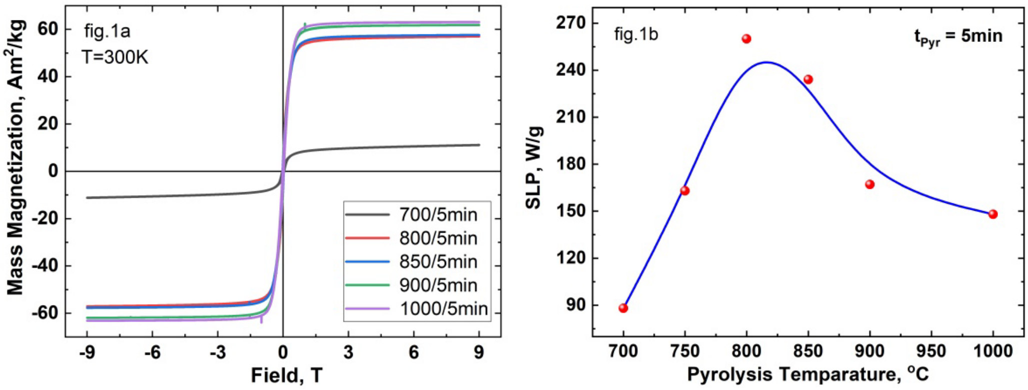
Magnetic nanoparticles (MNPs) have become a material of growing interest due to their perspective applications in various biomedical areas such as magnetic resonance imaging (MRI), drug delivery and magnetic hyperthermia. Magnetic hyperthermia aims to produce magnetically-mediated localized heating by low-frequency electromagnetic waves. The requirements to use MNPs for clinical purposes are their stability in biological environments and no toxicity, in addition to their appropriate magnetic properties to be remotely activated by an external magnetic field.

Iron-cementite (Fe-Fe_3C) magnetic nanoparticles in a carbon matrix were synthesized by a solid-phase pyrolysis of ferrocene ($FeC_{10}H_{10}$). The pyrolysis process was carried out in a closed quartz tube from 700°C to 1000°C for 5 minutes. Samples prepared at different pyrolysis temperatures were analyzed for their crystallinity, morphology, and magnetic features which in turn have an impact on magnetic heating efficiency.

Magnetic measurements at 300K show that mass magnetization at 9 T increases with increasing pyrolysis temperature up to 6 times from 11 Am^2/kg at 700°C to 63 Am^2/kg at 1000°C (Fig.1a). It means that, by varying the pyrolysis temperature, one can change the concentration of Fe and Fe_3C which have characteristically different magnetic properties. The heating efficiency of our samples was evaluated by preparing aqueous solutions of 6.5 mg/ml concentration and exposing them in AC magnetic field with parameters 375 kHz/60 mT. SLP values are collected in Fig.1b. The maximum SLP (Specific Loss Power) of 260 W/g, which is considered as a competitive value for further biomedical exploitation, is achieved for the 800°C sample (Fig.1b).



This work was supported by European Union's Horizon 2020 research and innovation programme under grant agreement No 857502 (MaNaCa).

Oral report

Biomedical Applications of Magnetic Nanoparticles

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Nanotechnology, using the enormous potential of nanoparticles, has made great strides in the treatment and diagnostics of diseases. It is believed, that nanoparticles of the "core-shell" type, controlled by a magnetic field, will be used in hyperthermia, chemotherapy, magnetic resonance imaging as carriers of drug delivery systems – theranostatic instruments with high bioavailability [1, 2]. The results of the particles physicochemical parameters study showed, that the structures obtained by us, belong to the Fe_3O_4 cluster, are nano-micro-sized structures of the "core-shell" type, have superparamagnetic properties, and, therefore, can be used as theranostic agents.

Keywords: nanobiotechnology, nano-micro-sized "core-shell" type structures, superparamagnetic, *H. perforatum* L.

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Oral report

Mathematical and Computer Modelling of the Effects of Interactions, Structure Formation and Polydispersity on the Dynamic Susceptibility and Magnetic Relaxation of Ferrofluids

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Linear response theory relates the decay of equilibrium magnetization fluctuations in a ferrofluid to the frequency-dependent response of the magnetization to a weak ac external magnetic field. The characteristic relaxation times are strongly affected by interactions between the constituent particles. Similarly, the relaxation of an initially magnetized system towards equilibrium in zero field occurs on a range of timescales depending on the structure of the initial state, and the interactions between the particles. The topic of this contribution is the relationship between the time scales for the linear response, and the time scales for relaxation from an initially aligned state.

In this work, ferrofluids are modelled as colloidal suspensions of spherical particles carrying point dipole moments, and undergoing Brownian motion. Recent theoretical and simulation work [1] on the relaxation and linear response of these model ferrofluids is reviewed, and the effects of interactions, structure formation, and polydispersity on the characteristic time scales are outlined. It is shown that:

(i) in monodisperse ferrofluids, the timescale characterizing the collective response to weak fields increases with increasing interaction strength and/or concentration;

(ii) in monodisperse ferrofluids, the initial, short-time decay is independent of interaction strength, but the asymptotic relaxation time is the same as that characterizing the collective response to weak fields;

(iii) in the strong-interaction regime, the formation of self-assembled chains and rings introduces additional timescales that vary by orders of magnitude; and

(iv) in polydisperse ferrofluids, the instantaneous magnetic relaxation time of each fraction varies in a complex way; the interactions cause the small (fast) particles to relax asymptotically at a rate dictated by the large (slow) particles, which dominate the instantaneous magnetization to which the small particles are coupled.

Support by the Ural Mathematical Center, Project No. 075-02-2022-877, is acknowledged.

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Oral report

A Single-Layer Flat-Coil-Oscillator-Based Technology as a Highly Sensitive Promising Detector for State-Of-The-Art Applications in Different Fields of Science

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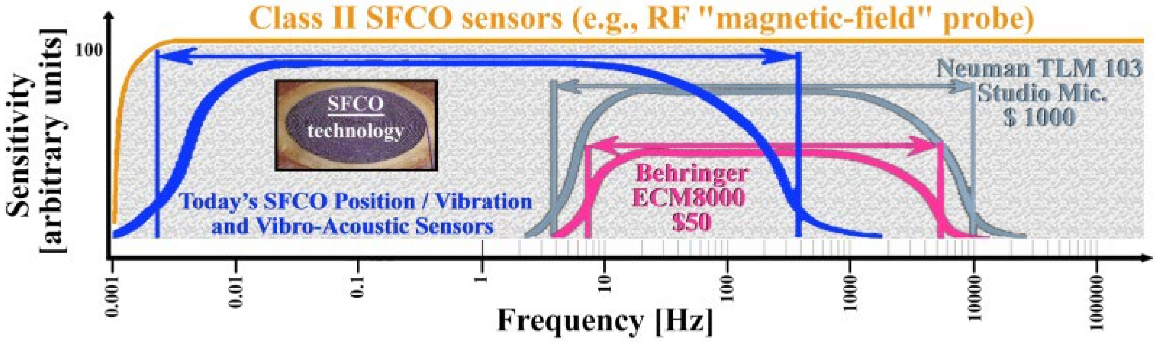
A low-power stable self-oscillator with a single layer flat coil was proposed by us in the late 1990s as a sensitive measurement method. It soon became a Technological Platform called a single-layer flat-coil-oscillator technology (**SFCO**-technology). Two classes of sensors were designed based on SFCO-platform: with (Class I) and without (Class II) the mechanical vibrating system. Both of them have already demonstrated their capabilities to solve problems of experimental physics and engineering. In particular, they allowed studying fine properties and clarifying the mechanism of superconductivity in high-T_c superconductors. This method helped also to increase resolution of detectors in seismology/geophysics and develop diagnostic techniques for use in physiology and biophysics. We also showed the feasibility of using these novel SFCO-sensors for non-contact far-field non-destructive scanning of various structures and media.

