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BOOK OF ABSTRACTS

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Magnetic Soft Robots

Monday, 8th July - 15:50: Keynote Speech Session - Oral - Abstract ID: 637

Dr. Xuanhe Zhao [1]

1. *MIT*

While human tissues are mostly soft, wet and bioactive; machines are commonly hard, dry and biologically inert. Bridging human-machine interfaces is of imminent importance in addressing grand challenges in health, security, sustainability and joy of living faced by our society in the 21st century. However, designing human-machine interfaces is extremely challenging, due to the fundamentally contradictory properties of human and machine. In this talk, we will highlight MIT SAMs Lab's recent development of soft robots that can potentially perform various tasks inside human body. The soft robots are constructed by 3D printing of a new biocompatible magneto-active polymer into various structures. Our approach is based on direct ink writing of an elastomer composite containing ferromagnetic microparticles. By applying a magnetic field on the dispensing nozzle while printing, we make the particles reoriented along the applied field to impart patterned magnetic polarity to printed filaments. This method allows us to theoretically and experimentally program ferromagnetic domains in complex 3D-printed soft robots, enabling a set of unprecedented functions including crawling, jumping, grasping and releasing objects, and transforming among various 3D shapes controlled by applied magnetic fields. The actuation speed and power density of our 3D-printed soft robots with programmed ferromagnetic domains are orders of magnitude greater than existing 3D-printed active materials and structures. We will demonstrate a set of clinically relevant applications uniquely enabled by the 3D-printed magneto-active soft robots.

Alginate magnetic hydrogels: design, structure and mechanical properties

Monday, 8th July - 16:30: Plenary Speech Session - Oral - Abstract ID: 204

Ms. Cristina Gila-Vilchez [1]***, Ms. Mari C. Mañas-Torres*** [1]***, Prof. Juan DG Duran*** [1]***, Prof. Luis Álvarez de Cienfuegos*** [2]***, Prof. Andrey Zubarev*** [3]***, Prof. Modesto T Lopez-Lopez*** [1]

1. *Department of Applied Physics, University of Granada,* ***2.*** *Department of Organic Chemistry, University of Granada,* ***3.*** *Ural Federal University*

Hydrogels are three-dimensional networks of flexible chains which retain considerable amounts of water or biological fluids. These soft materials, which behave as viscoelastic solids, have recently found great attention in several fields such as biomedicine, food and pharmaceutical industry. Among them, alginate hydrogels are biocompatible, non-toxic, abundant in source, cheap and readily available materials whose mechanical properties can be easily modified. In addition, a magnetic phase can be easily incorporated in order to generate magnetic hydrogels or ferrogels. Thus, one of the most recently proposed approaches for the preparation of hydrogels with appropriate internal structure and mechanical properties is the manipulation of these hydrogels via magnetic forces. This technique allows the non-contact manipulation and remote modification of these materials, since the dispersed magnetic particles could rearrange into columnar structures.

In this work, we describe a new two-step protocol that allows the preparation of macroscopically homogeneous alginate hydrogels containing up to 30 vol% of silica-covered iron microparticles (see Figure). We characterized the rheological and magnetorheological (MR) properties of the ferrogels, achieving high increases of the storage and loss moduli when the particle concentration as well as the intensity of the applied magnetic field were increased. We propose a theoretical model, based on the existence of clusters of particles, which reasonably predicts the strong MR effect obtained in our experiments [1]. In addition, we report an adaptation of the two-step protocol for the injection of the magnetic hydrogels, which gave rise to magnetic hydrogels that after injection retained similar morphology and mechanical properties than hydrogels not subjected to injection [2]. Finally, we also prepared anisotropic magnetic alginate hydrogels in which anisotropy was also induced by application of an external magnetic field, before or after the cross-linking process, and we studied how it affects to their rheological properties [3].

Acknowledgements: project FIS2017-85954-R (MINECO and AEI, Spain, cofounded by FEDER, European Union).

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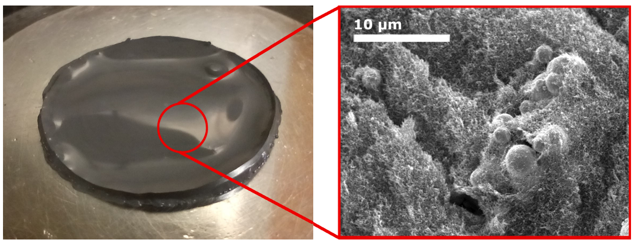
[1] Cristina Gila-Vilchez *et al.* 2019 *Smart Mater. Struct.* **28**, 035018. (doi: 10.1088/1361-665X/aafeac)

[2] Cristina Gila-Vilchez *et al.* 2018 *J. Rheol.* **62**, 1083–1096. (doi: 10.1122/1.5028137)

[3] Cristina Gila-Vilchez *et al.* 2019 *Phil. Trans. R. Soc. A* **377**, 20180207. (doi: 10.1098/rsta.2018.0217)



Magnetic alginate hydrogel - macroscopic and microscopic appearance.jpg

Spontaneous order in ensembles of rotating magnetic droplets

Monday, 8th July - 16:45: Plenary Speech Session - Oral - Abstract ID: 289

Mr. Andris P. Stikuts [1], ***Prof. Régine Perzynski*** [2], ***Prof. Andrejs Cebers*** [3]

1. Sorbonne Université, Laboratoire PHENIX; University of Latvia, Lab of Magnetic Soft Materials, 2. Sorbonne Université, Laboratoire PHENIX, 3. University of Latvia, Lab of Magnetic Soft Materials

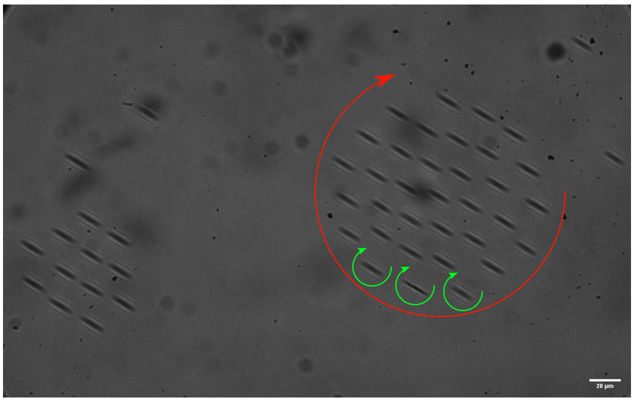
In recent years, systems of out-of-equilibrium assembly have gained considerable attention [1]. In this work we present experimental results on micro-droplets of magnetic fluid created by phase separation. We show that the droplets arrange themselves in regular hexagonal lattices when subjected to a rotating magnetic field.

If the volume of a magnetic droplet is below a critical value, the droplet elongates and rotates with the field. Such droplets do not coalesce but instead remain at a distance from one another, possibly due to inertial forces. Two nearby droplets have been observed to rotate around their center of mass, suggesting that hydrodynamic interactions are critical to the phenomenon. In time, the droplets organize themselves in a hexagonal lattice structure. The size of the droplets is locally extremely uniform. There is evidence that this property arises because the droplets exchange their material with nearby droplets in the lattice.

The magnetic droplets arrange themselves in rotating crystals of different size that follow the rotation of the magnetic field, albeit more slowly than the droplets that they are made of. Depending on the size and symmetry of the crystals, their overall shape stays the same during their rotation or it changes. The larger and the more symmetric the rotating crystal, the more rigid it is. Small crystals that are made of four droplets form a rhombus that undergoes periodic oscillations of their diagonal lengths.

The authors are grateful to D. Talbot for the synthesis of the sample and G. Kitenbergs for his helpful insights, as well as for the financial support from the Embassy of France in Latvia and PHC Osmose 2018 n°40033S.

1. V. Liljeström, et al., “Active structuring of colloids through field-driven self-assembly”, Current Opinion in Colloid and Interface Science, 2019, vol. 40, pp. 25-41.



Rotating crystals of magnetic droplets.png

Self-propelled Dipolar Nanocubes

Monday, 8th July - 17:20: Plenary Speech Session - Oral - Abstract ID: 468

Mr. Martin Kaiser [1], ***Dr. Sofia S. Kantorovich*** [2], ***Prof. Annette Schmidt*** [3], ***Ms. Yeimy Martinez*** [3]

1. *University of Vienna, Sensengasse 8, Vienna, 1090, Austria,* ***2.*** *University of Vienna,* ***3.*** *University of Cologne*

Microscopic active particles, including self-propelled cells, microorganisms and artificial swimming colloids have gained a lot of attention due to their relevance in such important fields as biology, biomedicine, nanoscience and nanotechnology. The term “active” describes the ability of certain particles or units to convert energy from their environment into motion, hence, kinetic energy [1]. This highly interesting property can arise from various mechanisms, such as localized concentration gradients, where an asymmetric distribution of reaction products (i.e., chemical fuel) on a coated particle propels the particle by self-diffusiophoresis.

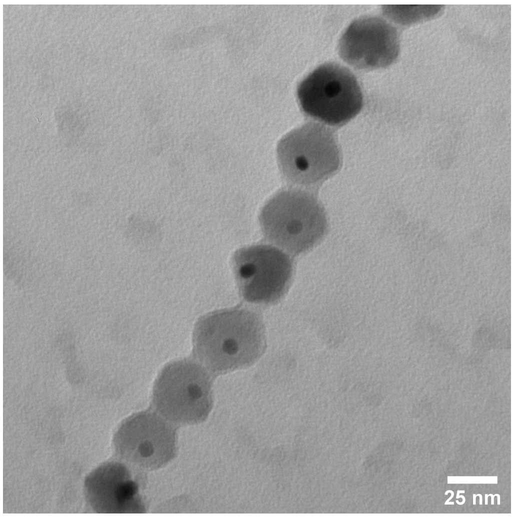
In this study, we use active matter to create a new type of nanomotor, which is oriented by an applied magnetic field and propelled by an active particle. One of those units consists of a dipolar cube that can be directed due to its interaction with a magnetic field, whereas a second non- dipolar active particle with a propulsion force directed into the cubes centre of mass, creates a field controlled swimming unit.

This scenario is investigated using molecular-dynamic simulations, setting the above described unit in an obstacle free environment, while applying a constant magnetic field. By computing the mean- square-displacement, we investigate if the diffusion of the self-propelled motor is enhanced in field direction and look at its dependencies on the unit parameters, which are compared with reported literature [2]. Furthermore, the fine interplay between dipolar and self-propulsion forces is investigated to reveal self-assembly, as well as dynamic properties of clusters containing the active-dipolar cube units.

In collaboration with Dr. Schmidt and Yeimy Martinez from the University of Cologne, those nanomotors are also investigated experimentally. This way, heterofunctional $CoFe_2O_4$@Pt nanostructures are designed as a proof of concept by using a coupled chemical fuel system based on the reduction of borohydrides.

[1] Ramaswamy, S (2010), Rev. Condens. Matt. Phys. 1, 323–345.

[2] C. Bechinger et al. (2016), Rev. Mod. Phys. 88, 045006



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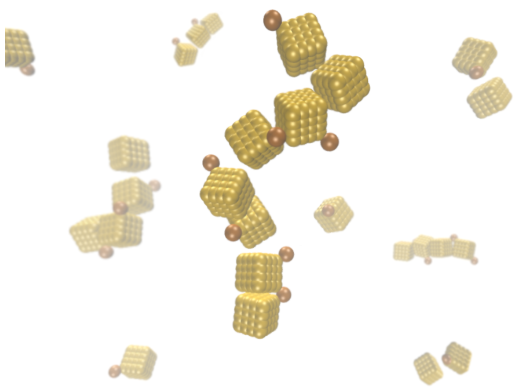

Abstract.png

Magnetic nanoparticles handling in droplet microfluidics

Monday, 8th July - 17:35: Plenary Speech Session - Oral - Abstract ID: 523

Mr. Simon Dumas [1]***, Dr. Marco Serra*** [1]***, Prof. Stéphanie Descroix*** [1]

1. *Institut Curie*

Droplet microfluidics has emerged as a powerful tool for high throughput bioassays. Many functions have been developed to handle microfluidic droplets allowing their generation, merging, splitting, sorting, but the manipulation of solid support in droplets remains a challenge. We report here a novel method using electroplated soft magnets to manipulate magnetic nanoparticles in sub-nanoliter droplets.

In many bioassays, such as ELISA or DNA size sorting for Next Generation Sequencing (NGS), a purification step of biomolecules of interest from a complex matrix is often needed. This can be achieved by solid phase extraction using magnetic microparticles as a solid support *(M. Serra, Lab Chip, 2017).*Our group pioneered a magnetic tweezers-based approach to extract and redisperse particles from droplets flowing in a capillary *(A. Ali-Cherif, Angew Chem, 2012).* Despite convincing results, this approach remains limited to 100nL droplet, micrometric beads and quite low throughput (<1Hz).

We aim in this work at revisiting this concept of magnetic tweezers approach in order i) to reduce the droplets size by several orders of magnitude to reach typical volumes for single cell analysis in droplets ii) to allow the handling of nanoparticles to drastically improve the biomolecules extraction iii) to be compatible with high throughput microfluidics.

Unfortunately, when decreasing the droplet size, interfacial forces become preponderant compared to the magnetic force, making the extraction of particles from droplets difficult. To tackle this, based on numerical simulations (Fig. 1), we developed an original microfluidic chip embedding electroplated soft ferromagnetic elements (NiFe 80:30) that focus an external magnetic field and increase considerably the local magnetic gradient.

In these conditions, we demonstrate that, magnetic nanoparticles (□ 100nm to 1µm) present in a 400pL droplet passing in between the magnets can be extracted (Fig. 2a-c) and released in an empty droplet using electrocoalescence (Fig. 3).

We believe that this original magnetic particles handling platform could be of great interest, allowing high throughput solid phase extraction, and bringing in the world of droplet microfluidics the possibility of doing complex multi-step bioassays.

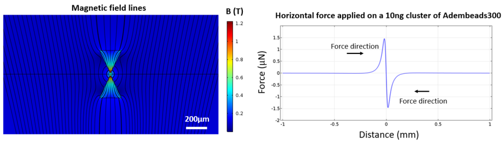

Figure 1: (Left) COMSOL simulation of a magnetic field focused by soft magnetic elements. (Right) The force applied on a cluster of 300 nm particles in the horizontal axis attracts it in between the magnets.

Figure 1 - magnetic field simulation.png

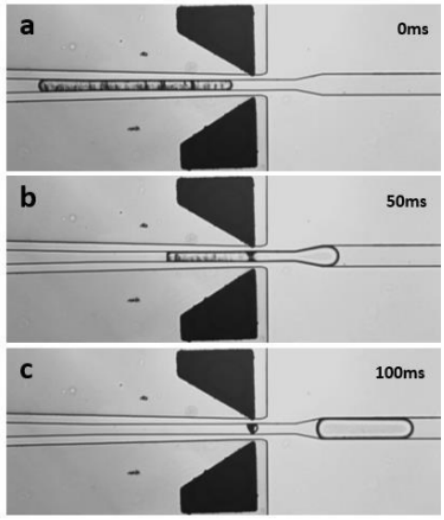

Figure 2: (a,b,c) Capture of around 10ng of magnetic particles (Adembeads300) from a 400pL droplet.

Figure 2 - particles capture.png

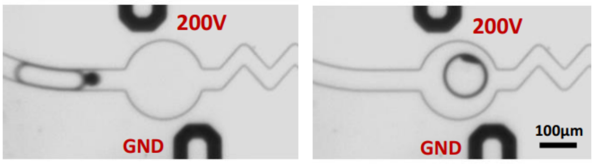

Figure 3: (a) Cluster of particles followed by an empty droplet arrive in the electrocoalescence region. (b) Droplets are merged together thanks to an electric field (200V AC).

Figure 3 - electro coalescence.png

Active magnetic spinner liquids: dynamic flocking, chirality switching vortices and transport

Monday, 8th July - 17:50: Invited Speech Session - Oral - Abstract ID: 122

Dr. Alexey Snezhko [1]

1. Argonne National Laboratory

Strongly interacting magnetic colloids driven out-of-equilibrium by an external magnetic field often develop nontrivial collective dynamics [1]. Active magnetic colloids proved to be excellent model experimental systems to explore emergent behavior and active (out-of-equilibrium) self-assembly phenomena.

Ferromagnetic micro-particles immersed in water and sediment on the bottom surface turn into colloidal rollers when energized by a single-axis homogeneous alternating magnetic field applied perpendicular to the surface supporting the particles. The activity in this system originates only from spinning degrees of freedom and self-propulsion emerges due to the presence of a solid interface. The rolling motion emerges as a result of spontaneous symmetry breaking of the particle rotations in external field in a certain range of excitation parameters. Experiments reveal a rich collective dynamics of magnetic rollers including a formation of chiral (polar) states and flocks [2]. On the basis of experiments and simulations we also demonstrate that a ferromagnetic roller gas exhibits normal (Fickian) diffusion with a linear in time growth of the mean-squared displacement, while statistics of displacements remains strongly non-Gaussian. The phenomenon is attributed to the strong heterogeneity of the local diffusive properties in this active system facilitated by the presence of long-range anisotropic hydrodynamic and magnetic interactions. Self-organized roller vortices have an ability to spontaneously switch the direction of rotation and move across the surface. We reveal the capability of certain non-active particles to pin the vortex and manipulate its dynamics [3]. Complex multi-vortex states in magnetic roller liquids are revealed.

The research was supported by the U.S. Department of Energy, Office of Science, Materials Sciences and Engineering Division.

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2. A. Kaiser, A.Snezhko, I. Aranson, “Flocking ferromagnetic colloids”, *Science Advances* 3, e1601469 (2017)

3. G. Kokot, A. Snezhko, “Manipulation of emergent vortices in swarms of magnetic rollers”, *Nature Communications* 9, 2344 (2018)

Magnetic nanoplatforms for combining Magnetic hyperthermia with other therapeutic treatments to tackle cancer

Tuesday, 9th July - 09:00: Keynote Speech Session - Oral - Abstract ID: 675

Prof. Teresa Pellegrino [1]

1. Università di Genova

The use of heat to cure cancer is very ancient. Nowadays, many techniques enable to precisely deposit the heat in very specific body regions thus providing more efficient heat treatment with less side effects. Among those methods, “magnetic hyperthermia” exploits magnetic nanoparticles as heat agents that can be excited under alternating magnetic fields (AMF). There are field intensity and frequency conditions of the AMF that are applicable in clinic, as they are safe for patients, and can excite magnetic nanoparticles with no limitations on the tissues and body penetration. In addition, magnetic nanoparticles that show superparamagnetic behavior at body temperature are also ideal carries for drugs or other therapeutic elements such as radioisotopes.

This talk aims at providing an overview of our ongoing research activity to combine magnetic hyperthermia with other clinical accepted therapeutic modalities (i.e. chemotherapy and radiotherapy). This presentation is divided into three sections. In the first one, I will focus on our progress on non-hydrolytic methods for the preparation of magnetic nanoparticles with optimal heat performance in MH. Our goal is to achieve the control on size, size distribution and crystallinity that in turn, enable to control the structural and magnetic properties of the magnetic nanoparticles. In a second part, I will report about our in vitro study on tumor cell models to determine the magnetic hyperthermia effects, with or without the association of chemotherapeutic drugs, on different subpopulations of cancer cells. In addition, our efforts to target magnetic nanoparticles towards cancer cells by means of antibody fragments and to combine platinum-based drug delivery therapy and magnetic hyperthermia will be discussed. Finally, in a third part, I will discuss our preclinical results to evaluate the magnetic hyperthermia efficacy of some of our magnetic materials on xenograft murine tumor model and the bio-distributions of some of the best performing materials we have developed.

Iron carbides and Iron-Cobalt Nanoparticles for Magnetically Induced CO2 Hydrogenation

Tuesday, 9th July - 09:40: Invited Speech Session - Oral - Abstract ID: 445

Prof. Bruno Chaudret [1]
1. *INSA Toulouse*

Iron carbides and Iron-Cobalt Nanoparticles for
Magnetically Induced CO_2 Hydrogenation

Bruno Chaudret

Laboratoire de Physique et Chimie des Nano-Objets
Institut National des Sciences Appliquées, 135 avenue de Rangueil
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The development of renewable energies is an essential requirement for a future sustainable world. However, both solar and wind power energies are intermittent The power-to-gas approach transforms CO_2 into methane using hydrogen produced by electrolysis. However, to-date large production units are required which take a long time to start and stop and are therefore not well fitted to intermittence. One idea to circumvent this problem is to use magnetic and catalytic nanoparticles which could be heated by magnetic induction. Thus magnetic heating is instantaneous, in principle the best way to transform electrical energy into heat and therefore well adapted to intermittence. For this purpose we have developed in Toulouse a new generation of iron carbide nanoparticles of unprecedented heating power. The particles are prepared by carbidization of preformed monodisperse Fe(0) nanoparticles under a CO/H2 atmosphere at 150°C. They consist essentially of crystalline Fe2.2C, display a SAR (heating power) of up to 3.3 kW/g and are able to hydrogenate CO_2 into methane in a flow reactor after addition of a catalytic Ru or Ni layer and excitation by an alternating magnetic field
The lecture will present the synthesis of the particles, their magnetic properties, their surface modification to deposit a catalytic layer and the development of a flow reactor for selective hydrogenation of CO_2 into methane. Further developments of the technique in solution or for electrochemical reactions will be mentioned.

Selected recent publications : * A Meffre, et al. Nano Letters 2015, 15, 3241
* A Bordet, et al. Angew.Chem.Int. Ed. 2016, 55, 15894
* C. Niether, at al. Nature Energy 2018, 3, 476
* J.M.. Asensio, et al. Nanoscale, 2019, 11, 5402
* C. Garnero,et al. Nano Letters 2019, 19, 1379

From high colloidal stability ferrofluids to magnetorheological suspensions-tuning the properties by composition

Tuesday, 9th July - 10:05: Invited Speech Session - Oral - Abstract ID: 453

Prof. Ladislau Vekas [1]

1. *Romanian Academy Timisoara Branch*

Particle size distribution and magnetic field induced particle aggregation are essential features both of ferrofluids and magnetorheological fluids. The extremely bidisperse ferrofluid based MR fluids come into play with completely new features in what concerns particle structure formation and yielding behavior depending on the composition adjusted on two hierarchical levels. By careful tailoring the composition and structure at nano and micro level the characteristics of magnetically controllable fluids are adapted to a wide range of requirements, from high colloidal stability, practically agglomerate-free concentrated ferrofluids to high kinetic stability MR fluids. There will be summarized results of electron microscopy, X-ray photoelectron spectroscopy, vibrating sample magnetometry, small-angle X-ray and neutron scattering, dynamic light scattering and magneto-rheometry investigations revealing the behavior of ferrofluids and magnetorheological fluids designed for various applications. The applications will be exemplified by leakage-free rotating seals operating in nuclear power units, a MR flow controller device in hydraulic machines and a hybrid semi-active MR damper for earthquake protection systems.

Facing the nanoparticle synthesis scaling-up challenge by investigating the iron precursors effect and the nanoparticle synthesis mechanism through in situ experiments

Tuesday, 9th July - 11:00: Plenary Speech Session - Oral - Abstract ID: 386

Prof. Sylvie Begin [1], ***Dr. Geoffrey Cotin*** [1], ***Dr. Damien Mertz*** [1]

1. *IPCMS UMR 7504*

Dendronized iron oxide nanoparticles have been demonstrated to be, *in vitro* and *in vivo*, very good contrast agents for MRI with a capacity to target melanoma after intravenous injection and a start-up is under creation. However, in order to have sufficient quantities of such nanoparticles for clinical studies and/or to consider their commercialization, it is necessary to develop production processes making it possible to produce them in large quantities. Iron oxide nanoparticles are synthesized by the thermal decomposition process which consists in the decomposition of an iron precursor in an organic solvent in presence of surfactants. The scaling-up of this synthesis has required the selection of the most suitable iron precursor and a better understanding of the key steps of the process. We investigated the first steps of the synthesis by analyzing the reaction media just after the homogenization step by different characterization techniques such as cryoTEM, liquid AFM and SAXS and, by following the germination and growth steps by *in-situ* TEM in a liquid cell. We evidenced thus that the formation of NPs goes through the formation of original structures in solution in which the nucleation takes place. Investigations of the decomposition mechanism of different iron precursors combined with modeling showed that the precursor's nature and hydration rate strongly affect the thermal decomposition kinetic and yields which, in turn, influences the NP size. We succeeded thus in increasing the synthesis and functionalization yield by 10 fold.

Directed and controlled propulsion of catalytically active CoFe2O4@Pt nanostructures

Tuesday, 9th July - 11:15: Plenary Speech Session - Oral - Abstract ID: 348

Ms. Yeimy Martinez [1], ***Mr. Lars Quilitzsch*** [1], ***Dr. Marc Effertz*** [1], ***Prof. Annette Schmidt*** [1]

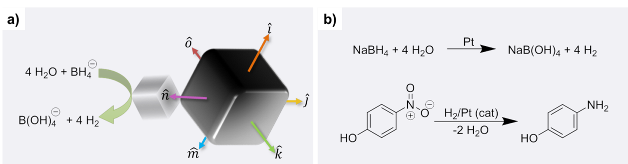
1. University of Cologne

Developing artificial swimmers at the nano- and microscale has emerged as a new class of active matter. These mobile structures are opening up novel applications ranging from biosensing to drug delivery in environments dominated by a low Reynolds number.[1] While keeping complexity low, such systems should also overcome the influence of Brownian motion, viscous drag and various surface phenomena. Nature has inspired numerous designs founded on the swimming patterns of microorganisms. Mimicking these features might thus enable the design of structures that propel themselves by taking up energy from their surroundings and transforming it into directed motion.[2] The controlled motion of these structures is thereby of interest for both fundamental research and emerging applications. Within this approach, considerable research is focused on the design of catalytically active Janus particles.[1] In general, the propulsion concept of these systems lies in the catalytic activity of anisotropic artificial structures for fuel consumption only at one side of a particle, thereby producing a chemical concentration gradient and steady-state flow of the surrounding medium that impulses the swimming object forward, resulting effectively in self-propulsion.

Here, we present novel heterofunctional $CoFe_2O_4$@Pt nanostructures activated through a coupled chemical fuel system based on the catalytic reduction of borohydrides. The nanostructures are prepared via a seed-mediated growth process, which entails a stable interface linkage between the $CoFe_2O_4$ and Pt domains.[3] The propulsion is generated by a concentration gradient considering fuel and reaction products in the vicinity of the catalytic nanoobject, and by railing their direction using a homogeneous magnetic field in order to reduce the predominant rotational diffusion for nanoscoped swimmers. This investigation includes the systematic synthetic approach implemented to prepare nanostructures in a size range smaller than 50 nm, the development of a new fuel system and the real-time tracking of the motion using dark-field light scattering microscopy.

Figure1. Schematic illustrations showing a) $CoFe_2O_4$@Pt nanostructures and b) fuel system proposed in this research

Bibliography:[1] Sánchez, S., Soler, L., Katuri, J. *Angew. Chem. Int. Ed.* **2015**, 54(5), 1414-1444. [2] Wang, J. Nanomachines: fundamentals and applications. John Wiley & Sons, **2013**. [3] Effertz, M., Dissertation, Universität zu Köln, **2017**.



Geometryfuel.png

Molecule-driven control of the magnetic anisotropy in superparamagnetic nanoparticles

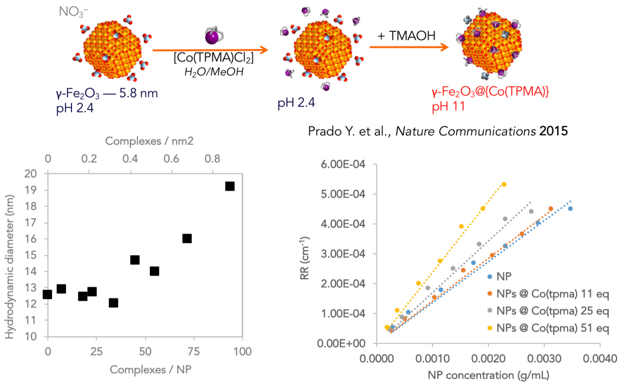
Tuesday, 9th July - 11:30: Plenary Speech Session - Oral - Abstract ID: 344

***Dr. Yoann Prado** [1], **Dr. Marie-Anne Arrio** [2], **Dr. Benoit Fleury** [3], **Dr. Vincent Dupuis** [1], **Dr. Jean-Marc Greneche** [4], **Dr. Nader Yaacoub** [4], **Dr. Philippe Sainctavit** [2], **Dr. Christophe Cartier-Dit-Moulin** [3], **Dr. Laurent Lisnard** [3], **Dr. Jerome Fresnais** [1]*

***1.** Sorbonne Université, Laboratoire PHENIX-CNRS UMR 8234, **2.** CNRS, Sorbonne Université, IMPMC, **3.** IPCM, **4.** IMMM*

Owing to their magnetic properties, iron oxide nanoparticles are of considerable interest for applications in medicine, from imaging to therapy, and in high-density data storage. In the case of small particles though, the so-called superparamagnetic limit is reached and the relevant magnetic properties lost. Retaining appealing magnetic properties (blocking temperature, coercive field) while maintaining a small nanoparticle size (*i.e.* forhigh-density data storage) has thus proved a highly challenging task. However, in these small nanoparticles, the magnetic properties are predominantly governed by the magnetic anisotropy. Modifying it represents thus one of the best approaches to improve the properties.

Alternatively we have recently been investigating a novel synthetic strategy to enhance the magnetic properties γ-Fe2O3 nanoparticles. Our synthetic strategy is based on the direct coordination of magnetic molecular complexes to the surface of the nanoparticles. Using molecular complexes as the enhancing-unit is a straightforward approach to improve the nanoparticles properties, i.e. more tahn 10 times the coercitive field and threefold the blocking temperature.
This strategy was succesfully applied to several complexes sharing the same Cobalt II ions surrounded by organic ligand that give the complexe several conformations. This will give us the opportunity to envisage those assemblies as new building blocks for applications in catalysis or even data storage.



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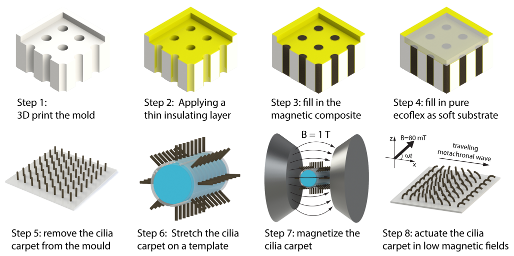
Artificial Magnetic Cilia Carpets with Programmable Metachronal Waves

Tuesday, 9th July - 11:45: Plenary Speech Session - Oral - Abstract ID: 517

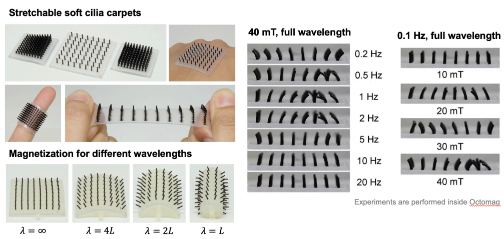
Mr. Hongri Gu [1], *Mr. Haoyang Cui* [1], *Dr. Quentin Boehler* [1], *Prof. Bradley Nelson* [1]

1. ETH Zurich

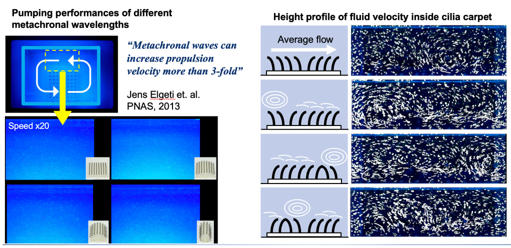
Metachronal waves are ubiquitous in natural cilia carpets. The emergent phenomena, originated from the phase difference between neighboring self-beating cilia, are essential for biological processes including locomotion, liquid transport, feeding and cell delivery. However, the understanding of such a large number, complex, under-actuated active system is limited especially from the experimental side. Here we report a robotic system of magnetically-actuated soft artificial cilia carpets with programmable metachronal waves. The soft cilia carpets can stretch and fold to conform curve surfaces in the magnetizer to encode magnetization patterns. The artificial cilia carpets show antiplectic metachronal waves with programmable wavelengths. By putting cilia carpet into the viscous liquid, we directly observe that metachronal waves promote efficient fluid transport near carpet surfaces, thus experimentally supporting the theoretical prediction. Furthermore, we develop a soft robot using metachronal waves to locomote inspired by the giant African millipede. This robotic system not only provides highly customizable experimental tools to study emergent behaviors of cilia at microscopic scales, but also implement bio-inspired functions on small-scale soft robots.



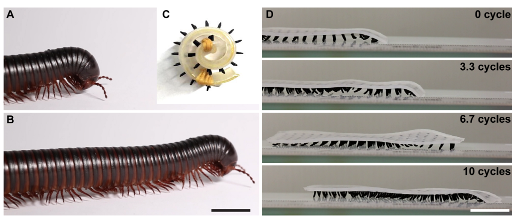
Fabrication and magnetization of magnetic soft cilia carpets.png



Characterizations of single hair motion under dynamic magnetic fields.png



Pumping performances of the cilia carpet.png



A millipede inspired soft robot.png

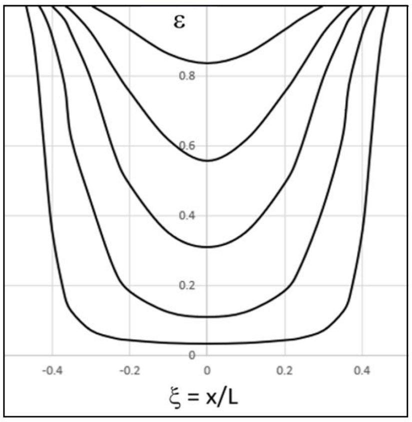
Synergism of ferrofluid and MR fluid: An Analysis

Tuesday, 9th July - 13:30: Invited Speech Session - Oral - Abstract ID: 427

Dr. Ronald Rosensweig [1]

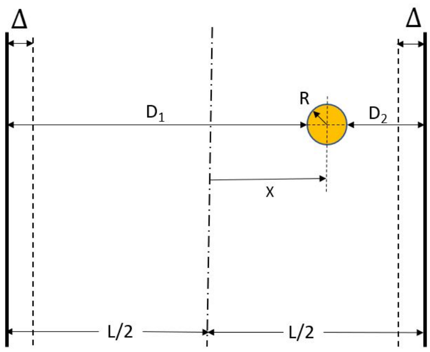
1. Exxon Corporate Labs (retired)

It is known that a suspension of relatively large micron-size particles dispersed in a ferrofluid of much smaller particles yields a magnetorheological fluid with superior properties. In the absence of applied field experiment reveals the presence of a nanoparticle cloud surrounding each micron-size particle. This work derives a thermodynamic model of cloud concentration distribution. It is found that van der Waals forces predominate over magnetic dipolar forces in forming the clouds. Additional analysis examines the influence of overlapping clouds on the interaction between approaching micron particles.



Concentration profiles of overlapping nanoparticle clouds

Icmf 15 concentration profiles.jpg



Sketch to develop nanoparticle cloud concentration.

Icmf 15 cloud nomenclature.jpg

Magnetic Properties of size and shape-controlled magnetite particles at nanoscale

Tuesday, 9th July - 13:55: Invited Speech Session - Oral - Abstract ID: 448

Prof. Jeyadevan Balachandran [1], ***Dr. Hiroaki Mamiya*** [2], ***Dr. Jhon Cuya*** [1], ***Dr. Kazumasa Suzuki*** [1], ***Dr. Hiroshi Miyamuya*** [1], ***Mr. Hiroya Fukumoto*** [1]

1. The University of Shiga Prefecture, 2. National Institute for Materials Science

In most cases, magnetic properties of the NPs are predicted from the classical magnetic theories based on the properties of the bulk counterpart. However, the discrepancy between the theoretical prediction and experimental data that frequently encountered has been considered mainly due to particle size distribution and the magnetic interaction between particles. In recent years, the advancement in the material synthesis and surface modification technology has made the synthesis of MNPs with uniform shape, size and size distribution and the surface modification techniques to coat each and every particle even at nanoscales has become possible. Here, the synthesis of magnetite NPs of definite shape and sizes using the same synthesis technique. Then, we also report the magnetic properties of particles with different sizes and shapes at nanoscale by measuring the interaction-free magnetite particles by prepared by coating the same with non-magnetic silica layer of different thicknesses. Furthermore, the magnetic anisotropic constants (K_{eff}) of magnetite NPs with different shapes and sizes were estimated from magnetic thermal decay curves. Among the magnetite NPs synthesized with different shapes, but almost of similar size, spherical NPs exhibited the highest K_{eff}. On the other hand, in spite there was no considerable difference in K_{eff}between octahedral shaped NPs with different sizes, the value increased for spherical particles for any decrease in their size. Details of synthesis techniques and magnetic evaluation will be reported.

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Ferrofluid in-field dynamics studied via Mössbauer spectroscopy

Tuesday, 9th July - 14:20: Plenary Speech Session - Oral - Abstract ID: 352

Dr. Joachim Landers [1], ***Dr. Soma Salamon*** [1], ***Ms. Hilke Remmer*** [2], ***Prof. Frank Ludwig*** [2], ***Prof. Heiko Wende*** [1]

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Being an element-specific resonant absorption technique, Mössbauer spectroscopy is often applied to study a material's magnetic structure, spin orientation and local electronic properties. As it utilizes the optical Doppler effect to measure shifts in the resonant absorption energies, Mössbauer spectra also reflect particle motion on the nanosecond timescale, thereby being able to provide information on nanoparticle dynamics in ferrofluids and soft matter composites [1].

In this study, we focused on ferrofluids containing spherical magnetite-maghemite nanoparticles with core diameters of ca. 5 - 25 nm and a coating thickness of ca. 5 nm in 70 vol% glycerol solution to illustrate the set of static and dynamic parameters accessible via Mössbauer spectroscopy. Detailed complementary AC-susceptometry mappings at 5 – 300 K and 0.1 – 1500 Hz displayed predominant Néel-type relaxation in particles of ca. 5 and 15 nm core diameter, while larger particles exhibit magnetic relaxation via Brownian motion only. For each of the samples, a series of Mössbauer spectra was recorded at ca. 230 – 270 K, to study the fluids at a wide range of dynamic viscosities, and in external fields of up to 0.5 T applied either perpendicular or parallel to the γ-ray propagation direction. Doing so, we could simultaneously characterize the particles' Néel-type relaxation, by analyzing the asymmetric line shape deformation up to the collapse of the sextet to a superparamagnetic doublet structure, and quantify Brownian particle motion via the absorption line broadening. Additionally, we could infer the average field-dependent particle alignment and degree of surface spin canting by analyzing the variation in relative line intensities and estimate the particles' coating thickness by comparing experimental and calculated diffusion coefficients. For one of the ferrofluid samples, particle agglomeration was detected. The average agglomerate size of the 22 nm particles was determined from temperature-dependent line broadening to ca. 70 nm, while agglomeration could also be deduced from the trend in field-dependent alignment, deviating from the standard Langevin model [2].

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[2] J. Landers et al., ACS Appl. Mater. Interfaces **11**, 3160 – 3168 (2019)

Analyzing moment correlations within clusters of magnetic nanoparticles

Tuesday, 9th July - 14:35: Plenary Speech Session - Oral - Abstract ID: 130

Dr. Philipp Bender [1]***, Dr. Dirk Honecker*** [2]***, Prof. Luis Fernández Barquín*** [3]

1. *University of Luxembourg,* ***2.*** *Institut Laue Langevin,* ***3.*** *Universidad de Cantabria*

We used small-angle neutron scattering (SANS) with a complete longitudinal neutron-spin analysis (POLARIS [1]) to analyze directional correlations between the magnetic moments of iron oxide nanoparticles aggregated to clusters. We present here the results for two different samples, namely **sample 1**, which is a powder of nearly monodisperse single-domain particles (from [2]), and **sample 2**, which is a powder of so-called magnetic nanoflowers (synomag®-D, micromod Partikeltechnologie GmbH, Germany from [3]).
At small magnetic fields, **sample 1** behaves macroscopically as a superparamagnet [2]. As a result, the detected spin-flip (i.e. purely magnetic) SANS cross section exhibits the expected pattern for a random distribution of the particle moments (Fig. 1(c)). However, analysis of the low-*q* SANS data reveals a tendency for magnetic anti-correlations (i.e. antiferromagnetic-like correlations) between neighboring particle moments (Fig. 1(d)). These anticorrelations are a result of dipolar interactions and exist despite the thermal fluctuations of the moments, which can be confirmed by kinetic Monte-Carlo simulations.
Here, we present additionally the POLARIS results of **sample 2**, the nanoflower powder. The individual particles are preferentially magnetized along one direction but, due to their nanocrystalline substructure, their internal magnetization is disordered [3]. They excel during magnetic hyperthermia experiments, which can be attributed to significant internal spin relaxations at high frequencies, and which we explain by the before-mentioned spin disorder. In powder form the nanoflowers aggregate, and by analysis of the magnetic SANS data of **sample 2**we can reveal the influence of dipolar interactions on the moment correlations of neighboring nanoflowers within particle clusters. These results may be in particular of importance with regard to biomedical applications of such nanoparticles, considering their tendency for aggregation in cellular environments [4].

[1] D. Honecker et al., *Eur. Phys. J. B* 7**6** (2010) 209.
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Coupled magneto-mechanical characterization of soft active magnetorheological elastomers

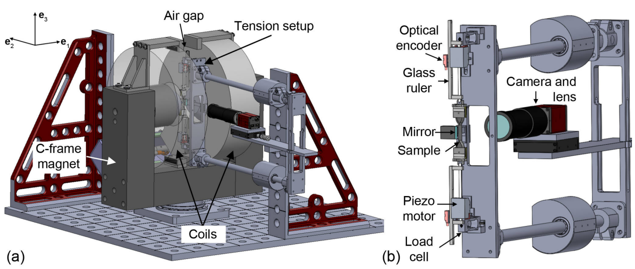
Tuesday, 9th July - 14:50: Plenary Speech Session - Oral - Abstract ID: 161

Dr. Laurence Bodelot [1], *Dr. Kostas Danas* [1], *Prof. Nick Triantafyllidis* [1]
1. *Ecole Polytechnique*

Magnetorheological elastomers (MREs) are composite materials made of magnetizable metallic particles embedded in a soft elastomeric matrix. They belong to the class of smart or active materials since some of their properties, in particular their stiffness, can be modified by the application of an external stimulus, a magnetic field in their case. In the presence of a magnetic field, they can also exhibit large deformations. Hence they stand as promising candidates for a large number of engineering applications linked to tunable damping, non-contact actuation, morphing surfaces or artificial muscles. The simplest form of MRE samples are isotropic due to a homogeneous dispersion of magnetizable spherical particles in their matrix but curing these composites under magnetic fields can impart them with anisotropic properties through the creation of particle chains in the direction of the curing field.

To our knowledge, there exists no precise and complete characterization of the fully-coupled magneto-mechanical response of MREs, which hinders the further design of MRE-based devices and the validation of magneto-mechanical models. The purpose of the present work is to develop a coupled experimental/numerical methodology for characterizing and modeling the coupled magneto-mechanical behavior of isotropic soft MREs that can sustain large deformations.

The first part of the presentation will introduce sample fabrication, including the question of interfacial adhesion between the magnetizable particles and their host soft elastomeric matrix. In the second part, the experimental setup (see Figure 1) developed to characterize the behavior of MREs under coupled magneto-mechanical mechanical loadings will be presented along with experimental results. Finally, a continuum phenomenological model of isotropic MREs will be introduced and it will be shown that an additional 3D finite-element model is necessary to identify the parameters of the model from the experimental data previously acquired.



C2 setup.jpg

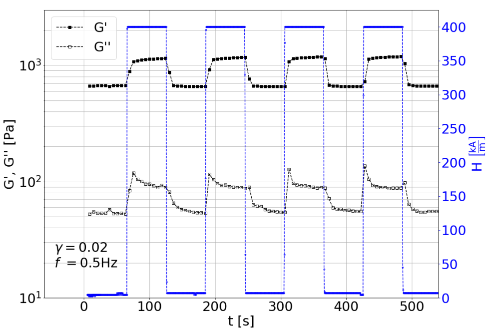
Effects of carbonyl iron particles on the rheological behavior of nanocomposite hydrogels

Tuesday, 9th July - 15:05: Plenary Speech Session - Oral - Abstract ID: 282

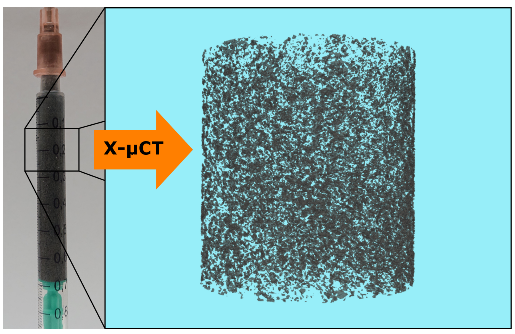
Mr. Lukas Selzer [1], ***Prof. Stefan Odenbach*** [1]

1. Chair of Magnetofluiddynamics, Measuring and Automation Technology, TU Dresden, 01069 Dresden, Germany

By incorporating magnetic particles into matrices of elastomers smart materials are created, whose stiffness can be manipulated by applying a magnetic field. Most commonly silicon-based elastomers are utilized because of their inertness and robustness, which makes them easy to handle. As a drawback it is not simple to chemically modify them for further functionality. Hydrogels on the other hand offer a great variety of stimuli-responsive behavior. They are polymeric or colloidal networks, which contain water as a swelling agent. Their highly water absorbing properties and excellent biocompatibility are the reasons they are used as super-absorbers and contact lenses, while further applications in biomedicine and sensorics are currently researched. In general they show a swelling/deswelling behavior depending on external stimuli. In the case of nanocomposite hydrogels (NC gels), the brittleness of classical hydrogels is improved by using nanoparticles as crosslinking material. Combining hydrogels with magnetic particles produces a multi-responsive hybrid material, allowing magnetic manipulation while retaining the swelling-behavior. Because of the aqueous environment inside the hydrogel, usually inert magnetite (Fe_3O_4) nanoparticles are used, however, due to the lower permeability of magnetite compared to pure iron, the resulting magnetic effects of the material are comparably small.
In our talk we will show results for the effects of micron-sized carbonyl-iron-particles (CIP) on the swelling behavior and rheological properties on hydrogels depending on an external magnetic field. For this we synthesize a silica-coating on commercial CIP to prevent oxidization in the aqueous environment. A NC gel consisting of N-isopropylarclamide and "Laponite RD" showing temperature-sensitive swelling-behavior with a reversible lower critical solution temperature of around 32 °C is combined with the coated CIP to produce a new hybrid material. In a modified Haake MARS III with temperature-controlled magnetic cell we can introduce a magnetic field during dynamic mechanical analysis, thus allowing us to monitor time-resolved responses of the hybrid material to a magnetic field. Additionally we perform X-ray µ-computertomography of samples in steady states to gain insights into the microstructure of the material and get further information of the particles on the single-particle level.
Financial support by DFG in the RTG 1865 is greatfully acknowledged.