SFCO-sensors are characterized by high sensitivity and the ability to detect mechanical vibration signals in an unprecedentedly wide frequency range – from quasi-stationary movements to ultrasonic frequencies (see Figure).



Physical principles of operation of SFCO-sensors are based on the change in frequency and / or amplitude of the measuring oscillator. In sensors with a vibrating system (Class I), the measured effect is determined by the distortion of the *MHz*-range testing field's configuration near the coil plane, leading to changes in the oscillator frequency. For the Class II SFCO sensors (e.g., the "magnetic-field" (**MF**) probe, the *Q*-meter, the *MF*-probe-based SFCO magnetometer, etc.) the main measured value is the amplitude of the test-oscillator. However, the reasons for changing the amplitude of the oscillator may differ from the case of the Class I sensors. In studies of dielectric media, one of the most probable mechanisms should be considered absorption of detecting coil's *RF* field's power by the medium under the study due to the "imposed" reorientation of the dipole structures of the medium by the measuring electromagnetic field of the oscillator.

In our report, we discuss both principles of operation of SFCO sensors, and numerous measurement-data obtained by these sensors in different fields of science and technology. Wide potentials of novel SFCO sensors for bio-medical diagnostics, as well as for magnetic nanomaterials' physical properties characterization will be also discussed.

Oral report

Magnetic Field Stimulation of the Distribution of $CoFe_2O_4$ Nanoparticles in Macroobjects and Living Cells

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An analysis of the interaction of magnetic nanoparticles (MNPs) of cobalt ferrite $CoFe_2O_4$ with cells and a living organ under the action of an external magnetic field of 1.2 T was carried out. We used magnetic $CoFe_2O_4$ nanoparticles coated with PEG (Fig. 1). MNPs with this PEG coating showed good biocompatibility.

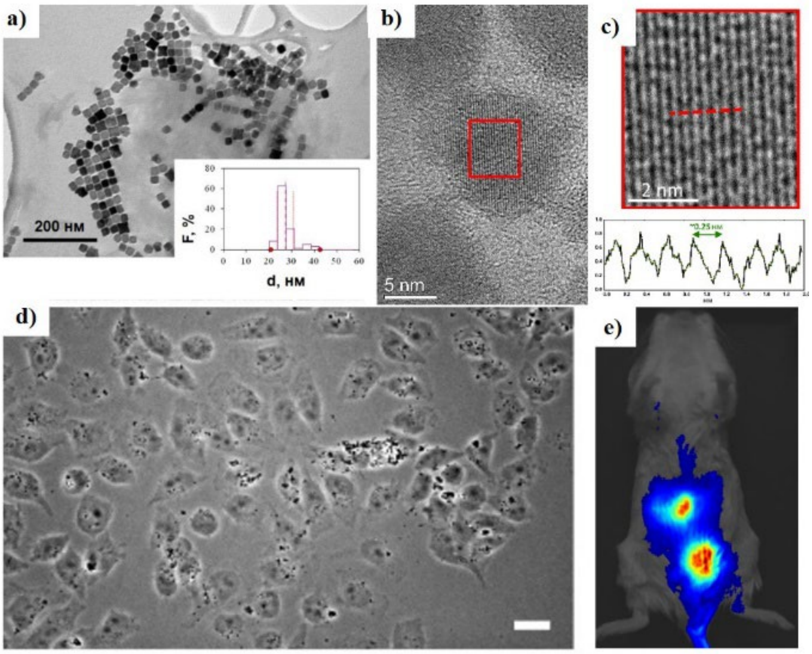

Figure 1. TEM image of $CoFe_2O_4$ nanoparticles[1] (a) and enlarged images of the marked area (b). Line profiles across atomic planes (c). Optical microscopy of living cells after incubation with MNP-12@BDP-TR in a magnetic field (d). Distribution of MNP in the laboratory mice after a single injection (e)

The application of a constant magnetic field of 1.2 T ensures efficient delivery of MNPs into the living cells. At the same time, we found that in the area of application of a constant magnetic field, nanoparticles with a diameter of 12 nm are localized mainly in cells, while nanoparticles with a diameter of 27 nm are found both in cells and in the intercellular space. In a living organism (laboratory mice) nanoparticles accumulate over time in different areas without exposure to an external magnetic field. The result with accumulation in the brain indicates the passage of the particles of the blood-brain barrier. After magnetic exposure, here is a shift in the accumulation of nanoparticles depending on the position of the magnet (Fig. 1). The possibility of manipulating MNPs inside a living organism opens up wide possibilities for their use as agents for magnetic hyperthermia.

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Oral report

3D Magnetic Printing: From Filament Fabrication to Hyperthermia Scaffolds

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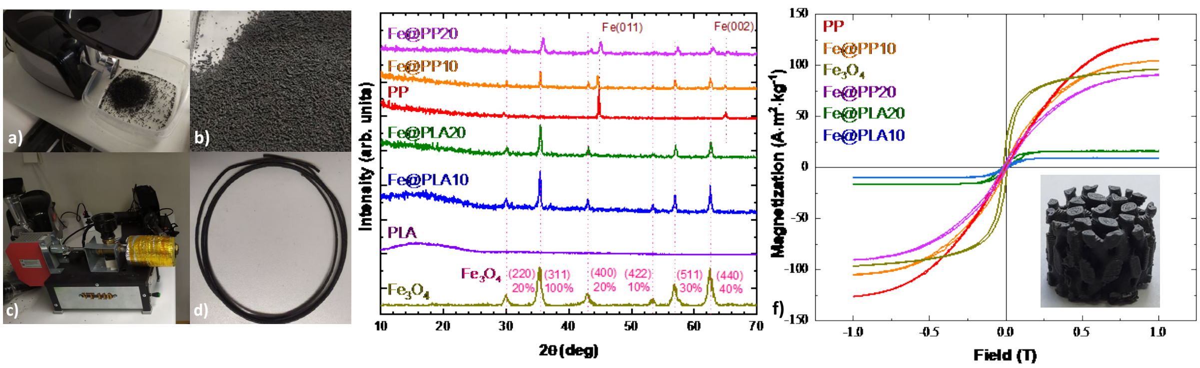
Three-dimensional printing technology has emerged as an attractive technique for producing scrupulously constructed biomimetic 3D structures with great precision and accuracy. Fabricating magnetic scaffolds using additive methods such as 3D printing reveals a plethora of cutting-edge applications such as tissue engineering, bone healing and regeneration, drug delivery, and magnetic hyperthermia. The development of novel polymeric composite magnetic materials is a critical initial step in this process. The current study outlines a process for fabricating (Fig. 1) and 3D printing polymer-bonded magnets via the Fused Deposition Modeling (FDM) method. Polymer-bonded magnets are composites that have permanent magnet material incorporated in a polymer binder matrix. Commercial magnetite magnetic nanoparticles are combined with PLA (PolyLactic Acid) powder (Fig. 1b), a common thermoplastic material used as 3D printing filament, using a low-cost mixing extruder (Fig. 1c). The powder mixture is synthesized and extruded to create the 3D printing filament (Fig. 1d), which is then structurally (Fig. 1e) and magnetically (Fig. 1f) characterized before the printing process. Finally, magnetic polymer scaffolds are successfully 3D-printed (one shown in Fig. 1f inset) using composite filaments of different concentrations in magnetite and finally evaluated in magnetic hyperthermia. Our results demonstrate that the magnetite nanoparticles may play a key role in the magnetic polymer filament fabrication as they can act as tuning factors on their final magnetic, structural and thermal properties.



Acknowledgment

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Oral report

Effect of $CoFe_2O_4$ Nanoparticles on Ionic Permeability of Phosphatidylcholine Membranes

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The effect of NPs on biological systems appears due to cell modification[1]. Since the cells are covered by membranes, the effects of NPs on biological systems depend on permeability of the membranes as well as on physical and chemical processes initiated by NPs in cell membranes. Permeability of a lipid bilayer covering a cell depends on NP size, shape, curvature of the membrane induced by NPs, polarity of membrane side groups, and particle-membrane interactions.
In our work[2], structural rearrangement of the membrane in the presence of $CoFe_2O_4$ NPs leads to 10-fold increase of ionic conductivity of phosphatidylcholine bilayer lipid membrane at an average distance between the nanoparticles of 0.25 μm. Current pulses and discrete distribution of their amplitudes can be explained by the appearance of an infinite percolation cluster of connected high conductive defects induced by NPs. The concentration dependence of conductivity corresponds to percolation transition realized by infinite fractal of fractional dimensionality $2 < \varepsilon < 3$. The electrical percolation threshold happens when ~ 0.2% coverage of the membrane surface is reached. Infinite fractal appears at 50% coverage of the membrane by large 100 – 200 nm crossing defects of high conductivity, surrounding small NP's of 14 nm diagonal. Structure of lipid membranes changes under NPs deposition. Lipid layers, where the tails of the lipid molecules are located demonstrate changes in the FTIR spectra at wavenumbers 980 cm^{-1} and 1025 cm^{-1} corresponding to Fe – OH and Fe–C-H bonds formation. Visualization of membrane areas at these wavenumbers by s-SNOM microscopy reveals distorted structure of the membrane around individual NPs.

Redistribution of integral intensities of the lines in NMR spectra indicates structural changes of membrane area, where lipid tails are located. Atoms of the CH_3–CH_2 groups are involved in the formation of Fe – OH and Fe = C-H bonds between lipid and NPs as detected by FTIR. The newly appearing lines correspond to alkyl H–C–H or –NH groups disturbed by NPs in the bulk part of the membrane.

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Oral report

Magnetic Heating Investigation of Iron-Cementite Nanoparticles in Carbon Matrix

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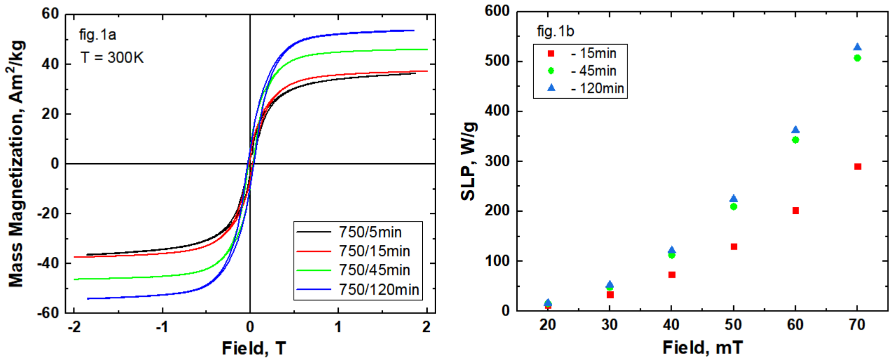
Magnetic nanoparticles due to their unique properties are of great interest in biomedical applications, such as magnetic hyperthermia, magnetic resonance imaging and drug delivery. Particularly non-toxic iron based magnetic nanoparticles with core-shell architecture offers tunable magnetic properties towards efficient magnetic heating making them appropriate candidates in magnetic fluid hyperthermia of cancer cells.

In this work, the structure, morphology, size distribution and magnetic behavior carbon coated iron-cementite (Fe-Fe_3C) magnetic nanoparticles prepared by ferrocene ($FeC_{10}H_{10}$) at 750 °C solid-phase pyrolysis with tunable pyrolysis duration from 5 to120 min, have been investigated using XRD, TEM, and PPMS.

An increase in the pyrolysis time also leads to an increase in the amount of iron in Fe-Fe_3C particles, as confirmed by XRD data. Magnetic measurements at room temperature show that the magnetization increases with increasing pyrolysis time. (Fig.1a). By recording, minor DC hysteresis loops at 60 mT (i.e. hyperthermia field), we evaluate the specific loss power (SLP) efficiency due to magnetic hysteresis losses (Fig.1b) which validate the calorimetric SLP values obtained from typical magnetic particle hyperthermia AC measurements. Particularly for the sample showing highest heating feature (T_p=750 °C, t_p=45min) SLP(calc)=343W/g while SLP(exp)=350W/g at 60mT.



This work was supported by European Union's Horizon 2020 research and innovation programme under grant agreement No 857502 (MaNaCa).

Oral report

Biofunctionaized Magnetic Nanodiscs Applied in Medicine

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One of the main problems of cancer treatment is the fight against metastases and individual cancer cells. In 2010, it was proposed to use permalloy nanodiscs with a vortex magnetization structure to fight brain glioma cancer cells [1]. In a previous study, we have already shown the antitumor effect of nickel microdiscs in Ehrlich ascitic carcinoma [2] and glioblastoma [3]. Others solutions are also known [4].

This paper presents a "Smart nanoscalpel" - a combination of three-layer Au/Ni/Au magnetic nanodisks with a quasi-dipole magnetization structure, immobilized by fluorescent dye molecules and DNA aptamers to human glioblastoma cells, and a software and hardware complex for remote control of the process of magnetomechanical microsurgery by exposure to alternating magnetic fields (up to 100 Hz) intensity (up to 200 Oe). As a result of experimental and theoretical studies, the following were selected: (1) signal shape, frequency, strength and duration of the magnetic field, (2) diameter, layer thickness, magnetic properties and technology for obtaining nanodisks (3) drug samples with aptamers; (4) the mechanisms of their interaction with molecular-cellular targets are being studied.

Efficacy was evaluated in vitro on Ehrlich ascitic carcinoma cells and primary cultures of human glioblastoma, as well as in vivo on mice with drug immunosuppression, which underwent xenotransplantation of human brain glioblastoma cells.

This research was funded by the Regional State Autonomous Institution "Krasnoyarsk Regional Fund for Support of Scientific and Scientific and Technical Activities", (application code № 2022060108781).

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Oral report

Schiff Base Copper Compounds as Radioenhancer Agents

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For the last years, copper complexes have been intensively implicated in biomedical research as components of cancer treatment. In this study, we provide highlights of the synthesis, physical measurements, structural characterization of synthesized Cu(II) chelates of Schiff Bases and their radioenhancement capacity *in vitro*. The methods of cell growth, viability and proliferation were used. All compounds exerted very potent radioenhancer capacities in different concentrations and acted in dose-dependent manner. The studied copper (II) compounds, in combination with irradiation, are more efficient at delaying cell growth and at reducing cell viability *in vitro* than the irradiation administered alone. In conclusion, the studied copper compounds have a good potential for radioenhancement.