Oscillatory measurements.png



Binary volumetric data.png

Evidence for existence of forbidden indirect optical band gap transitions and observation of spin injection from Co2CrAl into Silicon

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 16

Dr. Rashmi Singh [1], ***Mr. faizan ahmad*** [2], ***Mr. Kashif Nazeer*** [2], ***Dr. Rachana Kumar*** [3], ***Dr. Naresh Kumar*** [1], ***Dr. Animesh K. Ojha*** [4], ***Dr. Sunil Singh Kushvaha*** [5], ***Dr. Pramod Kumar*** [6]

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Band gap studies for thin films of Co_2CrAl deposited on Silicon and glass by DC sputtering were carried out employing Tauc plot. The procedures lead to a discovery of a forbidden transition in the band gap with an indirect forbidden band gap value of 0.5252 eV. The magnetic measurement observations revealed the $L2_1$ structural ordering and ferromagnetic nature of the film. The partial density of states (PDOS) of the electrons having up and down spins in the crystal lattice is calculated employing density functional theory (DFT) calculations using VASP code, as shown in the Figure 1 which is PDOS vs energy plot of Co_2CrAl calculated using VASP code. The optimized structure of Co_2CrAl is shown in the inset of the Figure 1.

We have also observed the spin injection from Co_2CrAl layer into an n-type Silicon (100) substrate. Upon obtaining structural and magnetic characteristics we obtained I-V characteristics of the device so as to ascertain the existence of a Co_2CrAl/Si Schottky contact which lead us to infer spin injection phenomenon from Co_2CrAl into Silicon due to tunnelling through the lowered Schottky barrier [1, 2].

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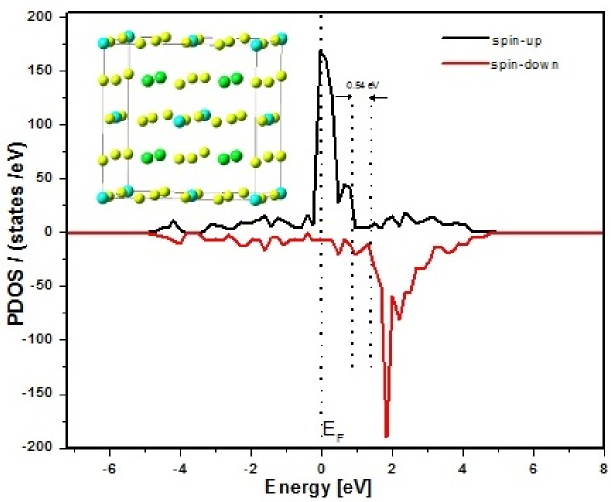

Figure1.jpg

Tunable Magneto-dielectric properties of Magnetic fluid at Radio-microwave frequencies

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 71

Ms. Mudra Jadav [1], *Prof. S P Bhatnagar* [1]

1. Maharaja Krishnakumarsinhji Bhavnagar University, Bhavnagar-364001, Gujarat

The modulation of dielectric properties by external magnetic field is called magneto-dielectric effect. Soft ferrites are useful in many radio-microwave devices like circulators, isolators, phase shifters, filters, radar absorber and nonlinear devices due to their magneto-dielectric effects. These devices can be designed to replace the bulk ferrite by magnetic fluid having ferrite nanoparticles to get benefit of flexibility in shape and tunable properties. Frequency dependent complex magnetic permeability is determined for a laboratory synthesized magnetic fluid containing magnetite nanoparticles using Vector Network Analyzer (VNA) in the frequency range 0.3 MHz to 3 GHz. The frequency dependence of real and imaginary component of complex magnetic permeability of magnetic fluid at no applied external field is shown in fig (1). The real component μ' decreases with increasing frequency and at resonance frequency (f_{res}), μ'=1. The imaginary component (μ") of complex magnetic permeability increases with frequency, show a maximum at the absorption frequency (f_{max}). The responsible mechanism can be explained by the relaxation of magnetic moments via either Neel's or Brownian relaxation under the influence of alternating field. Fig (2) and (3) show the frequency dependence of μ' and μ''component with externally applied static magnetic field with various field strengths between 0 to 600 Oe. The μ' decreases with increasing field strength in the low frequency region and it increases in the high frequency region of our considered range. The μ" peak shifts to high frequencies and its amplitude decreases with increasing field strength. This change can be attributed to the structure formation inside the fluid. When the external static magnetic field is applied, the magnetic moments will try to align in the field direction and form linear chain structures. The effect of parameters like particle concentration, external static magnetic field with various field strength and the static field orientation with respect to the EM wave propagation direction on magneto-dielectric properties of magnetic fluid is studied in this work. The properties like Resonance frequency (f_{res}), Absorption frequency (f_{max}), loss tangent (tan δ), Power loss, Heat generated, Reflection loss etc. are tunable with these parameters.

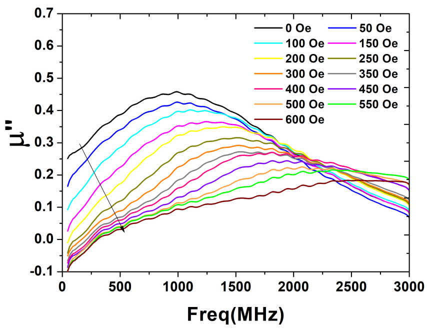

Fig.3field profile im permeability.jpg

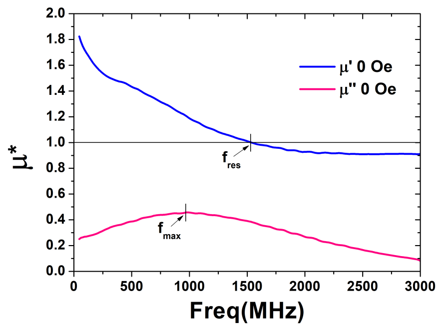

Fig1.complex permeability.jpg

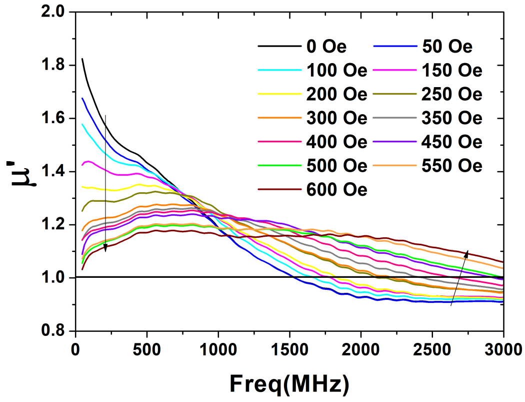

Fig2.field profile re permeability.jpg

Development of a liquid cell for soft X-ray MCD on ferrofluids

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 115

Dr. Fadi CHOUEIKANI [1], ***Mr. Victor PINTY*** [1], ***Dr. Edwige OTERO*** [1], ***Dr. Philippe Ohresser*** [1], ***Dr. Niéli Daffé*** [1], ***Dr. Sophie Neveu*** [2], ***Dr. Philippe Sainctavit*** [3]

1. *Synchrotron SOLEIL,* ***2.*** *Sorbonne Université,* ***3.*** *IMPMC*

Ferrofluids are well-known for their spectacular instabilities and their numerous applications in various domains. The highlight of ferrofluids results from the wide panel of chemical synthesis routes and the possibility to functionalize nanoparticles. The magnetic nanoparticles of the most common ferrofluids are MFe_2O_4ferrimagnetic and MO antiferromatic (where M is a 3d transition element). Soft X-ray Magnetic Circular Dichroism (XMCD) is a powerful method to probe theses 3d elements thanks to its chemical and orbital selectivity and its sensitivity to the valence states [1]. Thus, XMCD is a well appropriate technic for ferrofluids because it allows to separate contributions of the different magnetic ions in nanoparticles [2] and in more complex systems such as core-shell nanoparticles [3].

Despite the study of ferrofluids unsing several techniques (Mössbauer spectroscopy, conventional magnetometry, neutrons scattering…), Investigation of ferrofluids by soft XMCD is scarce compared to what has been developed for the solid state phase.

The measurement of XMCD on a ferrofluids is a challenge since soft X-ray beamlines require ultra-high vacuum (UHV) conditions. Up to now, all soft XMCD measurements were done on drop-casted ferrofluids on neutral substrate [2]. Developing a cell for liquids for XMCD on ferrofluids becomes necessity because it will offer to ferrofluids community a wide panel of investigations such as the probe of isolated or correlated nanoparticles, binary ferrofluids.

We present here the development of a compact liquid cell that is compatible with UHV environments of soft XMCD and with the most ferrofluids. This liquid cell (fig.1) consists in two 100 nm thick Si_3N_4 membranes that are separated by a 4 µm thick spacer which defines the sample volume. Two holes define the inlet-port and the outlet-port allows filling and refreshing the liquid during experiments. A photo-diode mounted at the rear of liquid cell allows the measurements of the transmitted X-rays through the liquid. This liquid cell is tested and very soon it will be mounted on the end-station of DEIMOS Beamline for final commissioning.

[1] Ohresser at *al. RSI*, 85(1): 013106. (2014).

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Structural and Paramagnetic Resonance Properties Correlation in Lanthanum ion doped Nickel Ferrite Nanoparticles

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 123

Dr. Ashok Kumar [1]***, Mrs. Sonia Gaba*** [2]***, Prof. Pawan Singh Rana*** [1]***, Dr. R. P. Pant*** [3]

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Nanoferrites low electrical conductivity, eddy current losses, high thermal, chemical and mechanical stability, wear resistance and catalytic activity have been explored for applications in the fields like hyperthermia, imaging, biological, chemical sensor, ferrofluids, high density data storage and EMI shielding etc. The phase transition from superparamagnetic (SPM) to ferri/ferro magnetic state or vice versa with temperature variation depends on particles size. Lanthanum (La^{3+}) ions doped nickel ferrite nanoparticles of different compositions were synthesized by sol-gel method and characterized by various analytical techniques. La^{3+} ions substitution induces dislocation and deformity in lattice to soften the lattice. XRD patterns confirmed the polycrystalline nature of nanoparticles with no extra phase as per JCPDS card no. 071-1232 with increase in lattice constants on substitution of larger ionic radii La^{3+} ions at Fe^{3+} sites. n_1 Fe-O stretching vibration of A- (Tetrahedral) and ν_2 Fe-O of B- (Octahedral) sites are observed at 598 cm^{-1} and 419 cm^{-1} respectively in IR transmission spectra. The broadening of both stretching vibrational modes with La^{3+} ion content is attributed to the reduction in grain size arising from the lattice distortion by cation distribution, interactions among nanoparticles and La^{3+} ion concentration. On increasing La^{3+} ion concentration, the variations in the intensity of ν_1 band are more pronounced as compared to $\nu_2$band which confirms the preferred substitution of La^{3+} ion at octahedral site by expanding the B-site radii. FESEM micrographs exhibit the homogeneous and agglomerated nanoparticles pattern of these doped analogues. EPR spectra exhibit broad ferromagnetic signal with no characteristic peak of SPM feature. The peak to peak line width and g-value increases with increasing La^{3+} ion concentration in samples. These morphological and magnetic properties can be exploited for their use in the development of stable ferrofluid for heat sink application and as sensing electrode in chemical/bio sensors.

Magnetically tuning of microwave propagation through ferrofluids

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 127

***Prof. Iosif Malaescu* [1], *Prof. Paul Fannin* [2], *Prof. Madalin Bunoiu* [1], *Prof. Catalin Nicolae Marin* [1]**

***1.** West University of Timisoara, Faculty of Physics, **2.** Trinity College, Department of Electronic and Electrical Engineering*

Development of electromagnetic applications demands continuous synthesis and studies of engineered materials. Recently, the realisation of a 'meta-skin' that uses split-ring resonators of liquid-metal embedded inside a silicon elastomer matrix has been reported [1]. Since ferrofluids are materials characterized by magnetic, electric as well as liquid properties and these properties can be magnetically tuned, they can be used in making various engineered materials with electromagnetic applications. Thus studies focused on the behaviour of microwaves propagating through ferrofluids, or when engaging with structures involving thin films of ferrofluid, are useful for applications.

Frequency (f) and field (H) dependencies of the complex magnetic permeability $\mu(f, H) = \mu'(f, H) - i\,\mu''(f, H)$ and complex dielectric permittivity $\varepsilon(f, H) = \varepsilon'(f, H) - i\,\varepsilon''(f, H)$ of a kerosene based magnetic fluid with magnetite particles, over the approximate frequency range 0.5 – 6 GHz and in various polarizing field, from 0 to 100 kA/m, have been measured by the technique reported in [2].

Based on these measured parameters, we present a study of the design of magnetically tunable propagation characteristics of some possible structures with thin films of ferrofluid.

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Influence of the size, shape and concentration of magnetic particles on the optical properties of nano-dispersive structures

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 107

Prof. Lali Kalandadze [1], ***Prof. Omar Nakashidze*** [1]

1. Batumi Shota Rustaveli State University

In general, the optical properties of nano-dispersive structures are very different from the properties of the bulk materials and depend on the structural parameters: the occupancy of the volume of the ultrafine medium with nanoparticles (q), the size and shape of the particles (f), the order of the particles, the properties of the medium, surrounding nanoparticles (ε_m).

In the present paper, using the discontinuous Ni films and magnetite magnetic fluids as examples we consider theoretically and experimentally the influence of the structural parameters on the optical properties of the nano-dispersive structures. The optical spectra strongly depend on composition and dielectric constants of particles and matrix. In its turn the dielectric constants are functions of the structural and electronic parameters and can differ from those for corresponding bulk materials. Thus optical spectra investigations can give very useful information about structural parameters of the ultrafine structures. In this work the optical properties of nano-dispersive structures are represented within the theoretical Maxwell-Garnett model. The behavior of the optical spectra of thin Ni films was explained in the framework of the effective medium approximation in two cases: $q<0.5$ and $0.5< q<1$. In this approach an effective refractive index (n+ik) of the nano-dispersive structures can be calculated as a function of the ε_m, q, and particle shapes. These calculations proved a good agreement between the experimental and the theoretical results.

Rheology of a ferromagnetic nematic liquid crystal in a magnetic field

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 133

<u>Mr. Tilen Potisk</u> [1], Prof. Daniel Svenšek [2], Prof. Harald Pleiner [3], Prof. Helmut Brand [1]

1. *University of Bayreuth,* ***2.*** *University of Ljubljana,* ***3.*** *Max Planck Institute for Polymer Research*

An old idea to generate a liquid ferromagnet was that by introduction of ferromagnetic nanoparticles in a nematic liquid crystal one could create a phase showing simultaneously ferromagnetic and nematic ordering [1]. Only recently this phase was successfully experimentally realized [2].

The ordering in a ferromagnetic nematic liquid crystal is described by two fields: the director field **n**, which describes an average orientation of the molecules of the liquid crystal, and the magnetization field **M**, describing an average orientation of the magnetic moments of the magnetic particles. Unlike usual nematics, the ferromagnetic phase is sensitive to very small magnetic fields. Measurements of the statics and the dynamics of a ferromagnetic nematic were performed on a sample confined between two parallel plates and were modeled using the existing macroscopic theory [3]. From the dynamic measurements of the intensity of the transmitted light, we found that the dissipative cross-coupling between the director and the magnetization plays a crucial role to explain the data [4].

To understand the dynamic behavior of a system it is necessary to measure the rheological properties. An important property of magnetic liquids is the ability to control the viscosity using an external magnetic field. In a usual nematic liquid crystal the typical magnetic fields needed to increase the viscosity appreciably are of order of 0.5 T, which is due to the small anisotropy of the magnetic susceptibility. We show that in a ferromagnetic nematic the viscosity can be doubled using a magnetic field of order of 10 mT [5].

We thank the Deutsche Forschungsgemeinschaft for partial support through the Priority program 1681.

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Nanostructure and thermodiffusive properties of tuned maghemite-NP/polar-solvent interface

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 134

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Colloidal dispersions of maghemite (γ-Fe_2O_3) nanoparticles (NPs) are here stabilized on polar solvents, water or dimethyl sulfoxide (DMSO), by applying a new process of preparation. Departing from the point of zero charge (PZC), the NPs are easily charged in a controlled way by adding acid or base solutions in order to tune the NP/solvent interface [1]. The relationship between colloidal nanostructure and thermodiffusive properties of these dispersions is explored varying the nature of the NPs' surface, the sign of its charge and the nature of the counter-ions [2]. An appropriate comprehension of the surface charge is a crucial point to control the inter-particle interactions and thermoelectric properties [3,4]. Thermodiffusive physical process is often investigated on ionic species dispersed in polar solvents and its understanding is indispensable to look into thermoelectricity applications [5,6]. Thermodiffusion measurements is here performed through a Rayleigh Forced Scattering (RFS) experimental method [7] applied to concentrated colloids ($\Phi > 2$ %). Strong specificities are evidenced on the interparticle repulsion and on the Ludwig-Soret coefficient, associated to the nature of the counter-ions and of the solvent. Analytical scattering techniques (DLS and SAXS) are used to measure the strength of the interparticle repulsions and to understand the nanosctructure.

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Finding key parameters to optimize structural and magnetic properties of magnetic multicore nanoparticles

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 167

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Magnetic Multicore Nanoparticles (MCNP) consisting of multiple, densely packed iron oxide cores are of high interest for different medical applications [1]. To tune their magnetic and structural properties, the influence of parameters used for their synthesis has to be understood.

Therefore, we investigated the influence of different synthesis parameters on particle formation and characterized the resulting MCNP based on their core and cluster structure, size (transmission electron microscopy: TEM, X-ray diffractometry: XRD), phase composition (XRD), magnetic properties (vibrating sample magnetometry) as well as hydrodynamic size and size distribution (dynamic light scattering).

The MCNP were prepared by adding an alkaline medium ($NaHCO_3$ solution) to an iron salt solution ($FeCl_2$ and $FeCl_3$) followed by a heating step to remove CO_2. During synthesis the following parameters have been varied: concentration of iron salt solutions, ratio of Fe^{2+} to Fe^{3+} ions, addition rate of alkaline medium, reaction temperature, boiling method and the way to remove salts after the synthesis.

By altering the ratio of Fe^{2+} to Fe^{3+} ions, we found that the optimum ratio is around the stoichiometric ratio of magnetite. Increasing the total concentration of iron salt increases cluster sizes. As main key parameters to tune particle characteristics we found the addition rate of the base and the reaction temperature. Decreasing the addition rate and/or increasing the temperature leads to an increase in core and cluster size. Combining the variation of both parameters allows the preparation of clusters (TEM) from 30 to 90 nm with hydrodynamic sizes from 100 to 240 nm and core sizes between 11 and 21 nm. For the magnetic properties an increase of coercivity up to 8 kA/m (Fig.1) is obtained for increasing core and cluster size. M_S remains constant at around 65 Am^2/kg for a wide range of parameters. By these procedures we are able to prepare magnetic nanoparticles with tunable magnetic properties in the transition range of superparamagnetism to ferrimagnetism.

Acknowledgements

This work was supported in the frame of DFG Priority Program (SPP) 1681 (DU1293/4-2 and MU2382/5-1).

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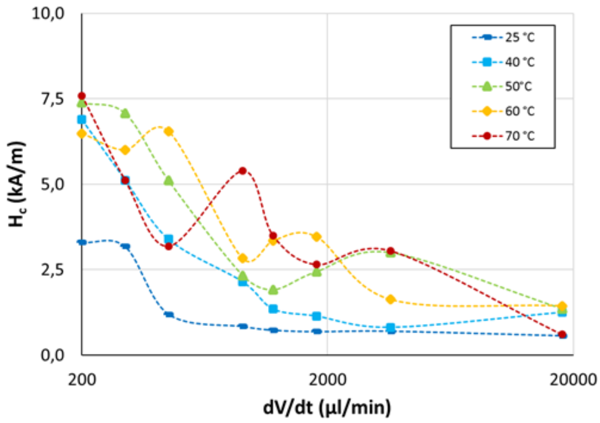

Fig. 1: Influence of base addition rate on the coercivity

Fig. 1 influence of base addition rate on the coercivity.png

Acoustic spectroscopy of functionalized carbon nanotubes in magnetic fluid

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 203

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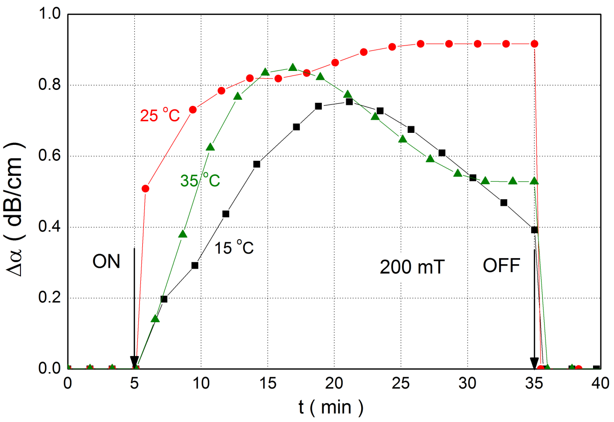
The acoustic spectroscopy was used for the study of structural changes of the multi-walled carbon nanotubes (MWCNT) functionalized by magnetic nanoparticles Fe3O4 diluted in the transformer oil under the influences of a magnetic field at various temperatures. Chemical vapor deposited MWCNT were purchased from Sigma Aldrich Co. (length around 1 µm, the outer diameter 25 nm and the wall thickness approximately 1 nm). MWCNT/ Fe3O4 composites were prepared in two steps; a) functionalization of MWCNT with carboxyl groups and b) subsequently labeling with magnetic nanoparticles. The measurements were done at different jump changes, a linear increase or decrease of the magnetic field and the application of constant magnetic field with the change of its orientation to the acoustic wave. The creation of new structures from nanotubes with nanoparticles by the presence of the magnetic field was confirmed by changes of the acoustic attenuation. Using this experiment, we have therefore confirmed that originally non-magnetic carbon nanotubes functionalized by magnetic nanoparticles can interact with a magnetic field (Fig. 1). From the measurements results that the lifetime (< 30s) of structures after switch off of the magnetic field was minimal. Such a rapid change can be due to the fact that nanotubes structures are held by magnetic forces resulted from the same direction of magnetic moments of magnetic nanoparticles. Our experiments have shown that a minimum magnetic flux density of 100 mT was required for the basic reorientation of multi-walled carbon nanoparticles with magnetic nanoparticles. At a linear change of the magnetic field was observed hysteresis effect which was temperature dependent. The effect of anisotropy of the acoustic attenuation was observed and its analyzation was done. Three types of the concentration of MWCNT/ Fe3O4 in transformer oil for the measurements were used and their influence on structural changes at various development of the magnetic field are discussed.

Fig. 1: The dependence of acoustic attenuation changes for the jump change of the magnetic flux density to 200 mT measured at various temperatures.



Kudelcik.jpg

Memory effect in nematic phase of liquid crystal doped with magnetic and non-magnetic nanoparticles

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 214

Dr. Veronika Lackova [1], *Dr. Natalia Tomasovicova* [1], *Prof. Shie-Chan Jeng* [2], *Mrs. Katarina Zakutanska* [1], *Dr. Przemysław Kula* [3], *Dr. Peter Kopcansky* [1]

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Memory effect shown by soft materials has attracted considerable research attention for its fundamental as well as applied aspects. Such effect refers to the ability of material to maintain switched state even after the removal of external stimulus. Scientists have been drawn to the study of liquid crystals, as a member of soft-matter family, due to their fascinating electro-optical properties and also the soft memory behavior. The presence of nanoparticles in liquid crystal media has achieved the success in many fields of soft matter research, where the combination of unique properties of nanoparticles with the anisotropy of liquid crystals provides new opportunities for novel materials.

Fig.1. Tuning of nonvolatile effect by presence of magnetic nanoparticles [1].

In the presentation will be discussed experimental results of dielectric properties for aerosil non-magnetic nanoparticles as well as their mixtures with magnetic nanoparticles in calamitic liquid crystal confirmed through capacitance-voltage measurements. On dispersing a small quantity of aerosil nanoparticles into liquid crystal media, the prepared hybrid exhibits a non-volatile memory effect in nematic phase at ambient temperature. Moreover, the observed hysteresis effect can be tuned by embedding small amounts of magnetic nanoparticles. The memory state can be even erased by heating the samples to isotropic phase and again restored to its initial state by passing through the phase transition.

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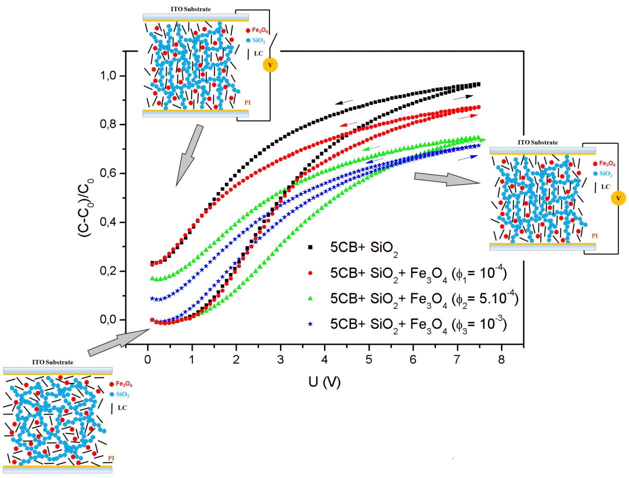

Graphical abstract.png

Alternating current magnetic susceptibility of ferronematics

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 215

***Dr. Natalia Tomasovicova* [1], *Dr. Jozef Kovac* [1], *Prof. Yuriy Raikher* [2], *Prof. Nandor Eber* [3], *Dr. Tibor Toth-Katona* [4], *Dr. Veronika Lackova* [1], *Mrs. Katarina Zakutanska* [1], *Dr. Peter Kopcansky* [1]**

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Experimental studies are reported focusing on the dynamic ac magnetic susceptibility of a ferronematic (i.e., a nematic liquid crystal doped with magnetic nanoparticles). It was found that a weak dc bias magnetic field (a few Oe) applied to the ferronematic in its isotropic phase increases the ac magnetic susceptibility considerably. Passage of the isotropic-to-nematic phase transition resets this enhancement irreversibly (Figure 1), but can be reinduced by applying the dc bias field again in the isotropic phase [1]. The effect has no analogue in the neat host liquid crystal. A model based on aggregation and disaggregation of the nanoparticles is proposed as an interpretation. It is demonstrated that tuning the concentration of the magnetic nanoparticles, the range of the dc bias magnetic field to which the ferronematic is sensitive without saturation can be increased by about two orders of magnitude [2]. This finding paves a way to application possibilities, such as low magnetic field sensors, or basic logical elements for information storage.
Figure 1 The temperature dependence of the ac magnetic susceptibility of the ferronematic.

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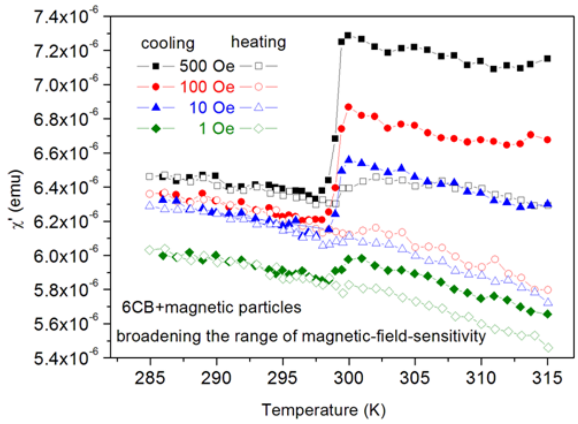

Ac susc.png

Detailed structural investigation of magnetoresponsive magnetic fluids and nanocomposites by small-angle neutron scattering data

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 219

Dr. Anatolii Nagornyi [1], ***Dr. Viktor Petrenko*** [2], ***Dr. Rodica Turcu*** [3], ***Dr. Oleksandr Ivankov*** [2], ***Dr. Vlad Mircea Socoliuc*** [4], ***Dr. Alexander Bunge*** [5], ***Prof. Leonid Bulavin*** [6], ***Dr. Mikhail Avdeev*** [2], ***Prof. Ladislau Vekas*** [4]

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Two kinds of magnetoresponsive nanomaterials, water based magnetic fluids and magnetoresponsive nanocomposites were studied in the given work. It is well known that steric stabilized water based ferrofluids with biocompatible surfactants are usually of limited concentration, up to approx. 5% volume concentration of magnetic nanoparticles. There are only a few successful attempts to increase the volume fraction of dispersed magnetic nanoparticles in order to increase the saturation magnetization of water based magnetic fluids, especially in case of steric stabilization. A possible reason is the micelle formation of the free (excess) surfactant in solution [1].Recently more concentrated water based magnetic fluids were obtained at the Laboratory of Magnetic Fluids from Timisoara. The main goal of the work was the detailed structural investigation of magnetite nanoparticles clusters with tailored size, composition, magnetic properties and appropriate design of surface properties. High magnetization magnetic clusters have been obtained by solvothermal method [2]. This method allows for tailoring cluster and the crystallite size by variation of the synthesis conditions. Thus, our investigated samples have cluster size within the range 50-150 nm and crystallite size about 15-30 nm depending on reaction conditions. The synthesized magnetic nanoparticles clusters were thoroughly characterized by several advanced techniques. Small-angle neutron scattering investigation was done to study the internal structure of the magnetic clusters, the arrangement of nanoparticles inside the cluster, the uniformity of the nanoparticles coating shell.

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Investigation of static magnetic fluctuations inside magnetorheological elastomers by means of neutron depolarization method

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 221

Dr. Maria Balasoiu [1], ***Dr. Sergei Kozhevnikov*** [1], ***Prof. Yuriy Nikitenko*** [1], ***Prof. Ioan Bica*** [2], ***Dr. Gennady Stepanov*** [3], ***Prof. Madalin Bunoiu*** [2], ***Prof. Yuriy Raikher*** [4]

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Physics and technology of magnetorheological elastomers (MREs)—compositions of various soft polymer matrices with micron-sized magnetic particles—undergo continuing development. The fundamental part of this work—understanding of macroscopic properties and structural features of those systems in dependence on such factors as the synthesis processes, composition content, rheological characteristics of the matrix, mesoscopic spatial order of the particles as well as the electrical and magnetic susceptibilities of the latter, is nowadays in high demand and extensively progressing.

Polarized neutron beams transmitted through magnetic media, provide an extremely sensitive intravision tool to find and investigate the mesoscopic-scale inhomogeneities of the local magnetic fields in MREs. When a neutron passes through or in a close vicinity of a magnetic cluster, the neutron spin is subjected to the Larmor precession around the local magnetic induction vector. Due to that, the neutron experiences depolarization, i.e., a perturbation that distorts the state of its spin in comparison with the in the incident beam. Therefore, from the depolarization curve, the dispersion of the magnetic induction inside the sample could be extracted and, on this grounds, the conclusions on the internal magnetic structure of a given MREs may be drawn.

In this work we report the results of measuring the time of flight (TOF) neutron depolarization (ND) effect at Larmor precession [1–4] carried out on two different types of magnetorheological elastomer samples and analyze the revealed differences in their magnetic structure.

The ND TOF data were obtained on the polarized neutron spectrometer REMUR installed at the pulsed reactor IBR-2 operated by the Frank Laboratory of Neutron Physics at JINR (Dubna).

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Dual effect of surfactant in ferronematics

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 232

Mrs. Katarina Zakutanska [1]***, Dr. Veronika Lackova*** [1]***, Dr. Natalia Tomasovicova*** [1]***, Prof. Sergei Burylov*** [2]***, Dr. Alena Jurikova*** [1]***, Dr. Marek Vojtko*** [3]***, Prof. Jan Jadżyn*** [4]***, Dr. Peter Kopcansky*** [1]

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Addition of magnetic nanoparticles to nematic liquid crystal in order to increase liquid crystal sensitivity is known for almost fifty years. Number of experimental and theoretical papers showed that nanoparticles modify various liquid crystal properties, such as magneto-optical properties, electro-optical properties, Fréedericksz transition threshold, phase transition temperature, etc. Previous articles [1,2], both experimental and theoretical, showed that isotropic to nematic phase transition temperature is shifted in ferronematics with spherical nanoparticles to lower values, while magnetic nanoparticles in the shape of rods shift the isotropic-nematic transition of nematics to higher values. Moreover, the effect is enhanced with increasing nanoparticle concentration. Monotonic dependence for spherical nanoparticles and non-monototic dependence for rod-like nanoparticles obtained in experimental work [2] have been explained by additional contribution of organic surfactant, which prevents the nanoparticle aggregation. The influence of surfactant on isotropic-nematic transition has not been studied yet, the papers devoted to surfactant effects were mainly focused on composites stability.

We report about surfactant effect on isotropic to nematic phase transition temperature in composite based on 4-cyano-4-hexylbiphenyl liquid crystal (6CB) and oleic acid coated spherical iron oxide nanoparticles. Since the amount of surfactant increase with nanoparticles volume fraction, composites with volume fractions up to 10^{-3} had been studied. Optical measurements, differential scanning calorimetry (DSC) measurements and capacitance measurements were employed to examine isotropic-nematic transition temperature of composites. The methods showed non-linear decreasing of isotropic-nematic transition temperature with increasing nanoparticle concentration and non-monotonic dependence of isotropic to nematic phase transition temperature on nanoparticle size. In addition, the shifts were significantly larger than it was predicted by theory [1]. Therefore, surfactant effect on isotropic-nematic transition was investigated. Transmission electron microscopy (TEM) and scanning electron microscopy (SEM) showed non-uniform oleic acid layers and from the size distributions the volume fractions of oleic acid were determined. Although the oleic acid prevents nanoparticle aggregation, the results indicate that the oleic acid surfactant modifies isotropic-nematic transition temperature significantly.

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Synthesis and characterization of high aspect ratio iron oxide nanorods with switchable orientation in a magnetic field

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 246

Mr. Stephan Hinrichs [1]***, Ms. Larissa Grossmann*** [1]***, Ms. Hannah Grotian*** [1]***, Dr. Andreas Meyer*** [1]***, Dr. Birgit Fischer*** [1]

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Goethite is an iron-oxide hydroxide. It is inherently anti-ferromagnetic in nature and thus often overlooked when it comes to magnetic materials. Nevertheless, the material shows interesting magnetic properties when scaled down to nanometer size. In this work we present goethite nanorods with a tunable aspect ratio. These rods align perpendicular to strong magnetic fields, because of the negative anisotropy of their magnetic susceptibility, but they align parallel to weak magnetic fields due to orientable surface moments.
The nanorods are synthesized by a hydrothermal approach in two steps. The starting point are precursor particles made from akaganeite, another iron-oxide hydroxide. These are mixed with polyvinylpyrrolidone (PVP) which acts as a stabilizing and growth guiding agent during the hydrothermal treatment. The solution containing the PVP coated particles is then adjusted to a pH value of 12 by sodium hydroxide and stirred for two hours. After this initial waiting period the particles are transferred into a stainless-steel autoclave reactor lined with teflon. The teflon reactor is sealed and pressurized with nitrogen up to a final pressure of ten bar. The mixture is heated up to 160 degrees and stirred for varying amounts of time. The amount of time depends on the desired aspect ratio. We found that short reaction times yield very long particles with an aspect ratio of up to 21, while prolonged reactions yield shorter particles with an aspect ratio of 5. (Figure 2)
The orientation of the particles inside a magnetic field was confirmed by small angle x-ray scattering (SAXS). (Figure 1) After the synthesis the particles were coated by a silica shell, which gives the advantages of easy functionalization and prolonged stability in different media.
Particles with and without silica shell were introduced into a thermoresponsive matrix, consisting of N-isopropylacrylamide. The popular polymer pNIPAM undergoes a coil to globule transition around 32 °C and can be used in biomedical applications. We studied the interactions between the goethite nanorods and the polymer matrix by observing the orientation with and without the matrix present.
We think this work gives some valuable insights into the interesting dynamics of goethite nanorods.

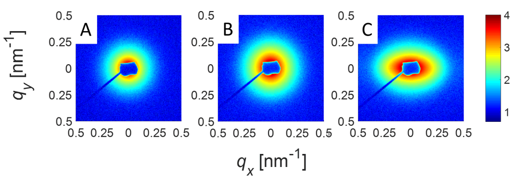

Figure 2: SAXS images showing the scattered intensity A: without an applied magnetic field, B: with an applied field of 75 mT and C: with an applied field of 1.1 T. The magnetic field was applied horizontally.

Saxs images of goethite in a magnetic field.png

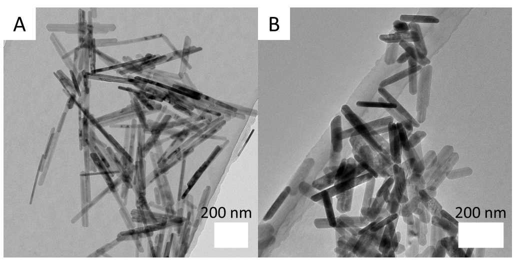

Figure 1: TEmicrographs of goethite nanoparticles synthesized in a hydrothermal reactor. A: Particles after 2 hours with an aspect ratio of about 12. B: Particles after 6 hours with an aspect ratio of about 5.

Temicrographs of goethite nanoparticles.png

Influence of Mg2+ ion doping on physical properties of copper nanoferrite for microwave absorption application

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 249

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Nanoferrites are extensively explored materials owing to their wide range of applications in the fields of magnetic fluids, high-density information storage, microwave devices, EMI shielding, gas sensor and biomedical as target drug delivery and magneto hyperthermia, imaging, etc. The versatile magnesium ferrite has high magnetic permeability and electrical resistivity with low dielectric losses. Magnesium and copper have strong preference for the tetrahedral and octahedral sites respectively. Copper ferrite forms normal spinel ferrite structure and magnesium ferrite forms inverse spinel ferrite. Mg–Cu composite ferrites have mixed spinel structure. Soft $Mg_xCu_{1-x}Fe_2O_4$(0□ x□1) ferrite nanoparticles were prepared by facile chemical co-precipitation method. The structural details and other physical properties of these samples were characterized by using powder X-Ray diffractometer, FTIR, TEM, EPR and VSM techniques. XRD patterns confirmed the single-phase cubic spinel structure of nanoparticles with no extra phase and crystalline size lies in the range 8-20 nm. It was found that the lattice parameter decreases with increasing cation substitution of Mg^{2+} due to the difference in atomic mass and ionic radius. IR transmission spectra showed characteristics tetrahedral and octahedral Fe-O stretching bands at 565 $cm^{-1}$and 418 cm^{-1} respectively. EPR spectra of all the samples exhibit a ferromagnetic single broad resonance signal which shifts to the higher field on increasing Mg ions concentration. The spin concentration and saturation magnetization decreases with increasing Mg^{2+}ion concentrations. These properties of magnesium doped copper ferrite are found to be suitable for microwave absorption application.

Size, Solid Concentration and Magnetic Field Dependent Magnetic Nanoparticles Structures in Magnetic Fluid

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 266

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Magnetic fluid (MF) is colloidal solution stably dispersing surfactant coated magnetic nanoparticles in either polar or non-polar solvents. However, depending on the size of the particles or strength of magnetic field nanoparticles in the solvent aggregate or self-organize by long-range dipole-dipole interactions under external magnetic field and magnetic field-free conditions. Although attempts have been made to understand the behavior of nanoparticles in MF through theory and simulation by many researchers over a couple of decades, experimental evaluation of the internal structure of MF is also necessary for a complete understanding. Experimental research of self-assembled structure in magnetic fields and lower temperatures are often evaluated by using small angle X-ray scattering (SAXS) and cryogenic transmission electron microscopy and the formation of chain-like structures has been confirmed. However, in most of the cases, a detailed analysis is difficult due to the polydispersity of the particles. Thus, in this study, the formation of nanoparticle structural characteristics under magnetic field strengths using MF suspension dispersing monodisperse particles with different diameters and solid concentrations.

Magnetite nanoparticles (MNPs) were synthesized by heating iron (□) acetylacetonate, in a mixture of oleic acid and oleylamine. MNPs with average diameters 11.5 ± 1.6 nm (Sample A), 16.4 ± 1.9 nm (Sample B), and 21.6 ± 1.9 nm (Sample C) were obtained by controlling the concentration of iron (□) acetylacetonate in the system. The nanoparticles were subsequently dispersed in kerosene to stable non-polar MF. Then, the microstructural characterization of these MFs under the external magnetic field lower than 54 mT was evaluated by SAXS. Interestingly, micro-structures were observed only in sample C (Fig. 1). On the other hands, macro-structural characterization of these MFs in by dark-field optical microscopy under external magnetic field of 30 mT exhibited needle-like macrostructures were formed not only in sample C but also in samples A and B. In other words, the formation of needle-like macrostructures does not necessarily mean the presence of microstructures in them. In addition, similar experiments were carried out using samples with solid concentrations. Detailed results of the above study will also be reported.

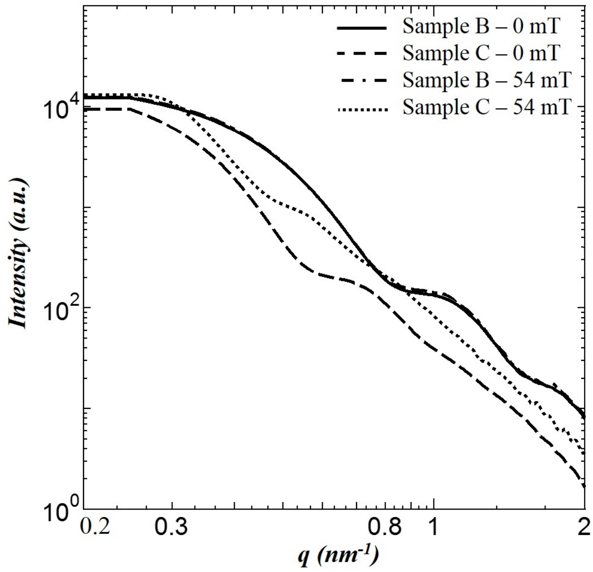

Fig. 1 saxs profiles of samples b and c in the absence and presence of the external magnetic field..jpg

Estimation of the magnetic properties of small quantities of nanoparticles with magnetophoresis supported by BEM calculations and the preparation of magneto-plasmonic nanostructures

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 285

Mrs. Valentina Piotto [1], *Prof. Moreno Meneghetti* [1]

1. University of Padova

Magnetic nanoparticles are used in many different fields where their mobility in a liquid environment is of fundamental importance. Among them, nanobiotechnology is an interesting field of application. However, not all the synthetic routes allow obtaining sufficient amount of sample for a magnetization curve, as a first characterization of the nanoparticles. One interesting synthetic route to produce magnetic nanoparticles is the Laser Ablation Synthesis in Solution (LASiS), which allows synthesizing nanoparticles without stabilizing molecules and, therefore, avoiding problems of biocompatibility. The synthesis produces particle with a dimensional distribution, which has to be taken into account considering their magnetophoretic dynamic. Many materials can be ablated for obtaining magnetic nanoparticles. Interesting magnetic materials to ablate are ferrites and Sr-ferrite ($SrFe_{12}O_{19}$) in particular, for its biocompatibility. Laser ablation of a bulk sample of Sr-ferrite in water produces magnetic nanoparticles with a complex composition made of Sr-ferrite and Fe oxides. The yield of the laser ablation synthesis is usually low and the magnetophoresis is a convenient methodology for study the magnetic properties of such nanoparticles with less than 1 ml of colloidal solution with a nanoparticles' concentration of 0.1 nM or less. The optical decreasing of the solution is then registered in the presence of a magnet as a function of the time, as schematized in Figure 1. The magnetophoretic motion of the nanoparticles in a magnetic gradient can be followed with optical extinction measurements supported by BEM calculations for the absorption/scattering properties of particles with different dimensions. It will be shown how the fitting of the experimental data (Figure 2) allows estimating the magnetization of the nanoparticles when the gradient of the magnetic field is known. A methodology for the functionalization of the nanoparticles with gold plasmonic nanoparticles for obtaining magneto-plasmonic nanostructures, useful for applications in the nanobiotechnology field, will be reported.

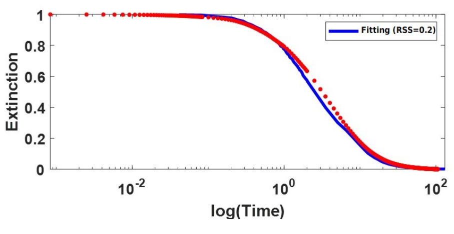

Figure 2.jpg

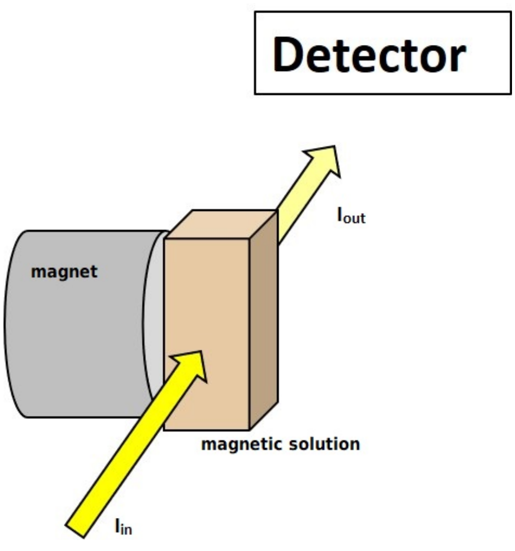

Figure 1.jpg

Efficient ferronematic coupling with polymer brush particles

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 306

Ms. Karin Koch [1], *Dr. Matthias Kundt* [1], *Prof. Alexey Eremin* [2], *Prof. Annette Schmidt* [1]

1. Universität zu Köln, 2. Otto-von-Guericke-Universität Magdeburg

The ability to control nematic phases in thermotropic liquid crystals (LC) by external fields opens a wide range for applications, e.g. in optical devices. While it is common to use electric voltage in such devices, the employment of magnetic fields is limited by the low magnetic anisotropy of the mesogens.

However, the incorporation of dipolar magnetic particles in nematic phases is expected to result in ferronematic phases that are readily responsive at moderate magnetic field strengths. [1] One of the main challenges for the experimental realization is the strong tendency of the nanoparticles to agglomerate, as a consequence of the strong molecular interactions of the mesogens and the dipolar interactions between the particles. [2]

Thus, compatibilization is a key step for the development of ferronematics. Our novel approach towards ferromagnetically doped LCs with enhanced volume fraction and stability is based on nanoparticles that are surface-modified with a side-chain LC polymer brush. We employ two different synthetic pathways with a variation of shell thickness, mesogen density and the spacer length. This results in an effective steric stabilization of the particles against agglomeration and offers a high degree of functionalization with respect to the mesogen.

The impact of the modified particles, differing in size, shape and magnetic anisotropy, on the phase behavior of 5CB (B_{th} = 250 mT at a layer thickness of d = 25 µm) is investigated with respect to particle concentration. By differential scanning calorimetry and determination of the order parameter we show a significant improvement in compatibilization as compared to conventionally stabilized particles.

The magnetic response of the ferronematic phases is investigated by capacitance measurements in a magnetic field. As compared to 5CB, the critical field strength is shifted to lower magnetic fields, and the shape of the Fréederickzs transition indicates an effective ferronematic coupling between the magnetic particles and the LC matrix. (Figure 2)

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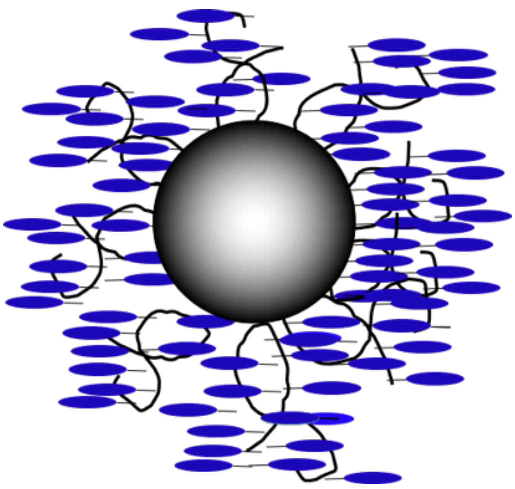

Figure 1. scheme of lc polymer brush particle.png

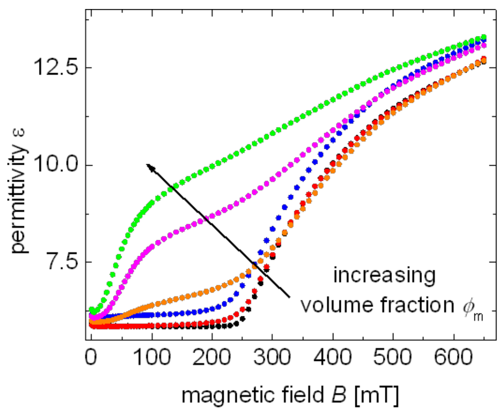

Figure 2. magnetic capacitance measurements for pure 5cb and 5cb doped with magnetic nanoparticles.png

Small-angle neutron and X-ray scattering studies of mitoxantrone loaded iron oxide nanoparticle complex for magnetic drug targeting

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 307

Dr. Artem Feoktystov [1], ***Dr. Jan Zaloga*** [2], ***Dr. Vasil Garamus*** [3], ***Dr. Rainer Tietze*** [2], ***Dr. Alexander Ioffe*** [1], ***Prof. Thomas Brückel*** [4], ***Prof. Christoph Alexiou*** [2]

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Superparamagnetic iron oxide nanoparticles (SPIONs) are a promising tool for drug delivery, diagnostics and other biomedical applications in anti-cancer treatment. With a suitable coating of SPIONs by pharmacologically active substances, which provide sufficient binding stability for drug molecules, the drug can be concentrated accordingly and the particles can be accumulated in a certain body region using magnetic field gradient. This approach increases the efficacy of therapy and reduces side effects[1]. A good understanding of the molecular drug adsorption mechanisms is desirable for proper design of the material for the potential application.

In the current work we present a complex study of the location of the anti-cancer drug Mitoxantrone (MTO) in the water-based biocompatible SPION system with lauric acid/albumin hybrid coating ($SEON^{LA\text{-}HSA}$)[2]. The effect of the drug addition on colloidal properties of the system was investigated by means of small-angle neutron (SANS) and X-ray (SAXS) scattering. The application of neutrons and X-rays allowed us to obtain structural information of SPION clusters and find out possible location of MTO by determining the change of interaction between clusters after drug adsorption. Thereby we were able to show that adsorption of the drug to the particles changes colloidal properties of $SEON^{LA\text{-}HSA}$ and partially weakens particle-particle interaction. The drug MTO is most likely adsorbed following electrostatic interaction mechanism, thus potentially reducing interactions of the particles with each other[3].

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Dispersion of magnetic nanoparticles in ionic liquid

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 316

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Spinel magnetic nanoparticles (MNPs) with different stoichiometry (Fe_3O_4, $CoFe_2O_4$ and $Co_{0,5}Zn_{0,5}Fe_2O_4$), has been prepared by the polyol method, in which metal (II) and iron (III) nitrates are dissolved in polyol and refluxed. X-Ray Diffraction (XRD) shows the presence only of cubic spinel phase (Pdf-3-864) with crystallites size around 4,5 nm (determined by Scherrer's equation). No other phases have been detected. Transmission Electron Microscopy (TEM) confirms the presence of almost spherical particles, with mean particles equal, within the experimental error, to values extracted from XRD. This indicate the high crystalline degree of the materials. By an exchange ligand process, MNPs has been coated by hydrocaffeic acid (HCA) and then dispersed in water. Thermogravimetric analysis (TGA) and Fourier Transform Infrared spectroscopy (FT-IR) have been used in order to investigate molecular coating of the particles and relative percentage of organic and inorganic (i.e. magnetic) part. In order to disperse in ionic liquid, water is added to create an aqueous dispersion, to which the 1-ethyl-3-methylimidazolium acetate (EMIMAC) will subsequently be added. This mixture thus formed is placed under vacuum. In addition, direct dispersion in EMIMAC was performed. Field and temperature dependence of magnetization of the powder and the dispersions in water and ionic liquid has been investigated. All the samples show superparamagnetic behaviour (i.e. $H_c = 0$, $M_r = 0$) at room temperature with value of saturation magnetization in line with expected for nanoparticles (M_s=70 Am^2/Kg). Measures at 5K, in the case of cobalt ferrite, the powder has values of H_c of 0,93 T and Ms of 90 Am^2/Kg. The direct dispersion presents H_c of 0,90 T and M_s 81 Am^2/Kg, higher values respect to indirect method (0,86 T and 76,5 Am^2/Kg). Interparticle interactions has been investigate by remanent magnetic measurement (i.e. DCD, IRM): dipolar interactions decrease in ILs dispersion respect to powder.

Colloidal aggregation of magnetic nanoparticles with opposite-charge species in salty environment

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 319

Mr. Mesut Demirelli [1], ***Dr. Natalie Malikova*** [1], ***Dr. Juliette Sirieix-Plénet*** [1], ***Dr. Véronique Peyre*** [1], ***Dr. Jérôme Fresnais*** [1]

1. *Sorbonne Université*

Colloidal stability of magnetic nanoparticles (MNPs) in salty environment is of the highest relevance in many biological or industrial systems. In the first case, the particles are internalized into cells, which are very complex media characterized by a high salinity and the presence of proteins and other species. The efficiency of the MNPs for the proposed biological applications is directly linked to their aggregation state in the cells. In the second case, nanoparticles dispersed in pure ionic liquids, which can be seen as extreme salty systems, have potential applications in heterogeneous catalysis, heat-transfer fluids and they can be used as gels for dye-sensitized solar cells and gas sensors (Bideau et al., *Chem. Soc. Rev.*, 2011, **40**, 907).

As a model system, we studied the colloidal stability of a medium composed of maghemite nanoparticles negatively charged by the adsorption of polyacrylate (Fresnais et al. *JCIS*, 2013, **24**, 395), of added ions with different concentrations and of a polycation, ionene (Malikova et al., *Phys. Chem. Chem. Phys.*,2015, **17**, 5650), with various charge densities. We can thus follow the evolution of the electrostatic interaction between oppositely charged species (negative NPs and polycations) in a salty environment going from aqueous salt-free solution, where the electrostatic interaction is supposed to dominate, to almost pure ionic liquid (Torimoto et al., *Advanced Materials*, 2010, **22**, 1196), where a new long-range force was recently evidenced (Lee et al., *PRL*,2017, **119**, 026002).

We varied the nature of the added salt using substituted ammonium salts and its concentration between 0 mol/L up to 11 mol/L in the case of ethylammonium nitrate. It was concluded, that

- Colloidal stability is obtained at *high* salt concentration, which is absolutely uncommon
- the concentration threshold for aggregation depends on the nature of the added salt, indicating that simple electrostatics is not sufficient to understand these systems.

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Magnetic relaxation dynamics in a ferromagnetic nematic liquid crystal

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 333

Dr. Hajnalka Nádasi [1]***, Prof. Ralf Stannarius*** [1]***, Prof. Alexey Eremin*** [1]***, Dr. Jing Zhong*** [2]***, Ms. Zhijun Wang*** [2]***, Ms. Hilke Remmer*** [2]***, Prof. Frank Ludwig*** [2]***, Dr. Nerea Sebastian*** [3]***, Prof. Darja Lisjak*** [3]***, Prof. Alenka Mertelj*** [3]

1. *Otto-von-Guericke-Universität Magdeburg,* ***2.*** *TU Braunschweig,* ***3.*** *J. Stefan Institute*

Soft magnetic materials, such as magnetic fluids, gels and elastomers, have recently come into focus of intensive research. The ability to easily manipulate optical and mechanical properties make them essential components for the design of smart materials. Recently, Mertelj et al. demonstrated that dispersions of magnetic nano-platelets in liquid crystals can exhibit ferromagnetic order [1,2]. Liquid crystalline order is expected to have a profound effect on the dynamics of the magnetic particles, which is still not fully characterised. Here, we report the study of magnetisation dynamics in a colloidal dispersion of barium hexaferrite nano-platelets in an isotropic fluid and a nematic liquid crystal phase using AC susceptometry. We demonstrate two modes of magnetisation existing in a liquid crystal matrix. A high-frequency mode is attributed to the dynamics of single particles whereas the low-frequency mode reflects the collective dynamics of the platelets and its interaction with a liquid crystal. The high-frequency mode is also observed in isotropic dispersions and corresponds to the Brownian relaxation dynamic of the magnetisation. In our study, we characterise the amplitude and frequency-dependence of the response as well as the effect of a bias field applied either parallel or perpendicular to the ac field.

A coupling between the director and the magnetisation leads to a strong rotational effect observed in a cylindrical cavity exposed to a rotating magnetic field. Using a torsional pendulum, we measure the magneto-mechanical torque in a wide range of frequencies and field amplitudes. The conversion efficiency of the magnetic torque into the mechanical is particularly strongly pronounced in our system since the Néel relaxation mechanism is suppressed.

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Ferrofluid incorporation into a sol-gel matrix

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 359

Dr. Alexandra Madeira [1]***, Dr. Agnès Bée*** [2]***, Dr. Vincent Dupuis*** [3]***, Mrs. Sophie NEVEU*** [2]***, Dr. Xingyu Wu*** [4]***, Dr. Jérémy Riporto*** [5]***, Dr. Hélène Thai*** [4]***, Dr. Mounir Kassouf*** [6]***, Dr. Maléki Balaki*** [6]***, Dr. Arnaud Spangenberg*** [7]***, Dr. François Royer*** [5]***, Dr. Emilie Garnet*** [5]***, Dr. Marie-Françoise Blanc-Mignon*** [5]***, Dr. Damien Jamon*** [5]***, Dr. Olivier Soppera*** [4]***, Dr. Dominique Berling*** [4]

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CoFe 2 O 4 nanocrystals exhibit interesting physical properties for electronics and telecommunications, such as a high saturation magnetization and a very efficient Faraday rotation. 1 Within the last decade, different chemical processes for the synthesis of CoFe 2 O 4 nanoparticles have been developed. Among them, the co-precipitation method has shown to be particularly interesting due to its simplicity, high yield and the quality of the material obtained (homogeneous size distribution and high crystallinity). 2 Even though high colloidal stability of such ferrofluid is obtained in water or in an apolar aprotic organic solvents, 3 aggregation occurs in alcoholic medium. In this manner, the magneto-optical properties of the ensemble are affected and their integration into other materials becomes limited.
The present work consists in the functionalization of magnetic CoFe 2 O 4 nanoparticles to improve their colloidal stability in alcoholic medium by using electrostatic or steric repulsion. In addition, further analyses on the interaction between the surfactants and the surface of the nanoparticles are presented. Finally, their incorporation into a sol-gel titanium oxide matrix and the physical properties of the final material are also addressed.

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High Temperature Synthesis of Ferrite Nanoparticles Using Continuous Flow Chemistry and Microwave Approaches

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 360

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Over the past decades, spinel magnetic iron oxide nanoparticles $M^{II}Fe_2O_4$ (with M = Fe, Co, Mn, Zn, Ni…) have attracted a large interest due to their unique magnetic properties[1]. Such properties are exploited in very various fields, ranging from biomedical applications to information storage. In order to control their properties (core and surface), different chemical processes have been developed including high temperature syntheses methods based on thedecomposition at high temperature of metallic salt precursors in high boiling-point solvents(polyols[2,3], etc). Although very attractive, it is still difficult to scale up such synthesis not to mention the problems related to reproducibility, safety and yield. Continuous-flow syntheses in milli/micro-fluidic channels have paved the way to safer and controlled chemical syntheses in the field of material science compared to batch[4]. In this work, we propose new chemical opportunities based on flow chemistry and microwaves to produce well-defined magnetic flower-like iron oxide nanoparticles using the so called « polyol » route. Herein, we carriedout the polyol synthesis using a continuous-flow heated millifluidic reactor. In parallel, thesame synthesis was studied in batch under microwave-assisted conditions. To end, kineticstudies were performed with both systems to understand the formation (nucleation andgrowth) of the flower-like nanoparticles.

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Magnetic field dependence of effective magnetic moment of multi-core nanoparticles

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 365

__Ms. Tamara Kahmann__ [1], Ms. Hilke Remmer [1], Prof. Frank Ludwig [1]

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For several biomedical applications of magnetic nanoparticles (MNPs), such as magnetic drug targeting and Magnetic Particle Imaging, the effective magnetic moment m_{eff} is an essential parameter. While for single-core MNPs, containing just one single-domain magnetic core, m_{eff} is given by the product of saturation magnetization and magnetic core volume, the situation is more complex for multi-core MNPs. Here, m_{eff} strongly depends on the size, packing density and interaction between individual magnetic crystallites [1]. The effective magnetic moment of multi-core MNPs with N randomly oriented independent nanocrystal magnetic moments m_s is given by $m_{eff} = \sqrt{N} \times m_s$ and it increases in the low-field limit proportionally to the square of the applied field [1].

Ahrentorp et al. [2] compared the effective magnetic moments of various single- and multi-core MNP systems with the nominal magnetic moments of the single magnetic crystallites. The effective magnetic moment was estimated from the zero-field susceptibility χ_0, which is proportional to m_{eff}^2.

In this contribution, we determine m_{eff} of both single- and multi-core MNPs by exploiting the magnetic field dependence of the Brownian relaxation time $\tau_{B,H}$, which is dependent on the magnetic moment via the Langevin parameter ξ. We have shown in [3,4] that $\tau_{B,H}$ of single-core MNPs can very well be described by the phenomenological equation derived in [5] (see curve for Ni nanorods). The obtained values for m_{eff} are compared with the ones derived from the static susceptibility χ_0 and the moments of single crystallites. The estimation of the effective magnetic moment from $\tau_{B,H}$ additionally allows us to determine the magnetic field dependence of the effective magnetic moment. Significant differences between multi-core MNP systems were found. The observed deviations from the theoretical behavior indicate an increase of m_{eff} with field amplitude. The experimental findings are complimented with simulations.

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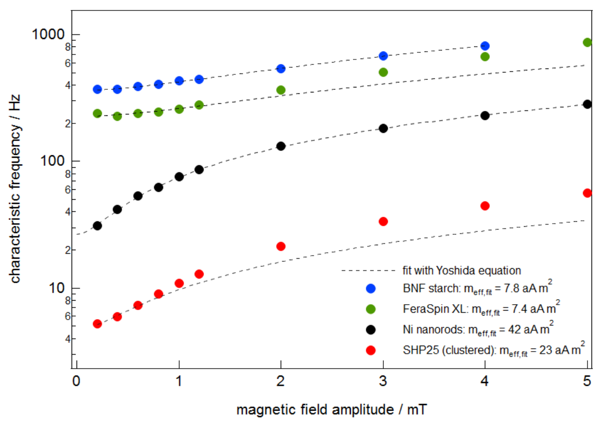

Characteristic frequency versus field amplitude.png

Preparation of hydrocarbon dispersion of colloidal iron oleate complex nanoparticles

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 388

Dr. Gunars Kronkalns [1]

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Many technological applications require a magnetic fluid that (MF) is stable for a long time at elevated temperature in the magnetic field in the air atmosphere. The stability of MF in high gradient magnetic fields at elevated temperatures can be offset by reducing the size of the magnetic nanoparticles. By the procedures of Fe oleate decomposition the iron oxide nanoparticles can be prepared in a wide range of narrow size distribution [1]. The aim of this work is to make a particularly stable MF for work in the magnetic field at elevated temperatures. The preparation of Fe oleate complex was carrid out according work [2]. Magnetic measurements are performed employing a vibration sample magnetometer (Lake Shore Cryotronics, Inc., model 7404 VSM)) with a maximum magnetic field of 1 T. Additionally, the particle size distribution was analyzed by employing indirect methods from the dynamic light scattering data of colloidal solution measured by Zetasizer Nano instrument Nano S90 ZEN 1690.

Fig.1. Spectrum of particle magnetic moments of the sample MFe – 3.

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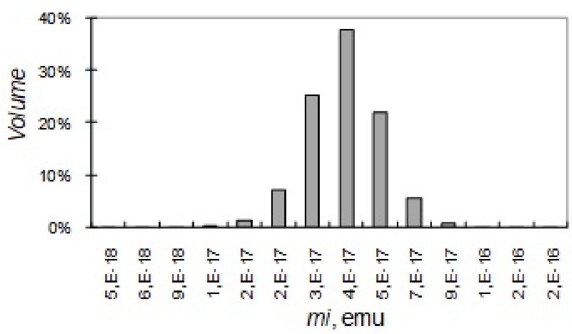

Prep-2.jpg

One single gold nanoparticle modifies the magneto-optical activity of CoFe2O4 nanoparticles confined in silica microcapsules

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 419

***Mr. Martín Testa Anta* [1], *Dr. Verónica Salgueiriño* [1]**

1. *University of Vigo*

The interaction of light with magnetic materials has lately become an active area of research, as offering a prospective route towards their implementation in magneto-optical devices intended for sensing and data storage applications. Particularly interesting results this interplay at the nanoscale, where a careful control on parameters such as interparticle distance, size and shape can lead to a tunable magneto-optical response.[1] Given the fact that most magneto-optical phenomena are typically weak, new approaches focused on the integration of magnetic and plasmonic functionalities have emerged. In this regard, different magnetic nanostructures have shown an enhanced magneto-optical activity induced by the surface plasmon resonance of noble metal nanoparticles, though the exact mechanism is not completely understood yet.[2,3]

In this work, we report the synthesis of a unique magneto-plasmonic composite, consisting of multiple cobalt ferrite nanoparticles plus one gold nanoparticle confined in silica microcapsules. The magneto-optical properties of the as-synthesized structures were characterized my means of Faraday rotation and ellipticity measurements, revealing that the presence of just one single gold nanoparticle within the capsules can actually influence the magneto-optical response from the whole system.[4]

Figure 1. Scheme of a silica microcapsule with magnetic and plasmonic functionalities (a), and corresponding Faraday rotation of the magneto-plasmonic capsules synthesized (b).

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A novel one-pot synthesis of Fe3O4@Ag core-shell magnetic nanoparticles

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 440

Prof. Zhili Zhang [1], Ms. Qianhui Cao [2]

1. Institute of Magnetic Fluids Research,School of Mechanical, Eletronic and Control Engineering,Beijing Jiaotong University, 2. Beijing Jiaotong University

As a kind of functional materials, Fe_3O_4 magnetic nanoparticles have attracted considerable attention for their unique properties of both nanomaterials and magnetic materials. They have been widely used in many fields, such as ferrofluid, biomedicine, catalyst, magnetic resonance imaging, gene detection, cell sorter and so on. As a kind of bimetallic core-shell structure nanoparticles， Fe_3O_4@Ag nanoparticles made of ferric oxide core and silver shell were prepared by coating Fe_3O_4 nanoparticles with Ag nanoparticles using a novel environmentally friendly one-pot synthesis in our resent study. Both Fe_3O_4 and Fe_3O_4@Ag nanoparticles were characterized by X-ray Diffraction (XRD), Transmission Electron Microscopy (TEM), Energy Dispersive X-ray Spectroscopy (EDS) and X-ray Photoelectron Spectroscopy (XPS). The hysteresis loops of both Fe_3O_4 nanoparticles and Fe_3O_4@Ag nanoparticles were measured at 298 K. The observed TEM images showed that Fe_3O_4 nanoparticles were coated with a layer of Ag nanoparticles and its mechanism of reaction was further discussed. These nanoparticles could exhibit good magnetic properties making them potential candidates for both diagnostic and therapeutic uses in biomedical applications. In particular, this research also provides a new strategy for coating magnetic nanoparticles with noble metal shells and a new route for synthesizing core-shell structure nanoparticles in large-scale production in a more environmentally friendly way.

Fig.1 Schematic synthesis of Fe3O4@Ag nanoparticles.

Fig.2 XRD patterns of (a)Fe_3O_4 nanoparticles and (b)Fe_3O_4@Ag nanoparticles.

Fig.3 TEM images of (a) Fe3O4 nanoparticles and (b) Fe3O4@Ag nanoparticles deposited on carbon-coated Cu grids.

Fig.4 Hysteresis loops of (a) Fe_3O_4 nanoparticles and (b) Fe_3O_4@Ag nanoparticles.

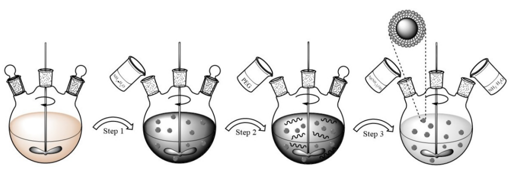

Fig1.jpg

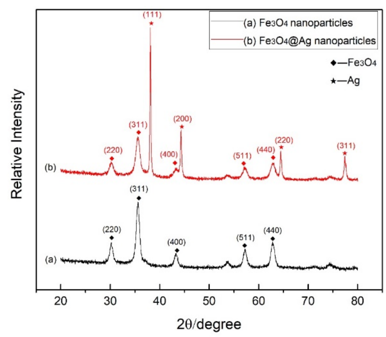

Fig2.jpg

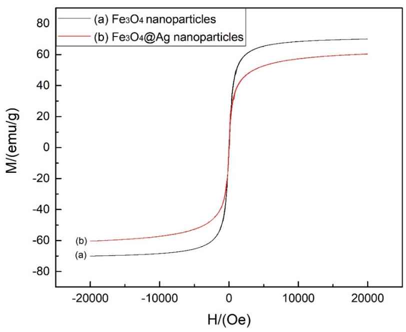

Fig4.jpg

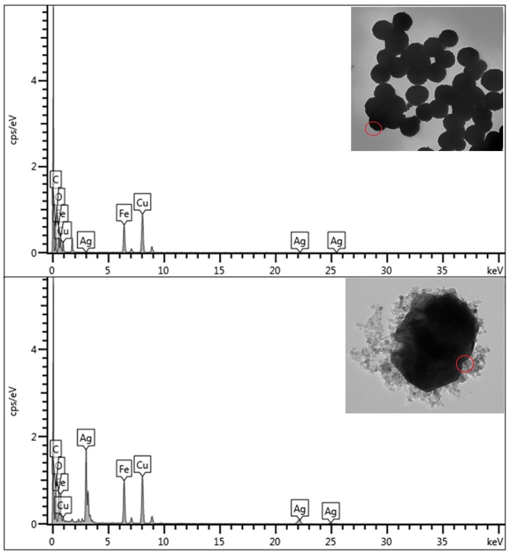

Fig3.png

Modeling of photonic band gap in 1D magneto-photonic crystals made by SiO2/ZrO2 or SiO2/TiO2 doped with magnetic nanoparticles

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 454

Dr. OUALI MOHAMMED ASSAM [1]

1. Mohamed Boudiaf University of M'sila, Department of Electronics, M'sila, Algeria

In this paper we study the band gap of one dimensional magneto-photonic crystal made by SiO_2/ZrO_2 or SiO_2/TiO_2 doped with magnetic nanoparticles using sol-gel process in different geometrical parameters configurations. We used a refractive index varied in the range of 1.51 to 1.57 for different structures we change the number of the layers, their thickness and incident angle. The results obtained give the designs of magneto photonic crystal devices.

Synthesis and characterization of magnetite nanorods

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 469

Dr. Emilie Secret [1], ***Ms. Yvonne Dorant*** [1], ***Mrs. Aude Michel*** [2], ***Dr. Jérôme Fresnais*** [3], ***Prof. Christine Ménager*** [4], ***Dr. Vincent Dupuis*** [5], ***Dr. Jean-Michel Siaugue*** [1]

***1.** Sorbonne Université, Laboratoire PHENIX-CNRS UMR 8234,* ***2.** Sorbonne Université, CNRS, PHysico-chimie des Electrolytes et Nanosystèmes InterfaciauX, PHENIX 4 place jussieu, 75005 Paris, France.,* ***3.** Sorbonne Université,* ***4.** Sorbonne Université, Laboratoire PHENIX UMR 8234 CNRS,* ***5.** Sorbonne Université, Laboratoire PHENIX*

Magnetic nanorods present several advantages compared to spherical magnetic nanoparticles for biomedical applications. For example, magnetic nanorods showed higher r_2 relaxivities[1] and stronger heating efficiency in magnetic hyperthermia[2] than their spherical counterparts, enabling applications in MRI, disease treatments by magnetic hyperthermia, or magnetogenetics. Shape-anisotropic nanoparticles have also been shown to increase blood circulation time[3] and tumor retention time[4] compared to spherical nanoparticles. Finally, Kolhar *et al.* demonstrated that, when functionalized with antibodies, nanorods lead to an increase in specific recognition and a decrease in non-specific interactions,[5] which could have a strong impact on targeted drug delivery or on biosensing applications.
In the work presented here, a three-step synthesis method was optimized in order to obtain iron oxide nanorods colloidally stable in water, with high aspect ratio and strong magnetic properties. The first step consists in the formation of akaganeite nanorods in presence of polyethyleneimine (PEI). For this step, the influence of the PEI (length and concentration) and of the concentration of the iron chloride on the shape and size of the nanorods were carefully studied. Then the second step is a controlled reduction of the akaganeite into magnetite with oleylamine, optimized to keep a good aspect ratio while improving the magnetic properties of the nanorods. Finally, the phase transfer of the magnetite nanorods into water, by ligand exchange between oleylamine and 3,4-dihydroxyhydrocinnamic acid, lead to water-stable magnetic iron oxide nanorods. At each step of the synthesis, the nanorods were fully characterized by TEM, XRD and SQUID measurements. The final water-suspended objects were also characterized by magnetic birefringence measurements.

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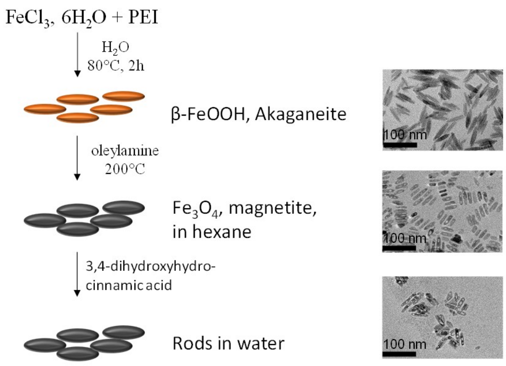

Figure 1. Synthesis scheme of the magnetic nanorods, with TEM images of one example of nanorods at each steps of the synthesis.

Image abstract nanorods icmf.jpg

Neutron imaging of paramagnetic ionic solutions

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 470

Mr. Tim Butcher [1], ***Mr. Georges Formon*** [2], ***Dr. Laurence Noirez*** [3], ***Prof. Michael Coey*** [1]

***1.** Trinity College Dublin, **2.** University of Strasbourg, **3.** Laboratoire Léon Brillouin*

Concentrated aqueous solutions containing rare earth or transition metal ions exhibit paramagnetic susceptibilities. Applying the method of neutron imaging offers unique possibilities for mapping concentration distributions. The element with the highest neutron absorption cross section is Gadolinium (Gd). In addition, Gd possesses a large spin magnetic moment of 7 μ_B due to unpaired 4f electrons. Consequently, solutions of Gadolinium nitrate ($Gd(NO_3)_3$) are ideal candidates for neutron imaging of paramagnetic solutions, enabling the direct study of their response to magnetic fields.

Exposing paramagnetic ionic solutions to an inhomogeneous magnetic field gives rise to the magnetic field gradient force, which is sufficiently strong to compete with density difference driven convection [1]. Thus, the confinement and magnetically induced migration of the Gd solutions in a miscible nonmagnetic liquid (such as a solution of Yttrium nitrate or pure D_2O) is possible with the stray field of a NdFeB permanent magnet. Neutron imaging experiments were performed to visualize and characterize these processes.

No effect of the magnetic field gradient was detected on a homogeneous solution. The magnetic field gradient force is unable to influence the motion of individual ions. However, in the case of an inhomogeneous solution it is possible to skew the concentration profile towards the direction of the magnet (see Fig. 2). Such a modified concentration profile is stable until the homogenisation of the solution by diffusion takes place, which is normally a lengthy process.

Confinement of the paramagnetic solution is possible when it is injected close to the magnet. Removal of the magnet leads to a collapse of the interface between the magnetic and nonmagnetic liquid, which is accompanied by geometrical fingering instabilities (see Fig. 3). If the magnetic field is maintained, the trapped ions diffuse into the nonmagnetic liquid on a long time scale. An envisaged application in microfluidics is the stabilisation of the ionic solution in "paramagnetic liquid tubes".

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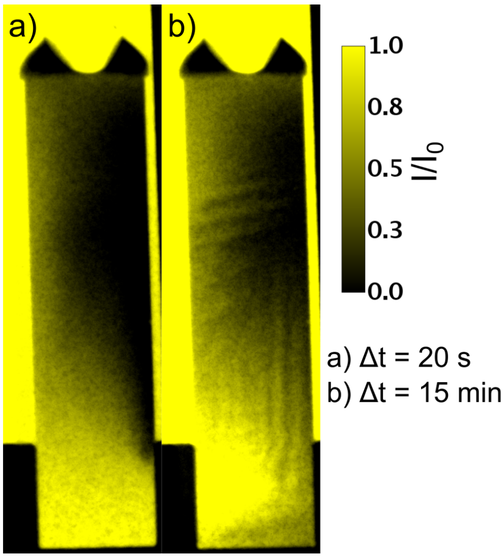

Fig3 fingering instability.png

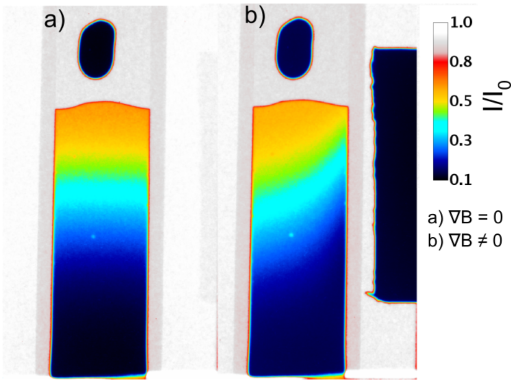

Fig2 diffusion gd solution in d2o.png

Fig1 sample holder.jpg

Anisotropic Magnetic Nanoparticles: Synthesis and Integration in Liquid Crystals

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 472

Mr. Martin Hähsler [1], ***Dr. Silke Behrens*** [1]

1. *Karlsruhe Institute of Technology / Heidelberg University*

Magnetic nanoparticles and their hybridization in organic matrices have attracted great interest with respect to fundamental investigations and application in various fields.
So far, different ways for the synthesis of uniform, spherical nanoparticles from different magnetic materials have been described. Reports on the preparation of magnetic nanoparticles with anisotropic morphology (e.g., nanorods) and dimensions below 100 nm, however, are scarce although the anisotropic nanoparticles have promising advantages over the spherical ones. The energy of the shape magnetic anisotropy, e.g., is increasing with increasing morphological anisotropy of the nanoparticles. The shape-selective synthesis of ferrites represents a challenging task as the surface energy typically favors the formation of spherical nanoparticles.
Hybridization of MNPs with liquid crystalline matrices enables the production of functional materials with interesting optical, electrooptical, magneto-optical and magnetic properties. Doping of liquid crystals with magnetic nanoparticles, e.g., may improve current liquid crystal display technologies through new or modified switching modes, lower operating voltages, and larger contrast ratios. In contrast to isotropic magnetic fluids, the long-term colloidal stabilization of magnetic nanoparticles in sufficiently high concentrations still remains a challenge due to both the magnetic dipolar and the liquid-crystal-mediated interactions, which typically result in aggregation and/or macroscopic phase separation. Up to now, only few examples describe the stabilization of shape anisotropic magnetic nanoparticles in liquid crystals.
Here, we address the synthesis of magnetic nanoparticles with shape anisotropy, i.e. ferrite or core/shell ferrite nanorods and hexagonal barium ferrite nanoplatelets (Figure. 1). Their structure and magnetic properties are characterized using electron microscopy (transmission electron microscopyand scanning electron microscopy), X-ray diffraction,
IR- and Raman spectroscopy, and an alternating gradient magnetometer. The magnetic nanoparticles are functionalized by different (pro)mesogenic, aliphatic and dendritic ligands. We show that the functional ligands on the magnetic nanoparticles surface influence magnetic nanoparticles-liquid crystal interactions. Depending on the type of ligand, the magnetic nanoparticles are colloidally stabilized in the liquid crystal (i.e. 4-cyano-4'-pentylbiphenyl).

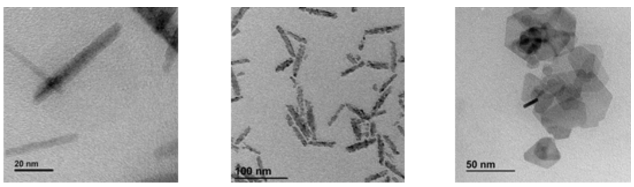

Figure 1. tem micrographs of i. iron oxide nanorods ii. fe3o4 cofe2o4 core-shell nanorods and iii. bafe11.5in0.5o19 nanoplates.png

Ferro and anti-ferromagnetic coupling in Nd-RE-Fe-B (RE=Pr, Tb, Dy) particles by reduction-diffusion process

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 497

Dr. Dongsoo Kim [1]

1. *Korea Institute of Materials Science*

A novel route to prepare Nd-Fe-B magnetic powders by reduction-diffusion (R-D) process was designed and investigated in this study. Precursors were synthesized from aqueous solutions with chloride salts. Magnetic particles of $Nd_{12}RE_3Fe_{77.5}B_{7.5}$ (RE = Pr, Tb, and Dy) were prepared by co-precipitation, followed by reduction-diffusion (R-D) process. The crystal structure and composition of the particles were confirmed by XRD, EDX, and SAED analysis, and the particle size and morphology were checked with TEM and SEM. The particles were formed with the mean size of 2.0 μm and the morphology was round in shape. After substitution of RE during R-D, the magnetic moment was increased after substitution of Pr into Nd-Fe-B, but decreased after substitution with Tb and Dy. It was revealed by the calculation of electron spin density that Pr was ferromagnetic, but Tb and Dy were anti-ferromagnetic to Nd and Fe in the Nd-RE-Fe-B crystal lattice. The magneto-crystalline anisotropy energy was increased from 0.2284 MJ/m^3 to 0.3910 and 0.3924 MJ/m^3 after the substitution of Tb and Dy for Nd in Nd-Fe-B, respectively. However, the magneto-crystalline anisotropy energy decreased to 0.2050 MJ/m^3 after the substitution of Pr for Nd. It is considered that the enhancement of the magneto-crystalline anisotropy of the crystal lattice came from the pinning of magnetic moments. Hence, the coercivity in Nd-Tb-Fe-B and Nd-Dy-Fe-B was increased.

Magneto optical properties of nanoplatelet based ferrofluid

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 509

Mr. Žiga Gregorin [1], ***Dr. Nerea Sebastian*** [1], ***Mrs. Patricija Hribar Boštjančič*** [1], ***Prof. Darja Lisjak*** [1], ***Dr. Natan Osterman*** [2], ***Prof. Alenka Mertelj*** [1]

1. Jozef Stefan Institute, 2. Faculty of Mathematics and Physics, University of Ljubljana, Jožef Stefan Institute

Colloidal suspensions of nanoparticles open new possibilities on examining and using new hybrid particle-fluid phenomena. A well-known example is a paramagnetic ferrofluid – a suspension of ferromagnetic nanoparticles in an isotropic solvent. Particles are randomly oriented and become aligned in the presence of an external magnetic field forming ordered magnetic phase. Long-time goal of science was creation of macroscopically ferromagnetic suspensions – so called "real" ferrofluids, that have spontaneous magnetic order without external magnetic field (Fig. 1).

The recently discovered magnetic nanoplatelet suspension [1] in an isotropic solvent is a new complex magnetic fluid with fascinating physical properties [2]. Its behaviour in static magnetic field has been thoroughly examined and understood [3]. On the other hand, properties in time-changing magnetic field – which come in handy for applications – have not yet been thoroughly examined.

The new material consists of nanoplatelets, thus strong coupling between orientation and flow is expected. With external magnetic field used for platelet alignment a counter flow is expected and, on contrary, in the absence of magnetic field particle alignment in flow can induce non-zero net magnetization even in an isotropic suspension.

Fig. 1: Polarized optical microscopy image of magnetic domains formed in zero magnetic field. Yellow arrows indicate the domain orientations.

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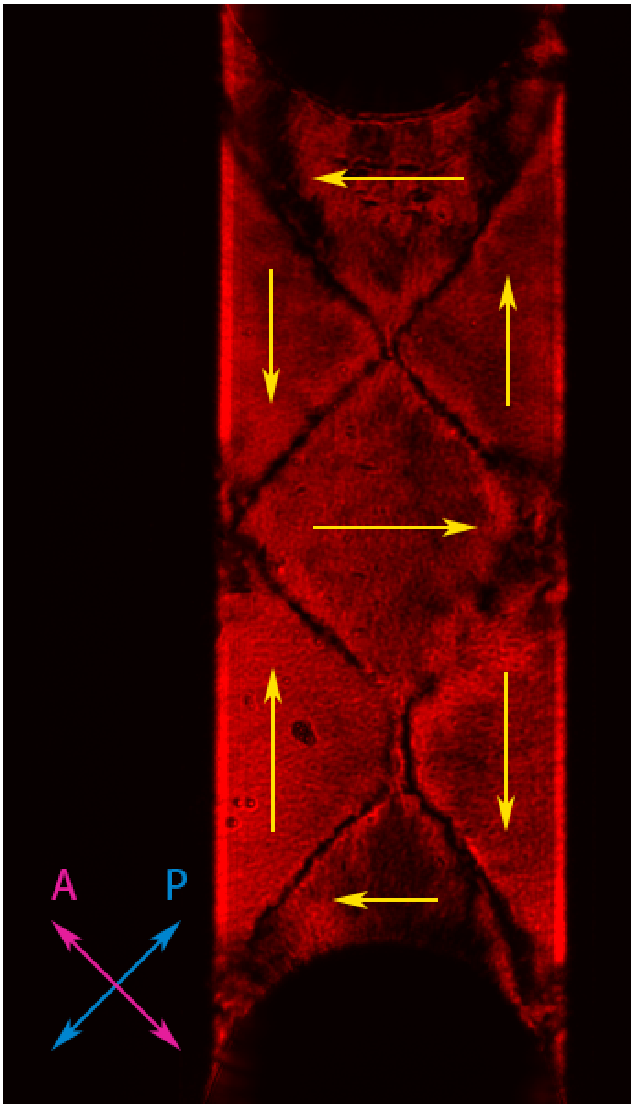

Domains.png

Large scale aggregation in magnetic colloids induced by high frequency magnetic fields

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 527

Dr. Vlad Mircea Socoliuc [1], ***Dr. Rodica Paula Turcu*** [2]

1. *Romanian Academy Timisoara Branch,* ***2.*** *National Institute for Research and Development of Isotopic and Molecular Technologies*

Due to drastic decrease of specific surface, the magnetically induced clustering has significant detrimental effect on the efficiency of magnetic colloids' bio-medical applications like magnetic hyperthermia, drug targeting and MRI [1]. We present evidence of large scale aggregation in an aqueous dispersion of magnetic microgels induced by 100kHz AC magnetic fields with amplitude ranging from 40 Oe to 120 Oe. The microgels with 250 nm z-average hydrodynamic diameter and 44 emu/g saturation magnetization are composed by 8nm magnetite nanoparticles imbedded in APTAC matrix. The magnetically induced aggregation was investigated by means of light extinction (LE) and small angle light scattering (SALS) [2] at room temperature. The SALS experiments (Fig.1) show the formation and growth of field direction elongated aggregates. Optical microscopy in 150 Oe DC magnetic field show aggregates with ~5mm thickness and more than 100 mm length at saturation (Fig.2). The extinction experiments (Fig.3) show the increasing of aggregate total volume with increasing magnetic field amplitude.

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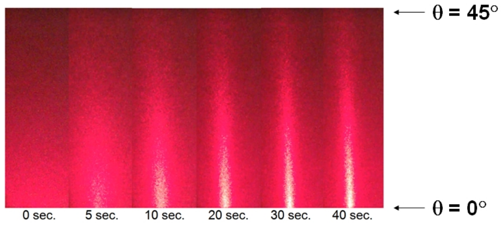

Figure1.jpg

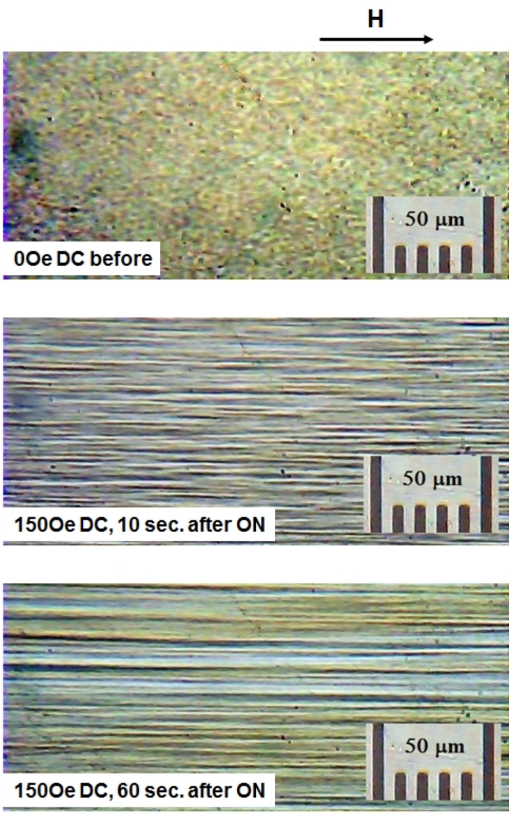

Figure2.jpg

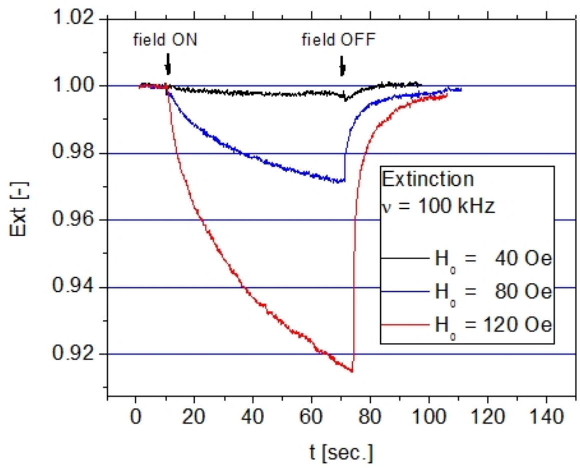

Figure3.jpg

Studying chain formation in ferrofluids and ferrogels by Mössbauer spectroscopy

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 531

Mr. Damian Günzing [1], *Dr. Joachim Landers* [1], *Dr. Soma Salamon* [1], *Dr. Hajnalka Nádasi* [2], *Prof. Alexey Eremin* [2], *Prof. Heiko Wende* [1]

1. University of Duisburg-Essen, 2. Otto-von-Guericke-Universität Magdeburg

Magnetic nanoparticles are important in a wide range of applications, so understanding their behaviour in different environments and under various external stimuli is mandatory. If a magnetic field is applied, the mobile particles tend to align in its direction. If it is energetic favorable, the particles build up chains.

We investigated this field induced chain formation by Mössbauer spectroscopy in this study. Therefore, we used commercial ironoxide (Fe_3O_4) nanoparticles with a diameter of about 10nm and a shell thickness of about 2nm. The single domain ferroparticles were dispersed in n-dodecan as a ferrofluid. An additional reference sample was prepared by the mentioned ferrofluid and the additional gelator 12-HOA as a ferrogel. The sample systems were prepared by H. Nádasi from the University of Magdeburg [1].

Mössbauer spectroscopy is a useful tool to investigate this kind of composite sample due to the independence of optical transparency. It also allows to obtain information on the Brown and Néel relaxation of the particle simultaneously, as well as the orientation of the particle's magnetic moments [2].