Abstracts of poster reports

Poster report

Influence of Metal Oxide Nanoparticles in the Stability and Conductivity of BLM

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In recent years, nanotechnologies and nanoparticles have been increasingly used in many fields of science and practice, which are due to their unique chemical and physical properties, high density and limited sizes of corners and edges on their surface. Potential technological applications of metal oxide nanoparticles play a vital role, causing considerable interest of researchers in the field of chemistry of materials, medicine, agriculture, information technology, biomedicine, optics, electronics, and catalysis. The specific size of the nanoparticle can alter magnetic, conducting, chemical, and electronic properties. Metal oxide nanoparticles have wide applications in biomedical applications as drug delivery systems for treatment and diagnosis. Currently they are widely used in medicine as targeted carriers of drugs for damaged tissue. Nanoparticle-cell interaction begins with their primary interaction with biological membranes [1]. Lipid bilayer is the basic structural element of biological membranes.

This work is devoted to the study of the effect of metal oxide nanoparticles (ZnO, CuO, and Al_2O_3), with an average size of 40 nm, on the stability and conductivity of BLM. The experiments were performed on BLM obtained from a mixture of 1,2-dipalmitoyl-*sn*-glycero-3-[phospho-*l*-serine] (DPPS) and 1,2-dipalmitoyl-*sn*-glycero-3-phosphocholine (DPPC) of the company Avanti Polar Lipids in a ratio 1:1. Voltage (0.20-0.55V) was applied to the BLM using chlorine-silver electrodes connected to the ADC and controlled by a computer. Experimental points were obtained depicting the dependence of the average BLM lifetime on the potential in the absence and presence of metal oxide nanoparticles in the solution with concentration 5μg/ml. The parameters characterizing the BLM stability (BLM lateral tension, the linear tension of the pore edge in the BLM, and the pore diffusion coefficient in radius space) were determined by fitting the experimental data with a theoretical curve for the dependence of the average lifetime of the BLM on the potential by the least squares method [2]. The stability of BLM in an electric field in the presence of different types of metal oxide nanoparticles is investigated. It was shown that the stability of BLM depending on the type nanoparticles is in the following order: $Al_2O_3 < CuO < ZnO$. It was shown that the presence of ZnO nanoparticles in the surrounding BLM solution leads to a more stable state of BLM than that of CuO and Al_2O_3.

This work was supported by Grant №21 T-1F244 of the Committee of Science RA.

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Poster report

Development of a Diagnostic Method for Crohn's Disease Using Ferromagnetic Nanoparticles Fe_3O_4-Au

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Crohn's disease is a chronic inflammatory disease in which the intercellular distance in the epithelial layer of the terminal fragment of the small and large intestine is increased [1]. Definition of the Crohn's disease from ulcerative colitis remains a diagnostic problem. Symptomatologies of these diseases are similar, but the Crohn's disease is manifested by a deep inflammation, which can affect any part of the digestive tract, while at the ulcerative colitis the lesion covers the area of the colon, and inflammation will only affect the superficial layers of its wall.

There are many methods to diagnose the Crohn's disease, such as magnetic resonance imaging, computed tomography, confocal endoscopy, ultrasound, biomarkers, laboratory tests [2]. In this work we propose the method for the Crohn's disease diagnosis based on using of hybrid Fe_3O_4-Au nanoparticles.

In the experiment, there were used wild-type mice of two groups: the group of control mice and the group of mice with gastrointestinal tract disease mimicking the symptoms of the Crohn's disease. The symptoms were induced by the oral injection of Sigma Aldrich sodium dextran sulfate solution. The idea was done to determine a possible penetration of nanoparticles (NPs) into the intercellular distance in the intestinal wall. To do that mice were also divided into subgroups depending on the diameter of the Fe_3O_4 nanoparticles. Mice received a solution of Fe_3O_4-Au nanoparticles at the concentration of 200 μg/ml through the gavage (esophagus). Three types of nanoparticles were used depending on the diameter of Fe_3O_4 NPs: d= 5 nm, 15 nm, and 25 nm.

The aim of this work was to determine the metabolic elimination time of the Fe3O4-Au hybrid nanoparticles in feces, blood, and liver samples. Magnetic properties of the dehydrated liver, blood, and feces samples were studied with the vibration sample magnetometry (VSM). Feces samples from mice, which did not receive a dose of nanoparticles, show diamagnetic behavior that is characteristical for biological tissues. For the group of healthy mice, which received nanoparticles with the diameter d= 5, 15, and 25 nm, the highest magnetic moment for feces samples was detected for the sampling time of 8, 24, and 24 hours, respectively. The nanoparticles were also found in feces of sick mice.

There was no magnetic signal for the liver samples. On contrary, ferromagnetic behavior, hence a presence of NPs, was detected for some blood samples of sick mice, suggesting a penetration of the nanoparticles into the blood.

Poster report

Effect of Nanoparticles on Erythrocyte Membranes at Irradiation

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In recent years, nanoparticles have attracted great interest in various areas of human science, in particular biomedicine, including anticancer, antibacterial, antioxidant, antidiabetic, and anti-inflammatory activities. They are also used for drug delivery to the target. Dosage's nanoparticles determine the power of delivering the drugs into the body for more therapeutic efficiency. However, for decreasing the number of side negative effects of nanoparticles it is necessary to additional studies of their effects on biological objects.

In this work, the effect of ionizing UV-radiation [1] and non-ionizing millimeter electromagnetic wave radiation [2] on the state of blood erythrocytes was studied. Irradiation was carried out both in the absence and in the presence of ZnO, CuO, and Al_2O_3 nanoparticles. The results were analyzed by UV-VIS absorption spectra of blood. In the absorption spectra during irradiation, an increase in the absorption intensity in the region of the Soret band at 420 nm was observed, which indicates the hemolysis of erythrocytes and the release of hemoglobin.

The presence of ZnO, CuO, and Al_2O_3 nanoparticles at irradiation contributed to an increase in the absorption intensity, i.e., leads to erythrocytes hemolysis. To assess exposure damage, DNA was isolated from blood leukocytes and examined by thermal denaturation and electrophoretically.

Being oxides, the studied nanoparticles can produce reactive oxygen species in the environment, which can promote erythrocyte hemolysis and cell apoptosis. In this case, the use of nanoparticles makes it possible to reduce the dose of irradiation of cancer patients during therapy.

This work was supported by Grant №21 T-1F244 of the Committee of Science RA.