To investigate the anisotropic diffusive mobility of the particles, we measured in two different geometries: on the one hand a setup where the incident gamma ray is perpendicular to the external applied magnetic field and on the other hand we used a parallel geometry. The temperature was another parameter we changed, because of the strong influence on the viscosity.

From the comparison of the experimental data to numerical and theoretical models we determined a magnetic field driven reversible chain formation with a mean chain length of up to approximately three particles in magnetic fields up to 750mT.

As reference techniques we used magnetometry data from SQUID measurements to gain information on the macroscopic magnetic properties. In addition, H. Nádasi et al. observed chain formation of roughly two particles by birefringence measurements [1].

This work is financially supported by the DFG priority program SPP1681 (WE2623-7).

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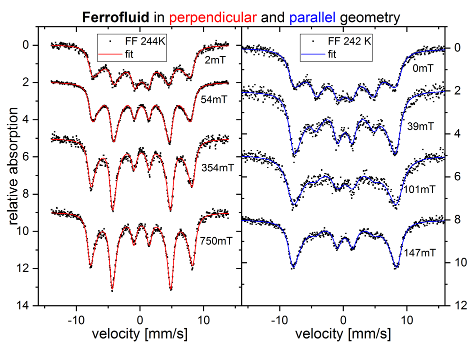

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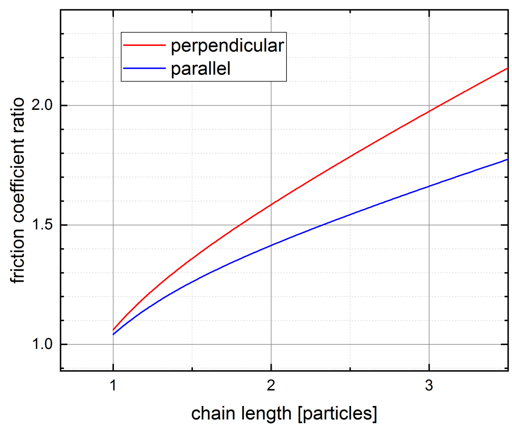
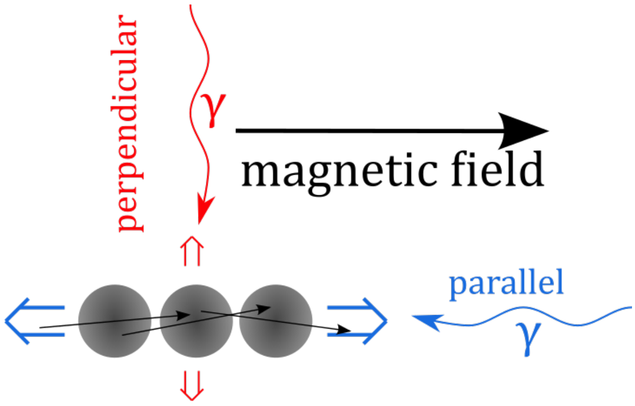


Chainlength.png



Schematic alignment.png

Design of highly stable ferrofluids in ionic liquids

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 543

Mr. Jesse Riedl [1]***, Mr. Ali Akhavan Kazemi*** [1]***, Dr. Fabrice Cousin*** [2]***, Dr. Emmanuelle Dubois*** [1]***, Dr. Sébastien Fantini*** [3]***, Dr. Sandrine Loïs*** [3]***, Prof. Régine Perzynski*** [1]***, Dr. Véronique Peyre*** [1]

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Thermoelectricity (TE) allows for the conversion of heat to electricity providing one possible methodology for the recycling of low-grade waste heat. Despite improvements, present TE solid materials have several limitations. Therefore, investigations in complex liquids (e.g. ionic liquids or nanofluids) have been proposed in recent years [1]. Here we present the application of novel ionic–liquid based magnetic complex fluids to this problem. Ionic liquids are a broad class of liquids, that consist solely of ions, and can be liquid at room temperature; with many properties ideal for TE materials [2]. In addition, our recent studies on aqueous dispersions of NPs have demonstrated that the addition of magnetic NPs can influence the TE coefficient [3] and enhance the liquid's TE efficiency [4]. We thus propose to combine the two avenues by using dispersions of NPs in ILs for TE applications. Here we present the first steps on our development pathway, primarily the dispersion of the NPs in the IL. In our first studies using ethylammonium nitrate as IL, we showed that the ability to disperse the NPs was controlled by the solid/liquid interface, in particular the nature of the counterions of the charged NPs [5].
Here we expand significantly on these conclusions, studying the degree of universality of these principles when applied to other ionic liquids. Maghemite (γ-Fe2O3 iron oxide) nanoparticles (NPs) with a diameter around 10 nm were dispersed in several ionic liquids chosen to explore the effect of employment of different cations and anions. The dispersions were analyzed by optical microscopy, transmission electron microscopy (TEM), Dynamic Light Scattering (DLS), small angle x-ray/neutron scattering (SAXS/SANS) and magnetic measurements. With these results confirming the generality of previously described trends and principles.
Acknowledgements: We acknowledge funding from Horizon 2020 FET-PROACTIVE project, MAGENTA, associated with the Grant n° 731976.

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Rectifying Magnetization Curves

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 544

Prof. Ingo Rehberg [1], ***Dr. Reinhard Richter*** [1], ***Dr. Thomas Friedrich*** [2], ***Mr. Stefan Hartung*** [1]

***1.** University of Bayreuth, Experimentalphysik 5,* ***2.** University of Lübeck*

The dipole strength of magnetic particles in a ferrofluid is obtained by rectification of the magnetization curves based on the inverse Langevin function. The method has an advantage compared to the fitting of magnetization curves to some appropriate mathematical models [1]: It does not rely on assuming a particular distribution function of the particles.

Figure 1 provides an example of this rectification method to display the aging of a ferrofluid. It makes use of data taken from the literature [2,3] describing the formation of magnetic clusters in a colloidal suspension of nanocubes. They characterize the aging of cubic nanoparticles (8wt%, ironoxide, edgelength 9 nm) in solution triggered by a magnetic field (800 kA/m for 4 h). Figure 1 (a) shows M(H) curves of that fluid for three different times. They were obtained with a vibrating sample magnetometer described in detail in Ref. [4]. The first data set was obtained for a relatively fresh sample, which had been exposed to a magnetizing field of about 800 kA/m for four hours. The magnetization curves in Fig.1(a) show an increasing slope with the time elapsed. This aging process is interpreted as the manifestation of the clustering of the magnetic particles.

Some features of the change of these curves can be more clearly seen in Fig.1 (b). Here the appropriately scaled slope of the inverse Langevin function of the magnetization data has been plotted. The ensuing curves yield the arithmetic mean of the dipole distribution at its center, and the harmonic mean as the asymptotic value for large polarizing fields.

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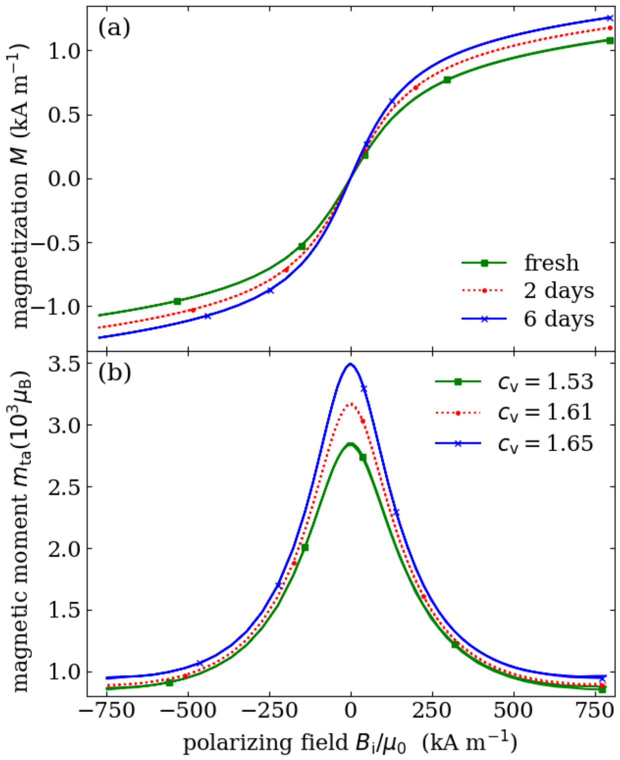

Cuboid aging.png

Nonlinear AC magnetic susceptibility of magnetic fluids

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 617

Dr. Barnabás Horváth [1], ***Dr. István Szalai*** [1]

1. *University of Pannonia*

AC susceptibility measurement techniques are useful tools to investigate the relaxation processes and structure of magnetic fluids. At large external magnetic field intensities the magnetization of the fluid is no longer a linear function of the external field strength, i.e. magnetic fluids show nonlinear characteristics. The aim of our work was to develop a measuring system which is capable to measure the nonlinear AC susceptibility of magnetic fluids at discrete frequencies and in the presence of external magnetic field. The susceptibility measurement is based on the determination of the frequency change of an LC oscillator. The sample fills the core of a solenoid which is the frequency determining element of the oscillator. Therefore, any change in the susceptibility of the sample causes a shift of the resonance frequency. With different solenoids the base frequency of the low intensity measuring field can be changed. A uniform, high intensity external magnetic field is generated by a Helmoltz coil pair, which is placed around the measuring solenoid. The axis of the Helmoltz coil is parallel to the axis of the measuring solenoid. To investigate the nonlinear susceptibility we used sinusoidal excitation, where the frequency of the external magnetic field is changed from 1 Hz to 1 kHz. Because the nonlinearity of the magnetization curve the frequency of the low intensity measuring field is modulated, and higher harmonics of the external field appear. The higher order components of the nonlinear AC susceptibility are extracted from the measured response by Fourier analysis. In our experiments we used water based ferrofluids (Ferrotec EMG700) containing magnetite particles with a diameter of ~10 nm. The dependence of the nonlinear susceptibility on the external magnetic field strength, and excitation frequency was investigated at different magnetite concentrations. The experimental results are discussed on the basis of static and dynamic magnetization curves.

Magnetic fluids based on iron nanoparticles produced by electric explosion of wire (EWW)

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 620

Dr. Joanes Berasategui [1]***, Ms. Ainara Gomez*** [1]***, Dr. M. Mounir Bou-Ali*** [1]***, Dr. Jon Gutierrez*** [2]***, Dr. Jose Manuel Barandiarán*** [2]***, Dr. Igor Beketov*** [3]***, Dr. Aleksander Safronov*** [3]***, Dr. Galina Kurlyandskaya*** [2]

1. *Mondragon Unibertsitatea,* ***2.*** *Universidad del País Vasco/Euskal Herriko Unibertsitatea,* ***3.*** *Ural Federal University*

In this work, new generation magnetic fluids have been formulated based on iron nanoparticles produced by electrical explosion of wire (EEW). In the first place, the characterization of the particles has been carried out, where it was determined that the main crystalline phase of the nanoparticles was α-Fe with the network parameter a = 0.2863 (3) nm. In addition, the nanoparticles present a high saturation magnetization value, reaching approximately 87% of saturation magnetization of bulk iron with an average particle size of 85 nm.

Magnetic fluids consisting of mineral oil, stabilizing additives and iron EEW nanoparticles have been formulated. For the sake of comparison, magnetic fluids consisting of mineral oil, stabilizing agents and commercial carbonyl iron particles (CIP-HQ quality from BASF, average size 1.25 µm) have also been formulated.

A magnetorheological analysis has been performed by a rotational rheometer and parallel plate configuration. The obtained results indicates that, when subjected to a magnetic field, magnetic fluid composed by EEW nanoparticles present higher shear yield values than the fluid with commercially avaiable micrometric CIP particle. As a result, it is concluded that EEW nanoparticles have a high potential for future industrial applications, such as smart dampers.

MnFe2O4@γ-Fe2O3 core-shell nanoparticles: magnetic anisotropy fields and exchange bias

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 628

Dr. Franciscarlos Gomes da Silva [1]***, Prof. Jérôme Depeyrot*** [2]***, Prof. Yuriy Raikher*** [3]***, Dr. Victor Stepanov*** [4]***, Ms. I.S. Poperechny*** [5]***, Prof. Renata Aquino*** [1]***, Ms. Geraldine Ballon*** [6]***, Prof. Julian Penkov Geshev*** [7]***, Dr. Emmanuelle Dubois*** [8]***, Prof. Régine Perzynski*** [9]

***1.** Universidade de Brasília, **2.** Instituto de Física - Universidade de Brasília, **3.** Ural Federal University, **4.** Institute of Continuous Media Mechanics, Ural Branch of RAS, Perm, 614013, Russia, **5.** Institute of Continuous Media Mechanics, Ural Branch of RAS, Perm, Russia, **6.** CNRS – LNCMI, 31400 Toulouse, France, **7.** Universidade Federal do Rio Grande do Sul, **8.** UPMC, **9.** Sor*

The magnetic anisotropy of $MnFe_2O_4$@γ-Fe_2O_3 CS nanoparticles (NPs), synthesized following the co-precipitation method described in [1,2], is investigated by various techniques at low temperatures, 1.5 K ≤ T ≤ 200 K. Quasi-static magnetization measurements are presented along with high-amplitude pulsed experiments performed at LNCMI, Toulouse, and are cross-analyzed by juxtaposition with FMR experiments at 9 GHz.
They allow to distinguish 3 types of magnetic anisotropies affecting the dynamics of the magnetic moment of the well-ordered ferrimagnetic (FiM) NP's core, which is here surrounded by a layer with a SGL arrangement[3,4]. (i)The uniaxial anisotropy originating from the structural core-shell interface[5]; (ii)Unidirectional EB anisotropy, associated with the spin-coupling at the FiM/SGL interface, which is observable only at low temperatures after a field-cooling process[6]; (iii)Rotatable anisotropy[7] caused by partially-pinned spins at the FiM/SGL interface, which manifests itself as an intrinsic field always parallel to the external applied magnetic field. The experimental results are discussed in the framework of a superparamagnetic theory[8], demonstrating the uniaxial symmetry of the rotatable anisotropy.

Acknowledgements

We acknowledge the support by contracts CAPES/COFECUB n°714/11 and PICS n°75939 from CNRS, contract PRONEX-FAPDF (2017-2021) n°0193.001194/2016 Brazilian agencies FAP/DF.

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Anomalous increase in the ferrofluid dynamic susceptibility in a strong alternating field

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 610

Dr. Andrey Kuznetsov [1], ***Dr. Alexander Lebedev*** [1], ***Dr. Victor Stepanov*** [1], ***Prof. Alexander Pshenichnikov*** [1]

1. *Institute of Continuous Media Mechanics UB RAS*

In this contribution, we report the experimental results on the magnetic response of a concentrated ferrofluid subjected to a linearly polarized alternating magnetic field. We show that contrary to the known theoretical predictions [1,2], the modulus of the ferrofluid dynamic susceptibility can *increase*with increasing field amplitude (the said modulus is defined here as the ratio between the amplitude of the magnetization fundamental harmonic and the field amplitude). Such anomalous behavior is observed if the field frequency is sufficiently high (ultrasonic frequencies) and if the particle size distribution is sufficiently wide. The effect also becomes much more pronounced as the particle concentration increases.

We hypothesize that the increase in the dynamic susceptibility with amplitude is possible when two key conditions are met: 1) the suspension viscosity and the field frequency are high enough to cause the blocking of the Brownian relaxation mechanism of particles and 2) particles with the large magnetic anisotropy, whose Neel relaxation mechanism can be “unblocked” by a strong AC field, are present in the ferrofluid. Theoretical calculations on the basis of the Fokker-Planck equation and Langevin dynamics simulations are performed to support this hypothesis.

The research was supported by Russian Science Foundation (grant No. 15-12-10003).

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Quantiative Magnetic Force Microscopy - An Imaging Tool for small magnetic Objects

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 651

Prof. Hans J. Hug [1], ***Dr. Andrada-Oana Mandru*** [1]

1. Empa - Swiss Federal Labs for Materials Science and Technology

Magnetic Force Microscopy (MFM) is a versatile technique to map the dependence of the micromagnetic state of a sample on the applied field and temperature with high spatial resolution. Here most recent developments will be discussed and the MFM's potential to image small magnetic particles is analyzed by modelling based on existing data on magnetic thin film systems.

Highest sensitivity is obtained by operation in vacuum using cantilever with quality factors up to 1 million (Fig 1a). These and the operation under vacuum conditions require suitable operation modes to control the tip-sample distance with highest precision even when the temperature is changed or strong magnetic fields are applied. Using frequency-modulate tip-sample distance control [1] MFM data acquisition becomes reproducible such that differential imaging to separate the different contributions to the measured signal can be disentangled. Among the latter is the topography, local variations of the Kelvin contrast, magnetic fields arising from spatial variations of the sample thickness and roughness, and stray fields arising from the micromagnetic state of the sample [2] (Fig. 1b). The latter usually is of most interest, but MFM measures the deconvolution of the sample stray field with the a-priori unknown tip equivalent magnetic charge distribution. We have developed calibration procedures for the latter almost two decades ago [3], and used the calibrated response of the tip to measure the density of uncompensated spins in exchange coupled systems [4], nd more recently the local Dzyaloshinskii-Moriya interaction [6], chirality of skyrmions [5] (Fig. 1c) and Néel walls [6].

These examples highlight the performance of MFM operated under vacuum conditions, in magnetic fields up to 7T, and at temperatures down to 10K using most recent techniques for tip-sample distance control and advanced data deconvolution techniques.

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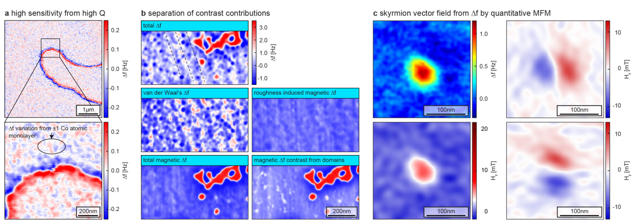


a MFM data obtained at room temperature on a Si/SiO2/Pt(10)/Co(0.6)/Pt(3) thin film using a cantilever with a Q = 1'000'000. Thanks to highest sensitivity the stray field of the domains in the only 3ML thick Co can be imaged.
b MFM maps the sum of all force gradients acting on the tip. Contrast contributions arising from the topography and film thickness and roughness induced stray fields must be subtracted from the measured contrast to obtain the stray field arising from the magnetic domains or the <10nm skyrmions in this case.
c If the response of the MFM tip is calibrated, the z-component of the stray field can be obtained from the measured frequency shift contrast. Because the magnetic field is a conservative field, the x- and y-field components can be obtained from the latter, such that the 3D vector field is obtained.

Mfm examples.jpg

Reinvention of magnetite: from hydrosols to radio-controlled enzymatic catalysts

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 660

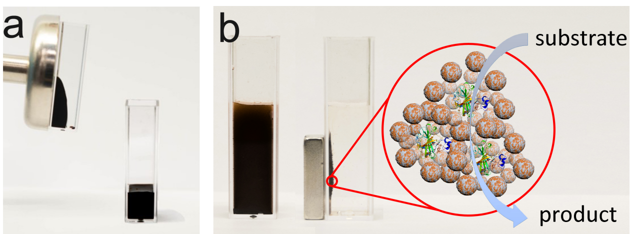
Mr. Andrey Drozdov [1], *Ms. Yulia Andreeva* [1], *Mrs. Olga Shapovalova* [1], *Dr. Vladimir Vinogradov* [1]

1. ITMO University

This work is dedicated to the creation of magnetite-based materials in mild conditions and synthesis of enzymatically-active two-component composites. We have developed a new synthetic procedure to produce pristine nanoparticles of magnetite via co-precipitation method without the usage of surfactants. Due to synthetic conditions, the isoelectric point of the synthesized material is shifted to pH 8.3, leading to high values of zeta potential at neutral pH level. As a result, the produced nanoparticles are electrostatically stabilized and forming stable hydrosols while having an unmodified surface. Together with narrow size distribution these features allows using such systems for various synthetic tasks. For instance, such hydrosols can undergo a room-temperature sol-gel transition to form magnetite-based inorganic hydrogels or xerogels. Such porous materials are demonstrating superparamagnetic behavior and high magnetization values, have developed microstructure, the surface area up to 140 m^2/g and can be used as adsorbents or carriers of bioactive molecules. The low temperature of transition and absence of aggressive chemicals allows to entrap peptides and enzymes within such materials and to form enzymatically active magnetite composites. The entrapped enzymes show excellent thermal stability and shift of their denaturation temperatures for 20-30 ^oC to higher values. For instance, immobilization of carbonic anhydrase shifts its denaturation temperature for 27 ^oC to higher values and allows it to operate even at 90 ^oC, while the free enzyme is denaturated at 68 ^oC.

Magnetic properties and excellent biocompatibility of such materials make them interesting candidates for the creation of recyclable adsorbents, drug delivery systems, or responsive biocatalytic materials with RF-controlled activity.

This work was supported by Russian Science Foundation, grant № 18-79-00266



a As synthesized magnetite hydrosol behaves as magnetic fluid

b Condensation of hydrosol with enzymes results in enzymatically active magnetic mateirals

Schematic representation of emagnetic composite.jpg

Investigation of magnetic structure of the ferrofluid with cobalt ferrite nanoparticles by polarized muons

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 598

Dr. Maria Balasoiu [1], Prof. S.G. Barsov [2], Dr. Svetlana Astaf'eva [3], Prof. Madalin Bunoiu [4], Dr. V.N. Duginov [5], Dr. Daniela Fluerasu [6], Dr. A.L. Getalov [7], Dr. K.I. Gritsay [5], Dr. E.N. Komarov [7], Dr. S.A. Kotov [7], Dr. S.N. Lysenko [3], Dr. G.V. Scherbakov [7], Prof. Cristina Stan [8], Dr. S.I. Vorob'ev [7]

__1.__ Joint Institute for Nuclear Research, Joliot-Curie 6, 141980 Dubna, Moscow region, Russia/"Horia Hulubei" National Institute of Physics and Engineering, Magurele-Bucharest, __2.__ Petersburg Nuclear Physic Institute of NRC "Kurchatov Institute, __3.__ Institute of Technical Chemistry, Ural Branch of RAS, __4.__ West University of Timisoara, Faculty of Physics, __5.__ Joint Institute for Nuclear Research, __6.__ "Horia Hulubei" National Institute of Physics and Engineering, __7.__ Petersburg Nuclear Physic Institute of NRC "Kurchatov Institute", __8.__ "Politehnica" University of Bucharest, Department of Physics, Faculty of Applied Sciences

The work presents new results on magnetic properties of the cobalt ferrite ferrofluids investigated using polarized positive muons (μSR [1]). In the matter, the frequency of the muon spin precession is proportional to magnetic field value and to the muon's g-factor (~13.5 kHz/G). This phenomenon allows measuring the magnetic field in the investigated samples.
Although, as reported in previous works [2, 3], the main part of muons stops in the medium in between the nanoparticles, this article shows that a small part of muons stopped in nanoparticles can be detected.
The difference between the μSR data of $CoFe_2O_4$ ferroliquids in field cooled (FC) and zero field cooled (ZFC) conditions have been studied. The experimental data were analyzed using the model of a system of single-domain magnetic nanoparticles.
The results of FC and ZFC measurements evidenced that single-domain nanoparticles with an average dimension of 8.5 nm have a high anisotropy coefficient. The mean value of the magnetic field in the system created by the randomly distributed $CoFe_2O_4$ nanoparticles was obtained. In the FC at 525 Oe case, a $CoFe_2O_4$ ferrofluid sample of 3.0% particle volume concentration acquires due to the magnetic nanoparticles an additional magnetic field of 4.7 Oe. It is noted that the magnetic anisotropy coefficient decreases with decreasing nanoparticle size.
The μSR facility [4] located at the output of the muon channel of the synchrocyclotron of the National Research Center Kurchatov Institute - PNPI (Gatchina) was used for the study of the samples.
The support of the 2018-2019 RO-JINR Projects and Grants is acknowledged.
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Thermal Conduction of the Magnetic Fluids Mixing Micrometer Size Paritlces

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 255

***Prof. Yasushi Ido* [1], *Mr. Syuhei Kondoh* [1], *Prof. Yuhiro Iwamoto* [1]**

1. Nagoya Institute of Technology

It is well known that the nonmagnetic fine particles in the magnetic fluids in the presence of magnetic field react like diamagnetic particles, and chain-like clusters of nonmagnetic fine particles are formed in the uniform magnetic field. It is expected that the thermal conductivity in the direction of the magnetic field changes drastically when a magnetic field is applied to the magnetic fluid mixing fine nonmagnetic particles with high thermal conductivity.
In this study, thermophysical properties of magnetic fluids mixing micrometer size particles such as spherical copper particles and carbonyl iron particles were investigated experimentally. In order to exmaine the behavior of dispersed micrometer size particles, vizualization experiments were performed by using a darkfield microscopy. The thermal conductivity of the fluid was measured by using the transient hot wire method. Copper particles and carbonyl iron particles were prepared as dispersed particles to prepare test fluids with particle voulume ratios of 4, 8 and 12 vol.% in our experiments.

From the vizualization experiments, it was confirmed that both magnetic particles and nonmagnetic particles form chain-like clusters in the presence of uniform magnetic field.The Landau-Lifshitz equation for estimating thermal conductivity was expanded to take into account of cluster formations of suspended spherical particles in the fluid, and the orientational state of dispersed particles in the magnetic fluids mixing micrometer size particles was estimated. Figure 1 shows the thermal conductivity of the magnetic fluid mixing 12 vol.% spherical copper particles. The index of state on the horizontal axis was obtained from the experimental results of thermal conductivity. From this figure, it can be seen that as the magnetic field becomes stronger, the index of state increases from near zero to a positive value, indicating that the dispersion state of the particles is aligned in the magnetic field direction from the random dispersion state. In the case of the magnetic fluid mixed with 12 vol.% spherical copper particles, it was found that when magnetic field is applied, the thermal conductivity increases by 27 % or more as compared with the case of no magnetic field.

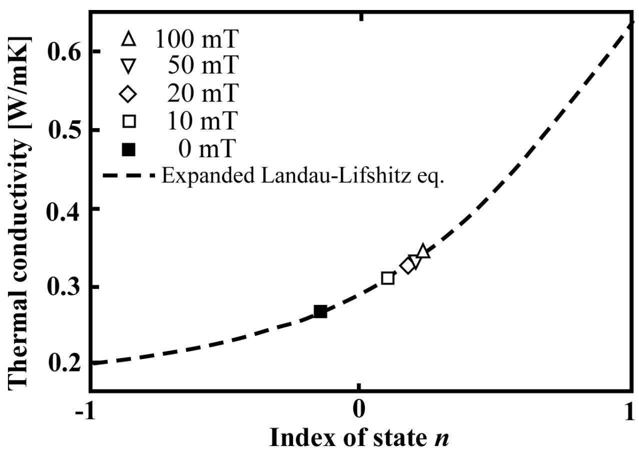

Fig1.jpg

Does electric field driven ferrofluid particle assembly result in alignment of their magnetic moments?

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 188

Dr. Michal Rajnak [1], ***Dr. Dirk Honecker*** [2], ***Dr. Artem Feoktystov*** [3], ***Dr. Viktor Petrenko*** [4], ***Dr. Mikhail Avdeev*** [4], ***Dr. Vitaliy Pipich*** [3], ***Dr. Juraj Kurimský*** [5], ***Dr. Bystrik Dolnik*** [5], ***Dr. Milan Timko*** [1], ***Dr. Peter Kopcansky*** [1]

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Recently, electric field driven particle assembly in transformer oil-based ferrofluid was observed on macro and nano scale [1]. This is feasible due to the dielectric contrast between the particle and the carrier liquid, giving rise to the effective particle polarization. The electric field induced ferrofluid structural changes are dependent on the electric field intensity and frequency, and result in the electro-viscous effect [2]. This behavior is analogous to magnetic field driven particle assembly in ferrofluids originating from alignment and mutual dipolar interaction of magnetic moments of particles in a magnetic field. As a result, the geometrical particle alignment is coupled with the alignment of the particles' magnetic moments. The aim of the presented study is to investigate the potential electro-magnetic coupling in a transformer oil-based ferrofluid, i.e. if the electrically driven alignment of magnetic particles (iron oxide) in transformer oil initiates an alignment of their magnetic moments. In this contribution, we present particle cluster formation seen with Small Angle Neutron Scattering (SANS) method. The experiments were carried out in electric fields up to 6 kV/cm, at temperatures ranging from room temperature up to 353 K. Further analysis demonstrates that the electric field driven particle assembly is determined by the competing nature of electric and thermal energy. Then, correlation in the orientations of magnetic moments inside the clusters is probed by polarized neutrons (SANSPOL). For the SANSPOL experiment, the ferrofluid was placed in a cuvette equipped with two electrodes, fixed between two poles of an electromagnet. An analysis of the scattering data for two neutron spin states allows us to extract the nuclear and magnetic scattering and to assess the correlation between the geometrical and magnetic structure.

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Transition Metal Oxide Based Nanofluids: Novel Properties

Tuesday, 9th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 475

Prof. Kalyan Mandal [1], ***Mr. Souvanik Talukdar*** [1], ***Mr. Indranil Chakraborty*** [1], ***Ms. Priyanka Saha*** [1]

1. S. N. BOSE NATIONAL CENTRE FOR BASIC SCIENCES

Transition metal oxides nanostructures receive considerable attention due to their extensive technological applications in high density magnetic storage media, high frequency devices, magnetically assisted drug delivery, cell isolation, MRI contrast agents, immobilization of proteins and enzymes, biosensors and so on. Though they have tremendous potential to be used in many biomedical applications, they do not disperse well in polar as well as in non-polar solvents. However they can be functionalized with suitable ligands to get biocompatible and water dispersible nanoparticles with interesting multifunctional properties [1,2]. For example, intrinsic multicolour fluorescence in $CoFe_2O_4$ nano hollow spheres from blue, cyan, and green to red is observed (Fig.1) upon functionalization with a small organic ligand such as Na-tartrate because of ligand-to-metal charge transfer from tartrate ligand to lowest unoccupied energy level of $Mn^{2+/3+}$ or Fe^{3+} of the NPs and Jahn−Teller distorted d−d transitions centered over Mn^{3+} ions in the NPs. $CoFe_2O_4$ nanoparticles (NPs) functionalized with surfactants having π-acceptor/π-donor head group along with different chain-length show much higher coercivity compared to bare particles due to NP-ligand interaction which modifies the splitting of d-orbital energy levels as well as spin motion of surface Co^{+2} ions [3]. Many of the above oxide nanostructures show excellent photocatalytic activities and potential for various biomedical applications depending on their shape, size and surface functionalizations [4].

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Figure caption:

Fig.1: Intrinsic multicolour fluorescence in $CoFe_2O_4$ nano hollow spheres

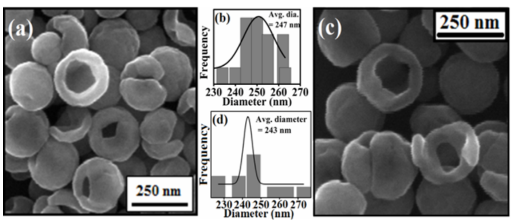

Fig1a.png

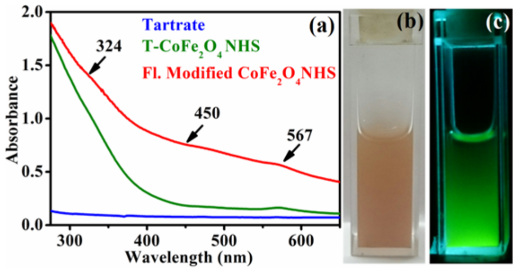

Fig1b.png

Behavior of ferrofluids at solid/liquid interfaces under external magnetic and electric fields: neutron scattering data

Tuesday, 9th July - 16:50: Plenary Speech Session - Oral - Abstract ID: 126

Dr. Viktor Petrenko [1], ***Dr. Anatolii Nagornyi*** [1], ***Dr. Michal Rajnak*** [2], ***Dr. Igor Gapon*** [1], ***Prof. Leonid Bulavin*** [3], ***Dr. Milan Timko*** [2], ***Dr. Mikhail Avdeev*** [1], ***Dr. Peter Kopcansky*** [2]

1. *Joint Institute for Nuclear Research,* ***2.*** *Institute of Experimental Physics,* ***3.*** *Kyiv Taras Shevchenko National University*

Ordered arrays of magnetic nanoparticles (MNP) are of current interest due to various potential applications. The effects of self-assembly of nanosized objects are interesting themselves from the fundamental point of view. In this work, this problem is considered for MNP in ferrofluids (FF). The behavior of MNP at interfaces differs from that in bulk as a result of specific adsorption properties, which can be an important factor in applications. A special question for FF concerns the effects of external fields (magnetic, electric or both) on their structure stability at interfaces.

The work was aimed at obtaining structural information about MNP ordering on substrates contacting FF under different conditions. For this purpose, neutron reflectometry was used to compare structural organization of FF at interfaces with that in bulk [1]. As a conclusion, both kinds of structure are correlated and determined by the type of magnetic component in MNP regulating the particle interaction, as well as the MNP concentration in FF. Formation of visually observable patterns in a diluted low-polarity ferrofluids exposed to external electric fields was recently presented [2]. It was shown by small-angle neutron scattering that the magnetic nanoparticles aggregate in DC electric field with a strong dependence on the field intensity. At the same time formation of quasi-layers of nanoparticles on silicon surface after application of non-homogeneous magnetic (fig.1) and electric fields was observed by neutron reflectometry. Thus, at a magnetic flux density about 35-75 mT, the analysis of the reflectometry data gives a three-layered structure, hence showing the formation of two effective adsorption layers with different content of magnetic nanoparticles in them [3]. In this connection, the possibility for anchoring MNP from FF on substrates by external magnetic fields is discussed.

Fig.1. Effect of magnetic nanoparticle assembly formation at a planar interface between a transformer oil-based ferrofluid and Si monocrystal under non-homogeneous magnetic fields by specular neutron reflectometry.

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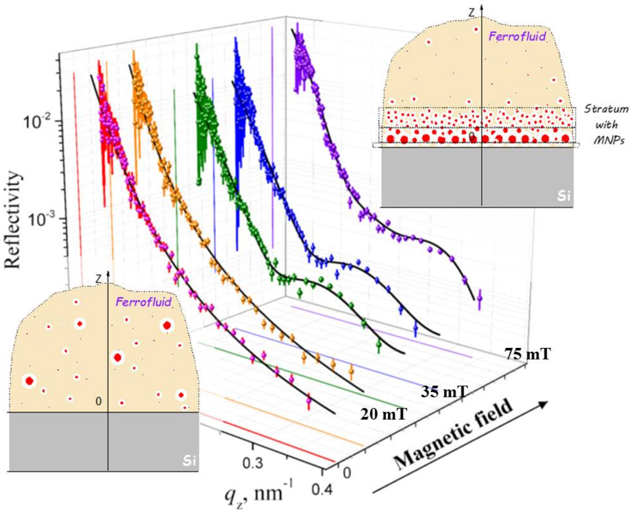

Mf mf nr2019.jpg

Properties and domain formation in ferromagnetic fluids

Tuesday, 9th July - 17:05: Plenary Speech Session - Oral - Abstract ID: 327

Dr. Nerea Sebastian [1], ***Mrs. Patricija Hribar Boštjančič*** [2], ***Mr. Žiga Gregorin*** [1], ***Dr. Natan Osterman*** [3], ***Prof. Darja Lisjak*** [1], ***Prof. Alenka Mertelj*** [1]

1. J. Stefan Institute, 2. J. Stefan Institute, J. Stefan International Postgraduate School, 3. Faculty of Mathematics and Physics, University of Ljubljana, J. Stefan Institute

Experimental realization of liquid magnets, that is, fluids with spontaneous magnetization, has been a long-standing challenge. However, significant breakthrough has been recently achieved in two unique systems. First, spontaneous stable ferromagnetic ordering was achieved in suspensions of $BaFe_{12-x}Sc_xO_{19}$ magnetic platelets in nematic liquid crystalline hosts [1,2], where the system is governed by the nematic elastic interactions (Fig.1a). On the other hand, spontaneous mesomorfic and ferromagnetic ordering in the suspensions of the same magnetic nanoplatelets in isotropic solvent was obtained in suspensions in isotropic solvents at high enough volume fractions [3]. The nanoplatelet functionalization strategy, ensuring strong enough electrostatic repulsion enabled stable suspensions. While at low volume fractions isotropic suspensions are observed, at high enough volume fractions anisotropic magnetic and electrostatic interactions promote mesomorphic nematic ordering of the plates [3] and the inter-platelet magnetic dipole interactions are adequate to promote macroscopic ferromagnetic order (Fig. 1b), resulting in a macroscopic magnetization **M**lying along the nematic order parameter. The colloidal nematic is distinctively characterised by negative birefringence and optical dichroism. It has been shown that uniform magnetic domains of few millimetres can be systematically annealed under zero-field conditions (obtained by locally cancelling Earth's magnetic field). In this contribution, we report on the preparation, properties and magnetic domain formation of these novel ferromagnetic fluids.

Fig.1: Polarized optical microscopy images of: a) magneto-optic response of a magnetic polydomain ferromagnetic nematic liquid crystal and b) magnetic domains and domains walls formed under confinement in a high concentrated suspension of magnetic nanoplatelets in 1-butanol for different annealing conditions.

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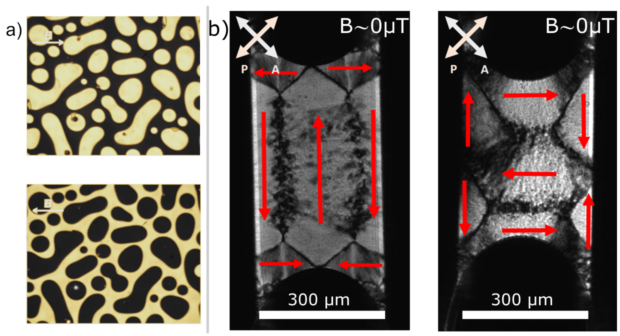

Fig1-magnetic-fluid-domains-icml2019.jpg

Covalent hybrid elastomers based on magnetic nanoparticles and elastic polymer

Tuesday, 9th July - 17:20: Plenary Speech Session - Oral - Abstract ID: 353

Mr. Julian Seifert [1], ***Dr. Martin Dulle*** [2], ***Prof. Joachim Wagner*** [3], ***Dr. Margarita Kruteva*** [2], ***Prof. Annette Schmidt*** [1]

1. Universität zu Köln, 2. Forschungszentrum Jülich GmbH, Jülich Centre for Neutron Science JCNS (JCNS-1) & Institute for Complex Systems (ICS-1), Jülich, 3. Universität Rostock

The incorporation of magnetic nanoparticles into polymeric matrices, such as gels and elastomers, leads to magnetically tunable hybrid materials. By employing magnetic nanoparticles as multifunctional, inorganic crosslinkers, we obtain magnetic node networks with a novel particle-matrix interaction due to a direct covalent coupling between magnetic and elastic component.[1,2] Moreover, direction-dependent properties are induced in these magnetic node networks by incorporation of elongated magnetic nanoparticles that show geometric as well as magnetic anisotropy.

Here, we present the synthesis of magnetic node networks based on spindle-like α-Fe_2O_3 particles and an elastomeric matrix. These materials are prepared by a polycondensation reaction, schematically shown in Fig. 1, leading to a network formation based on a large number of effectively connecting polymer segments per magnetic node particle.

Due to the covalent coupling, homogenous elastomers with a high particle content of up to 35 m% can be achieved. The mechanical properties of the magnetic node networks strongly depend on the particle volume fraction. With increasing particle volume fraction, an increasing Young´s modulus and a decrease of the strain at break (Fig. 2 and 3) are observed, attributed to a variation of the crosslinking density and a particle filler effect.

In addition, by the incorporation of spindle-like hematite particles into these elastomers, direction-dependent properties become accessible as a key step for the realization of actuators showing a reversible contraction along one axis.[3] This new type of magnetically responsive material is expected to have promising applications for dampers or in robotics, where the mechanic properties need to be reversibly manipulated.[4]

Acknowledgment

Financial support is acknowledged from DFG-SPP 1681 “Feldgesteuerte Partikel-Matrix-Wechselwirkungen”. (SCHM1747/10)

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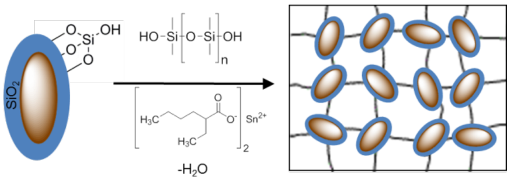

Fig 1 reaction scheme.png

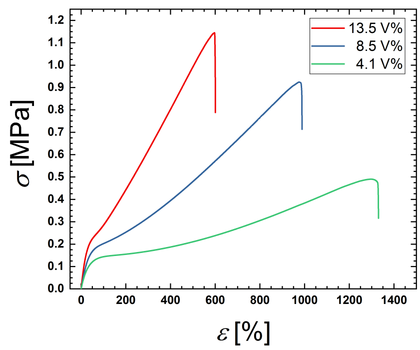

Fig 2 stress-strain curves.png

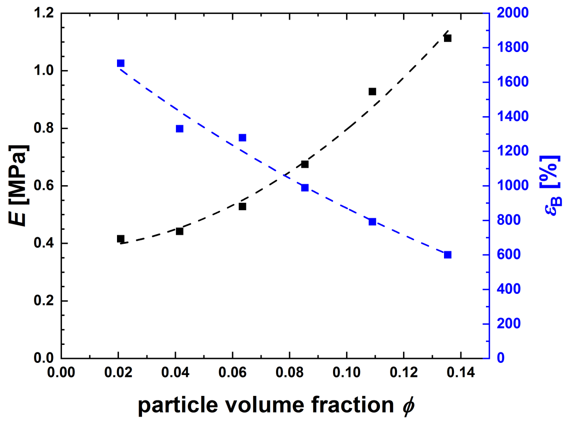

Fig 3 e and strain at break vs particle fraction.png

Magnetic anisotropies in self-assembled binary ferrofluids

Tuesday, 9th July - 17:35: Plenary Speech Session - Oral - Abstract ID: 315

Dr. Amélie Juhin [1], ***Dr. Niéli Daffé*** [2], ***Dr. Marcin Sikora*** [3], ***Dr. Jovana Zecevic*** [4], ***Dr. Claire Carvallo*** [5], ***Mrs. Sophie NEVEU*** [6], ***Dr. Yohan Guyodo*** [1], ***Dr. Vincent Dupuis*** [7], ***Dr. Dario Taverna*** [5], ***Dr. Jean-Michel Guigner*** [5], ***Dr. Nadejda Bouldi*** [8], ***Dr. Mauro Rovezzi*** [9], ***Dr. Veronica Gavrilov*** [7], ***Dr. Philippe Sainctavit*** [1]

1. CNRS, Sorbonne Université, IMPMC, 2. Paul Scherrer Institute, 3. AGH University, 4. Utrecht university, 5. Sorbonne Université, IMPMC, 6. Sorbonne Université, 7. Sorbonne Université, Laboratoire PHENIX, 8. Heidelberg University, 9. ESRF

Recent investigations have underlined the relevance of studying nanoparticle assemblies in ferrofluids, in order to optimize the efficiency of biomedical applications or develop new magneto-optical applications.[1] However, apart from theoretical predictions and few experimental confirmations, little is known on how to induce different morphologies of particle assemblies. In particular, the idea of tailoring self-assembled and field-induced structures, with particles of unconventional shape or by mixing ferrofluids with different magnetic anisotropy, has hardly been explored. Magnetic binary ferrofluids are particularly appealing because they offer an unprecedented interplay of magnetic dipole interactions.
In this work we investigate how the magnetic properties of a $CoFe_2O_4$ self-assembled ferrofluid are modified upon the binary mixing with a $MnFe_2O_4$ferrofluid. In the ferrofluid composed of pure 25 nm $CoFe_2O_4$nanoflowers, spectacular zero-field self-assemblies, which have been so far only predicted by simulations,[2] have been revealed by cryogenic Transmission Electron Microscopy (Figure 1). When such $CoFe_2O_4$ nanoflowers (with strong magnetic anisotropy) are mixed with $MnFe_2O_4$ flowers of similar size (with low magnetic anisotropy), cryo-TEM-EDX analysis shows that $MnFe_2O_4$ nanoparticles destroy the chains of $CoFe_2O_4$ particles. The influence on collective magnetic properties has been measured at low temperature in Zero Field Cooled and Field Cooled conditions using a combination of bulk magnetometry and of First Order Reversal Curve measurements that provide the distribution in coercivities and interparticle interactions in the frozen phase. In addition, magnetization curves were measured for each type of particles by element selective x-ray magnetic spectroscopies performed on synchrotron facilities, using a dedicated sample cell allowing to preserve particle assemblies.[3]

Our results shed new light on the structuration properties of binary ferrofluids in connection with their magnetic properties, and they provide a new set of observables that can allow to constrain simulations of binary ferrofluids.

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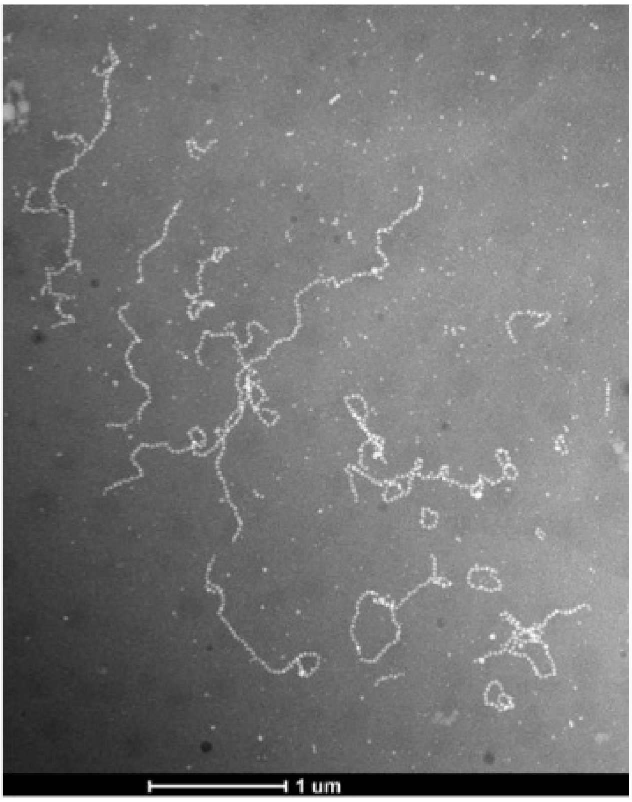

Figure1.jpg

Magneto-thermoelectricity in ferrofluids

Tuesday, 9th July - 17:50: Invited Speech Session - Oral - Abstract ID: 450

***Dr. sawako nakamae* [1], *Dr. Thomas Salez* [2], *Dr. Bo-Tao Huang* [2], *Dr. Marco Bonetti* [3], *Prof. Michel Roger* [3]**

***1.** Commissariat à l'Energie Atomique et aux Energies Alternatives, **2.** SPEC-CEA, CNRS,Université Paris Saclay, **3.** Service de Physique de l'Etat Condensé (DSM/IRAMIS/SPEC) - CNRS/UMR 3680*

The unique properties of magnetic nanoparticles and their interactions with their environment have given rise to innovative experimental possibilities outside the field of conventional magnetism. One such example is in the field of energy science, and in particular, thermal engineering using magnetic fluids (ferrofluids). In particular, research on refrigeration (magnetocalorics) and local heating (magnetic hyperthermia) technology has garnered much attention in the past decades. In recent years, we have reported another technological path for exploiting ferrofluids in the field of renewable energy, namely, magneto-thermoelectricity for waste-heat recovery. An enhanced thermoelectric property of ferrofluids is believed to stem from a combined effect of the magneto-thermodiffusion of magnetic particles and their self-organization (layered structures) near the electrodes.

In this presentation, a compilation of experimental results on the thermoelectric and magneto-thermoelectric effects in ferrofluids based on weak electrolytes will be given. These results are compared to the theoretical models on the thermoelectric potential production and analyzed in terms of key physical parameters such as the diffusion coefficient, the Eastman entropy of transfer and the electrophoretic charge number of colloidal particles. Our current understanding, limitations as well as the possible future direction for magneto-thermoelectric ferrofluids research will be discussed.

This work received financial support from; ANR TEFLIC (Grant No. ANR-12-PRGE-0011-01), LABEX-PALM (Grant No. ANR-10-LABX-0039-PALM) and the European Union's Horizon 2020 research and innovation programme under grant agreement No. 731976 (MAGENTA).

Magnetically driven micro-propellers: from travelling carpets to hydrodynamic bound states

Wednesday, 10th July - 09:00: Keynote Speech Session - Oral - Abstract ID: 638

Prof. Pietro Tierno [1]

***1.** University of Barcelona*

In this talk I will review recent progress in the realization of microscale coloidal rotors driven in a viscous fluid by external, time-dependent magnetic fields. The first part will be focused on the formation and propulsion of highly maneuverable colloidal carpets which can be steered via remote control in any direction of the plane [1,2]. These colloidal micropropellers are composed by an ensemble of spinning rotors and can be readily used to entrap, transport, and release biological cargos on command via a hydrodynamic conveyor-belt effect. An efficient control of the cargo transportation combined with remarkable “healing” ability to surpass obstacles demonstrate a great potential towards development of multifunctional smart devices at the microscale. In the second part I will describe the emergence of long-living hydrodynamic bound states between model microswimmers, namely hematite microparticles that translate at a constant and frequency-tunable speed close to a bounding. At high driving frequency, Hydrodynamic interactions (HI) dominate over magnetic dipolar ones, and close propelling particles couple into bound states by adjusting their translational speed to optimize the transport of the pair. The physical system is described by considering the HIs with the boundary surface and the effect of gravity, providing an excellent agreement with the experimental data for all the range of parameters explored. Moreover, in dense suspensions, these bound states can be extended to one-dimensional arrays of particles assembled by the sole HIs. These results manifest the importance of the boundary surface in the interaction and dynamics of confined propelling microswimmers [3].

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Waves and instabilities on the surface of a ferrofluid

Wednesday, 10th July - 09:40: Invited Speech Session - Oral - Abstract ID: 446

Prof. Eric Falcon [1]

1. *Université Paris Diderot / CNRS*

Magnetic fluids display rich and complex dynamics in response to an external applied magnetic field.

Here, I will present experimental studies showing how the magnetic field tunes the natural oscillations of a drop [1] and its origami by a folded elastic membrane [2], as well as how it modifies the dispersion relation of surface waves leading to the first observations of magnetic solitary waves [3], and of a regime of magnetic wave turbulence [4, 5]. Using a magnetic liquid is also an ingenious way to study the interplay between hydrodynamic instabilities [6], or the macroscopic analogous of the two-dimensional melting of solid-state physics [7].

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top view radial oscillations of a centimetric ferrofluid puddle on a vibrated plate for 4 different forcing frequencies.jpg

Particle rotation driven systems

Wednesday, 10th July - 10:05: Invited Speech Session - Oral - Abstract ID: 77

Prof. Andrejs Cebers [1], ***Prof. Mihails Belovs*** [1], ***Dr. Martins Brics*** [1]

1. *University of Latvia*

Ensembles of externally driven rotating particles constitute a benchmark case in the study of active systems. Here we review some particular cases. The first example considers the ensemble of rotating magnetic particles interacting by lubrication forces. At low angular velocity of particle rotation they make ordered structures with solid body rotation. At higher angular velocities stick-slip motion of external layers with respect to the internal layers arises. Average stick-slip velocity in dependence on the driving force obeys a square root law. These results are rationalized by the model of the Frenkel-Kontorova type where, for example, in the case of an ensemble of 19 particles, 6 particles of the internal layer play the role of substrate the spatial period of which is twice as large as that of the external layer with 12 particles. Numerical simulations show that at driving force larger than the critical stick-slip motion of the external layer arises, which occurs by synchronized pairs. Experimental data on the systems close to the ones considered are discussed.

The second example considers the dynamics of elongated magnetic droplets in a rotating field. According to the prediction of the simplified model at the frequency of the rotating field above the critical the shock wave of the tangent angle of the centerline arises, which is caused by the transition to the asynchronous regime of droplet rotation.

Very interesting transitions from the synchronous to the asynchronous regime take place in the case of motion of the magnetotactic bacteria in a rotating field, which is considered in the next example. In the synchronous regime of the puller type bacteria motion they create, due to the attraction caused by the force dipoles acting on the fluid, ordered structures, which rotate in direction opposite to the direction of rotation of the field. In the asynhronous regime pairs of bacteria may synchronize to the runaway trajectories characteristic for the single bacterium.

As the last example a suspension of dielectric particles in the electrical field is considered. In the presence of free boundaries particle rotations due to the Quincke effect are synchronized and create Couette type macroscopic flow.

Numerical simulation of the wave turbulence on the surface of a ferrofluid in a horizontal magnetic field

Wednesday, 10th July - 11:00: Plenary Speech Session - Oral - Abstract ID: 154

Dr. Evgeny Kochurin [1], ***Prof. Nikolay Zubarev*** [1]

1. Institute of Electrophysics, Ural Branch of the Russian Academy of Sciences

It is known that the dynamics of nonlinear capillary waves on the surface of a liquid can be quite complicated. Zakharov and Filonenko (1967) proposed a theory of weak turbulence of capillary waves. According to which, a stationary wave turbulent motion with an energy spectrum, now called the Zakharov-Filonenko spectrum, is formed at the boundary of the liquid. Physical experiments [Dorbolo, Falcon, Phys. Rev. E, (2011)] carried out for ferromagnetic fluids in a magnetic field show that the external field significantly changes the spectral exponent of the wave turbulence. So far there was no theoretical explanation for this fact.

In the present work, a direct numerical simulation of the interaction of capillary waves on the surface of a ferromagnetic liquid in an external horizontal magnetic field is carried out. It is shown that the interaction of oppositely traveling nonlinear waves can lead to the transfer of energy to small scales (direct energy cascade). In the quasistationary energy dissipation regime, the probability density functions for the slope angles of the boundary tend to a normal Gaussian distribution (figure 1), and the shape of the boundary acquires a complex, chaotic form (figure 2). The spectrum of surface disturbances in this regime is described by power-law dependence with the exponent -5/2 (figure 3). In terms of energy, the obtained spectrum coincides with the Iroshnikov-Kraichnan energy spectrum. This fact indicates the observed wave turbulence of the liquid surface has related nature with the weak MHD turbulence of the interacting Alfvén waves. In general, the results of the work are in qualitative agreement with the results of experimental studies [Dorbolo, Falcon, Phys. Rev. E, (2011)].

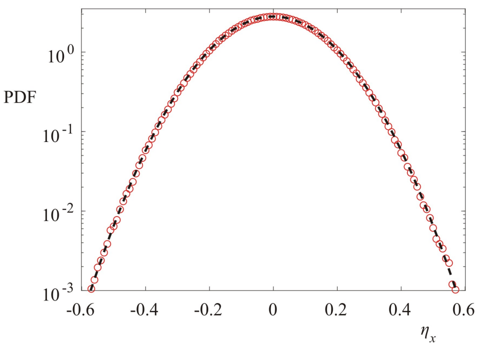

Fig1.jpg

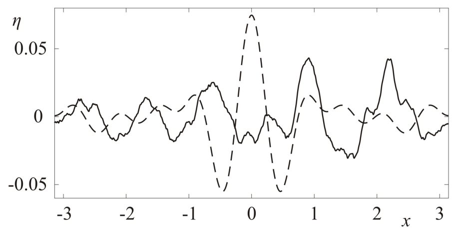

Fig2.jpg

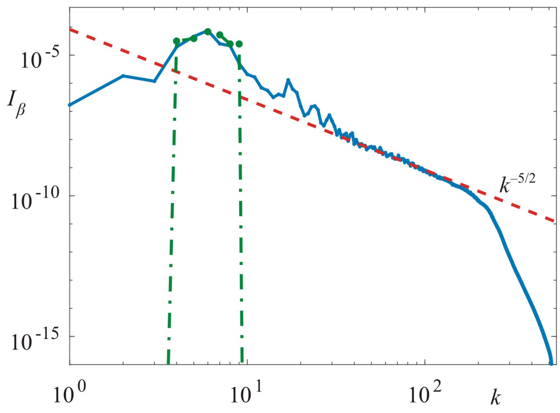

Fig3.jpg

Mixing of miscible magnetic and non-magnetic fluids with a rotating magnetic field.

Wednesday, 10th July - 11:15: Plenary Speech Session - Oral - Abstract ID: 502

Prof. Mikhail Krakov [1]

1. *Belarusian National Technical University*

Of considerable interest is the process of mixing fluids, accompanied by a combination of advective flows and diffusive mass transfer. These mechanisms of mass transfer are comparable in the case of small volumes of fluid, characteristic of meso- and microfluidic systems.

In the present work, the mixing process during rotation of a magnetic field has been studied numerically. To identify the mechanisms of influence of the magnetic field on the mixing process, a closed rectangular cavity is considered, having a horizontal size of 5 mm and a vertical 1 mm. This cavity is ¼ filled with a magnetic fluid, and ¾ with a base fluid. The magnetic fluid is located in the lower part of the cavity. Since the processes of diffusion and advection substantially depend on the viscosity of fluids, two fluids are considered: water-based (W) and transformer oil-based (TO) magnetic fluids. The magnetic field is assumed to be uniform with a period of rotation *T*. The equations of motion, diffusion, and magnetic field are solved by finite volume method. The problem is described by dimensionless parameters: the Grashof concentration number $\mathrm{Gr_c} = \beta_c g h^3/D^2$, the Grashof magnetic number $\mathrm{Gr_m} = \mu_0 M_S{}^2 h^2/\rho D^2$, the Schmidt number $\mathrm{Sc} = \nu/D$, the dimensionless magnetic field $\hat{H} = H/M_S$.The mixing efficiency in the cavity volume is characterized by the index $MI = 1- [(1/N)\sum_{i=1}^{N}(c_i/c- 1)^2]^{1/2}$, where *N* is the number of points in the region, *c* is the average concentration. Fig. 1 shows the value of this index for a TO fluid for time corresponding to 1 second after switching on the magnetic field, 10 s and 100 s. It is seen that there is an optimal frequency of rotation of the magnetic field, which provides the fastest mixing, and it varies depending on the time available for mixing. A similar situation is observed for a W fluid, but mixing in this case is more intense. Note that for a stationary magnetic field (right big markers in Fig. 1 and Fig. 2) TO fluid practically does not mixes with the base fluid in contrast with the rotating field.

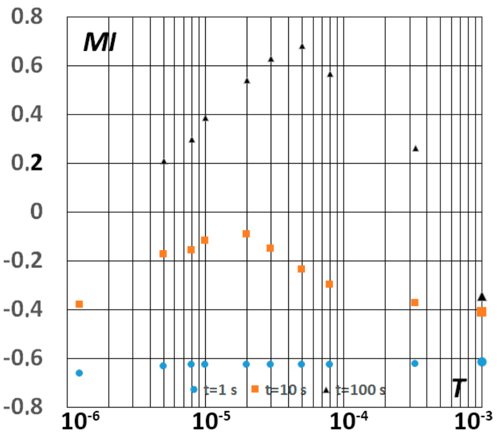

Fig.1.png

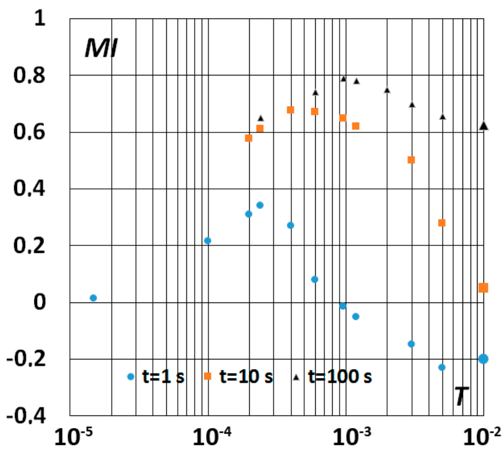

Fig.2.png

Rivalry of diffusion, external field and gravity in micro-convection of magnetic colloids

Wednesday, 10th July - 11:30: Plenary Speech Session - Oral - Abstract ID: 337

Dr. Guntars Kitenbergs [1], *Ms. Lāsma Puķina-Slava* [1], *Prof. Andrejs Cebers* [1]

1. University of Latvia, MMML lab

When an interface of a thin layer of miscible magnetic and nonmagnetic fluids is exposed to a magnetic field, which is perpendicular to the cell, one can observe a peculiar instability (Fig.1). We call it the magnetic micro-convection. The instability only develops above a critical field, when pondermotive forces induce flows that form characteristic finger like patterns across the interface, until diffusion smears the concentration gradients [1]. The induced flows have promising applications, like magnetic micromixers [2] and surface patterning [3].

Over time we have investigated magnetic micro-convection extensively. We have found that characteristic velocities are proportional to square of magnetic field, while size of initial fingers remains constant. This corresponds well with a theoretical Brinkman model [4]. However, the fluid interface can be largely distorted by a parasitic gravity induced convective motion, which is faster than diffusion. The density of the magnetic fluid which has colloidal particles in carrying liquid is larger than that of the carrying liquid alone. It turns out that the average density difference between both fluids is enough to induce a flow of the denser magnetic fluid underneath the less dense nonmagnetic fluid.

To stop the parasitic flow, one can turn the experiment sideways. In such a case the denser fluid is below the less dense. However, this changes the stability conditions. The interface is additionally stabilized by the density difference. We quantified it and it agrees with an extended model [5].

Another way to stop parasitic flows is by decreasing the cell thickness. We address this issue, discuss results and compare to the model and previous experiments. Finally, we discuss how diffusion, magnetic properties and density differences interplay in formation of magnetic micro-convection.

This work has been supported by a PostDocLatvia project 1.1.1.2/VIAA/1/16/197 and French-Latvian bilateral program OSMOSE project no. LV-FR/2018/5

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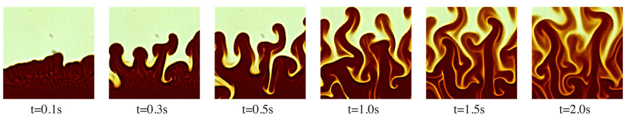

Fig.1 development of the magnetic micro-convection fingering pattern.png

Discontinuous shear thickening in suspensions of ferromagnetic particles

Wednesday, 10th July - 11:45: Plenary Speech Session - Oral - Abstract ID: 361

***Dr. Georges Bossis* [1], *Dr. Olga Volkova* [2], *Dr. yan grasselli* [3], *Dr. Alain Ciffreo* [2], *Mr. Massamba Thiam* [2]**

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Very concentrated suspensions of iron particles in a polar liquid can be obtained thanks to the use of superplasticizer molecules used in cement industry. At high volume fractions, these suspensions show a discontinuous shear thickening. The numerical simulations of Mari et al (JOR 2014) were successful in reproducing this behavior by introducing frictional forces between the particles. By measuring the electrical resistance of these suspensions of iron particles of micronic size in different rotational geometries, we have obtained an experimental proof of the formation of a percolating network of frictional contacts associated with the discontinuity, both in rate and stress controlled modes. In this last case, the rheological curve, including the yield stress and the stick-slip behavior observed above the critical stress, is modeled with the help of the Wyart-Cates model (PRL 2014) and of a relaxation equation for the frictional contacts. We shall dicuss the ability of this model to reproduce our experimental results and more specifically the change of critical stress and critical shear rate observed in the presence of a magnetic field. At last, we will show that the jamming transition is also present in a capillary flow, and that it manifests through the formation of a non-consolidated porous medium at the constriction between the barrel and the capillary. This formation can be monitored by the application of a low magnetic field , opening potential new applications in the domain of dampers and force control devices.

Impact of the spin viscosity on ferrofluid dynamics: Myth or reality?

Wednesday, 10th July - 13:30: Invited Speech Session - Oral - Abstract ID: 451

Prof. Mark Shliomis [1]

1. *Ben-Gurion University*

Entrainment of a ferrofluid placed in a rotating magnetic field is known as the spin-up phenomenon. It occurs when the fluid is contained in a cylinder and a uniform field rotates in the circular cross-section. The spin-up has a fifty-year history: it was first studied by Moskowitz & Rosensweig (1967) experimentally and by Zaitsev & Shliomis (1969) theoretically. Since then, many have worked to determine mechanisms of spin-up generation, but still have not overcome big disagreements between theoretical predictions and observations. Here we revise the spin-up problem.

The rotating field causes rotation of magnetic particles about their own axes, so each particle becomes the center of a microscopic eddy. It is generally considered that some part of their total spin is converted to the spin-up flow. The crucial role in the conversion plays a so-called spin viscosity η’, whose value is not known: a discrepancy between different estimates of the spin viscosity spanning 8-10 (!) orders of magnitude (Finlayson, 2013).

According to our calculations, $\eta'\sim10^{-19}$-10^{-20} kg m/s, much less than previous estimates. For a ferrofluid with $\eta'=10^{-19}$ kg m/s exposed to a field of 8-12 kA/m rotating at 300 revolutions per *second*, the theory predicts fluid rotation at 3-4 revolutions per *day*, i.e., essentially no fluid flow. This is a consequence of a huge difference between the total moment of inertia of micro-eddies (radius α) and the macroscopic vortex of characteristic scale R: their ratio $\sim(\alpha/R)^2$ is negligible. So, the beautiful idea that the spin-up effect is due to transition of the latent angular momentum to the visible flow proved to be untenable. Thus one should look for another possible mechanism of the phenomenon.

The reason for the spin-up in a long vertical cylinder may be magnetization inhomogeneity caused by the thermal effect, that is mainly due to energy dissipation in micro-eddies. At a field frequency of 500 Hz, one obtains a temperature difference of about 6 K between the axis and the wall of a cylinder and more than 10 revolutions of the fluid per minute. Experimental results of Pshenichnikov and Lebedev are in agreement with the theory.

Dynamic magnetic response of ferrofluids: The influence of interparticle dipolar correlations

Wednesday, 10th July - 13:55: Invited Speech Session - Oral - Abstract ID: 141

Prof. Alexey Ivanov [1]***, Mrs. Olga Kuznetsova*** [1]***, Prof. Philip Camp*** [2]

1. *Ural Federal University,* ***2.*** *University of Edinburgh*

The dynamic magnetic response of a ferrofluid to a weak AC magnetic field was studied using statistical mechanical theory and Brownian dynamics (BD) simulations, taking account of dipole-dipole interactions between the constituent ferromagnetic colloidal particles, and the presence of a range of particle sizes. Computer simulations were performed for monodisperse and bidisperse systems of spherical particles, with the orientational relaxation times of the magnetic moments set according to the rotational Brownian mechanism. The viscosity of the fluid was assumed constant, and the characteristic time of Brownian rotation was therefore dependent on the particle size. Systems with particle volume concentrations up to 40% and initial Langevin susceptibilities up to 3.2 were investigated.

The first conclusion is that the effects of interactions are very significant. With realistic parameters, the amplitude of the dynamic magnetic response is enhanced by up to 100%, and the frequency of maximum power loss was reduced by up to 50%, as compared to the noninteracting case.

The second conclusion is that systematic improvements on the description of interparticle correlations yield successively accurate predictions for the dynamic magnetic susceptibility. As compared to BD simulations, a modified Weiss (MW) [1] theory is essentially perfect over the whole range of parameters tested, including in the region where Weiss theory fails.

The third conclusion is that the effects of particle-size polydispersity are very pronounced. It was demonstrated that the qualitative appearance of the susceptibility spectra can be changed by including interparticle interactions between small-particle and large-particle components.

The general phenomena described herein are not limited to ferromagnetic particles undergoing Brownian rotation only; they will also occur with superparamagnetic nanoparticles undergoing Néel rotation, and with paramagnetic micron-sized particles in magnetorheological fluids, the essential features being that there are strong interparticle interactions, and a separation of reorientational timescales. The MW theory outlined here can also be applied to magnetic polymers (ferrogels), magnetic particles trapped in biological tissue, and many other areas of application.

A.O.I. acknowledges support from Russian Science Foundation Grant No. 15-12-10003.

[1] Ivanov A.O., and Camp P.J. Phys. Rev. (2018) **98**, 050602(R).

Modeling the deformation in hybrid magnetic elastomers: comparing micro- and mesoscopic approaches

Wednesday, 10th July - 14:20: Plenary Speech Session - Oral - Abstract ID: 323

Dr. Sofia S. Kantorovich [1], *Dr. Pedro A. Sanchez* [2], *Dr. Oleg Stolbov* [3], *Prof. Yuriy Raikher* [4]

1. University of Vienna, Vienna, Austria and Ural Federal University, Ekaterinburg, Russia, 2. Wolfgang Pauli Institute c/o University of Vienna, Vienna, Austria and Ural Federal University, Ekaterinburg, Russia, 3. Institute of Continous Media Mechanics, Ural Branch of RAS, Perm, Russia, 4. Institute of Continuous Media Mechanics, Ural Branch of RAS, Perm, Russia

Hybrid magnetic elastomers (HMEs), i.e. polymeric matrices filled with a mixture of magnetically soft (MSp) and magnetically hard (MHp) microparticles, have recently attracted a lot of attention because of their potentially versatile magneto-elastic properties. In the absence of an applied field, interparticle interactions in an HME can be separated in three groups: MH with MH, MH with MS, and, finally, MS with MS, as they are magnetised by MH. All these interactions force particles to displace and rotate, thus, giving rise to mesoscopic deformations. In result, the shape of an HME is determined by the balance of all the intrinsic magnetic and elastic forces.
Here, we analyse deformations of an HME representative volume that consists of a single MHp surrounded by an elastically bound assembly of MSps, employing two alternative approaches. In the first, mesoscopic one, the MSp shell is modelled as a magnetisable elastic continuum with given susceptibility and elastic modulus, Fig.1a. Assuming incompressibility, the shell deformation is obtained by numerical solution of a set of continuum magnetoelasticity equations. The second approach is based on the coarse-grained molecular dynamic simulations, where the MHp is considered as a sphere bearing a fixed central dipole and enveloped in a corona of MSps linked by elastic springs, Fig. 1b.
Both approaches predict elongation of the sample in the field direction given the latter is coaligned with the MHp dipole, Fig. 2a. In the field antiparallel to the dipole, both models predict flattening of the sample, i.e., widening in the equatorial plane, Fig. 2b. However, whereas in the mesoscopic model the local properties of the MS shell are invariable, the coarse-grained simulation admits and reveals nonuniform spatial redistribution of the MSps and their links.
In conclusion, to the best of our knowledge, our results for the first time point out the ability of HMEs for shape changes (from prolate to oblate and vise versa) under an applied uniaxial field. The deformation becomes more complex in the field tilted with respect to the magnetization of a MHp.
The work was cofunded by RFBR-DFG grant #19-52-12028; O.S. and Y.R. were supported by RFBR-DFG project 19-52-12045.

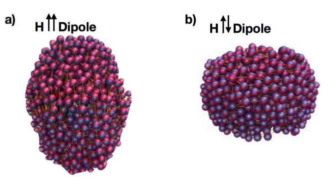


Fig. 2. Deformation of HME representative volume: (a) applied field is parallel to the central dipole of MHp; (b) applied field is antiparallel to the central dipole of MHp.

Fig2 icmf2019.jpg

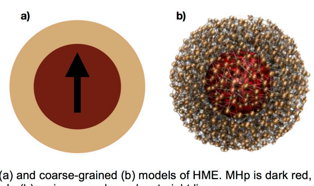


Fig. 1. Mesoscopic (a) and coarse-grained (b) models of HME. MHp is dark red, magnetically soft particles are golden. In (b) springs are shown by straight lines.

Fig1 icmf2019.jpg

Effect of magnetic interparticle interaction on magnetic hyperthermia

Wednesday, 10th July - 14:35: Plenary Speech Session - Oral - Abstract ID: 28

Prof. Andrey Zubarev [1], ***Dr. Larisa Iskakova*** [1]

1. *Ural Federal University*

Magnetic hyperthermia is a progressive method of treatment of cancer and other tumor diseases. The idea of this method is the injection of a ferrofluid, containing nano-sized ferromagnetic particles covered by special bio-active shells, into the region with the diagnosed tumor. Due to the shells, magnetic particles are captured by the tumor cells. Then the particles and, therefore, the tumor cells, are heated by an alternative magnetic field. Numerous investigations show that magnetic hyperthermia allows heating in vivo tumor region up to temperatures 42°C - 50°C. In this temperature range the tumor cells die, whereas the healthy cells, being more temperature resistive, survive. It is the key point of the therapy effect. Obviously, to increase the medical efficiency of this method, the accurate prediction and the control of the local temperature within the treated tissue is required.

Experiments demonstrate that magnetic nanoparticles, being embedded into biological cells, as a rule, are tightly bounded to the tissue and, therefore, are immobilized there. For these particles the most of known theoretical investigations of this phenomenon deal with the simplest system of non-interacting particles, re-magnetized according to the Neel mechanism.

Some experiments show that magnetite particles, with diameter in the range 25-30nm, are the most efficient for these applications. For the particles of these sizes the time of the Neel remagnetization lies in the range . This is much more than the typical time of the real hyperthermia process, which, usually, is about half an hour. Therefore, the concept of the Neel remagnetization can not describe the heating of the particles of these sizes.

We present a model of the heat production in a system of the particles, whose Neel remagnetization time greatly exceeds the actual time of the heating. Effect of magnetic interparticle interaction on the heat production is in focus of our attention. Our results show that in the case of uniform spatial distribution of the particles in the host medium, interparticle interaction enhances the thermal effect. If the particles form heterogeneous structures – the interaction weakens this effect.

Modelling the cross-linking process and magnetomechanical properties of particle cross-linked gels

Wednesday, 10th July - 14:50: Plenary Speech Session - Oral - Abstract ID: 318

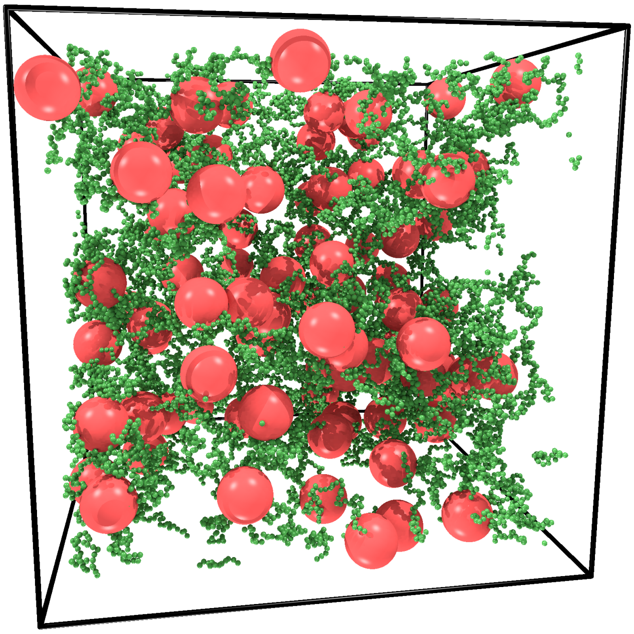
Dr. Rudolf Weeber [1], *Prof. Christian Holm* [1]

1. Institute for Computational Physics, University of Stuttgart

Magnetic gels and elastomers are of interest, as their shape and elasticity can be controlled by external magnetic fields. So far, the experimental realizations of this behavior make use of two underlying mechanisms: exerting a force on the magnetic particles through the application of a field gradient, and changing the interactions between magnetic particles by aligning their moments to an external field. Theoretical studies and simulations have suggested the presence of a third mechanism for cases in which magnetically blocked particles act as cross-linkers of the gel. When these particles are rotated by an external field, the polymers covalently bound to their surface have to follow the rotation. This, in turn, is expected to lead to a strain on the polymer chains and a shrinkage of the gel.

To our knowledge, this deformation mechanism has not yet been demonstrated experimentally. One obstacle is posed by counter-acting effects which make it difficult to identify suitable material parameters. As an example, connecting more polymers to the magnetic cross-linkers increases the deformation stress, but at the same time makes the material more stiff.

Previous simulations and theoretical models mostly made use of pre-determined network structures. These tend to be based either on regular lattices or on placing random connections between the particles by means of a criterion chosen a priori. While a strong dependence of the gel's magnetomechanical behavior on the network structure was observed in these studies, it can be hard to pin-point the mechanism causing that dependence. Therefore, the aim of this contribution is two-fold: first, a scheme for simulating the cross-linking process of the gel using coarse-grained molecular dynamics is introduced. With this scheme, we generate more realistic network structures based on properties such as magnetic particle density and polymer properties. Second, the magnetomechanical properties of the resulting gels are explored. Based on this approach, it should be possible to more closely link properties of the magnetomechanical behavior of a gel to quantities controllable in the synthesis process such as the length and polydispersity of the polymers.



Snapshot of a model gel created by simulating the cross-linking process starting from a solution of polymers and magnetic particles.png

The effect of magnetically soft component on the magnetic properties of hybrid elastomer composites

Wednesday, 10th July - 15:05: Plenary Speech Session - Oral - Abstract ID: 379

***Dr. Oleg Stolbov* [1], *Dr. Tatiana Becker* [2], *Dr. Dmitry Borin* [3], *Prof. Klaus Zimmermann* [2], *Prof. Yuriy Raikher* [4]**

***1.** Institute of Continous Media Mechanics, Ural Branch of RAS, Perm, Russia, **2.** Technical Mechanics Group, Technische Universität Ilmenau, **3.** TU Dresden, **4.** Institute of Continuous Media Mechanics*

Hybrid magnetorheological elastomers (h-MREs) are composites whose filler comprises both magnetically soft (MS) and hard (MH) micron particles with typical difference in size between the MH and MS ones about an order of magnitude. The MH micropowder, when being admixed to an elastomer matrix, is in non-magnetized state. This ensures that before curing the composite, the spatial distribution of both phases is uniform. Finally, the sample is subjected to a strong field that endows the MH particles with permanent magnetic moments, which they retain after the field removal.

With the MH component being an ever present source of internal fields, the MH and MS fractions are always magnetically coupled, and this predetermines unique magnetomechanical functionality of h-MREs. Hereby, we analyze the effect of the MS phase on the macroscopic remanent magnetization of such composites.
At a first sight, the issue is simple. According to the theory, if to surround an MH core with an MS shell, the magnetic field outside of this set would be lower than that of the “bare” core. In other words, the surrounding of an MH particle with a uniform assembly of MS particles causes magnetic screening. Let us compare then two h-MRE samples (A and B), which are identical except that A does not contain MS phase, whereas B does. The screening hypothesis readily yields that the field outside of B is weaker than that of A, and the same for their remanences.

Our experiments, however, evidence the opposite. To account for those observations, we propose a new model assuming that magnetic “initiation” breaks the spatial homogeneity of the MS fraction in h-MREs. Namely, (i) the MS particles form dense “bridges” connecting the MH ones; (ii) those bridges work as magnetic circuits, thus making the local field to exceed the external one; this, in turn, augments the remanence of the MH particles they are attached to. Presumably, similar structuring is a general feature of any h-MRE.
Development of theoretical models was funded by the RFBR-DFG project 19-52-12045; experiments were accomplished with the financial support of the projects BE 6553/1-1, BO 3343/2-1 within SPP1681 and PAK907.

To the theory of Neel remagnetization of a ferromagnetic particle

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 45

***Prof. Andrey Zubarev* [1], *Dr. Larisa Iskakova* [1]**

***1.** Ural Federal University*

The work deals with theoretical study of magnetic hyperthermia produced by an immobilized single-domain ferromagnetic particle under the action of an external oscillating magnetic field.

Usually, in theoretical models, the dynamics of the magnetic moment of an immobilized single-domain particle is described by the phenomenological Debye equation. This equation can be derived from solution of the corresponding Fokker-Plank equation for the particle moment orientations in quasi-stationary approximation, when period of the field oscillations is much more than the characteristic Neel time. However, estimates show that for magnetite particles with the typical diameter 20 nm and more, the opposite relation between these characteristic times takes place. Therefore, for the particles of this size the Debye relation is, strictly speaking, non-justified and its application requires, at least, careful relation. We present generalization of the quasy-stationary Debye equation to the case of relatively high frequencies of the applied field (i.e. for the arbitrary relation between the field period and the Neel time) and analysis of the difference in the predictions of the intensity of the heat production based on the Debye equation and on the more accurate equation of the particle remagnetization. Our results show that if amplitude of the applied field is not very small, the traditional Debye approach, leads to significant deviations (more than an order of magnitude) of the calculated intensity of the heat production from that based on the statistical Fokker-Plank analysis.

Shear rate dependence of viscosity and normal stress differences in Ferrofluids

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 63

Dr. Adriano Rosa [1], ***Prof. Francisco Cunha*** [1]

1. *University of Brasília*

In this work we investigate numerically the viscosity and normal stress differences of mono- and polydisperse ferrofluids undergoing both a simple shear flow and a transverse applied magnetic field. The simulations are carried out by means of a Brownian Dynamics integration algorithm. For all simulations we assume that the dipole moments are fixed to the magnetic particles. In the case of polydisperse suspensions the particles present a typical log-normal distribution of magnetic diameters which are covered with a layer of surfactant of constant width. The long-range dipolar interaction between the magnetic moments are computed by Ewald's summation technique and the surfactant influence is modeled as a steric repulsive force between pairs of particles. The attractive van der Walls force is also incorporated in the numerical simulations. The results show that the increase in viscosity with the magnetic field intensity is strongly dependent on ferrofluid polydispersity and on the strength of the dipolar interactions. By examining the suspension microstructure into the numerical box, we can see anisotropic structures like chains of particles for the regimes of low shear rate regime, specially in the polydisperse cases. The results also indicate the presence of a suspension shear-thinning behavior with two different shear rate dependence (figure 1). In addition, normal stress differences are observed even in the absence of dipolar interactions, as a consequence of particle collisions and the anisotropy induced by the imposed shear (figure 2). The dipolar interactions increase these normal stress differences and make their dependence on the shear rate nonmonotonic (figure 3). For low shear rates, the dipolar interactions dominate and the formation of structures like chains in the direction of the magnetic fields leads to an increase in the first normal stress difference. For very high shear rates, the flow breaks these anisotropic structures and the dipolar interactions become unimportant.

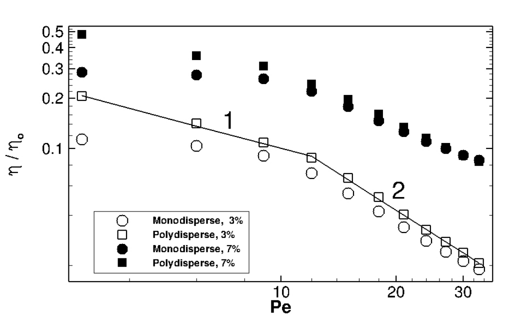


Figure 1.jpeg

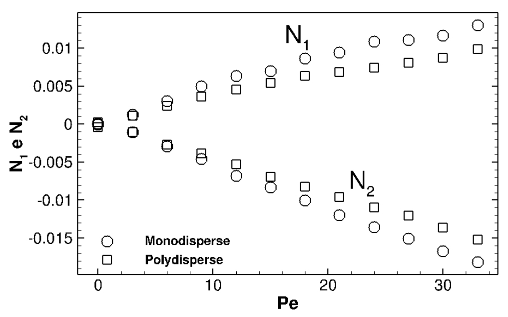


Figure 2.jpeg

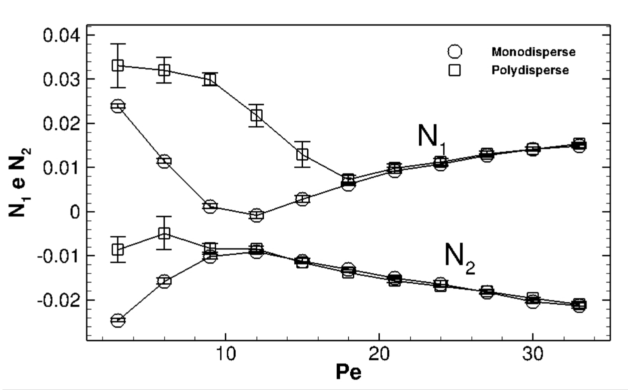


Figure 3.jpeg

Effect of Non-Uniform Magnetic Fields on the Characteristics of Ferrofluid Flow in a Square Enclosure

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 76

Mr. Myoungwoo Lee [1], ***Prof. Youn-Jea Kim*** [1]

1. Sungkyunwan University

The importance of heat management has been emphasized in various industrial fields and cooling technology of efficiently removing heat is required. Recently, ferrofluid is attracting attention as a new cooling medium because it has higher thermal conductivity than conventional heat transfer fluid. Furthermore, it has the advantage of easily moving fluid by using electromagnetic coils or permanent magnets. When a magnetic force is applied to ferrofluid, the magnetic particles in the fluid are magnetized and then, it changes the physical and chemical properties of the fluid. For those reasons, the flow of ferromagnetic fluids can be controlled by magnetic fields. And the temperature gradient is generated depending on the direction and intensity of the magnetic field.

In this study, the heat transfer characteristics of oil-based Fe_3O_4(ferrofluid) by the magnetic field in a square enclosure were investigated. The magnetic force was adjusted by changing the intensity and direction of the permanent magnet. The results showed that this change caused the disturbance of the boundary layer of the ferrofluid that was why the thermal diffusion was increased. Different types of vortices were generated and the temperature distribution was changed accordingly. When the same heat source was applied, temperatures up to 11% lower depending on the position of the permanent magnet and the direction of the magnetic field. Finally, the optimum point that has a higher heat transfer rate than the reference model was derived by modifying the strength and direction of the magnetic field.

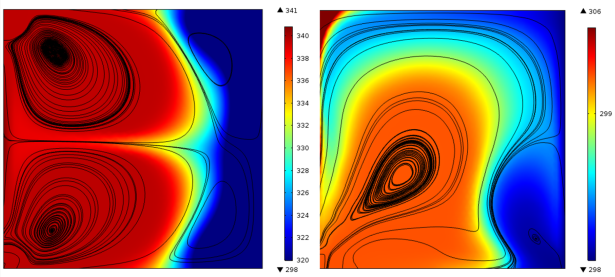


Fig. Simulation results for different strengths of the permanent magnet.

Fig.png

Axisymmetric nonlinear waves in cylindrical ferrofluids

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 128

Prof. Emilian Parau [1]***, Dr. Mark Blyth*** [1]

1. *University of East Anglia*

Axisymmetric nonlinear waves on the surface of a cylindrical ferrofluid column subjected to a magnetic field are investigated numerically. An azimuthal magnetic field is generated by an electric current flowing along a stationary metal rod of finite depth which is mounted along the axis of the column. The magnetic field can be used to suppress the long-wave Rayleigh instability and stabilise a ferrofluid column (Rosensweig 1985).

Two different numerical method are developed and used to compute fully nonlinear travelling solitary waves and periodic waves (Blyth & Parau 2014, 2019). The first method extends a finite-diffference based method developed for cylindrical jets by Jeppson (1970). The second method is an AFM (Ablowitz, Fokas & Musslimani 2006) method applicable to studying water waves in a cylindrical geometry. This formulation involves only surface variables and is used to compute fully nonlinear axisymmetric periodic and solitary waves on a ferrofluid column.

Elevation waves and depression solitary waves obtained by Bashtovoi, Rex & Foigel (1983) and Rannacher and Engel (2006) using a weakly nonlinear theory are confirmed in the appropriate ranges of the magnetic Bond number. New nonlinear branches of solitary wave solutions with decaying oscillations are discovered. Limiting configurations with a trapped toroidal-shaped bubble, static waves or exhibiting a cusp are investigated. A comparison between our numerical results and experimental observations of Bourdin, Bacri & Falcon (2010) is also performed.

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Computer simulations of anisotropic structures in magnetorheological elastomers

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 137

Dr. Dmitry Chirikov [1]

1. *Ural Federal University named after the first President of Russia B.N. Yeltsin*

Magnetorheological elastomers based on micron-sized magnetic particles in polymer matrices are interesting for scientists and engineers due to rich set of physical properties valuable for many industrial and biomedical applications.

Experiments show that the properties of the composites with internal anisotropic structures, formed by the particles, are greatly different from those of their isotropic analogs. Note, that these structures are created at the stage of the composite synthesis under the action of an applied magnetic field.

In (D. Gunther, D.Yu. Borin, S. Gunther, S. Odenbach. Smart Mater. Struct. 21 (2012) 015005, 7pp), anisotropic magnetorheological elastomers were studied by using X-ray tomography. It was established that even small changes of concentration of magnetic particles led to the formation of completely different types of aggregates. As, in the composites with low concentration of the particles, chain aggregates were observed. With increasing concentration of the particles, tubular structures appeared. The quantitative theory of the formation of tubular structures has not yet been constructed.

In this work the computer simulation method, developed for modeling of the anisotropic heterogeneous structures, is presented. This method is based on numerical solution of the system of differential equations of all particles motion. The advantage of the computer experiment is the ability to take into account the magnetic forces of all particles, without any assumptions about structures.

The magnetic forces was estimated on the basis of the following assumptions:

1. the mutual magnetization of the particles;
2. the uniform magnetization of the particle in its volume;

3. linear magnetization law.

To perform the computer simulations, the software was written for Linux operating system. The source code of the program was written in Fortran and compiled using gfortran. After executing the program, the required physical data was calculated and the obtained results was written in the text file. Visualization of the results was carried out by reading data from the text file with their subsequent graphic processing. We used software VMD (Visual molecular dynamics) to get the graphic illustration. Some visualization results are presented in the figures (fig_1.jpg, fig_2.jpg and fig_3.jpg). They reproduce the laboratory experimental results.

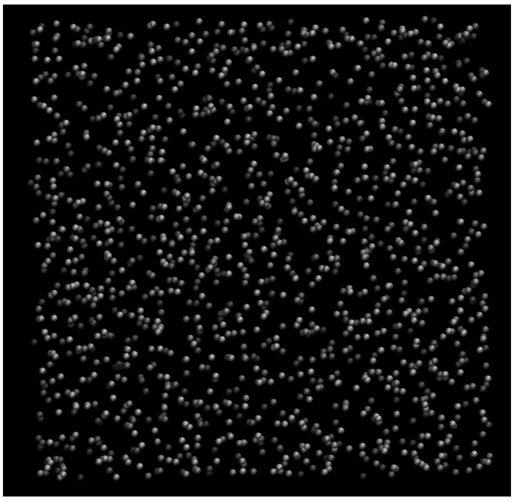


Fig 1.jpg

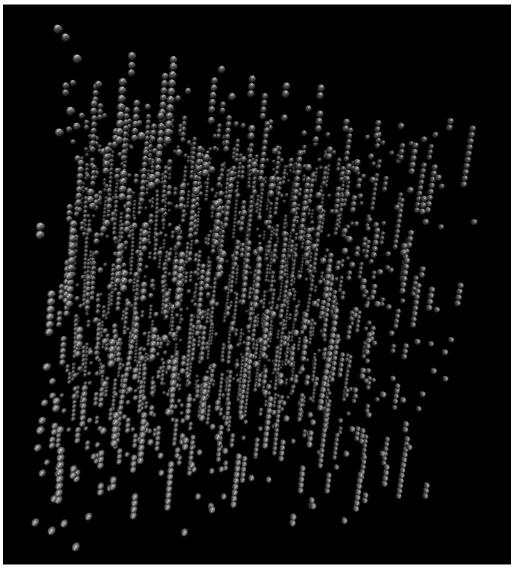


Fig 2.jpg

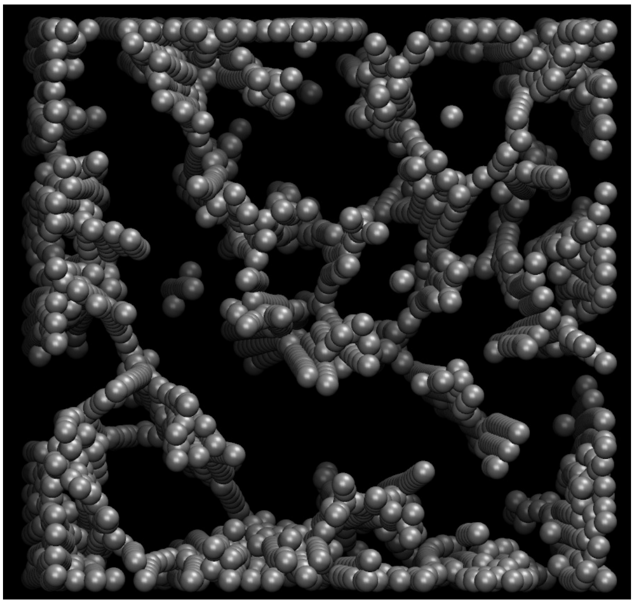


Fig 3.jpg

Rheological performances of nano-ferrite based magnetic suspensions

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 146

Mr. Ankur Chattopadhyay [1], *Dr. Purbarun Dhar* [1]

1. *IIT Ropar*

The present article depicts the steady and oscillatory behaviours of the nanoscale ferrite (MFe_2O_4) based suspensions. The primary objective is to illustrate the determining influence of substituting the M^{2+} site in MFe_2O_4 nano-ferrites by different magnetic metals (Fe/Mn/Co). Anhydrous nanoparticles of requisite amount (concentration - 40 wt%) were dispersed in the non-polar fluid (silicone oil) and mechanically stirred for ~ 10 mins to obtain a homogeneous suspension. The present experiments were carried out with the help of a rotational rheometer (MCR 102, Anton Paar, Germany), having parallel plate configuration at constant gap of 1 mm. The suspensions were exposed to four different values magnetic fields (0, 0.35T, 0.7 T and 1 T). The temperature has been maintained constant at 300K and the typical uncertainty involved in the measurements was within ± 5%. The steady rheological behaviours were obtained by measuring the shear stress (fig. 1a) and viscosity (fig. 1b) as a function of shear rate from 0.01 to 100 s^{-1}. The MR suspensions exhibit shear thinning behaviours and augmented yield characters under magnetic fields (fig. 1). Doping with Mn in MFe_2O_4 results in superior yield stress compared to Fe. However, substitution of Co leads to reduced responses compared to Fe_3O_4 based fluids. These observations signify that there is a strong dependence of the magnetic moment of the M^{2+} atom ($n\mu_B$, where n = 5, 4, and 3; for Mn, Fe, and Co respectively) upon the respective yield responses. To probe the oscillatory behaviours, frequency sweep tests (frequency spectra range - 1 to 100 Hz, at a given strain of 1%) have been performed at 1T (fig. 2). It is observed that the doping by the Mn/Co does not result in any significant alterations of the magneto-viscoelastic responses of the corresponding MR fluids (fig. 2a). However, reduced loss factors have been noticed in cases of Mn and Co compared to Fe, particularly at higher frequencies; thereby indicating notable improvements in dissipative characters (fig. 2b). Hence, it can be inferred that overall responses of the nano-ferrite based MR suspensions is a strong function of the magnetic properties of the dopant atom.