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Poster report

Synthesis and Characterization of a Novel Multifunctional Magnetic Bioceramic Nanocomposite

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The development of bioactive three-dimensional scaffolds to aid bone regeneration has recently been one of the key areas of focus in bone tissue engineering [1],[2]. The utilization of bioceramic scaffolds with magnetic characteristics for bone augmentation is an emerging approach in tissue engineering, particularly when large bone cavities remain unfilled following tumor excision. Thus, stem cell activation and differentiation towards the osteogenic lineage via tailored magnetic field application and in situ apatite synthesis resulting from bioceramics can work together synergistically to promote bone repair [3],[4]. This study's main objectives were to create a new magnetic bioceramic nanocomposite and, using the foam replica method, to build a multifunctional three-dimensional scaffold that can deal with a number of challenging issues, such as physicochemical and biological features, bioactivity, and biocompatibility, as well as malignant bone tissues through hyperthermia and infection through local antibiotic release. The synthetic approach initiates with the synthesis of $CoFe_2O_4$ nanoparticles, followed by the fabrication of Mg_2SiO_4-$CoFe_2O_4$ nanocomposite, employing a two-pot sol-gel synthesis method for coating the magnetic nanoparticles. Finally, three-dimensional scaffolds were fabricated via the polymer foam replica technique. The as-synthesized materials were characterized by X-Ray Diffraction, Thermogravimetric Analysis, Fourier transform infrared spectroscopy, and Dynamic Light Scattering. Magnetic characterization of the $CoFe_2O_4$ nanoparticles (non-coated) and the nanocomposite (coated) was carried out to investigate the magnetic response at each synthetic stage. Magnetic Particle Hyperthermia characterization was performed to investigate the heat induction properties of different specimens containing magnetic particles. The specific loss power along with the specific absorption rate of the studied specimens was calculated. The targeted administration and release of active/pharmaceutical substances in the field of bone regeneration as well as the use of magnetic hyperthermia applications for supplementary cancer tumor therapy are rapidly increased.

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Poster report

FORC -Analysis as a Powerful Tool for Investigation of Magnetic Behaviour in Magnetoactive Nanocomposites

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First Order Reversal Curve (FORC) analysis is on top of popularity to describe magnetic interactions in ferromagnetic materials [1]. The measurement of sets of FORCs provides detailed information from different paths of magnetization, which enables the determination of the Switching Field Distribution (SFD) and interaction fields for all the phases that contribute to the hysteresis loop [2].

In this work, FORC-analysis was applied to study magnetic interactions in polyvinylidene difluoride (PVDF) composites containing: (i) hard magnetic nanoparticles ($CoFe_2O_4$), (ii)

$CoFe_2O_4$ nanoparticles with additional piezoelectric inclusions $BaTiO_3$ (BTO) and (iii) mixture of $CoFe_2O_4$ and γ-Fe_2O_3 nanoparticles. For each nanocomposite sample, 150 FORC curves were measured at room temperature on a LakeShore vibrating magnetometer.

It was shown that for the composite with only $CoFe_2O_4$ nanofiller, two magnetic phases are present, due to the distribution of particles in the matrix in such a way that finely dispersed nanoparticles remagnetize in a near-zero external magnetic field creating a magnetically soft phase, and nanoparticles knocked into aggregates remagnetize in high fields and have a wide range of switching fields, which indicates the presence of a strong dipole–dipole interactions between the aggregates. The values of the interaction fields of hard magnetic particles are ΔH_{int} ~ 1300-1400 Oe. FORC analysis shows that the addition of BTO particles to nanocomposites does not lead to significant changes in their macroscopic magnetic properties. The values of the interaction fields of hard magnetic particles are ΔH_{int} ~ 1400 Oe. For a mixture of soft magnetic and hard magnetic particles, the presence of a larger amount of a magnetically soft phase is clearly expressed. Moreover, the values of the fields of interaction of hard magnetic particles ΔH_{int} ~ 1500 Oe.

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Poster report

Magnetic Affine Sorbent Based on Starch-Coated Iron Oxide Nanoparticles for Isolation of Recombinant Proteins

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Magnetic nanoparticles (MNPs) are widely used as an affinity sorbent for the isolation of various target molecules, due to such important properties as ease of preparation methods, small size, high specific surface area and, as a result, high sorption capacity. Magnetic properties makes it easy to isolate and concentrate biomolecules of interest using magnetic separation. This reduces sample preparation time and avoids the need for expensive chromatographic equipment and columns.

In this work, starch-coated iron oxide MNPs (starch-MNPs) were synthesized by a simple and cost-effective co-precipitation method with cornstarch as a stabilizing agent. The method allowed us to synthesize starch-MNPs with the required magnetic response and dispersibility in aqueous solutions without additional surface functionalization and starch pretreatment stages. The structural and magnetic characteristics of the synthesized material have been studied by transmission electron microscopy, Mössbauer spectroscopy, and vibrating sample magnetometry. The nature of bonds between ferrihydrite nanoparticles and a starch shell has been examined by Fourier transform infrared spectroscopy. Starch-MNPs have been tested as an affinity sorbent for one-step purification of several recombinant proteins (cardiac troponin I, survivin, and melanoma inhibitory activity protein) bearing the maltose-binding protein (MBP) as an auxiliary fragment. MBP is widely used as a fusion partner to increase the expression level, improve the folding and solubility of the protein of interest, and implement its one-step purification on amylose-activated resin. The synthesized starch-MNPs have showed excellent purification efficiency, high binding capacity (100–500 μg of proteins per milligram of the starch-MNPs), stability, as well as reusability.

This study was supported by the Russian Science Foundation and the Krasnoyarsk Territorial Foundation for Support of Scientific and R&D Acitvities, project No. 22-14-20020.

Poster report

Heating of Magnetic Ferrihydrite Powders in the FMR Mode

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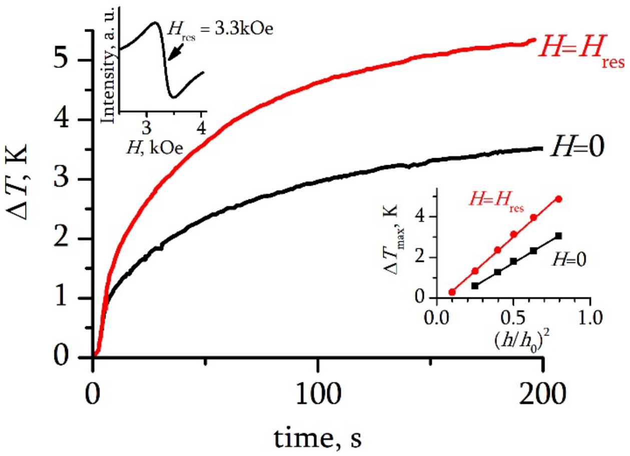
Currently, searches are underway for safe and effective components for hyperthermia, an auxiliary method of cancer treatment due to a general or local increase in temperature to 41-45°C. We examine a new method for the implementation of magnetic hyperthermia: the heating of ferrihydrite nanoparticles is carried out as a result of ferromagnetic resonance - the selective absorption of the energy of microwave electromagnetic field by ferromagnetic particles in an applied constant magnetic field.



Ferrihydrite nanoparticles with average size of 2.5 nm were biogenically synthesized by the bacteria Klebsiella oxytoca. The left inset in figure shows the ferromagnetic resonance (FMR) curve of ferrihydrite nanoparticles recorded at room temperature. The resonant field is H_{res} ≈3.3 kOe.

For practical applications of powder, heating in a narrow temperature range is required. The temperature increase depends on the absorbed power and duration of microwave exposure. Figure shows the results of studies of the time dependence of the temperature increment ΔT of particles at various values of the constant magnetic field H in the microwave field (f=8.9 GHz). In a resonant field (H = 3.3 kOe), the greatest increase in the temperature of nanoparticles is observed, which indicates the resonant nature of the absorption of microwave energy. Dependence of saturation temperature on normalized microwave power is shown in the right inset. We observe a linear relationship according to the equation $c\mathrm{d}T=\omega V\chi'' h^2/2\mathrm{d}t$ [1], where c is heat capacity, V

is volume, χ'' is imaginary part of magnetic susceptibility of sample, ω is circular frequency and h is the amplitude of the magnetic component of the microwave field.

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Poster report

Magnetically Induced Orientation of Functionalized Graphene Oxide Liquid Crystals

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Graphene oxide (GO) is the oxygenated form of graphene with magnificent physicochemical properties and functionalization possibilities [1]. The dispersed GO exhibits a stable liquid crystalline (LC) phase depending on the concentration, average aspect ratio of GO flakes, and pH of solvent media [2]. The self-assembling property of GO LCs maximizes the use of graphene-based devices. From this point of view, stability is the most important characteristic for the long-term operation of such devices, namely the stability against the various types of created defects.

In the frame of this work, we focus on the synthesis of GO and its LC phase formation. Improvement of structural features of GO LC phases was done by the addition of organic molecules, such as different types of amino acids. The effect of the magnetic field on the stability of the LC phase of the synthesized GO was studied. The orientation of GO flakes was manipulated by the applied external magnetic field using an axially magnetized magnet. The lamellar smectic phase formed between the crossed polarizers was observed because of the applied magnetic field.

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Poster report

Sensitivity Enhancement of a Biosensor Based on Bioluminescence Using Gold Nanoparticles

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Detection of microbial contamination in food and beverages is one of the most important aspects in food safety [1]. Among the more recent rapid methods for detection of microorganisms in food, adenosine triphosphate (ATP) bioluminescence is very suitable for online monitoring of bacterial contamination in food and beverages due to no need for a culturing step or large equipment to fulfill the measurement, rapidity and sensitivity [2].

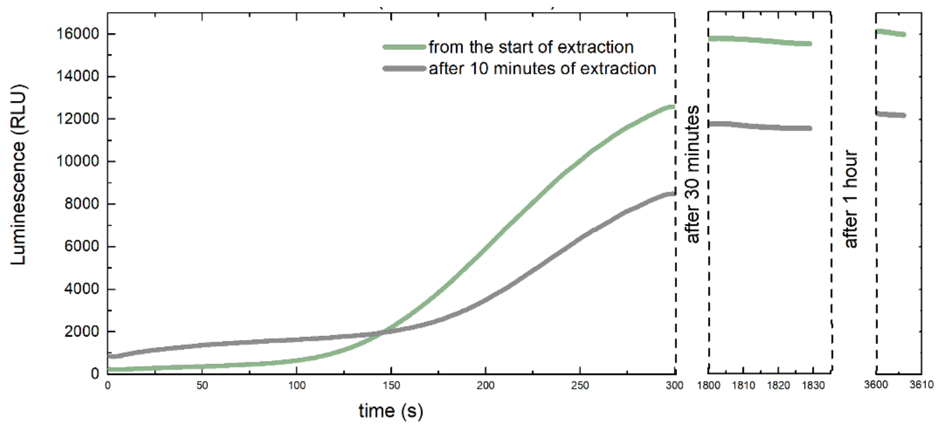

Figure. ATP extraction efficiency signal by BAC from the start of extraction and in 10 min after the extraction

In this work, we studied the influence of BAC and Triton detergent free and detergent-stabilized Ag and Au NPs on firefly BL system and ATP extraction efficiency from lactic acid bacterial cells. Au NPs showed a significant signal increase related to their optical characteristics and MEB effect. For that reason, MEB systems can be used to enhance the sensitivity of bioluminescence signals with varied prospective applications in the biological sciences.

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Poster report

SDS-coated Magnetic Iron Oxide Nanoparticles for Water Purification: Synthesis, Adsorption and Cytotoxicity

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Magnetic separation has been applied in many areas to remove, isolate or concentrate the desired components from sample solution. Magnetic iron oxide nanoparticles (MNPs) are widely studied as a new adsorbent with a large surface area and low diffusion resistance to separate and remove chemical particles [1]. To prevent agglomeration and increase the sorption capacity, the surface of magnetic nanoparticles can be modified with various coatings. In this work, sodium dodecyl sulfate (SDS) was used as a coating of MNPs to increase the sorption capacity of methylene blue (MB) dye. Figure 1 shows that the sorption capacity is 250 times higher for SDS-coated MNPs compared with bare MNPs [2].

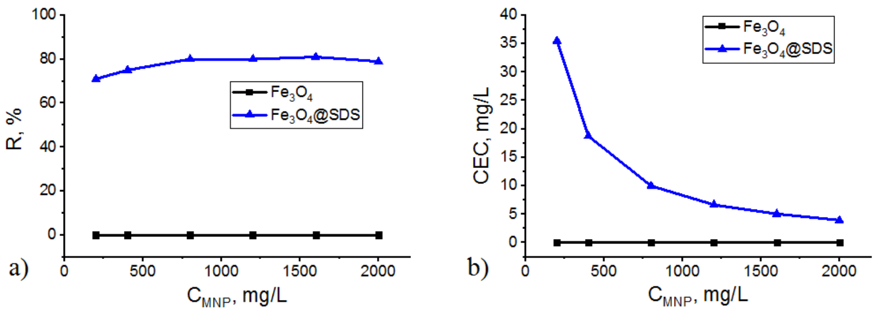

Figure 1. (a) Degree of extraction of MB and (b) the static capacity of the sorbent on the concentration of MNPs [2]

The cytotoxicity of MNPs with SDS surface modification was assessed to study the effect of drinking water on living organisms. Three cell lines were used: peripheral blood mononuclear cells of healthy donors (PBMC), human hepatocarcinoma (Huh7), human pigmented melanoma (SK-MEL-28). For a comparative assessment of the proliferative activity of cell cultures, cultivation was carried out with a tetrazolium salt WST-1 (Roche Diagnostics GmbH, Germany). The 10 μg/ml MNPs water suspension was studied, as the tested concentration for water purification from methylene blue.

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Poster report

Apoptosis Induced by the Action of Aptamer-Functionalized Magnetic Nanoparticles under Ferromagnetic Resonance

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Local hyperthermia is most often used in combined cancer treatment to enhance the effect of chemotherapy and radiotherapy [1]. The principle of the method is in the selective death of tumor cells with an increase in temperature to 44-45 °C due to the specific features of tumors compared to healthy tissues.

In our work, we present a method for inducing apoptosis of tumor cells by heating nickel ferrite nanoparticles under ferrimagnetic resonance. The method of construction and the characteristics of nanoparticles are presented in work [2]. Before studies *in vivo* in an animal model, we must test resulting nanoparticles *in vitro* in cancer cell lines.

To reduce the effect of nickel cytotoxicity, the nanoparticles were coated using tetraethyl orthosilicate (TEOS) and 3-aminopropyltriethoxysilane (APTES). This coating not only reduced the toxicity of nanoparticles in three cell lines of breast cancer: MCF-7, BT-20, and BT-474 cell lines, but also made it possible to functionalize nanoparticles with aptamers for targeted delivery to tumor cells [3]. The nanoparticles showed non-toxicity for all three cell lines with concentration up to 4 mg/mL.

To assess cell death under ferromagnetic resonance, nanoparticles were added to the cell suspensions to a final concentration of 4 mg/mL. The number of living cells after 10 minutes of exposure in microwave with field strength H=2.29 kOe in a constant magnetic field decreased from 90% in control groups (cells exposed to microwave, but without the addition of nanoparticles) to 78-80% in experimental groups. Cell death occurred through the release of caspases 3/7 (caspase 3/7 level increased by 2-2.5 times) and the formation of reactive oxygen species.