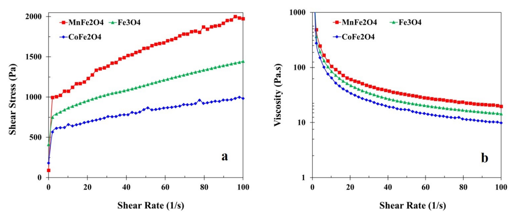


Fig 01.jpg

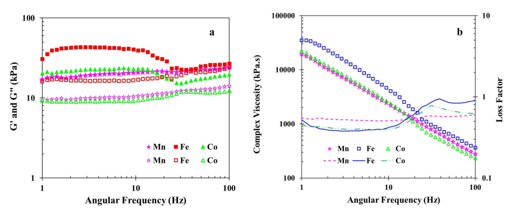


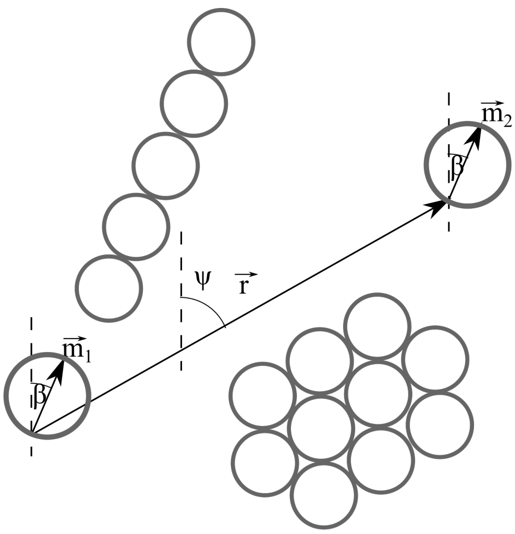
Fig 02.jpg

Structures of paramagnetic particles in precessing magnetic field

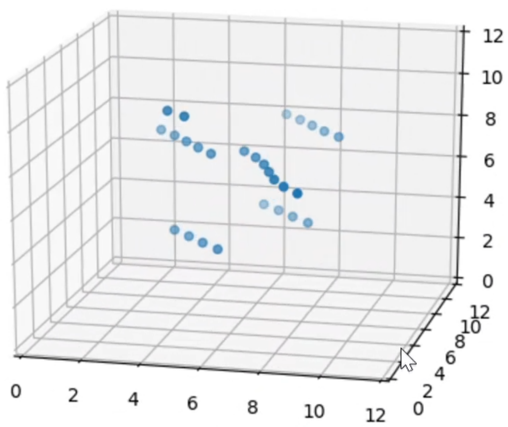
Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 147

Dr. Jānis Cīmurs [1], *Mr. Jānis Užulis* [1]
1. University of Latvia

Paramagneticparticles get magnetized in external magnetic field. Magnetization ofthe particle depends on external magnetic field and particleanisotropy axis direction. If such particles are exposed toprecessing field in viscous fluid they can form chains or planesdepending on field parameters. Theoretical calculations show field-parameter range in which particles form chain and in which they formplane. Numerical simulations show that besides chain and planestructures, particles can also form short chains arranged in plane.
Dynamicsof individual particle in precessing field is known from previousresearch, where it is shown that in precessing field individualparticle can rotate synchronously with the field or periodically lagbehind the field. Theoretical calculation for particle structures arebased on minimum of mean interaction energy between particles knowingdynamics of individual particle.In numerical simulations onlymagnetic interaction between particles and particle interaction withexternal field is taken into account, which is compensated by fluiddrag. Simulations are done by self-written program.
Thistalk will give insight how theoretical and numerical results areobtained. It will be shown in which cases particles would obtainchain and plane structures in precessing field. In numericallyobtained results it will be seen how these chains or planes ofparticle form and will be shown situation when it is hard todistinguish between these two structures.
Itis crucial to know how to control self-assembly of particles bychanging external field parameters. It can be further used forcreating nano scale objects that could be used in medicine and forbuilding materials with unique proprieties. Model with this kind ofmagnetic particles can also help to explain some behavior of magneticfluid drops seen experimentally.
This work is supported by PostDoc Latvia project no: 1.1.1.2/VIAA/1/16/060



Paramagnetic particles in precessig field can form chains or planes.png



Example structure of particles in simulation.png

Studying frequency-dependent properties of soft magnetic materials using computer simulations

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 176

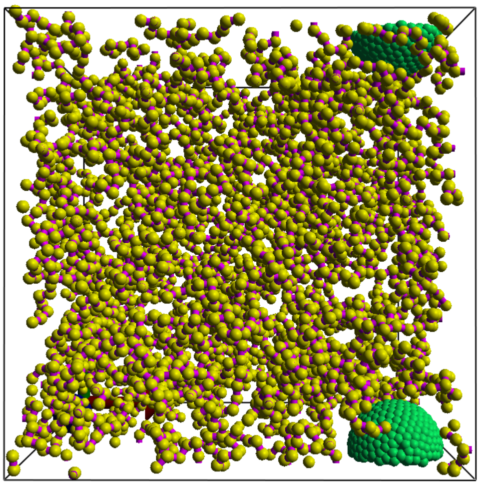
Mr. Patrick Kreissl [1], ***Dr. Rudolf Weeber*** [1], ***Prof. Christian Holm*** [1]

1. *Institute for Computational Physics, University of Stuttgart*

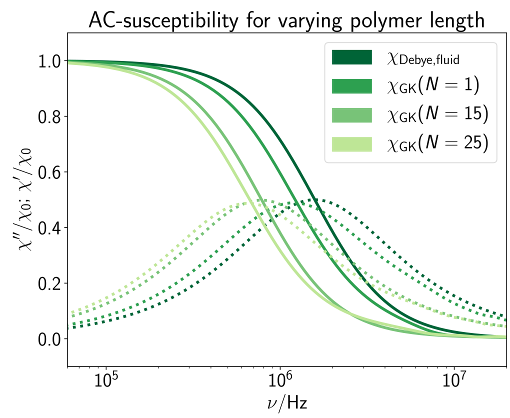
Soft magnetic composite materials form an interesting class of materials, that has been connected to both technical and bio-medical applications. They consist of magnetic nano-/microparticles embedded in a polymer solution or gel. An intriguing feature of these composites is the ability to dynamically change properties such as their shape and stiffness, by use of an external magnetic field. This behavior originates from the coupling of the magnetic properties of the embedded particles to the (vico)elastic properties of the surrounding polymer matrix. Understanding the coupling in depth is imperative when it comes to tailoring the properties of soft magnetic materials to the needs of a specific use case. Unfortunately, in many materials, the details of this coupling are not fully known and difficult to determine experimentally.

We therefore present a computational model for soft magnetic systems, that allows us to study how changes of the polymer characteristics/interactions affect nanorheological properties. Our simulations use particle-based molecular dynamics coupled to a lattice-Boltzmann hydrodynamics solver. This very efficient hydrodynamics solver is well-suited for the mesoscale. Magnetic particles are modeled as so-called raspberry-particles which consist of discrete coupling points, that are fixed relative to a central bead. The polymers are resolved as bead-spring chains connected by harmonic bonds, where the beads are also coupled to the fluid.

An important experimental method to assess material properties of soft magnetic systems is AC-susceptometry, where susceptibility spectra are obtained by measuring a probe's frequency-dependent magnetization response to an applied magnetic AC-field. Using appropriate theoretical models (Debye model, Gemant-DiMarzio-Bishop model *etc.*), it is possible to extract, for instance, the local viscosity and even mechanical stresses from these spectra. Our simulation setup allows us to perform comparable measurements, where we use linear-response theory to obtain the AC-susceptibility from steady-state simulations. By changing single aspects of the system, like polymer density, polymer length, polymer–particle interaction *etc.* we study the resulting signature in the AC-susceptibility spectrum. Moreover, the mentioned theoretical models allow us to derive elastic properties from the AC-spectra and compare these to direct viscoelastic measurements in the simulation.



Representative snapshot of a simulation.png



Ac-susceptibility spectra for varying polymer length.png

Magnetic particle rotation driven densely packed swarms

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 180

Dr. Martins Brics [1], ***Prof. Andrejs Cebers*** [1]

1. *University of Latvia*

Swarms of externally driven rotating particles form a benchmark case for active systems [1]. Here we show some detailed results of [2]. We examine what happens to ensembles of magnetic particles (in single layer densely packed magnetic spheres) in a rotating external magnetic field. We assume that particles are interacting by lubrication forces, magnetic dipole-dipole attraction and steric repulsion forces. At low rotational frequencies of the external magnetic field particles make ordered structures and the whole swarm rotates around its center of mass as a solid body. At higher frequencies stick-slip motion of the most outer layer with respect to all internal layers arises. Increasing the frequency even more a chaotic motion of particles is observed, although in this case there exists also some interesting periodic solutions, e.g. in the case of 19 particles, two rings with 7 and 12 particles which rotate in opposite directions are observed. This is opposite to the case of moderate frequencies when layers also rotated with different angular velocities but in the same direction .

In detail we investigate what is the typical shape of the swarm, how such parameters as rotational angular velocity of swarm, critical frequency when stick-slip motion start depends on the number of particles in swarm. Such particles tend to form an ordered hexagonal crystal. The preferred shape of small swarms thus is a perfect hexagon. However, this structure become less and less stable the more shells of particles are added and thus other structures which are close to circle are observed. The rotational angular velocity of the swarm and the critical frequency, when the stick-slip motion starts, depends on the shape of the swarm, but both of them in general decreases with the increasing radius of the swarm. The analytical calculation for the rotational angular velocity states, that for large clusters the rotational angular velocity is proportional to $1/r^2$, which very well agrees with the numerical simulations.

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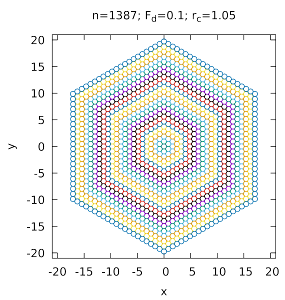
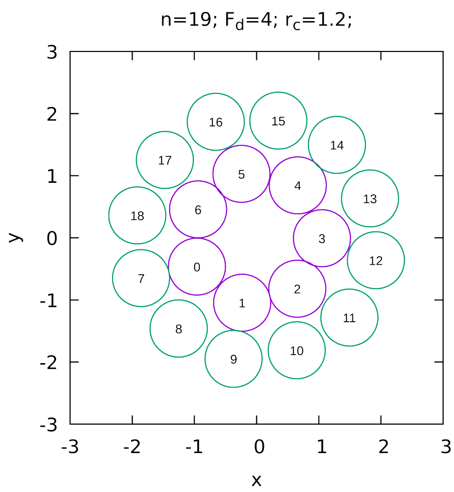
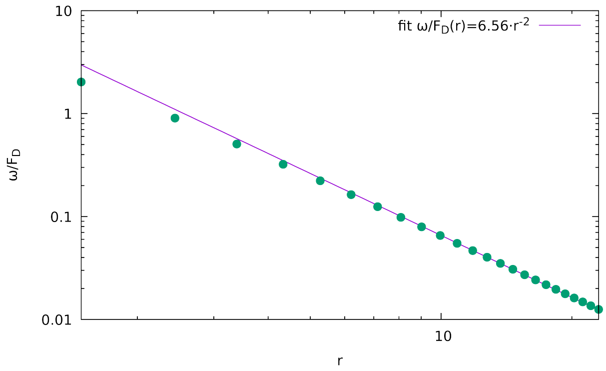


Configuration of 1387 particles forming a perfect hexagon.png



Configuration of 19 particles where particles in the inner and outer ring rotate in opposite directions.png



Rotational angular velocity dependence on the radius of swarm.png

Mathematical modeling of inverse ferrofluid emulsion: nonlinear nagnetization

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 197

Mr. Igor Subbotin [1]

1. Ural Federal University named after the first President of Russia B.N. Yeltsin

This work is focused on the mathematical modeling of the magnetic properties of an inverse ferroemulsion, which is a system of nonmagnetic fluid micro droplets (radius □ 5-10 mm), suspended in magnetic fluid carrier. Under the action of an external magnetic field these droplets elongate along the applied field direction [1-2]. This behavior is pronounced for emulsions with rather weak values of the interfacial tension (□ 10^{-6} N/m) and provides the growth of emulsion magnetic susceptibility in rather weak external magnetic field (□0 −0.5 kA/m) [3]. Further long-tail decline of emulsion magnetic susceptibility is can be explained by the decline of the magnetic susceptibility of the ferrofluid with the external magnetic field growth [4].

In this work the model of inverse ferroemulsion is presented. Nonlinear magnetization law of the ferrofluid under the action of an external magnetic field is given by the Modified Mean Field model [3]. The mutual interdroplet interaction is taken into account by the averaging of the influence of droplets on the internal field configuration. This idea is same as we use to the modelling the “ferrofluid-in-oil” emulsions [5] and allows to use the homogeneous effective magnetic field inside the ferrofluid instead real complex configuration of internal magnetic field. In additional the influence of droplet polydispersity is taken into account. The results of modelling is provide a good qualitative and quantitative comparison with the experimental data [1-2].

Acknowledgments

The work is supported by the Ministry of Education and Science of the Russian Federation (Project No. 3.1438.2017/PP).

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Modelling a hybrid journal bearing with magnetorheological fluids using the ideal bingham model

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 199

Mr. Stefan Lampaert [1], ***Dr. Ron van Ostayen*** [1]

1. *Delft University of Technology*

Hydrodynamic journal bearings are used pervasively in all types of machine design due to their superior friction and wear properties. However, a drawback of this machine component is that both friction and wear tend to be large at low speeds or high loading conditions which may lead to eventual system failure.

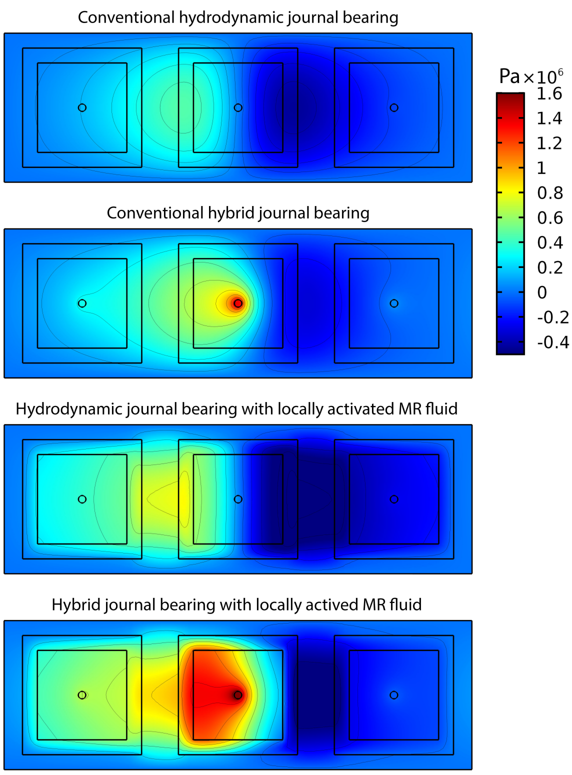
One efficient way to overcome this drawback is to use a hydrostatic journal bearing instead resulting in a large load capacity at low speed or high loading conditions. However, this in turn, has the drawback that it uses a high-pressure hydraulic supply that is sensitive to failure, basically moving the problem to another component in the system.

Therefore, hybrid journal bearings are designed that try to combine the performance of hydrodynamic and hydrostatic journal bearings such that sufficiently low wear and sufficiently high load capacity are achieved for the complete range of speeds and loading conditions.

This work presents a new type of hybrid journal bearing in which a magnetorheological fluid is used in combination with local magnetic fields, such that the hydrodynamic and hydrostatic working regimes are not compromised. The performance is modelled with the use of a FEM model in which the ideal Bingham plastic fluid model is used such that the behaviour of the fluid in the film is most accurately described. No regularization method is required. Both the yield stress and the viscosity increase in function of the magnetic field.

The four figures show the pressure distribution in a hybrid journal bearing. The local magnetic field is applied only in the square shaped annuluses. The supply pressure is applied at the circles at the centre of these annuluses. The four figures present the different pressures resulting from the situation with or without a local magnetic field and with or without a supply pressure.

The results demonstrate that the efficiency in load capacity is increased significantly by activating the magnetic field for both the hydrostatic and hydrodynamic regime. Additional advantage of this concept is that the local viscous behaviour can be controlled meaning that the behaviour of the bearing can be modified during operation.



Conventional hydrodynamic journal bearing
Conventional hybrid journal bearing
Hydrodynamic journal bearing with locally activated MR fluid
Hybrid journal bearing with locally actived MR fluid
Pa ×10⁶
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4

Figure.jpg

The interplay of particle structure and mechanical properties in NdFeB-loaded magnetorheological elastomers

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 237

Mr. Malte Schümann [1], Mr. Julian Morich [1], Prof. Stefan Odenbach [1]
1. Chair of Magnetofluiddynamics, Measuring and Automation Technology, TU Dresden, 01069 Dresden, Germany

Magnetorheological elastomers (MR-elastomers) are a class of smart materials, where the embedment of magnetic particles in an elastomeric matrix leads to the ability to control the mechanical behavior by the application of external magnetic fields. A key to gain a deeper understanding of MR-elastomers is the analysis of the internal particle structure which strongly determines the macroscopic material behavior.
A MR-elastomer with 40 wt% of NdFeB particles was synthesized. The arrangement and the magnetically induced motion of the particles were evaluated by means of X-ray microtomography. The sample was gradually magnetized up to an external field of 2 T. At each point of magnetization a 250 mT field was applied during tomography and mechanical testing.
The successive magnetization leads to a non-reversible transition from an isotropic particle distribution to particle chains. Figure 1 shows a 3D-reconstruction of the particle structure at the initial state (left) and after application of a 2 T magnetic field (right). The pair correlation function (PCF) provides a convenient method to analyze the spatial arrangement of particles [1]. For this investigation, a direction dependent implementation of the PCF was applied to evaluate the anisotropy of the particle structure. This method enables to determine the point of commencing chain formation. Mechanical characterizations show a significant magnetorheological effect (MR-effect), an increase of the Young's modulus in presence of a 250 mT magnetic field. This reversible effect increases with progressing magnetization and chain formation. The results point out a certain external magnetic field where both an anisotropic particle structure begins to form and significant MR-effects begin to occur. This is visualized in figure 2, showing the peak values of the PCF in particle chain direction and MR-effects for all steps of external magnetization. A particle tracking was performed to evaluate the rotation and translation of the individual particles [2].
Financial support by DFG in the project OD18/21 within SPP1681/PAK907 is gratefully acknowledged.
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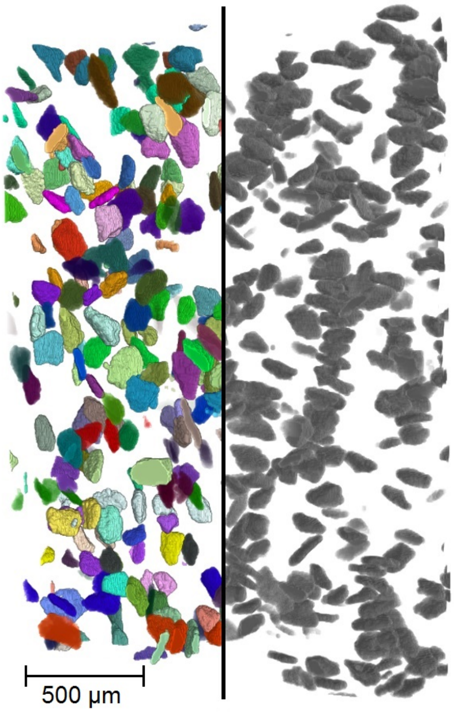

Fig1 particles.jpg

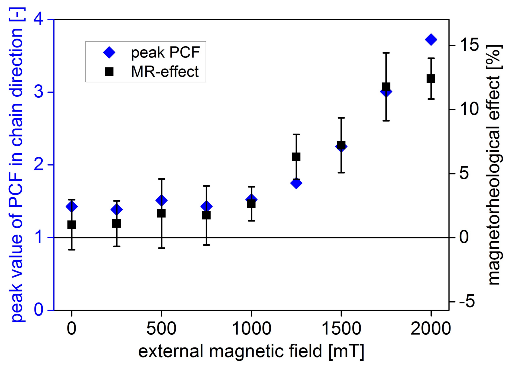

Fig2 pcf and mre.jpg

Influence of internal conditions on the magnetic filaments self-assembly

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 281

Dr. Elena Pyanzina [1], ***Mrs. Tatyana Belyaeva*** [1], ***Mrs. Anna Akisheva*** [1], ***Dr. Ekaterina Novak*** [1]

1. *Ural Federal University*

One of the key topics in current research on novel microstructured soft materials and technologies is the fundamental understanding of the self-assembly properties of colloidal systems. Cutting-edge experimental techniques allow create the permanent stabilization of small polymer-like aggregates (magnetic filaments). Using Langevin dynamics simulations, we focus on analyzing in detail their self-assembly under the influence of two internal parameters: additional pointed attraction and particle sizes. Simple open chains, closed rings and branched structures with “X” and “Y” junctions are used. To analyze the effect of additional interactions on the processes of self-assembly in the system of magnetic filaments, we compared the obtained results with data on conventional dispersions of filaments where only magnetic and steric interactions are presented. Analysis of data did not reveal new scenarios for the self-assembly of magnetic filaments. Such attraction only stimulates already known transitions, for example, the formation of long linear structures for chain filaments. Also, we were interested the impact of particle’s size in the self-assembly. Following the seminal theoretical work on the effects of polydispersity on the properties of ferrofluids, we consider a bidisperse model as a first approximation to a polydisperse system. We study four types of individual magnetic polymer chains: consisting of only large particles; with all large, but one small particle located at one chain end; with two small particles at the chain ends; with three small particles, two of them at the chain ends and one in the middle. Also we study three types of individual magnetic polymer rings: consisting of only large particles; half of small and large particles; four equal parts, which alternate depending on the particle size. Using replica-exchange molecular dynamics simulations, we study the radius of gyration and magnetic moment of a single magnetic filament in a wide range of temperatures. We observe that the presence of even a little fraction of small particles can significantly affects magnetic filament structural behaviour. All obtained results will form the basis for developing theoretical models and provide recommendations for the design of novel magnetoresponsive systems.

Characterization of a magnetic fluid exposed to a shear flow and external magnetic field using small angle laser scattering

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 290

Dr. Dmitry Borin [1], ***Mr. Cristoph Bergmann*** [1], ***Prof. Stefan Odenbach*** [1]

1. Chair of Magnetofluiddynamics, Measuring and Automation Technology, TU Dresden, 01069 Dresden, Germany

Small angle light scattering (SALS) is a proven method for the investigation of structures on micro- to mesoscopic length scales. Small angle scattering experiments were successfully used to detect the chain structures formed by nanoparticles in ferrofluids in the past [1]. The SALS method has the great advantage, that it is easily realizable in the lab utilizing laser radiation.

In our contribution, we present a study on the structuring processes in a low concentrated biocompatible magnetic fluid with clustered particles. Such fluids are typically used for biomedical experiments and contain iron oxide nanoparticles which are clustered into aggregates with a mean hydrodynamic diameter of about 200 nm. Application of an external magnetic field drastically influences the physical behaviour of the fluid. An effect directly related to chain formation of the nanoparticles resulting in chains with a dimension of several micrometers [2]. The existence of these relatively big structures allows us to use SALS with a laser source for the microstructural characterization of the fluid. Moreover, a combination of a microfluidic chip, an electromagnet and a magnetic circuit with the SALS-setup provides the possibility to study the fluid under simultaneous influence of an applied magnetic field and shear flow. In our presentation we will show the investigation of shear- and field-dependent structural changes in a magnetic fluid by the analysis of the laser light's scattering pattern (fig. 1). SALS measurements are accomplished with a full characterization of the fluid using conventional shear magneto-rheometry, magnetometry, microscopy as well as dynamic light scattering.

Figure 1: Laser lightscattering patterns for the studied magnetic fluid at a magnetic field of B=25mT for various mechanical load cases: 1 – no shear flow; 2 – shear flow (0.25 s^{-1}) is applied, t=1s; 3 – shearflow (0.25 s^{-1}) isapplied, t=10s; 4 – shear flow is interrupted, t=1s; 5 – no shear flow, t=10s;6 – shear flow is interrupted, t>12s.

Financial support by DFG in the project Bo 3343/2-1 (within SPP1681/PAK907) is greatfully acknowledged.

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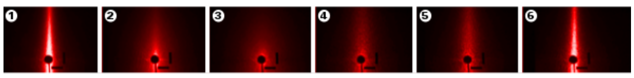

Figure 1.png

Dynamic susceptibility and characteristic relaxation times for the multicore magnetic nanoparticles

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 298

Dr. Vladimir Zverev [1]***, Mr. Vadim Kamaltdinov*** [1]***, Prof. Alexey Ivanov*** [1]

1. *Ural Federal University*

Nowadays, several methods for reconstructing the spatial distribution of magnetic particles are developed. They are based on measurements of the dynamic susceptibility and/or magnetolaxometry methodology. An ensemble of magnetic nanoparticles is used as a sensitive element because they can penetrate into any parts of the body due to their size. For purposes of medicine the most promising are particles with a relatively large size, on the order of 20 nanometers and more [1]. However, magnetorheological fluids with such particles have a higher degree of exposure to the process of agglomeration and sedimentation. The appearing of multicore particles is a natural step of overcoming obstacles [2]. This type of particles can be described as particles that contain an ensemble of nanocrystals with varying degrees of packing density, and the spatial structure of this ensemble is fixed by a polymer shell.

This work is focused on the theoretical investigation of the dynamic response of multicore particles in an alternating magnetic field. Particles are modeled as a cluster from an ensemble of interacting ferroparticles. It is assumed that the relaxation of the magnetic moments of ferroparticles occurs by a Neel mechanism. The rotational motion of the magnetic moment of a random ferroparticle is determined from the solution of the corresponding Fokker-Planck equation. Interparticle dipole-dipole interactions are considered at the level of the modified first order mean field theory be means of an additional term to the energy of the system [3]. The obtained analytical solutions for the probability density of the orientation of the magnetic moment of a random particle are used to determine the dynamic susceptibility. Two cases of mutual orientation of the external magnetic field and the axis of easy magnetization are considered. Theoretical results are compared with data obtained from simulations that was carried out using a molecular dynamics method.

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Dynamic susceptibility of interacting superparamagnetic particles under static magnetic field

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 313

Prof. Ekaterina Elfimova [1]***, Mr. Alexander Ambarov*** [1]***, Dr. Vladimir Zverev*** [1]

1. *Federal State Autonomous Educational Institution of Higher Education «Ural Federal University named after the first President of Russia B.N.Yeltsin»*

We investigate the dynamic response of an ensemble of spherical, uniformly magnetized, uniaxial superparamagnetic nanoparticles to a weak, linear polarized AC magnetic field. It is assumed that the magnetic easy axis of all particles is codirectional and it does not change with time. Two cases of mutual orientation of AC and DC magnetic fields are considered: parallel and perpendicular.

The rotational motion of a particle magnetic moment is described by the probability density which is the solution of the Fokker-Planck equation. The interparticle dipolar interactions are taking into account with the help of additional term into the Fokker-Plank equation. This term describes the overall magnetic field produced by all other magnetic dipoles in addition to an external AC magnetic field. The analytical expression of the probability density is evaluated and used for the calculation of the real and imaginary dynamic susceptibilities. It is shown how various features of the susceptibility spectrum of a monodisperse dispersion depend on the concentration, dipolar coupling constant, the strength of the DC field, parameter of the magnetocrystalline anisotropy, and the mutual orientation of AC and DC magnetic fields.

Rheological properties of nanocomposite particle made from supramolecular magnetic filaments

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 320

Dr. Ekaterina Novak [1], *Dr. Elena Pyanzina* [1], *Dr. Pedro A. Sanchez* [1], *Dr. Sofia S. Kantorovich* [2]

1. *Ural Federal University*, 2. *University of Vienna*

In the past decade, the active study of nanoparticles has opened new perspectives in the physics of soft materials that properties can be effectively controlled by external magnetic field. The idea of creating magnetic filaments (semiflexible polymer-like chains of magnetic nanoparticles permanently crosslinked with polymers) has existed for many decades. These systems have been recently pointed as promising building blocks for the creation of new magnetoresponsive materials. The advantage of such magnetic supramolecular polymers is that they can be used as an alternative to nanoparticles in magnetic fluids to obtain a desired and easily controlled response. Moreover, the shape and size of filaments allow filtration and mixing in systems which size does not exceed hundreds of nanometers. In this contribution, using Langevin dynamics simulations, first we focused on solutions of filaments, the magnetic nanoparticles in which are not only interacting via dipole-dipole potential, but also via short-range attractive forces (Lennard-Jones type). Such filaments tend to aggregate in dense spherical droplet-like clusters. The examples of the filaments and the clusters could be found in Fig. 1 A. The sketch of a linear filament, stretched for the simplicity can be found in Fig.1 B. The resulting composite soft colloid is placed in the microchannel, where its behavior in the shear flow is investigated, varying a wide range of system parameters. The thickness of the channel varies from the one comparable to the size of the nanocomposite magnetic particle to that of 10 radii of gyration. Two values of the magnetic interaction intensity are selected, that correspond to two regimes: the dipole energy is comparable to the thermal one, and the dipole energy is several times higher than the thermal energy. We also studied several shear-rates. We find the relationship between magnetic forces, central attraction and shear-rates at which the cluster deforms but does not break and eagerly follows the flow. This way we study the possibility of transport-based applications based on the soft colloids made through self-assembly of magnetic filaments.
Fig. 1. A. The cluster of filaments. B. Schematic representation of a single filament.

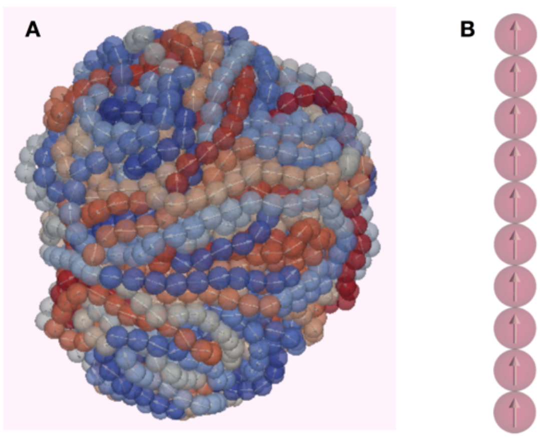

Fig.1.png

Mesophase transformations in magnetic colloids outside of equilibrium

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 324

Dr. Dmitry Zablotsky [1]

1. University of Latvia

Self-assembly is a major route by which colloids are able to spontaneously organize into a variety of large scale structures. Magnetic colloids exhibit field-dependent mechanical response due to complex microstructural transformations that lead to their directional assembly in various aligned mesophases when subjected to electromagnetic fields. This self-assembled system represents unique opportunities for a strongly anisotropic reconfigurable active material susceptible to external stimulation by electromagnetic fields to gain control over the reversible interaction between colloidal particles. Dynamic self-assembly implies structuralization outside of the equilibrium. The time-dependent external stimuli are a straightforward and flexible route to manipulate the internal structure and trigger the phase transformation.

We will report the results of a complex experimental investigation of the structural behavior of a model magnetic colloid employing a range of advanced rheological techniques. For the first time we will show evidence of nano-hydrodynamic instabilities and at least one, possibly two mesophase transformations in magnetic colloids under dynamic excitation. Additionally, using hybrid molecular dynamics and multi-particle collision dynamics simulations with explicit coarse-grained hydrodynamics to resolve the coupling of collective hydrodynamic and electromagnetic interactions in colloids outside of equilibrium we observe the self-assembly of magnetic nanoparticles into a hierarchy of aligned mesostructures and elucidate the nature of their transformation. We will present quantitative comparison of our simulated rheometric studies with micromechanical models and experimental data.

Ferrohydrodynamics and ultrasound

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 325

Prof. Victor Sokolov [1]

1. MIREA – Russian Technological University

Study of the features of propagation of small amplitude ultrasound wave in magnetic fluid occupies a significant place in the development of compressible ferrohydrodynamics (FHD), since the results of such studies make it possible now to appraise existing various FHD equations in a linear approximation, under conditions of reliable experimental data, of course. The principal aim of the report is overview of the main results obtained in the framework of a new approach to the ideal compressible FHD. An important tool is the concept of frozen-in magnetization field. The condition of frozen–in magnetization leads to new equation of magnetization evolution. We have ignored dissipation entirely, trusting that it can be added later by using the standard phenomenological methods.

The FHD spectrum consists of three different waves: the Alfvén-type wave, the slow and fast magnetosonic waves . Thus we have predicted existence of two new waves: the Alfvén-type wave and slow magnetosonic wave. The Alfvén-type wave in magnetic fluid similar Alfvén wave in perfectly conducting fluid. However Alfvén-type wave propagating in non-conducting magnetic fluid in an external magnetic field is accompanied by oscillations of the magnetization.

When an external magnetic field is applied, magnetic fluids develop anisotropic properties, in particular, acoustical anisotropy due induced aggregation in linear chains aligned with the direction of applied magnetic field. We have employed our theory to described the experimental data for the ultrasound velocity anisotropy in magnetic fluids based on the various liquids using theoretical expression for the propagating velocity of fast magnetosonic wave and good quantitative agreement between theory and experiment was demonstrated. We therefore believe that the magnetizable chains are frozen into the fluid motion. The slow magnetosonic wave is longitudinal mode. It propagates along the magnetizable chains.

Effect of graphite on the sedimentation and strength of magnetorheological fluids

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 326

Mr. Manish Kumar Thakur [1], ***Dr. Chiranjit Sarkar*** [1]

1. *Indian Institute of Technology Patna*

Nowadays many devices based upon magnetorheological fluid (MRF) are developed such as MR brake, MR damper, and MR clutch. The effectiveness of the developed devices reduces due to some problem such as sedimentation and agglomeration of MRF particles. In this research, our focus is on the design and improvement of the MR clutch. MRF is the main component of MR clutch, so the synthesis of good quality MRF is a prime concern. In this paper graphite containing MRF is synthesized. Graphite is used as a lubricant in transmission devices. In this study plate-like, graphite particles are used as an additive in MRF. Magnetorheological fluid 80 (MRF 80), and magnetorheological fluid based on graphite 80 (MRFG 80) are synthesized and characterized. The MRF 80 and MRFG 80 prepared by carbonyl iron particles (80 % by wt) and graphite (0.5% and 1% by wt). MRF is characterized or evaluated by Rheometer. Results show the effective use of graphite in MRF. MRFG 80 has a higher value of shear stress than the MRF 80.

Modelling and experiments of capillary flow of magnetic fluids under uniform field

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 330

Mr. Yuri Sinzato [1], ***Prof. Francisco Ricardo Cunha*** [1]

1. *University of Brasília - UnB*

The present work aims to investigate the flow of a ferrofluid undergoing a uniform magnetic field in axial symmetry through both theoretical and experimental approaches. The experiments are carried out by means of a capillary tube flow connected to a syringe pump experimental setup at the creeping flow limit. The uniform longitudinal magnetic field is applied by means of an electrically activated solenoid. The proposed theoretical models are solved by means of a perturbation method based on a regular asymptotic solution, as well as numerical integration. The magnetoviscous effect is investigated for a fully developed laminar flow. The equations are made non-dimensional in order to identify the physical non-dimensional numbers such as the Péclet number, the particle volume fraction and the parameter of effective applied magnetic field. The theoretical velocity and magnetization profiles are presented. In addition, the global quantities like wall viscosity and the relative viscosity are also determined by means of numerical simulation and experiments. The simulations results are in very good agreement with the experimental data at low Péclet number. In addition, a comparison between experimental results in capillary flow and rotating disk rheometer indicates a good agreement under the condition of weak magnetic fields. Surprisingly, for a moderate magnetic field, the capillary tube device predicts a lower magnetoviscous effect, suggesting a possible influence of particle shear induced-migration due to shear rate gradient.

Liquid flow and control without solid walls

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 331

Dr. Peter Dunne [1], Dr. Takuji Adachi [2], Mr. Arvind Dev [1], Mr. Lucas Giacchetti [2], Dr. Alessandro Sorrenti [3], Prof. Michael Coey [4], Prof. Bernard Doudin [1], Prof. Thomas Hermans [2]

***1.** IPCMS UMR 7504, **2.** ISIS UMR 7006, **3.** ETH Zurich, **4.** Trinity College Dublin*

Solid walls become increasingly important when miniaturizing fluidic circuitry to the micron scale or smaller.[1] They limit achievable flow-rates due to friction and high pressure drop, and are plagued by fouling[2]. Approaches to reduce the wall interactions have been explored using hydrophobic coatings[3,4], liquid-infused porous surfaces[4–6], nanoparticle surfactant jamming[7], changing the surface electronic structure[8], electrowetting[9,10], surface tension pinning[11,12], and atomically flat channels[13]. An interesting idea is to avoid the solid walls altogether. Droplet microfluidics achieves this, but requires continuous flow of both the liquid transported inside the droplets and the outer carrier liquid[14]. We demonstrate a new approach, where wall-less aqueous liquid channels are stabilised by a quadrupolar magnetic field that acts on a surrounding immiscible magnetic liquid[15]. This creates self-healing, uncloggable, and near-frictionless liquid-in-liquid microfluidic channels that can be deformed and even closed in real time without ever touching a solid wall. Basic fluidic operations including valving, mixing, and 'magnetostaltic' pumping can be achieved by moving permanent magnets having no physical contact with the channel. This wall-less approach is compatible with conventional microfluidics, while opening unique prospects for implementing nanofluidics without excessively high pressures.

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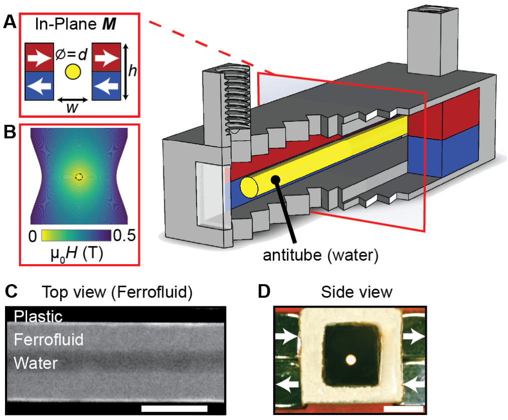

Figure 1 basic properties of confined fluids-01.png

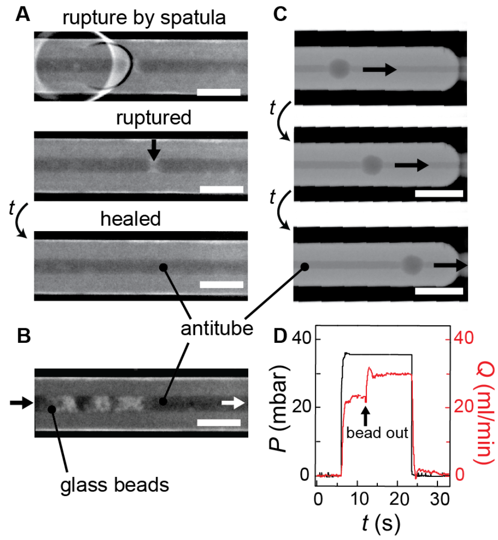

Figure 2 magnetically confined fluids-01.png

Modelling and simulation of ferroparticle diffusion in ferrofluid layers

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 332

***Dr. Olga Lavrova* [1], *Dr. Viktor Polevikov* [1]**

***1.** Belarusian State University*

Several mathematical models are developed for equilibrium states of ferrofluid thick layers in externally applied uniform magnetic fields. To model weakly-, moderately- and highly-concentrated ferrofluids under assumption of uniform particle distribution, the Maxwell's equations for different magnetization laws could be considered [5]. The Maxwell's equations should be coupled with the mass-transfer equation for ferroparticles when the diffusion of particles is essential [3, 4]. Moreover, the Young-Laplace equation should be additionally coupled to the above-mentioned equations for the ferrofluid layers with free surfaces [3, 4].

The mass-transfer equation for ferroparticles in weakly-concentrated ferrofluids has an explicit analytical solution for the particle concentration in a static limit for the Langevin magnetization law [2]. The mass-transfer equation in moderately-concentrated ferrofluids is developed in [1], taking into account magnetic dipole-dipole and steric interactions between particles. The magnetization law is assumed to follow an expansion over the Langevin law. The mass-transfer equation in moderately-concentrated ferrofluids could be reformulated in a static limit as a nonlinear algebraic equation for the particle concentration [3].

Based on the developed mathematical models and numerical techniques for their realization, simulations are performed for the problem of Rosensweig instability in [4]. It is observed that the onset of instability does not depend on the diffusion of particles (interacting or not). However, diffusion causes an elongation of peaks in a long-term range (several days) with the highest concentration in the peak region.

Simulations are performed for the problem of magnetic shielding by a thick ferrofluid layer in [5]. It is observed that the shielding effectiveness factor is higher for more concentrated ferrofluids.

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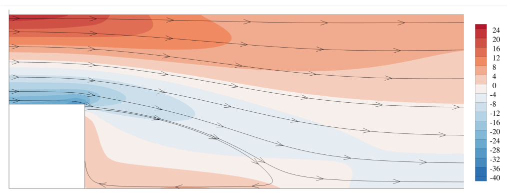
New insights on boundary layer control using magnetic fluids: a numerical study

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 334

Mr. Ciro Alegretti [1], *Prof. Francisco Cunha* [2], *Prof. Rafael Gontijo* [1]

1. University of Campinas, 2. University of Brasília

This work investigates the effects of an applied magnetic field on the laminar flow of a ferrofluid over a backward-facing step. Both constitutive equation and global magnetization equation for a ferrofluid are considered. The resulting formulation consists in a coupled magnetic-hydrodynamic problem. Computational simulations are carried out in order to explore the physics of the flow and the consistency of theoretical aspects of our formulation. The unidirectional sudden expansion in a ferrofluid flow is investigated numerically under the perspective of Ferrohydrodynamics in a two-dimensional domain using a Finite Volumes Method. The boundary layer detachment induced by the sudden expansion results in a recirculating zone, which has been extensively studied in purely hydrodynamic problems for a wide range of Reynolds numbers. Similar investigations can be found in literature regarding the sudden expansion under the Magnetohydrodynamics framework, but none considering a colloidal suspension of magnetic particles out of the superparamagnetic regime in the framework of Ferrohydrodynamics. The vorticity-stream function formulation is implemented. Our simulations show a clear coupling between the flow vorticity and the magnetization field. We observe a systematic decay on the length of the recirculation zone as we increase the magnetic parameters of the flow, such as the intensity of the applied field and the volume fraction of particles. The results are discussed from a physical perspective in terms of the dynamical non-dimensional parameters. We argue that the reduction of the recirculation region is a direct consequence of the magnetic torque balancing the action of the torque produced by viscous and inertial forces of the flow. For the limiting case of small Reynolds and magnetic Reynolds numbers, the diffusion of vorticity balances the diffusion of the magnetic torque on the flow. This mechanism controls the growth of the recirculation region.



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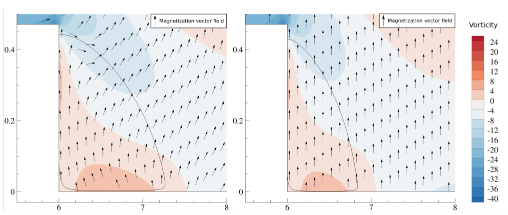

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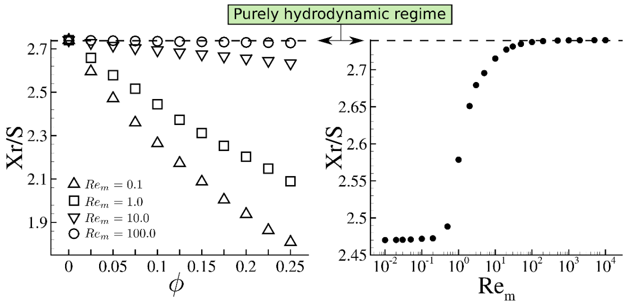

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New Magnetic Analysis to Investigate Properties of Physical Quantities on a Largely-Deformed Interface of Magnetic Fluid

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 340

Dr. Yo Mizuta [1]

1. *Department of Applied Physics, Faculty of Engineering, Hokkaido University*

Numerical analysis of magnetic fluid especially for fast dynamic phenomena such as the transition among interface profiles requires rigorous as well as efficient fluid and magnetic analysis even under largely-deformed interface profiles. The present research employs the Equation for Interface Motion (EIM) for the fluid analysis, and the Magnetic Analysis for General Use (MAGU) has been developed for the magnetic analysis. They were used to analyze some dynamic phenomena. Furthermore, validation of the results was argued from the standpoint of magnetic laws and energy conservation.

For comparing calculated results and improving the methods, we have developed another magnetic analysis based on the Indirect Boundary Element Method (IBEM), starting with Green's theorem, and unknown magnetic potential ϕ and normal magnetic flux b are obtained separately through the distribution σ of monopole on the boundary. Every boundary composing a two-layered domain of fluid and vacuum is divided into infinitesimal face elements (FE's) for area integral. For improving correctness, ϕ, b and $\sigma$are arranged on the vertex elements (VE's) among FE's instead of on the center of each FE, which requires proper treatment of multiple b's on the sharp edge where boundaries cross.

If the interface in the two-layered domain is flat, and a homogeneous vertical magnetic field is applied both on the top of the vacuum and the bottom of the fluid, then the same field is expected to appear on the interface. Fig_1 shows such magnetic field vector calculated as above. It was confirmed that ϕ and b are continuous across the interface, symmetric when rotated at a right angle, and almost homogeneous on the interface with the value applied on the top and the bottom. After these confirmations, the interface is deformed. Fig_2 shows the magnetic stress calculated from ϕ and b obtained as above, and Fig_3 is the mean curvature of the interface profile calculated by use of the interpolation method. They are essential quantities closely related with the magnetic stress difference and the surface tension, and interface phenomena of magnetic fluid can be understood from their properties. Other quantities for validation process are also ready for calculation.

Internal ferrohydrodynamics and magneto-solutal advection influenced evaporation dynamics of sessile droplets

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 345

Mr. Abhishek Kaushal [1], *Mr. VIVEK JAISWAL* [1], *Dr. Purbarun Dhar* [2]

1. Indian Institute of Technology Ropar, 2. IIT Ropar

Understanding the thermo-hydrodynamics and species transport behavior in microliter droplets has become a focused area of research in recent times owing to its importance in many industrial and bio-medical applications. Evaporation of microscale droplets has important applications in inkjet printing, hot-spot cooling, surface patterning, droplet-based microfluidics, painting, bio-sensing and DNA mapping. The present article reports the influential role of magnetic field ambience on the evaporation kinetics and internal hydrodynamics of paramagnetic sessile droplets. Experimental investigations and theoretical analyses were carried out to understand the modified evaporation dynamics under the applied external magnetic field. In this work, the main focus is on understanding the complex dynamics of multiphysics system that effects the evaporation process. Experiments were performed with three different paramagnetic salts dissolved in a polar fluid and by varying the applied external magnetic field. The change in geometric parameters of droplet such as contact angle, contact radius and droplet height has been observed over the period of time and enhancement in the evaporation rate has been found to hold a direct proportionality to the applied magnetic field strength. A magneto-thermo-solutal Marangoni and Rayleigh advection based mathematical formulation has been proposed. The internal circulation determined from particle image velocimetry (PIV) experiments is found to be in good agreement with the model predictions. The present study sheds insight into the role of magneto-solutal advection in the evaporation kinetics of sessile droplets.

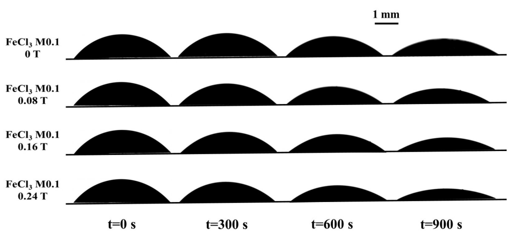

Fig.1: Time snaps of FeCl3 droplets (0.1 M) at different magnetic field strength.

Array.jpg

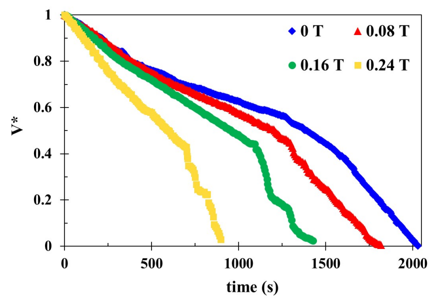

Fig.2: Temporal variation of V* (V*= the ratio of instantaneous volume (V) to the initial volume (V_0) of droplet of 0.1M $FeCl_3$) at different magnetic field strength.

Volume vs time.jpg

Stability of plane parallel flows of magnetic fluids

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 366

***Mr. Pavel Zenon Sejas Paz* [1], *Prof. Francisco Cunha* [2], *Prof. Yuri D Sobral* [1]**

***1.** University of Brasília - UnB, **2.** University of Brasília*

In this work, we present a study on the stability of a 2D plane Poiseuille flow of magnetic fluids in the presence of an applied magnetic field. The fluid is incompressible and the magnetization of the magnetic fluid is governed by Shliomis' equation. Dimensionless quantities are defined and the equations are perturbed around the equilibrium state. The eigenvalues of the linearised system are studied with respect to the dimensionless parameters of the problem. We obtain stability diagrams in terms of the dimensionless parameters (hydrodynamic and magnetic) and we find that the stability of the flow can change significantly when the magnetic effects become important, and that this change is strongly dependent on the direction of the applied magnetic field. Furthermore, we show that the superparamagnetic limit (\tau->0) recovers the same purely hydrodynamic stability criteria, regardless of the applied field and of the values of the other dimensionless magnetic parameters. Finally, we also study the inviscid (Re -> infinity) limit and we derive the equivalent Rayleigh criterion for magnetic fluids.

Computational Simulation of Fluid Flow Magnetic in Cavities

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 372

Prof. Camila Vieira [1], ***Prof. Yuri D Sobral*** [1], ***Prof. Francisco Cunha*** [1]

1. *University of Brasília - UnB*

In this work we study flows of magnetic fluids in a lid driven cavity. We propose a vorticity-stream function formulation to solve the flow using a finite differences scheme. The magnetization of the magnetic fluid is governed by Shliomis' equation and the magnetic fluid is considered as a weakly magnetizable media. Therefore, the magnetic field can be considered as permanent. We identified the main dimensionless physical parameters of the problem as the Reynolds number, magnetic pressure coefficient, magnetic relaxation time, saturation magnetization and the dimensionless intensity of the applied field. The magnetic field is generated by a conductive wire through which a permanent electric current passes. With this well-known geometry, we study the effects of each of the terms of the magnetization equation on the flow. We observed that the convective term of the magnetization equation carries magnetization in the flow causing changes in the local magnetization of the fluid in the steady state. The vorticity term intensifies angular deviations of magnetization and a correlation between the change of orientation of the magnetization and the signal of the vorticity was noticed. In order to obtain flows with more intense distributions of velocities and vorticity throughout the cavity, we studied several configurations of moving walls in the cavity. Significant changes were observed in the flow in the permanent regime in some cases. It was observed that for high values of the magnetic pressure coefficient, the steady state regime of the flow is not stationary.

Computer simulation of magnetic nanogels and their suspensions

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 375

Mr. Ivan Novikau* [1], *Ms. Elena Minina* [1], *Dr. Pedro A. Sanchez* [2], *Prof. Christos N. Likos* [1], *Dr. Sofia S. Kantorovich* [3]

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Colloidal gel particles are nowadays among the most interesting building blocks of magnetoresponsive materials due to the interesting properties they exhibit, derived from the combination of an internal semiflexible network structure and the magnetic response led by the inclusion of magnetic nanoparticles within such network. For instance, while keeping their overall particle structure, these soft materials are able to swell and shrink strongly, with changes of several times their average volume, and to change in the same proportion the amount of solvent and smaller particles or molecules they contain. Current experimental techniques allow their synthesis with characteristic sizes as small as tens of nanometers [1].

Recently, we introduced a minimal computer model of magnetic nanogels based on a coarse-grained representation of the polymer network, analyzing the effects of the concentration of magnetic nanoparticles and the fraction of polymer crosslinks on the structure and initial magnetic susceptibility of a nanogel particle [2]. Here we extend that preliminary study to the simulation of a monodisperse suspension of nanogels with ferromagnetic inclusions. We discuss the zero-field self-assembly properties and magnetic properties of this system depending on the concentration of nanogels and their magnetic content.

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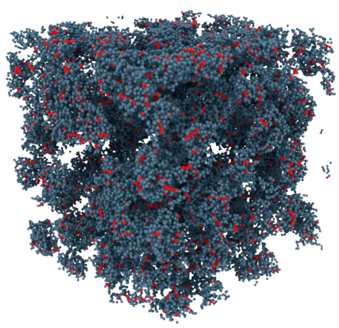

Snapshot of a suspension of magnetic nanogels.png

On the magnetization of a dilute suspension in a uniform magnetic field: influence of dipolar and hydrodynamic particle interactions

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 383

Mr. Gesse Roure [1], ***Prof. Francisco Ricardo Cunha*** [1]

1. *University of Brasília - UnB*

The lack of investigations that quantifies the magnetization of a dilute magnetic suspension undergoing a shear flow and a uniform field in the presence of dipolar and hydrodynamics interactions motivates this work. Firstly, the problem of a single magnetic particle in a simple shear flow in the presence of an external uniform magnetic filed is examined. From this solution, we study the influence of non-equilibrium effects on the magnetization at condition of strong flows, including the spinning behavior of the particles (figure 1). Secondly, we use a non-renormalized cluster expansion in order to derive the magnetization O(φ^2) in a sheared suspension of non-Brownian magnetic from a solution of a creeping flow problem of two magnetic spherical particles interacting magnetically and hydrodynamically in the presence of a uniform applied magnetic field, where φ is the particle volume fraction. The theoretical results suggest that under condition of strong flows the aggregative nature of the dipolar interactions cause a decreasing in the magnetization component in the field direction, thereby generating attractive force in the direction perpendicular do the field. In contrast, the dispersive character of the viscous hydrodynamic interactions produces a substantial increasing in the same component of magnetization even under condition of strong flow (figure 2). This is attributed to the misalignment produced by the hydrodynamic disturbances on the particle dipoles orientated with the flow direction.

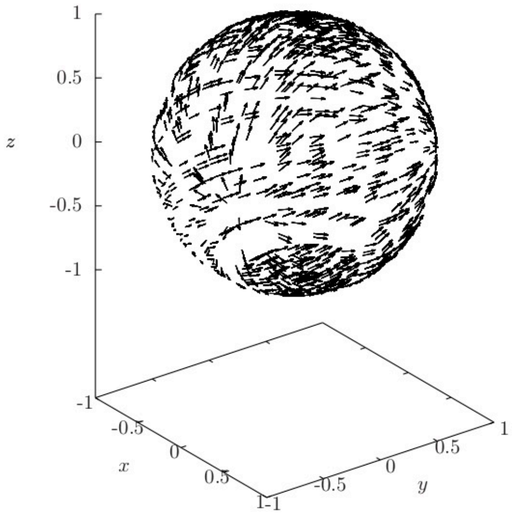

Fig1icmf.jpg

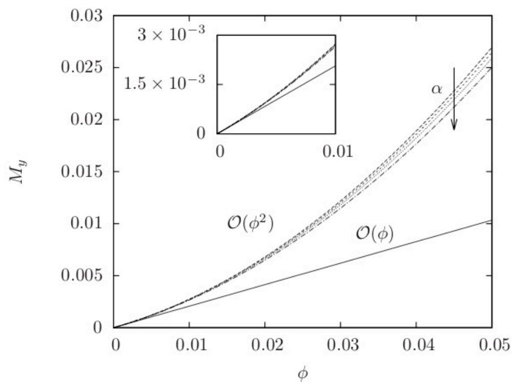

Fig2icmf.jpg

On out-of-fluid characterisation of magneto-mechanical response of topologically and magnetically diverse magnetic nanoscale filaments in applied fields.

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 387

Mr. Deniz Mostarac [1]***, Dr. Ekaterina Novak*** [2]***, Dr. Pedro A. Sanchez*** [2]***, Prof. Oleg Gang*** [3]***, Dr. Sofia S. Kantorovich*** [1]

1. University of Vienna, 2. Ural Federal University, 3. Columbia University

Construction of smart materials with sophisticated magnetic response by incorporating magnetic nanoparticles(NP's) within permanently cross-linked structures, opens up the possibility for synthesis of more complex, highly magneto-responsive systems.[1] Construction of appropriate magnetic filaments (MF's) (MF's polymer-like structures in which magnetic colloids are represented as monomers) has recently been made possible using DNA origami technology,[2,3,4] based on programmable DNA-NP assembly.(see Fig. 1) The principal aim of this novel technique is to create individual DNA-NP complexes with well-defined binding sites. Such an approach leverages the benefits of anisotropic and selective interactions, by fabricating enclosures for NP's with controllable (by means of DNA sequence encoding) binding vertices. These vertices determine the self-assembly of NP's, and finally, the geometry of the possible superstructures that the enclosures can hybridise into.

Characterisation of both mechanical and magnetic behaviour of magnetic filaments is needed in order to be able to utilise this new technology appropriately. Equilibrium properties, mobility and the magnetic response of MF's are, in part, determined by the topology of the filament, and the magnetic nature of the NP's. (see Fig. 2) Using MD simulations, we compare the mechanical and magnetic response of filaments, to static and rotating magnetic fields, for ferromagnetic and super-paramagnetic colloids within different crosslinking scenarios. Building up on our analysis of the projection of magnetic moments along the orientating magnetic field direction, on both the filament and colloid level, we contextualise the implications in terms of in-field magnetic susceptibility. We quantify the rotating applied magnetic filed induced motion of a filament, depending on the angular frequency and amplitude of the applied filed, with respect to magnetic nature of the NP's.

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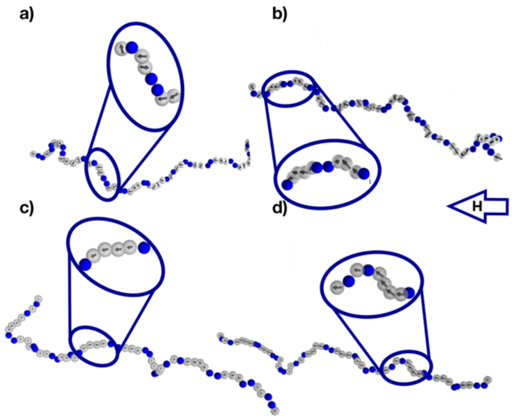

Fig. 2 magnetic nanoscale filament snapshots with ferromagnetic colloids for low (**a**) and high (**b**) dipole moment-magnetic field coupling, and filament with super-paramagnetic colloids in low (**c**) and high (**d**) dipole moment-magnetic field coupling scenarios. We highlight the difference in dipole moment orientation, magnitudes and orderings between the snapshots.

Fig 2 icmf.png

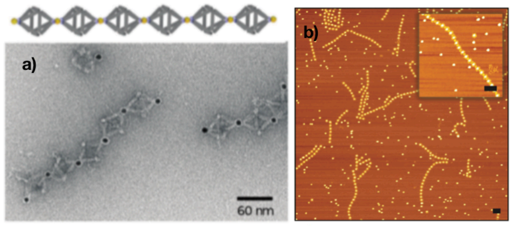

Fig. 1 crosslinking of enclosures with complementary binding sites. a) Negative stained TEM image of arrays of similarly encoded octahedra cages linked by particles.[4] b) AFM image of complementarily encoded cages, hybridised into linear arrays, with NP's embedded within the enclosures.[2]

Fig 1 icmf.png

Magnetorheological behaviour of particle-doped nematic liquid crystals

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 393

Ms. Josefine Jahn [1], ***Mr. Martin Hähsler*** [2], ***Ms. Karin Koch*** [3], ***Dr. Silke Behrens*** [2], ***Prof. Annette Schmidt*** [3], ***Prof. Stefan Odenbach*** [4]

1. *Chair of Magnetofluiddynamics, Measuring and Automation Technology, TU Dresden,* ***2.*** *Karlsruhe Institute of Technology,* ***3.*** *University of Cologne,* ***4.*** *Chair of Magnetofluiddynamics, Measuring and Automation Technology, TU Dresden, 01069 Dresden, Germany*

Liquid Crystals are materials, which have properties between conventional liquids and solid crystals. Caused by their bipolar chemical structure, the molecules interact among each other and build anisotropic structures depending on different conditions as temperature or concentration. The molecules dipole moment is also responsible for their alignment in magnetic fields. However, since the magnetic properties of liquid crystals are far weaker than the dielectric ones, strong magnetic fields are necessary for a controlled alignment of the molecules. Thus, the doping with magnetic particles opens up the possibility to control the molecules orientation at much lower magnetic fields. In this work, the magnetorheological behaviour of a composite of 4-cyano-4'-n-pentylbiphenyl (5CB) and $CoFe_2O_4$ nanoparticles was investigated. The nanoparticles were electrostatically stabilized and functionalized with (pro)mesogenic ligands to tune the interactions between the particles and the 5CB-host. The influence of these interactions on the rheological behaviour was focussed and experimentally investigated. Therefore, the viscosity of the pure and the particle-doped 5CB was measured in a rheometer at varying shear rates, temperatures and magnetic fields. The results show for both materials a lower viscosity in the nematic state (fig.1), which indicates a flow alignment of the nematic director, so the ordered molecules can easier slide of each other. Further, a decreased transition temperature due to the particles was measured and indicates a lower need for thermal energy for a distortion of the molecular ordering and a local destabilization of the nematic structure. As a next point, the measured viscosity increase is much higher than the theoretically expected one regarding the Einstein equations which is caused by a strong anchoring effect of the ligands in both, the nematic and the isotropic state. The investigations in magnetic fields (perpendicular to the flow direction) at different shear rates show a strongly pronounced magnetoviscous effect (MVE) and a shear thinning of the pure and doped 5CB (fig 2). This points out a magnetic alignment of the molecules, which interacts with the flow alignment. Additionally, a clear pronounced Frèedericksz transition threshold was detected. Financial support by DFG in the project DFG-SPP1681 is gratefully acknowledged.

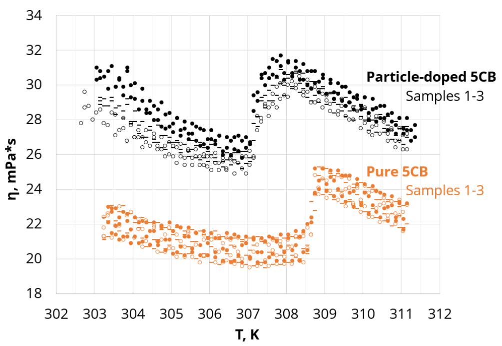

Figure 1 phase transition temperature of pure and particle-doped 5cb.png

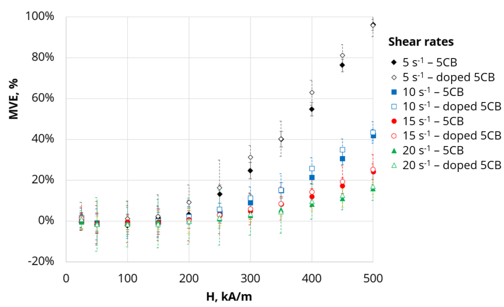

Figure 2 magnetoviscous effect of pure and particle-doped 5cb.png

Rotation of spherical hard magnetic particles inside polymeric matrix a magnetic hybrid elastomer

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 435

Dr. Gennady Stepanov [1], Dr. Dmitry Borin [2], Mr. Anthony Bakhtiiarov [3], Prof. Pavel Storozhenko [4]

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Magnetic hybrid elastomers (MHE) are intensively studied as materials perspective for designing controllable damping devices and acceleration sensors. Among their components, MHE contain magnetically hard and magnetically soft fillers dispersed in a polymer matrix. MGE was synthesized which contained a magnetically hard FeNdB filler (75% by weight) and soft magnetic Fe (25%) in a polymer silicone matrix. The total filler concentration was 32% by volume. In this series of experiments a magnetically hard filler with grain size 20-100 µm and coercive force 9000 Oe was used. In order to identify and determine the specifics of the magnetization of the elastomer, within the frames of the present study there were used MHE samples containing FeNdB as the only filler at a concentration of 78% by weight. The viscoelastic properties of MHE were controlled by variation of the ratio between components A and B of the silicone resin and by addition of silicone oil into the composition. The magnetic properties of magnetic hybrid elastomers have been investigated. It was shown that they have a coercive force less than the pure magnetic filler included in the magnetic elastomer. This was explained by the rotation of the magnetic particles inside the polymer matrix after magnetization.

On the Figs.1-2 show the dependence of the magnetic susceptibility for MGE with an average hardness - 400 kPa. The figures clearly show the processes of re-magnetization (arrow 2) and rotation (arrow 1) of particles in a polymer matrix. The processes of rotation and magnetization reversal are seen simultaneously, a consequence of the equality of the forces of rotation by the magnetic field and the elasticity of the polymer matrix. For a soft sample, the overall hysteresis curve has an asymmetric form. The arrows show the direction in which the magnetic field changes. The hysteresis curve depends on the direction of the change in the magnetic field.

Acknowledgments

This work is supported by the (DFG) and the (RFBR) within the projects DFG BO 3343/2-1 and RFBR 19-53-12039.

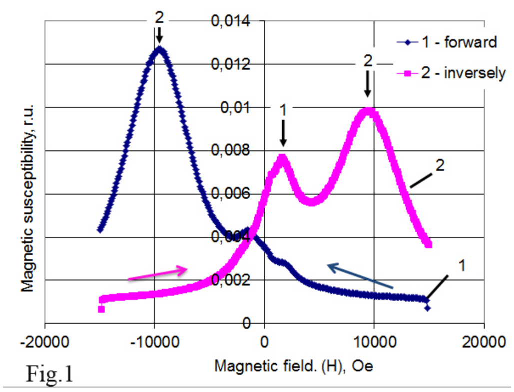

Fig.1.jpg

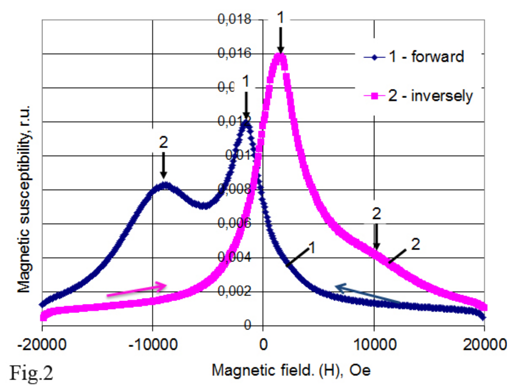

Fig.2.jpg

Elastic stress in ferrogels with chain aggregates

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 439

Mr. Anton Musikhin [1]***, Prof. Andrey Zubarev*** [1]***, Dr. Dmitry Chirikov*** [2]

1. *Ural Federal University,* ***2.*** *Ural Federal University named after the first President of Russia B.N. Yeltsin*

Ferrogels are modern smart materials, consisting of magnetic nano – or micron-sized magnetic particles distributed in a polymer matrix. Combination of the properties of polymer materials with a high response to the magnetic field offers great opportunities in the various high-tech areas, such as magnetically controlled dampers and shock absorbers, sensors, artificial muscles, scaffolds for growing of biological tissues and cell cultures. One of the most interesting features of these materials is their ability to change shape and rheological properties under the action of an external magnetic field. These magnetorheological effects have been studied in many experimental works; however lack of their theoretical analysis restrains progress in the field of study and application of these materials. We present a theoretical study of the influence of macroscopic shear and longitudinal deformations on stress in magnetic polymer composites in which magnetic particles form linear chains. Such systems are obtained when the sample is polymerized under the action of an external magnetic field. The magnetic field in this model is directed perpendicular to the shear and parallel to the tension. Our results show that the chains break at a certain value of the deformation. In this case, the full stress experiences a jump down. This effect is observed for both types of the deformation (Fig. 1).

Fig. 1. Shear stress (left) and tension (right) vs. magnitude of the strain.

In addition, our results on the longitudinal deformation quite well coincide with experimental data (see Fig. 2). Unfortunately, we have not found in literature the similar results for shear deformations to compare with our modelling.

Fig. 2. Elastic stress and results of measurements of [1] vs. the sample elongation.

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[1] C. Bellan, G. Bossis, *International Journal of Modern Physics B*, **16** (2002) 2447-2453.

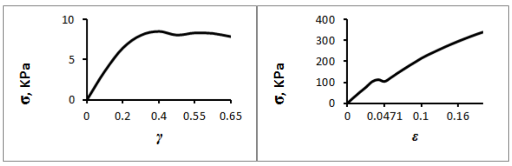

Fig. 1.png

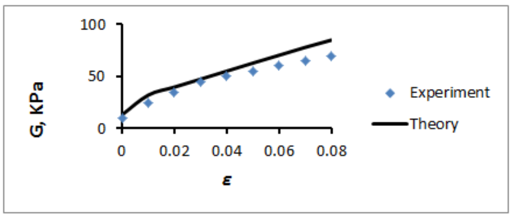

Fig. 2.png

Nanorheological investigations comparing different dynamic magnetic measurement methods

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 474

Ms. Hilke Remmer [1], *Ms. Tamara Kahmann* [1], *Mr. Sebastian Draack* [1], *Dr. Thilo Viereck* [1], *Prof. Meinhard Schilling* [1], *Prof. Frank Ludwig* [1]

1. TU Braunschweig

Magnetic nanoparticles (MNP) play an important role for many biomedical applications, such as homogeneous MNP-based bioassays or Magnetic Particle Imaging. The behaviour of the MNP depends not only on their properties like magnetic moment and hydrodynamic size but also on the properties of their embedding matrix, proposed that the MNP dynamics are influenced by Brownian relaxation. Thus, the MNP can also be used as probes for nanorheological investigations [1-3].
Here, we apply different measurement techniques (ac susceptibility (ACS), magnetorelaxometry (MRX) and Magnetic Particle Spectroscopy (MPS)) to study the MNP dynamics and to derive information on rheological properties of the medium. The diversity of setups allows us to investigate the dynamics of the MNP in a time range between µs (ACS) up to several seconds (MRX) and in a magnetic amplitude field range between a few hundred µT (ACS) up to 25 mT (MPS). As samples we use well-blocked Brownian particle as well as multicore particle systems, which show both Brownian and Néel relaxation. The MNP are suspended in different glycerol-water solutions as Newtonian system. The figure exemplarily depicts the imaginary parts of the ACS spectra measured on suspensions of the multicore particles FeraSpin™ XL. The peak at 100 kHz is independent of the viscosity change and caused by Néel relaxation, while the Brownian maximum continuously shifts with increasing viscosity to lower frequencies. The dashed lines show the fits with the generalized Debye model, providing viscosities in very good agreement with the theoretical expectations. Measurements of the same viscosity series with MPS show a very complex, non-monotonic behavior of the harmonics spectra, which can be understood when considering real and imaginary parts [4]. Experimental data will be compared to simulations. In addition, results measured on MNP in viscoelastic matrices (e.g. gelatin) will be presented.

Funding by the DFG via SPP1681 (LU 800/4-3 and VI 892/1-1) is acknowledged.

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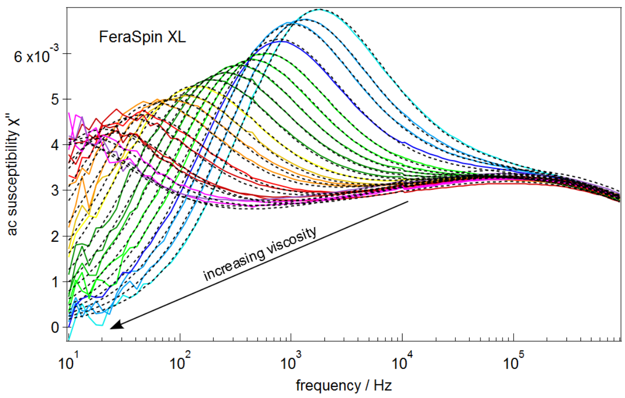

Imaginary part of acs spectra of feraspin xl for various viscosities.png

The initial magnetic susceptibility of high-concentrated, polydisperse ferrofluids: universal form

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 481

Dr. Anna Soloveva [1], ***Prof. Ekaterina Elfimova*** [1]

1. Federal State Autonomous Educational Institution of Higher Education «Ural Federal University named after the first President of Russia B.N.Yeltsin»

In this work we address the question of the universal theoretical expression of high initial magnetic susceptibility of concentrated ferrofluids. On the one hand, the second-order modified mean-field (MMF2) theory [1] proposes susceptibility as a virial series in powers of density, which is appropriate for describing of the monodisperse systems. On the other hand, the extended version of MMF2 theory (MMF2+) [2] good predicts Monte-Carlo simulation results for the polydisperse ferrofluids, but it doesn't work in monodisperse case. Here new theoretical approach has been developed for calculating of the initial magnetic susceptibility in a form of a fraction, whose expansion in a Maclaurin series over powers of density exactly coincides with the MMF2+ theory. The method is based on the Helmholtz free energy, which is re-summed in to logarithmic function.

The theoretical predictions have been tested rigorously against results from Monte Carlo simulations of monodisperse dipolar hard spheres fluids, and of polydisperse systems with broad particle-size distribution. It turns out that behavior of the new susceptibility formula is very close to the MMF2 theory for monodisperse systems; this allowed accurate to describe the simulation data. In the case of polydisperse systems, the new susceptibility expression approximates the MMF2+ theory and simulation data good enough. The new theoretical approach proves to be more reliable than virial constructions, which are very sensitive to the number of counted terms.

Moreover, the new susceptibility formula is able to predict the extremely high susceptibility measurements of dense magnetite ferrofluids at low temperatures [3]. It should be noted that none of the known theories previously could explain the record-breaking values of magnetic susceptibility [3] even with taking into account the volume compression of the carrier liquid under cooling and the temperature dependence of the saturation magnetization of the ferroparticle bulk material.

This work was supported by the Ministry of Education and Science of the Russian Federation [Contract No. 02.A03.21.0006 and Project No. 3.1438.2017/4.6].

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Modeling Magneto-Sensitive Elastomers: Approximation Strategies and Consequences

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 493

Dr. Dirk Romeis [1], ***Dr. Vladimir Toshchevikov*** [1], ***Dr. Marina Saphiannikova*** [1]

1. *Leibniz-Institute for Polymer Research Dresden*

Magneto-sensitive elastomers are field-controllable composite materials with magnetically switchable properties. They consist of a soft-elastic polymer network with immersed magnetizable micro-particles. Applying an external magnetic field, these composites can undergo large deformations. Describing this magneto-induced deformation represents a challenging task since the behavior strongly depends on initial conditions and assumptions. We will present an approximation scheme based on the dipole-dipole interaction model to describe the effects of different particle rearrangement mechanisms on the macroscopic deformation behavior. The presented formalism allows a simplified qualitative analysis of magneto-induced deformation and helps to reveal some fundamental relations governing the mechanical properties of magneto-sensitive elastomers.

Magnetic properties of magnetoactive elastomers

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 519

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Magnetoactive elastomers are the systems consisting of magnetic particles distributed in a nonmagnetic elastic matrix. We consider different models of magnetoactive elastomers using Molecular Dynamics Simulations. One of them is the system consisting of magnetic particles which have a shape like a “flake”. We take into account the shape anisotropy of magnetic particles in such a system. In the Fig. 1 you can see a basic model for flake-like particles, when a magnetic particle is surrounded by non-magnetic ones. In order to introduce the elastic interactions, we consider fixed nonmagnetic particles which are connected with flake-like particles by harmonic springs (classical harmonic interaction). We use four springs for each flake-like particle with different rigidities. We use the soft package ESPResSo to perform computer simulations: we have Langevin dynamics and periodic boundary conditions. We consider systems with different harmonic spring rigidities and magnetic moments of dipolar particles.

We use the FORCs (first-order reversal curves) diagrams to study how the matrix influences internal magnetic interactions. In order to plot the FORCs distribution we use a classical method [C. R. Pike et al., J. Appl. Phys. 85, 6660 (1999)]. We can use this method during study of the magnetic elastomers without known microstructure. When it is no data about a microstructure in experiments, the FORCs diagrams can provide some information about it. It is convenient to use the FORCs method in computer simulations because we can find the correspondence between obtained diagram and microstructure implicitly. This is impossible to do during the experiment.

The research was supported by RSF (project No. 19-12-00209).

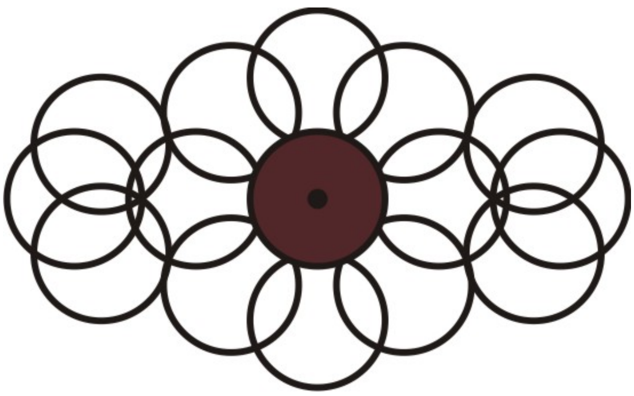

Fig. 1 - flake.jpg

Constitutive Modeling of Magneto-Sensitive Elastomers

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 569

Mr. Sanket Chougale [1]***, Dr. Dirk Romeis*** [1]***, Dr. Marina Saphiannikova*** [1]

1. *Leibniz-Institute for Polymer Research Dresden*

Magneto-sensitive elastomers (MSEs), also known as magneto-rheological elastomers, belong to a class of field-controllable materials with magnetically switchable properties. MSEs are polymer composites consisting of micron-sized magnetic particles dispersed within an elastomer matrix. In the presence of an external magnetic field the induced magnetic interactions and the corresponding particle rearrangements change the mechanical properties substantially. Additionally, these rearrangements can steer changes in the macroscopic shape of the sample, known as the magneto-deformation effect. The application of the magnetic field also introduces a field-dependent anisotropy with an axis of symmetry along the direction of the field. Thus, in the presence of a magnetic field we may assume that MSEs can be modelled as a transversely isotropic material. Based on this hypothesis we aim to derive an effective material model from the magnetic energy of MSE composites in the dipole approximation. Here, we will present some of our preliminary results in developing a constitutive equation for MSEs. For this purpose uniaxial deformations are considered in longitudinal as well as in transverse direction to the applied field and we compare the anisotropic contributions to the stress due to the magnetic interactions with existing predictions for transverse isotropic materials.

Steady states of non-axial dipolar rods driven by rotating fields

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 580

Dr. Jorge Domingos [1], Mr. Everton de Freitas [1], Prof. Wandemberg Ferreira [1]

1. Federal University of Ceará - UFC

A two-dimensional system of magnetic colloids with anisotropic geometry (rods) subjected to an oscillating external magnetic field is studied in this work. Specifically, the structural and dynamical properties of the steady states are analyzed as a function of the misalignment of the intrinsic magnetic dipole moment of the rods with respect to their axial direction, and also as a function of the intensity and frequency of oscillation of the external magnetic field. The system is studied by means of Langevin Dynamics simulations. The misalignment of the dipole, relative to their axial direction, is inspired by recent experimental and theoretical studies, and this fact is relevant in the microscopic aggregation states of the system (Fig.1). The dynamical response of the magnetic rods to the external magnetic field is strongly affected as a function of such a characteristic (Fig.2). Regarding the synchronization between the direction of the dipole of magnetic colloids and the direction of the external magnetic field, it is observed that its magnitude as well as the frequency of oscillation are important parameters, which define very distinct regimes of synchronization. We observed three different well-defined phases (Fig.3) depending on how synchronized the system are with the external field. A set of steady states diagrams are presented, showing which magnitude and frequency ranges the different self-organized structures observed (Fig.4).

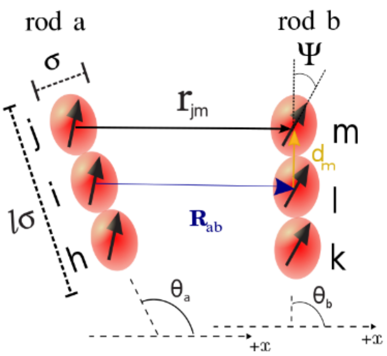

FIG. 1: Schematic illustration of the interaction between two magnetic rods with indication of the important parameters of the pair interaction potential.

Fig1.png

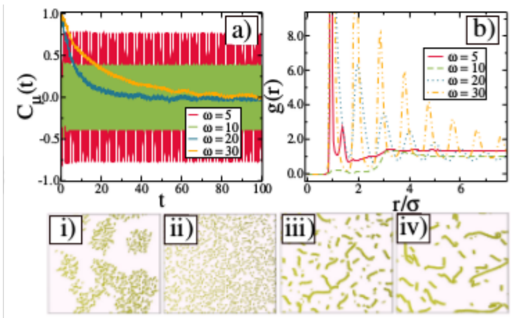

FIG. 2 : Characterization of $\Psi = 60°$ phases for $B = 20$ for different ω. (a) Dipole-dipole autocorrelation function. (b) Pair correlation function. (i)-(iv) Steady states: (i) $\omega = 5$; (ii) $\omega = 10$; (iii) $\omega = 20$; (iv)$\omega = 30$.

Fig2.png

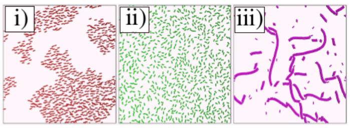

FIG. 3 : Examples of different phases observed: (i) Dynamical aggregate; (ii) Isotropic fluid; (iii) Clustered fluid.

Fig3.png

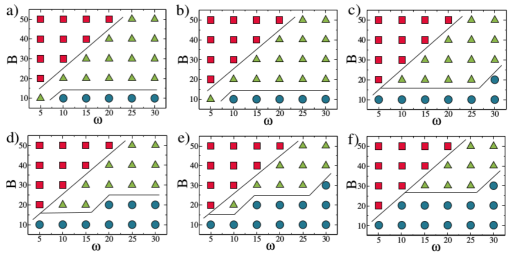

FIG.4 : Steady state diagram illustrating the self-organized structures as a function of the intensity B and the frequency ω of the external magnetic field for different values of misalignment: (a) $\Psi = 15°$; (b) $\Psi = 30°$; (c) $\Psi = 45°$; d) $\Psi = 60°$; (e) $\Psi = 75°$; (f) $\Psi = 90°$. Symbols represent different phases: □ Dynamic aggregate, △ Isotropic fluid, ◯ Clustered fluid. The solid lines are guides to separate the regions of different phases.

Fig4.png

An alternative way to study magnetic fluid magnetization and viscosity

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 583

Dr. Petr Ryapolov [1], **Dr. Vyscheslav Polunin** [1], **Mrs. Elena Shel'deshova** [1]

1. Southwest State University, Kursk, Russia

To carry out complex measurements of the elasto-magnetic parameters of a magnetic fluid (MF) column in a strong magnetic field – the frequency of the oscillations, the displacement of the liquid when pressure is applied as well as measuring the magnetization and viscosity of MF samples – two different experimental setups were created and described in [1].

A concentration series of MFs based on kerosene was studied. The concentrations of MF-1□MF-3 samples are 10.56%, 6.32%, 3.93%, respectively. Figure 1 presents experimental data for the magnetization curves in the 3–750 kA/m intensity range and calculated data obtained from the model theory for the 200–800 kA/m intensity range. The values of the magnetostatic magnetizationM_{xs}, shown in Figure 1 by squares, are calculated by formula (7) in [1]. To obtain M_{xs}, an array of experimental data is used to measure the gradient of the magnetic field intensity at the base of the MF column and static measurements of the displacement of the MF column under pressure. The magnetodynamic magnetization M_{xd} is calculated by formula (20) in [1] using the results of measuring the oscillation frequency of the MF column. These data are shown in Figure 1 by triangles. Experimental results of direct measurement of magnetization (magnetization curve) of the objects under study are plotted with lines.

The values of magnetization shown in Figure 1, obtained by the method of 'direct' determination and calculated according to the data of static and dynamic experiments for MF-1□MF-3 samples are in good agreement.

The viscosity of the samples is calculated by the formula (18) proposed in [2]. To reduce the magnitude of the errors, the new method was used based on the approximation of the coefficients in formula (18). The dependencies of viscosity on the field are presented in Figure 2. The horizontal line shows the viscosity obtained on a rotational viscometer.

This work was supported by the project part of the state assignment of the Ministry of Education and Science № 3.2751.2017/PP.

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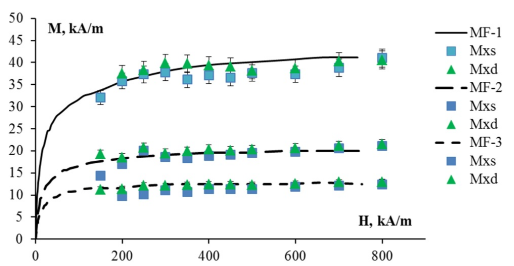


Figure 1

Figure 1.jpg

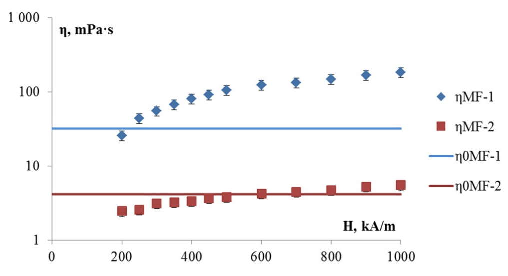


Figure 2

Figure 2.jpg

Direct Numerical Simulation of Magnetic-Fluid Flows with interfaces: Deformation of a Magnetic Droplet

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 590

Mr. Vincent Bianco [1], ***Prof. Ruben Scardovelli*** [2], ***Prof. David Trubatch*** [3], ***Prof. Philip Yecko*** [1]

1. Cooper Union, 2. University of Bologna, 3. Montclair State University

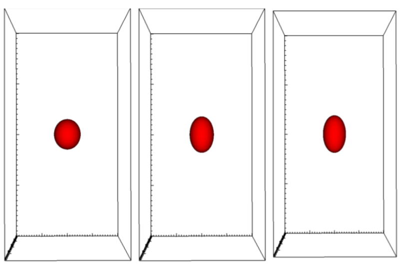
The MAG-PARIS Code provides a platform for simulation of flow dynamics in a fluid system with a magnetizable fluid that is driven by an applied magnetic field. MAG-PARIS is developed from the Parallel Robust Interface Simulator (PARIS) code, which allows simulations of systems with interfaces between two fluids, and also systems with a free fluid-air boundary.

MAG-PARIS uses single-fluid implementation of the incompressible Navier-Stokes equations, with a color function to account for the relative proportion of the two fluids (with different magnetic properties) in each fixed-size, cubic, computational cell. A staggered grid for fluid velocities provides high accuracy in the conservation of mass for each fluid, which is particularly important in some applications, including magnetic drug targeting. Local curvature of interfaces, which drives surface-tension, is computed by a height function.

Particular to MAG-PARIS is the solution of the quasi-static magnetic field at each time step. The Laplace equation for the magnetic potential is solved with prescribed boundary conditions and a spatially varying magnetic susceptibility (determined by the spatial distribution of the magnetizeable fluid), which is variable in time.

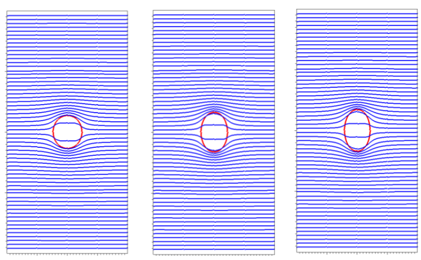
In the code, magnetic forces act in 'cut' cells that contain a boundary between the two fluids. Consistent with the computation of the surface-tension force, the local surface normal (the direction in which the magnetic force acts) is computed via a discrete gradient of the color function. The force is proportional to the difference in magnetic susceptibility across the interface and the squared magnitude of the local magnetic field (Korteweg-Helmholtz formulation of the force density).