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Poster report

Magnetic Properties of 3D Printed Composites from Mesoscale Ferrite Particles and Biodegradable Poly (lactic acid) Polymer

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3D printing technology enables the production of personalized medical devices such as implants and scaffolds [1,2]. The incorporation of functional inclusions, such as magnetic micro- and nanoparticles, provides the opportunity to add additional properties to such materials. In particular, magnetic properties can be used for drug trigger release or hyperthermic therapy [3]. In this work, composite magnetic filaments for 3D printing with tunable magnetic properties were prepared from thermoplastic polylactic acid polymer with the addition of magnetic ferrite particles of different size and chemical composition [4]. The magnetic particles used were cobalt ferrite $CoFe_2O_4$ nanoparticles, a mixture of $CoFe_2O_4$ and zinc-substituted cobalt ferrite $Zn_{0.3}Co_{0.7}Fe_2O_4$ nanoparticles (<20 nm), and barium hexaferrite $BaFe_{12}O_{19}$ microparticles (<40 μm). The maximum coercivity field H_C = 1.6 ± 0.1 kOe was found for the filament sample containing 5 wt% barium hexaferrite microparticles, and the minimum H_C was found for a filament with a mixture of cobalt and zinc–cobalt spinel ferrites. The ability of the FDM 3D printing process to produce parts with simple (ring) and complex geometric shapes (honeycomb structures) using the magnetic composite filament was demonstrated.

This work was supported by the Russian Science Foundation under grant no 21-72-30032.

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Poster report

Single-Step Solid State-Pyrolysis of Carbon-Fe_3C Submicron Spheres

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Magnetic carbon submicron spheres have received considerable attention because of their ability to be steered by a magnetic field and generate heat when exposed to an alternating magnetic field. They were widely used to purify water by absorbing pollutants providing also good recyclability [1-3]. The carbon spheres with a diameter of 500-800 nm were successfully synthesized by a single-step solid-state pyrolysis of iron (III) phthalocyanine as metal precursor at temperatures of 800 °C and 900 °C. The influence of different pyrolysis parameters such as temperature, pressure and duration, on the morphology, structure and magnetic properties was investigated. Transmission Electron Microscopy (TEM) and X-Ray Diffraction (XRD) studies reveal that cementite (Fe_3C) nanoparticles (NPs) with a diameter of 14 nm to 80 nm are embedded in amorphous carbon spheres. Fe_3C NPs have a crystallite size of 13.8 ± 0.7 nm and 9.5 ± 1.3 nm for the samples fabricated at T = 800 °C for 5 min. and T = 900 °C for 1020 min., respectively. The decreasing crystallite size is justified by the appearance of new iron-containing phases caused by partial thermal disintegration of the Fe_3C. The magnetic properties confirm the presence of randomly oriented single-domain and non-interacting particles for the sample fabricated at 800 °C. The temperature dependence of coercivity for single-domain NPs is described by the modified Kneller's law due to the broad size distribution. A transition to multi-domain state is observed with increasing the pyrolysis temperature up to 900 °C.

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Poster report

The DFT Study of Iron-doped Hydroxyapatite

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Hydroxylapatite (HAp = $Ca_5(PO_4)_3OH$) is known as a main mineral component of bones. The innate bio-compatibility of HAp ceramics is promising for numerous medical applications [1]. The Fe-HAp (Fe doped HAp) presents magnetic properties and can be used in magnetic hyperthermia, MRI diagnostics, as a part of grug delivery systems. However, the reported Fe- HAp materials [2-4] show insuperior magnetic properties – the magnetization is lower than that expected from iron content. In order to improve the Fe-HAp material and to find optimal synthesis conditions the knowledge about atomic structure and iron oxidation state are required.

In this study we applied the state of the art density functional theory (DFT) methods [5] to determine the atomic and electronic structure of iron dopants in HAp material [6]. Figure 1 illustrates some of the obtained structures, which differ by iron charge state and position: interstitial (i) site or cation substitution (Ca(I), Ca(II) or P).

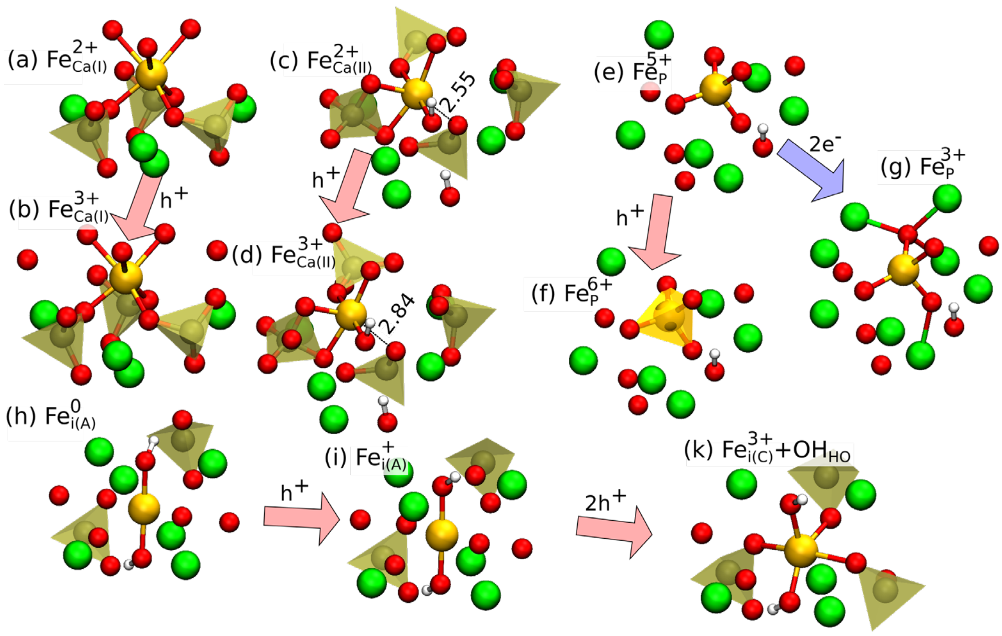

Figure 1. Illustration of local atomic structure of iron for some of the possible Fe-HAp configurations.

We also calculated the Fe K-XANES spectra and compared them with the experimental data available in the literature. The comparison show that some of the iron-oxide groups replace the phosphate groups in HAp (Figure 1e-g), which result in the low-spin iron species. This opens the room for improvement of the magnetic properties by domination of high-spin iron configurations, i.e. $Fe_{Ca(I)}^{3+}$ (Figure 1b) and $Fe_{i(C)}^{3+}$ (Figure 1k).

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Poster report

Laser Assisted Fabrication of Magnetic Nanoparticles for Biomedical Applications

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Magnetic nanoparticles (NPs) offer many attractive possibilities for biomedical applications because (i) their sizes are smaller or comparable to those of biological entities that provides a controllable route of 'tagging' them; (ii) they can be manipulated by an external magnetic field that opens up many applications involving the transport of magnetic NPs to a targeted region of the body; (iii) magnetic NPs can covert the energy from the exciting field and serve as hyperthermia agents. It should be noted that NPs will be effective in these applications if they satisfy the requirements of specified size, shape, composition and structure at least, they should be non-toxic and have narrow size distribution. Nowadays, for synthesis of magnetic NPs a series of methods have been developed. [1-4]

Among different synthesis methods an approaches based on laser ablation in solution can meet all these requirements. The liquid-mediated laser-assisted process represents an eco-friendly, fast, and efficient method for the preparation of NPs. Additionally laser ablation in liquids does not require the use of stabilizing agents and can provide the direct synthesis of composite NPs, such as magnetic oxide or carbide NPs, magnetoplasmonic bimetallic alloy NPs, as well as doped NPs.

We have developed a liquid assisted laser ablation approach for the preparation of metallic (Fe, Co, Ni, Gd), composite binary (Gd–Si) and ternary (Gd-Si-Ge), as well as doped ZnO and CuO NPs. The Nd:YAG laser (LOTIS TII, LS2134D), operating in a double-pulse mode at 1064 nm (energy 80 mJ/pulse, repetition rate 10 Hz, pulse duration 8 ns), was used for ablation. Magnetic properties of the formed NPs were investigated in the temperature range $5 < T < 550$K and in external fields up to 10 T. Magnetic measurements showed that the resulting NPs didn't exhibit hysteresis at low temperature (6 K), which is typical to nanosized magnetic materials demonstrating superparamagnetic behavior. Magnetization increased after laser processing of samples due to ordering in the grain structure and the magnetic moments at the surface.

The capabilities of the laser assisted synthesized magnetic NPs for biomedical applications such as hyperthermia and antimicrobial activities will be discussed.

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Poster report

Ehrlich Ascitic Carcinoma cells Viability under Influence of FMR Hyperthermia

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The hyperthermia with the use of magnetic nanoparticles consists in heating a certain tissue area to a temperature close to the cell's tolerance limit [1-3]. Effect of hyperthermia can be achieved is based on the ferromagnetic resonance method. Solving the problem of targeted delivery of magnetic nanoparticles, as a heating mediator, to tumor cells, aptamers are being used [4].

The aim of the work is to determine the cell viability of Ehrlich's ascitic carcinoma under influence FMR hyperthermia with functionalized aptamers of magnetite nanoparticles.

The magnetite is the convenient material for modifying its surface for delivery to target cells. A two-component modification of its surface has carried out using tetraethylorthosilicate (TEOS) and 3-aminopropyltriethoxysilane (APTES). The resulting hybrid material has processed by attaching FAS9 aptamers. FAS9 aptamers are oligonucleotides complementary to Ehrlich's ascitic carcinoma [5]. Ehrlich ascitic carcinoma cells have exposed to a microwave source frequency of 8.9 GHz and a constant magnetic field strength resonant for magnetite (Hres=2.9 kOe) for 10 minutes for each sample. The cell viability has assessed by cytometric analysis using YO-PRO-1 (Thermofisher, USA) and propidium iodide (Thermofisher, USA) on CytoFLEX (Beckman Coulter, USA) of the Center for collective use FRC KSC SB RAS, Krasnoyarsk. The viability was analysis performed immediately after exposure and 1 and 2 hours later.

It was found that during FMR-hyperthermia there was a significant decrease in the percentage of survival EAC cells from 92% in the control to 79% in the group with nanoparticles. Also, hyperthermic exposure led to the increase apoptosis cells of up to 11.5% (3-5% in control) and increase in necrotic elements after two hours up to 9% (4% in control).

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Poster report

A New Sensor for Non-invasive Assessment of the Onset of Pathological Changes in the Body

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Research on the search for alternative methods for assessing the physiological state of biological systems led to the development of the hardware complex "BIOSCOPE". The principle of operation of the "Bioscope" is based on measuring the intensity of light scattered in a light-tight chamber.

When approaching the "Bioscope" of inanimate objects with ambient temperature, the readings of the equipment do not change. However, already from 5-6 m, the "Bioscope" reacts to the presence of a person.

Various biological objects affect the readings of the "Bioscope" to varying degrees, at the same time, the signals of the equipment also change when their physiological state changes. This indicates the possible application of the developed equipment for non-invasive assessment of the functional state of biological systems in various biomedical research.

Experiments on the effect of stress influences, as well as a number of pharmacological drugs on the animal body revealed a high sensitivity and specificity of the signals of the "Bioscope" to changes in the physiological state of the animal.

Data have been obtained that create prerequisites for the practical use of the "Bioscope" hardware complex for early prediction of infection and the beginning of the formation of pathological processes in the body. In particular, it is shown that a 3-minute recording of the signals of the "Bioscope" can reveal the beginning of the development of neoplasms in the mammary gland in women.

The absence of analogues of the "Bioscope" on the world market creates all prerequisites for preserving the priority of Armenia in its wide use in medical practice.

Poster report

Au-Fe_3O_4 Nanohybrids: Synthesis and Characterization

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Magnetic iron oxide nanoparticles (Fe_3O_4 NPs) are under extensive investigation for selective drug delivery in cancer treatment [1-2]. Covered with the hydrophilic, biocompatible and non-toxic polymer polyvinylpyrrolidone (PVP) Fe_3O_4 NPs are used for targeted drug delivery [3]. Furthermore, gold nanoparticles (Au NPs) decorating the surface Fe_3O_4 NPs of are used for controlled release of a drug by photothermal stimulation mediated by localized surface plasmonic resonance (LSPR). LSPR allows the Au NPs, as hot spots, efficiently trigger a drug release in the PVP-Fe_3O_4 composites under controlled conditions [4].

Herein, we report on the synthesis of Au-Fe_3O_4 nanohybrids via a chemical precipitation method with a chemisorbed Au NPs to the octahedral PVP-Fe_3O_4 NPs surface. The results of transmission electron microscopy (TEM) are presented in Fig. 1 (a-c) and show Au NPs are attached to PVP-covered Fe_3O_4 NPs at a number ratio of 25:1 (Fig.1 (e)). Fig 1. (d) shows size distribution of Fe_3O_4 NPs. Absorbance spectra of Au, Fe_3O_4, and Au-Fe_3O_4 NPs are shown in Fig. 1 (f). Au NPs (red line) have the typical behavior with the plasmon peak at 520 nm. In comparison with the absorbance spectrum of Fe_3O_4 NPs (black line), the spectrum for Au-Fe_3O_4 NPs (green line) demonstrates the shift of the light plasmon peak to 536 nm, which is an effect of Au-Fe_3O_4 nanohybrids.

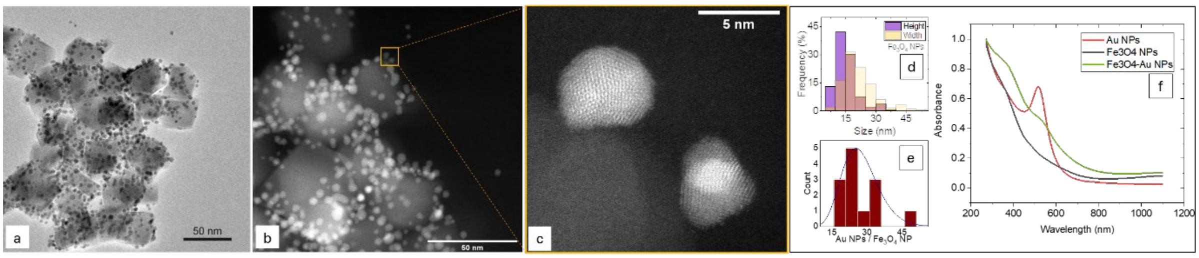

Figure 1. TEM (a) and HAADF (b-c) images of synthesized Au-Fe_3O_4 nanohybrids; size distribution of Fe_3O_4 NPs (d) and number of Au NPs per Fe_3O_4 NP (e); absorbance spectra of the synthesized NPs (f).

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