As a test case, we simulate deformation of a droplet of magnetic fluid under an imposed, spatially uniform magnetic field. The magnetic field is distorted by magnetization of the drop, but spatially uniform at the edges of the computational grid due to the boundary conditions. Starting from a spherical initial condition, the droplet elongates in the direction of the imposed field and reaches an equilibrium shape. In simulations, we obtain equilibrium shapes consistent with theoretical predictions and experimental results.



simulation of deformation of a droplet of ferrofluid (magnetic susceptibility: 15, volume: 98 microliter) in a uniform vertical magnetic field (150 A/m); time series of approach to equilibrium shape from spherical initial condition

Droplet deformation.png



simulation of deformation of a droplet of ferrofluid (magnetic susceptibility: 15, volume: 98 microliter) in a uniform vertical magnetic field (150 A/m); cross-sections showing: (i) outline of the droplet and (ii) level curves of the magnetic potential

Droplet deformation field.png

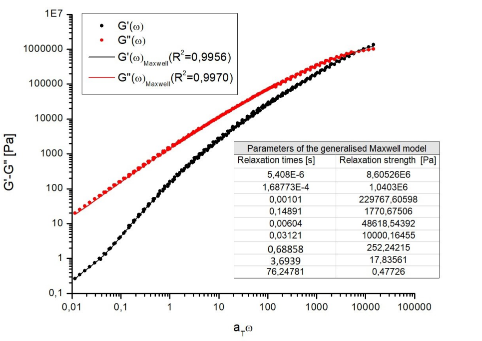
Rheological modifications of a heavy crude oil in the presence of magnetic additives and uniform magnetic field

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 607

Ms. Maria Daniela Contreras-Mateus [1], ***Prof. Arlex Chaves-Guerrero*** [1], ***Prof. Emiliano Ariza-León*** [2], ***Prof. Modesto T Lopez-Lopez*** [3]

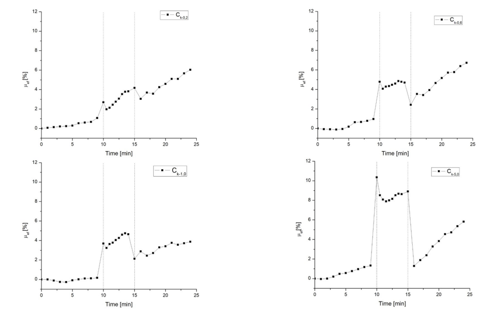
1. Escuela de Ingeniería Química, Universidad Industrial de Santander-UIS, 2. Escuela de Ingeniería de Petróleos, Universidad Industrial de Santander-UIS, 3. Departamento de Física Aplicada, Facultad de Ciencias, Universidad de Granada

Heavy crude oils are viscoelastic colloidal suspensions whose dispersed elastic phase is attributed to asphaltene aggregation mechanisms over a semi-continuous viscoelastic matrix of maltenes (saturates, aromatics and resins). Under certain thermodynamic conditions, these components are prone to self-associate and to precipitate, which result in dramatic increases in viscosity and non-Newtonian rheological behavior. The aim of the present research was to evaluate an improved magnetic technology to decrease the high viscosity and viscoelasticity by acting on the aggregation mechanisms; to accomplish this, mixtures of heavy crude oil and ferrofluid (Ferrotec's EMG 1300 dry magnetic nanoparticles suspended in kerosene) were exposed to an external magnetic field (MF). From the rheological characterization, master curves were built applying the time-temperature superposition principle to evaluate the mechanical response of the material (-5 °C-60 °C) and then to model its behavior, employing the Generalised Maxwell Equation. It was observed that this model fits the experimental data (R^2~0.990). From the relaxation spectrum, it was verified that the structural organization of the material is coordinated by asphaltene aggregates (>10 wt%), which are responsible for the 95-99% increase of viscosity, as well as the elastic character. Based on these results, the crude oil was diluted in ferrofluid achieving reductions of both viscosity (~94%, 35% by nanoparticles at 0.2 wt%) and dynamic moduli. Additionally, it was designed a characterization methodology employing a uniform static MF in two configurations: 1) a magneto-rheometer (MCR 302 Physica-Anton Paar) and 2) a flowline system in laboratory-scale. In the magneto-rheometer, it was observed a magnetoviscous effect, which was potentiated with the increasing mass concentration of magnetic nanoparticles in the ferrofluid (0.2%; 0.6%; 1.0%; 5.0%). Likewise, it was proved that the crude oil-ferrofluid mixtures follow the bi-dispersed model, in which a small fraction of large particles (>16 nm) form chains determining the field-dependent changes of viscosity, in spite of the magnitude of the viscous forces that contribute to hinder those interactions. On the other side, in the flowline system with a uniform diametral magnetic field device, an increase in the volumetric flow rate of 35% was observed, as proved by Tao and Huang (2011).



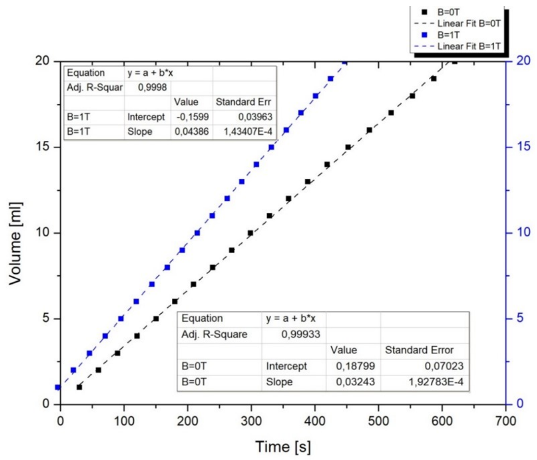
Master curve of dynamic moduli of a heavy crude oil *versus* reduced frequency at the reference temperature of 30 °C. The lines show fits of the generalised Maxwell model.

Master curve.jpg



Viscosity of mixtures of heavy crude oil and ferrofluid (0.2%; 0.6%; 1.0%; 5.0% concentration of magnetic nanoparticles) *versus* time. Shear rate: 25s⁻¹. Region I: magnetic flux density B=0, region II: magnetic flux density B= 0.6473 T and region III: magnetic flux density B=0.

Viscosity versus time.jpg



Volumetric flow of a mixture of heavy crude oil and ferrofluid (2.5% of magnetic nanoparticles) in a flowline system in the absence and presence of a uniform diametral magnetic field (B=1T).

Volumetric flow.jpg

Self-Assembly in Charged Magnetic Discs: a Computer Simulation Study

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 625

Ms. Margaret Rosenberg [1], ***Dr. Sofia S. Kantorovich*** [2]

1. University of Vienna, 2. University of Vienna, Vienna, Austria and Ural Federal University, Ekaterinburg Russia

In the last decades, a new branch of science called magnetic soft matter (MSM) has emerged and rapidly developed, spurred on by advances in synthesis techniques. These gave rise to the availability of magnetic particles of a wide variety of shapes, including cubes [1,2], ellipsoids and rods [3,4]. Such colloids are of particular interest as it has become clear that colloidal anisometry can be used as an effective control parameter to tune both self-assembly scenarios and thermodynamic, rheological and phase behavior of dipolar (magnetic) soft matter [5].

In this work, we present our first results on the study of charged magnetic discs. We employ molecular dynamics simulations, using ESPResSo [6]. Our discs are composed of a number of soft charged spheres, where the central particle in a disc possesses a magnetic moment of a constant length, permanently oriented perpendicular to the disc surface. In order to investigate the self-assembly and structural properties of the discs we vary the amplitude of an applied magnetic field, the magnetic dipole and the disc volume fraction. Furthermore, we analyze at which electrostatic conditions the system exhibits self-assembly or/and field alignment, based on cluster analysis, RDFs and structure factors calculated parallel and perpendicular to the field.

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Stability of a Column of Ferrofluid Centred around a Rigid Wire

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 635

Ms. Sarah Ferguson Briggs [1]

1. *Imperial College London*

The stability of a ferrofluid centred on a rigid wire is investigated in a fully three-dimensional setting. An electric current runs through the wire, generating an azimuthal magnetic field. The stability of the system at zero Reynolds number is explored by solving Stokes equations. We consider an inner and outer ferrofluid with different magnetic susceptibilities, producing a magnetic stress at the interface of the fluids. When the inner fluid has a larger magnetic susceptibility, the system is linearly unstable to axisymmetric perturbations only, and is stabilised by a sufficiently large magnetic field. When the outer fluid has a larger magnetic susceptibility, we find the system is unstable to axisymmetric and non-axisymmetric modes. Then, considering solely one column of ferrofluid, whose magnetic susceptibility varies radially, we produce a stability condition for the axisymmetric system, valid both in the highly viscous and inviscid limits.

Shock waves and other types of dynamics in a one-dimensional ferrogel model

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 642

Dr. Segun Goh [1], ***Dr. Andreas M. Menzel*** [1], ***Prof. Hartmut Löwen*** [1]

1. Heinrich-Heine-Universität Düsseldorf

Interactions between magnetic particles and a surrounding polymeric matrix alter the physical properties of magneto-elastic composite materials [1]. This type of behavior is characteristic for ferrogels or magnetorheological elastomers, in which the elastic properties of the gel matrix and the rearrangement of the magnetic particles are significantly coupled to each other. For example, changes in the elastic moduli of almost an order of magnitude can be induced by external magnetic fields [2]. As an extreme event, the reversible collapse of initially well-separated particles to a state of virtual touching of the particles has been observed under strong mutual magnetic attraction [3].

We investigate the dynamics of such touching and reseparation events of magnetic particles in ferrogels employing a one-dimensional minimal model. Spherical particles carrying induced magnetic dipole moments are connected by harmonic springs and aligned in a straight configuration [4]. Our continuum theory and explicit simulations reveal a possible bistability in the energy landscape and various different associated dynamic scenarios. Depending on the initial conditions, the dynamic processes can take the particles from the separated to the touching state and vice versa, also inhomogeneously along the system. Especially, although our particle dynamics is overdamped, we reveal that the long-time relaxation dynamics can be governed by a shock-wave-type propagation of interfaces between condensed clusters and regions of separated particles. Other dynamic processes comprise simple relaxation dynamics, pair formation, or shock-wave dynamics of particle pairs.

In the future, we aim at combining our dynamical characterization with recently developed statistical means [5] in terms of dynamical density functional theory.

Acknowledgments

This work was supported by the German Research Foundation (DFG) through the SPP 1681 on magnetic hybrid materials.

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Scale Dependence of Ni Nanorod Oscillatory Rotation Dynamics in Poly(ethylene oxide) Solutions

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 312

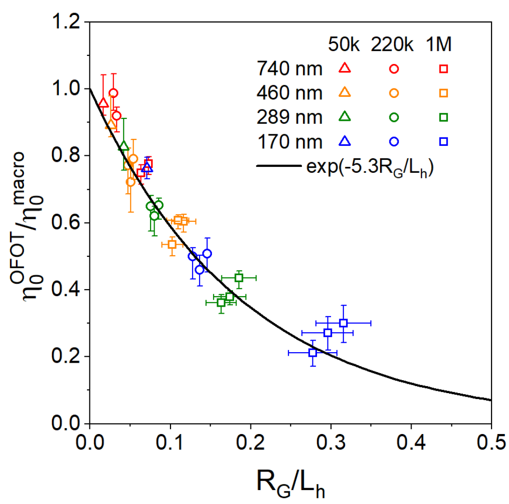
Mr. Micha Gratz [1], ***Dr. Andreas Tschöpe*** [1]

1. *Saarland University*

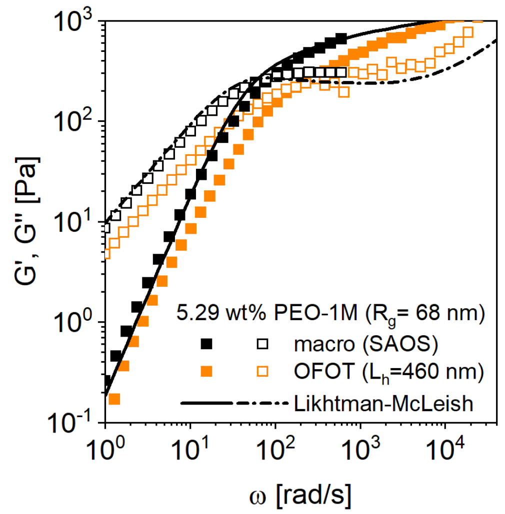
In microrheology, the motion of colloidal particles is analyzed in order to retrieve the viscoelastic properties of the medium in which they are dispersed. When applied to complex soft matter, the size of the tracer particle is an important aspect. Sufficiently large colloidal probes sense their environment as a homogeneous continuum with the macroscopic properties. Below a critical size, however, the structural inhomogeneity is resolved and the particle motion reflects local properties.

The present study focuses on the size scale effect in the rotational dynamics of Ni nanorods dispersed in poly(ethylene oxide) solutions. The nanorods were synthesized by the anodized aluminum oxide (AAO) template method. The collinear ferromagnetic and optical anisotropy of the nanorods enables optical detection of their rotation when exposed to an oscillating magnetic field. The molecular weight and solution concentration of the macromolecules were used as control parameters to access to a wide range of structural length scales in the nm-regime with an associated broad spectrum of stress relaxation times. Variation of the probe size was achieved by using colloids of Ni nanorods with different rod length. The apparent local dynamic modulus, derived from oscillating-field optical transmission (OFOT) spectra, was compared with results from macroscopic reference measurements of the polymer solutions.

In semi-dilute solutions, the local zero-shear rate viscosity was reduced as compared to the macroscopic values. The relative viscosity decreased exponentially with the ratio R_g/L_h, i.e. the polymer radius of gyration divided by the nanorod hydrodynamic length, but was independent of concentration in the entanglement regime. The latter result suggested that correlation length and Edwards tube segment length are of minor importance at the given nanorod length scales. The local dynamic modulus, measured with nanorods at $R_g/L_h \approx 0.15$, was in reasonable agreement with reference data from small amplitude oscillatory shear (SAOS) measurements and calculated spectra based on the Likhtman-McLeish model. With decreasing length of the nanorods, the contribution of entanglements to the local viscoelastic properties decreased.



Zero shear viscosity scaling.png



Dynamic modulus.png

Investigation of some thermal parameters of ferrofluids in the presence of a static magnetic field

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 241

Prof. Madalin Bunoiu [1]***, Mrs. Georgeta Matu*** [1]***, Prof. Catalin Nicolae Marin*** [2]***, Prof. Iosif Malaescu*** [1]

1. *West University of Timisoara, Faculty of Physics,* ***2.*** *West University of Timisoara*

Based on the conventional thermal conduction method [1], we have measured the effective thermal conductivity, k_{eff}, for a ferrofluid sample with magnetite particle dispersed in kerosene and stabilized with oleic acid, having the saturation magnetization $M_{sat}=33$ *kA/m*, the density $\rho_F=1210$ *kg/m*^{3} and the volume fraction,$\varphi=10.3\%$. The measurements were made in the presence of a static magnetic field H, ranging between (0 - 100) kA/m. The results show that in zero polarizing field, k_{eff} of the sample increases by 31% in comparison with the thermal conductivity of the carrier liquid k_F, (kerosene) and increasing further by the growth of the applied static magnetic field (figure 1). The obtained experimental results for k_{eff} of the ferrofluid sample in zero polarizing field were compared to the computed values of k_{eff} using some theoretical models [2] for the thermal conductivity (figure 2).

Furthermore, we have computed other thermal parameters of the ferrofluid sample, such as: the magnetic specific heat (C_M) and the effective diffusivity of the ferofluid (D_{eff}) both in the absence and presence of the applied static magnetic field [3]. In Table 1, the values obtained for thermal parameters k_{eff}, C_M and D_{eff} of ferrofluid sample, both in zero magnetic field and for two values of H are listed.

The results have a special practical importance suggesting that the investigated ferrofluid may be potential candidate for the incorporation into the heat transfer devices and other thermal applications.

Acknowledgments.*This work was supported by a grant of the Romanian Ministry of Research and Innovation, CCDI-UEFISCDI, project number PN-III-P1-1.2-PCCDI-2017-0871/47PCCDI/2018-2020, within PNCDI III.*

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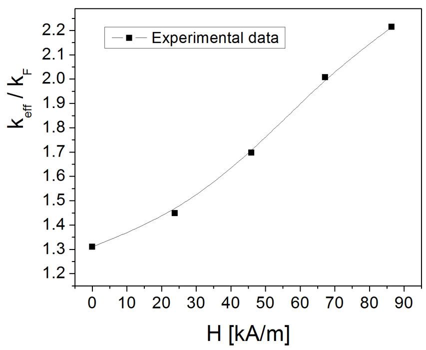

Figure1.jpg

Table 1. The obtained values of the thermal parameters

Thermal parameter	Applied magnetic field		
	H=0	H=46 kA/m	H=86 kA/m
k_{eff} [W/K.m]	0.191	0.246	0.321
C_M [J/kg.K]	0	0.00996	0.03514
10^7 x D_{eff} [m^2/s]	0.82	1.06	1.39

Table1.jpg

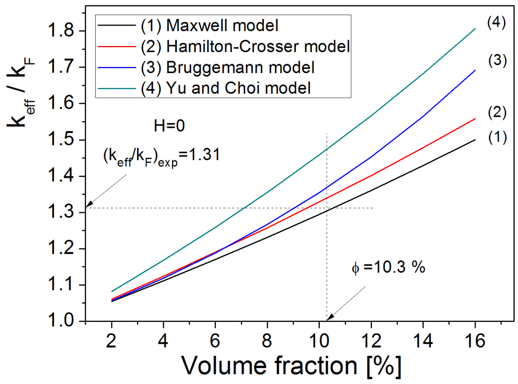
(1) Maxwell model
(2) Hamilton-Crosser model
(3) Bruggemann model
(4) Yu and Choi model
H=0
$(k_{eff}/k_F)_{exp}$=1.31
ϕ =10.3 %
(4)
(3)
(2)
(1)
k_{eff} / k_F
Volume fraction [%]

Figure 2.jpg

Effect of magnetic nanoparticles on partial discharges in transformer oil

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 322

Dr. Juraj Kurimský [1]***, Dr. Michal Rajnak*** [2]***, Prof. Roman Cimbala*** [1]***, Mr. Jakub Rajnič*** [1]***, Dr. Milan Timko*** [2]***, Dr. Peter Kopcansky*** [2]

1. *Faculty of Electrical Engineering and Informatics, Technical University of Košice, Letná 9, 04200 Košice,* ***2.*** *Institute of Experimental Physics SAS, Watsonova 47, 04001 Kosice*

Dispersions of superparamagnetic iron oxide nanoparticles (SPION) in transformer oils can exhibit enhanced insulating properties as compared to pure transformer oils. The increased breakdown voltage of various magnetic nanofluids has been proven by numerous researchers. However, partial discharges (PD) in such magnetic nanofluids have been reported rarely. Herein, we report on an experimental study of PD in transformer oil with four different volume concentrations of SPION (from 0 to 0.0008 vol%). To observe the PD, a specific high-voltage setup was designed. Thanks to the small amount of SPION in the oil (transparency), the PD events in the form of visible corona discharges were visualized by a CCD camera. Furthermore, the PD inception and extinction voltage, apparent charge and quantities derived from the PD recurrence, as pulse repetition rate and phase resolved patterns, were analyzed in dependence on SPION concentration. Even though weak concentrations, it was found that the PD inception voltage increases quasi linearly with increasing SPION concentration but the extinction voltage is practically unaffected. The pulse repetition rate is decreased as a result of the increasing SPION concentration. The decreased PD activity is clearly concluded also from the reducing shape and growth of the visual corona discharge patterns. To interpret the observed suppression of PD in transformer oil-based magnetic nanofluids, the injected charge trapping on the dispersed nanoparticles is considered. Moreover, a possible effect of the local magnetic fields around the SPION on the space charge migration is taken into account, too.

Ellipsometry of magnetic fluid in a magnetic field

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 549

Prof. Constantine Yerin [1]***, Mrs. Victoria Vivchar*** [1]

1. *North Caucasus Federal University*

Under the action of electric or magnetic fields in magnetic fluids a some of optical effects can be detected. Optical effects in transmitted light such as birefringence and dichroism are known. The magneto-optical effect in reflected light such as magneto-optical Kerr effect (MOKE) remains relatively poorly studied. In this paper, we present an ellipsometric study of MOKE in reflected light in a kerosene based magnetic fluid with magnetite nanoparticles. We investigate the sample with a volume concentration of 0.1%. Sample is produced by Scientific-Technology Company “Magnetic Fluids”, Naro-Fominsk, Russia. For research, we used the spectral ellipsometer Ellipse-1891. The magnetic field was created by an electromagnet and was perpendicular to the plane of the incident and reflected rays. In a magnetic field, the surface of a magnetic fluid is not horizontal and this hinders the study of reflected light. To prevent this effect, the sample cuvette was covered with an equilateral glass prism. The angle of incidence of light on the surface of the magnetic fluid was 60 degrees. Ellipsometry measures two parameters: the amplitude component Ψ and the phase difference Δ. The polarization state of the light incident upon the sample may be decomposed into an s- and a p- component (the s- component is oscillating perpendicular to the plane of incidence and parallel to the sample surface, and the p- component is oscillating parallel to the plane of incidence). The reflection coefficients of the s- and p- components of light are denoted by R_s and R_p, respectively. The change in ellipsometric parameters Ψ and Δ under the action of magnetic field was measured. Fig. 1 shows the spectral dependence of changes in parameters in the wavelength range 400-1000 nanometers. The field dependence of the amplitude parameter change $\delta\Psi=\Psi_H - \Psi_0$ at magnetic field strength *H* about 100 Oe in fig. 2 are shown.

The influence of a magnetic field on a magnetic fluid leads to a change in the ellipsometric parameters of light reflected. Field dependence of the amplitude parameter change δΨ(H) is non-linear.

Acknowledgments

Support by Russian Foundation for Basic Researches (project No. 18-03-00279a).

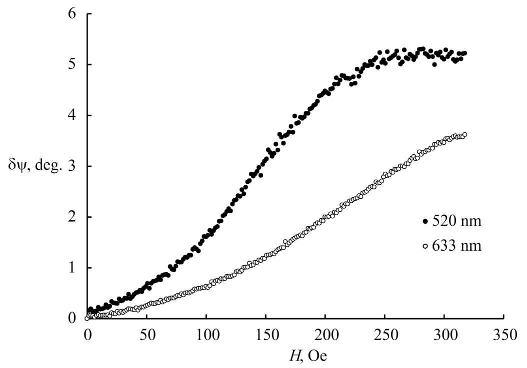

Fig-1.jpg

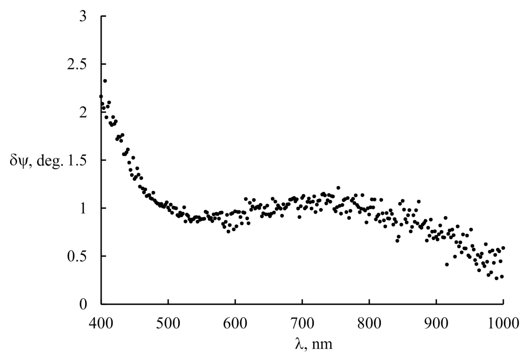

Fig-2.jpg

Investigation of Structural Changes in Oil-based Magnetic Fluids by Surface Acoustic Waves

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 270

Prof. Peter Bury [1], Dr. Jozef Kudelcik [2], Mr. František Černobila [1], Dr. Marek Veveričík [1], Dr. Stefan Hardon [2], Dr. Peter Kopcansky [3], Dr. Milan Timko [4], Dr. Michal Rajnak [4], Dr. Katarína Pavlovičová [5]

***1.** Žilina University, Department of Physics, **2.** University of Zilina, **3.** institute of e, **4.** Institute of Experimental Physics, **5.** Institute of Experimental Physics, Slovak Academy of Sciences*

Surface acoustic waves (SAWs) are used first time to study structural changes in transformer oil–based magnetic fluids under magnetic fields. The measurement of the attenuation of SAW propagating along magnetic fluid is showed, analogous to the case of liquid crystals [1], as an effective tool to study such processes in the cases when the obviously utilized longitudinal acoustic waves [2] are not available. The magnetic particles $FeO.Fe_2O_3$ in several different volume concentrations, from 0.05 % to 3.50 %, were added to the transformer oil MOL. Both linear increasing magnetic field and jumped magnetic field were applied to study structural changes. The interactions between magnetic field and magnetic moments of nanoparticles lead to the aggregation of magnetic nanoparticles and following chain or cluster formations that have the influence on the SAW attenuation. The measurement of the acoustic anisotropy (Fig. 1) gives additional useful information about the structure of nanoparticles formations. The effect of the SAW attenuation anisotropy is analyzed by applicable theoretical model. Temperature of magnetic fluids, as it is demonstrated in Fig. 1, indicates also very important influence on structural changes due to the change of viscosity and thermal motion with increasing temperature that both affect the process of cluster creation. Obtained results are compared and discussed.
Fig. 1. Anisotropy measurements of SAW attenuation at 300 mT and temperatures 15, 25 and 35 ºC for 2.5 % magnetic fluid based on MOL.

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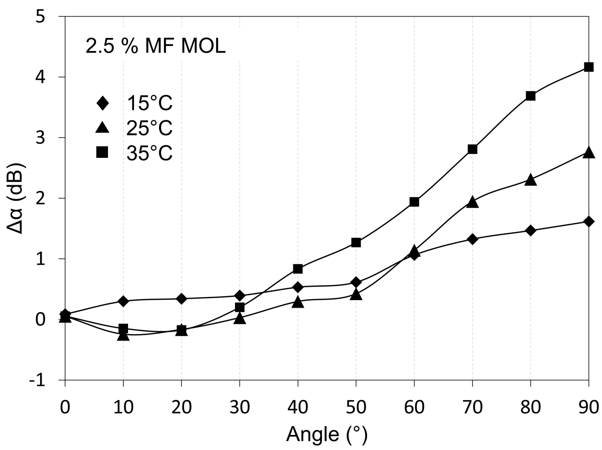


Fig. 1.jpg

Polishing characteristics by simultaneous imposition of magnetic and electrical fields utilizing a magnetic compound fluid

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 568

Prof. Hitoshi Nishida [1], ***Prof. Kunio Shimada*** [2], ***Prof. Yasushi Ido*** [3], ***Ms. Satomi Fujioka*** [4], ***Dr. Hisashi Yamamoto*** [1]

1. *National Institute of Technology, Toyama College,* ***2.*** *Fukushima University,* ***3.*** *Nagoya Institute of Technology,* ***4.*** *Ferrotec Corporation*

In this study, the novel polishing method was developed to apply simultaneously magnetic and electric fields on the flat surface with utilizing a magnetic compound fluid (MCF), which has been proposed as another magnetic responsive fluid involving magnetic fluid (MF) and magneto-rheological fluid (MR). The authors have clarified the precise polishing characteristics for flat and cylindrical inner surfaces until now by utilizing the MCF. However, their polishing efficiency were comparatively low as for high hardness of the polished materials. For this reason, as we focused on the distinction that MCF has feasibility of having both electric conductivity and dielectricity according to its components, we aimed to realize the potential of high polishing efficiency on the tough materials to be polished by utilizing an electric as well as a magnetic field and by introducing the physical mechanism such as electrorheological fluid (ER) effect.

Our used polishing slurry was an MCF involving abrasive grains and α-cellulose fibers. Figure 1 shows the schematic experimental device, and Table 1 shows the specifications of our used polishing tool. The polishing is carried on by the processing force of the magnetic clusters, which are constructed by particles of the MCF, on the abrasive grains, and by the relative motion of the abrasive grains to the polishing surface.

Figure 2 shows the relationship between the removal amount and the polishing time. The removal amount does not differ between E = 250 V / mm and E= 0 V / mm. However, at polishing time t = 40 min, in the case of E = 500 V / mm, it is more than twice that in the case of E = 0 V / mm. On the other hand, the time change in the electric current was found to increase gradually at E = 500 V / mm. Moreover, the increase of the removal amount by the application of the electric field and the average value of the electric current are suggested to have correlation.

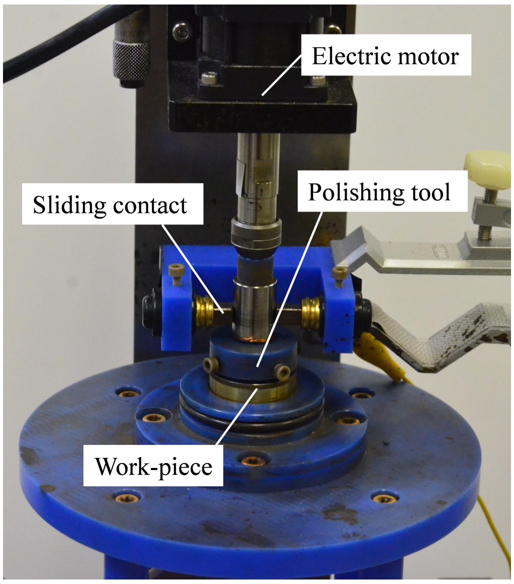


Figure 1 experimetal setup.jpg

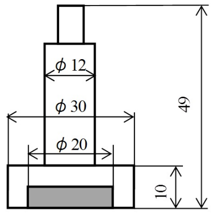
Size of permanent magnet	ϕ 20 mm ×5 mm
Material of permanent magnet	$Nd_2Fe_{14}B$, N40
Maximum magnetic flux density of permanent magnet	340 mT
Structure of tool	

Table 1 specifications of polishing tool.jpg

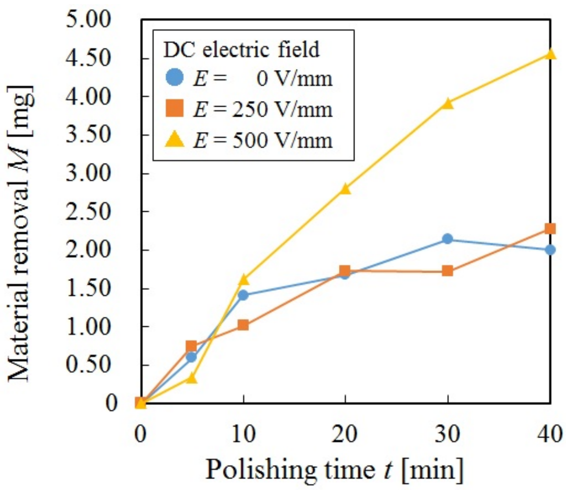


Figure 2 relationship between material removal and polishing time.jpg

Impact of Cattaneo-Christov double diffusion in magnetized upper-convected Maxwell nanofluid flow past an inclined stretching sheet: A generalized Fourier and Fick's perspective

Wednesday, 10th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 162

Dr. Arnab Bhattacharyya [1], ***Dr. Rajan Kumar*** [1], ***Prof. Gauri Shanker Seth*** [1]

1. Indian Institute of Technology (Indian School of Mines) Dhanbad

The present investigation deals with the systematic analysis of the boundary layer Cattaneo-Christov double diffusion model of both heat and mass transfer in an upper-convected Maxwell nanofluid over an inclined stretching surface. The upper-convected material derivative has been constructed to frame generalized Fourier's and Fick's phenomenon on behalf of the Cattaneo-Christov model. The highly coupled boundary layer governing equations including momentum, energy and mass conservation equations are transformed to similarity equations via appropriate dimensionless variables. The effects of Brownian motion and thermophoresis are taken into account. Influence of pertinent flow parameters inside the flow regime, namely, magnetic field, fluid relaxation parameter, thermal relaxation parameter, nanoparticle concentration relaxation parameter are deliberated through tables and graphs to predict the double diffusive phenomenon. One of the noteworthy outcomes of this investigation is that the application of external magnetic field leads to a reduction in the velocity of the fluid. This is due to the fact that magnetic field induces a retarding body force, namely, Lorentz force which has a tendency to oppose the motion of the fluid. As a result of which a downfall in the velocity profile is perceived. On the other hand this investigation also authenticates that higher temperature distribution profile is noticed in the absence of thermal relaxation parameter i.e. for so called Fourier's law as compared to Cattaneo-Christov heat flux model. Thus the significance of the current literature is to explore its unique endeavor towards the generalized version of conventional Fourier's law and Fick's law at nanostructure level.

Self-assembled layering of magnetic nanoparticles in a ferrofluid onto solid surfaces

Wednesday, 10th July - 16:50: Plenary Speech Session - Oral - Abstract ID: 160

Prof. Katharina Theis-Bröhl [1]***, Dr. Erika C. Vreeland*** [2]***, Dr. Andrew Gomez*** [3]***, Dr. Dale L. Huber*** [3]***, Mr. Apurve Saini*** [4]***, Prof. Max Wolff*** [5]***, Dr. Brian B. Maranville*** [6]***, Dr. Erik Brok*** [7]***, Dr. Kathryn L. Krycka*** [6]***, Dr. Joseph A. Dura*** [6]***, Dr. Julie A. Borchers*** [6]

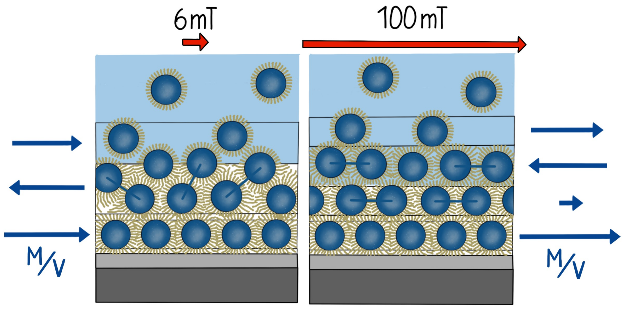
1. *University of Applied Sciences Bremerhaven, Germany,* ***2.*** *IR Dynamics, Albuquerque, NM, United States,* ***3.*** *Sandia National Laboratories, Albuquerque, NM, United States,* ***4.*** *Division for Materials Physics, Uppsala University, Sweden,* ***5.*** *Division for Materials Physics, Uppsala University, Uppsala, Sweden,* ***6.*** *Center for Neutron Research, National Institute of Standards and Technology, Gaithersburg, MD, United States,* ***7.*** *Nano-Science Center, Niels Bohr Institute, University of Copenhagen, Denmark*

This work describes the three-dimensional self-assembly of colloidal magnetite nanoparticles from a very dilute water-based ferrofluid onto a silicon surface and the dependence of its magnetic structure on the applied field. The nanoparticles used are highly spherical, have a core diameter of 25 nm and a small size distribution. They were assembled onto a silicon wafer that was coated with an APTES layer.

The detailed characterization of the layering and the magnetization behavior in the layers was achieved using polarized neutron reflectometry [1]. With additional input from small-angle neutron scattering measurements, a full characterization of the core/shell nanoparticle dimensions, degree of chaining, arrangement of the nanoparticles within the different layers, and the magnetization depth profile was provided. The nanoparticles not only wet the silicon surface but also self-assemble into several layers on the functionalized silicon substrate as can be seen in Fig. 1. The layers which build up are close-packed with concentrations up to 200 times higher than that in the ferrofluid. These layers are followed by more loosely packed ones. The layering behavior is field dependent. For both different field cases used is notable that a very dilute loose particle layer, which has a low volume concentration that nearly matches that of the free ferrofluid, forms between the ferrofluid and the 3D self-assembled particle structure. This layer plays a key role as the magnetization orientation of the entire stack is triggered by this loose particle layer.

The reason for this behavior is the different remagnetization mechanism of free and bound monodomain nanoparticles. In bound particles the magnetization might flip via a process known as Neél relaxation whereas in a liquid suspension, each nanoparticle is able to physically rotate by Brownian motion, which occurs on a much faster timescale and costs less energy. The competing energetics of the free and bound layers leads to the partial formation of quasi-domain structures in the latter with a lower net magnetization triggered by dipolar coupling.

[1] K. Theis-Broehl et al., ACS Appl. Mater. Interfaces, 2018, 10, pp 5050.



Fullsizerender.jpg

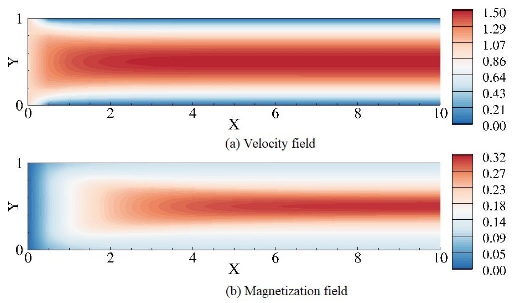
Reconstructing a continuous magnetization field based on local vorticity cells, CFD and Langevin dynamics: a new numerical scheme

Wednesday, 10th July - 17:05: Plenary Speech Session - Oral - Abstract ID: 374

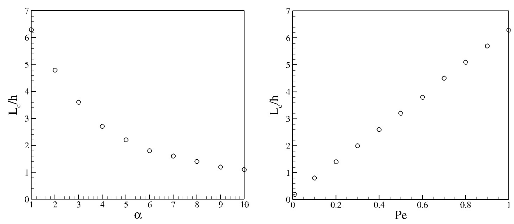
Mr. Douglas Carvalho [1], *Prof. Rafael Gontijo* [1]

1. University of Campinas - Unicamp

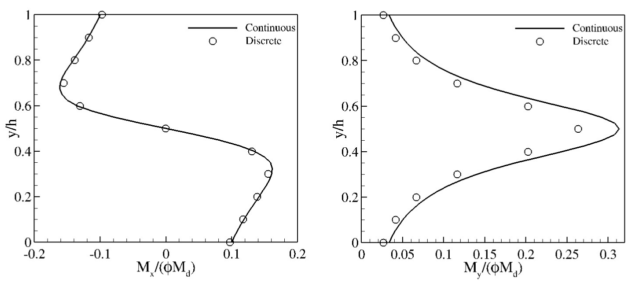
This work aims to reconstruct a continuous magnetization field of a ferrofluid plane flow by using a discrete Langevin dynamics approach for the magnetic particles. The continuous magnetization field is obtained through a numerical solution of Ferrohydrodynamic equations using a numerical code developed by the authors. It is extremely important to understand the micro-structural behavior of the magnetic particles in order to comprehend the phenomenology of the suspension's magnetization dynamics. The discrete Langevin simulations of a collection of magnetically interacting particles takes into consideration hydrodynamic and magnetic interactions to which the particles are subjected. Hence, the particles interact magnetically through their permanent magnetic dipole moments and also with an external applied magnetic field. The particles may be also subjected to hydrodynamic drag, long-range hydrodynamic interactions in creeping flow, and, due to their small size, to Brownian fluctuations. It is assumed that the dipole moments of the magnetic particles are fixed to themselves, meaning they rotate along the particle's angular velocity without delay. For this purpose, particle rotation, promoted both by Brownian and magnetic torques, is also explored in our simulations. The equations governing the motion of magnetic particles suspended in a viscous fluid are solved by direct numerical simulations for different Péclet number and dimensionless magnetic field configurations. In order to draw an accurate comparison between the data obtained through both the continuous and discrete methods, under the same physical conditions, our governing equations were made non-dimensional. In general, a very good agreement among the continuous and discrete magnetization profiles was obtained.



Velocity and magnetization fields.jpeg



Entrance length as a function of two physical parameters peclet number and dimensionless magnetic field.jpeg



Comparison among the continuous and discrete magnetization components profiles.jpeg

Coarsening dynamics of transient ferrogranular networks under the influence of a horizontal magnetic field - network alignment and magnetization in experiments and simulations

Wednesday, 10th July - 17:20: Plenary Speech Session - Oral - Abstract ID: 207

Mr. Justus Miller [1], Mr. Armin Kögel [1], Dr. Pedro A. Sanchez [2], Dr. Sofia S. Kantorovich [3], Dr. Reinhard Richter [1]

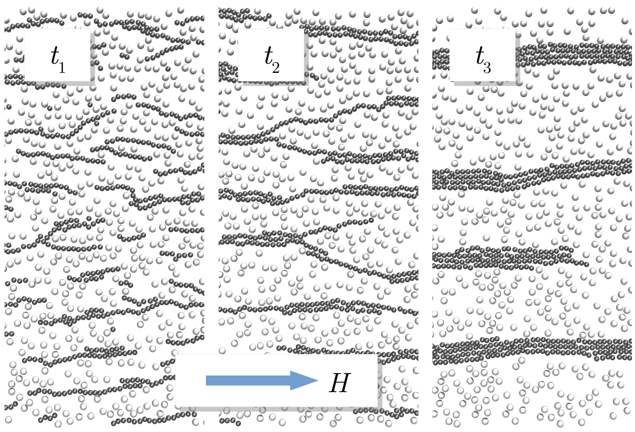
1. Experimentalphysik 5, University of Bayreuth, Bayreuth, 2. Wolfgang Pauli Institute c/o University of Vienna, Vienna, Austria and Ural Federal University, Ekaterinburg, Russia, 3. Computational Physics, University of Vienna, Vienna, Austria and Ural Federal University, Ekaterinburg, Russia

By means of experiments and computer simulations we investigate the phase separation taking place in a shaken mixture of glass and magnetised steel spheres after a sudden quench of the shaker amplitude. Transient networks of steel spheres emerge immediately after quenching and slowly evolve to reach a phase separation. Such evolution is governed by the interplay between the magnetic interactions of the steel spheres, that make them to aggregate into clusters, and the collisions with the glass spheres, that play the role of a viscoelastic bath. In our first work we analyzed the evolution of this system using network specific parameters like the mean number of neighbours or the network efficiency, uncovering the existence of three dynamic regimes [1]. This behaviour corresponds to the viscoelastic phase separation of dynamically asymmetric mixtures, firstly studied by H. Tanaka [2].

Here we present new results for the evolution of the transient networks formed in this system, corresponding to the case in which it is exposed to a horizontally applied homogeneous magnetic field. With increasing field strength, the early branched network structures observed at zero field tend to be replaced by linear chains and elongated clusters. We quantitatively characterize the average orientation of the network edges with respect to the direction of the applied field and explore the consequences for the magnetisation curves.

[1] Armin Kögel, Pedro A. Sánchez, Robin Maretzki, Tom Dumont, Elena S. Pyanzina, Sofia S. Kantorovich, and Reinhard Richter, Soft Matter vol. 14, 1001 (2018).

[2] Hajime Tanaka, J. Phys.: Condens. Matter, vol. 12, R207 (2000).



Example of evolution of transient networks of magnetised spheres dark under the effect of a horizontal magnetic field and a viscoelastic bath of non magnetic spheres light .png

Vibrating sensor unit made of a magnetoactive elastomer with field-adjustable characteristics

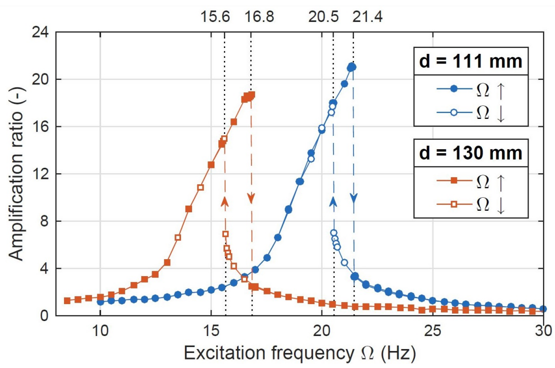
Wednesday, 10th July - 17:35: Plenary Speech Session - Oral - Abstract ID: 347

Dr. Tatiana Becker [1], Prof. Valter Böhm [2], Dr. Florian Schale [1], Prof. Klaus Zimmermann [1]

1. Technical Mechanics Group, Technische Universität Ilmenau, 2. Ostbayerische Technische Hochschule Regensburg

The present work deals with the investigation of the oscillatory behaviour displayed by a vibrating sensor unit made of a magnetoactive elastomer (MAE). Since this type of smart materials consists of an elastic matrix and micro-magnetic particles, it reveals exceptional magnetic-field-dependent material properties that makes it promising for designing sensor systems with variable operative range.

The concept of an MAE-based acceleration sensor unit for detection of external mechanical stimuli is considered. The forced vibration response under the bending of an MAE element subjected to in-plane harmonic kinematic excitation of the housing is studied. Vibrating elements are made of MAE material with a carbonyl iron powder content of 30 vol% and an averaged particle diameter of 6 µm. They are utilised in the form of a fixed-fixed beam with a large central part as a seismic mass suspended on two sides. The overall length of the beam is 60 mm. The cross-sectional dimensions of two suspending beams are specified by numerical simulations using the finite-element method on condition that the basic eigenfrequency of a sample, being far below the second one, corresponds to the transverse bending.
It is found that the amplitude-frequency characteristics of MAE vibrating units can be changed considerably by means of a magnetic field. It is produced by two cylindrical magnets that are magnetised axially and positioned symmetrically above and below the MAE. By varying the distance between the magnets, i.e. the magnetic field strength, the MAE displays different steady-state responses for the same applied harmonic excitation of its base (figure 1). As a result, the resonance occurs at various ranges of the excitation frequency, and the “configuration” of the MAE unit can be tuned reversibly between the low/high frequency response and the resonance response. Moreover, the resonance hysteresis is observed depending on whether the excitation frequency increases or decreases that leads to the appearance of quasi-discontinuous jumps in the response amplitude. The nonlinear effect of the excitation amplitude value on the response amplitude is investigated.
Financial support by Deutsche Forschungsgemeinschaft (DFG) under the projects BE 6553/1-1, ZI 540-17/3 within PAK907 and SPP1681 is gratefully acknowledged.



Amplification ratio of the steady-state response of an mae vibrating unit on the excitation frequency for two distances d between the magnets.jpg

Mesomagnetomechanics of hybrid elastomer composites: magnetization of elastically trapped particles

Wednesday, 10th July - 17:50: Invited Speech Session - Oral - Abstract ID: 239

***Mr. Mikhail Vaganov** [1], **Dr. Dmitry Borin** [2], **Prof. Stefan Odenbach** [3], **Prof. Yuriy Raikher** [4]*

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Hybrid magnetorheological elastomers (h-MREs) are soft polymers filled with a mixture of magnetically soft (MS) and hard (MH) micropowders. The MH component works as an ever present source of internal magnetic fields ensuring constant presence of the coupling between the MH and MS particles. At the same time, a soft matrix of an h-HREs sample allows for displacements of the particles under their mutual interaction. Due to that, such materials combine the properties of both classical MREs (only MS filler, no remanent magnetization) and elastically bonded magnets (the filler is exclusively MH).

The intricate mesoscopic coupling of the magnetic and mechanical degrees of freedom in h-MREs predetermines their unique functionality at the macroscopic scale. However, given the complicated physics of these materials, to get a reliable understanding of their behavior is a challenging goal. Aiming at that, we discuss magnetization curves of real h-MREs together with results of their theoretical modelling.

As a key issue, we consider an MH (namely, NdFeB) microparticle embedded in an elastomer and treat it, as suggested by the experimental evidence, as a tight clot of interacting nanograins, each of which magnetizes according to the Stoner-Wohlfarth scenario. Hence, any field-induced rotation of such structure as a whole against the matrix perturbs both the easy axis direction of and the local field experienced by each nanograin. Our model shows how the joint effect of those changes modulates the net magnetic moment of the particle and, through it, affects the angular position of the particle defined by the actual balance of the magnetic and mechanical torques imposed on it. The developed framework enables one to (*i*) explain the training effect (non-coincidence of the first few magnetic hysteresis loops) and (*ii*) analyze the dependence of reference characteristics (e.g., coercive force and remanence) of the MRE magnetization curves on the mechanical compliance of the matrix, orientational distribution of the grain easy axes, etc.

Development of theoretical models was funded by RFBR according to the research project 18-32-00817. Computer simulations and experimental measurements were accomplished with financial support by RFBR-DFG projects 19-52-12045, Bo 3343/2-1 and SO 18/24-1 within SPP1681 and PAK907.

Biocomputing agents based on magnetic nanoparticles for biosensing and theranostics

Thursday, 11th July - 09:00: Keynote Speech Session - Oral - Abstract ID: 662

Dr. Maxim Nikitin [1]

1. *Moscow Institute of Physics and Technology*

Theranostics, a fusion of two key elements of medicine – diagnostics and therapy of the organism's disorders, promises to bring the efficacy of medical treatment to a fundamentally new level and to become the basis of personalized medicine. Smart nanomaterials, which combine multiple functionalities in a single agent and can react to external stimuli to implement a pre-programmed action, could be perfect agents for theranostics.

Recently, we showed [1,2] that nano- and microparticles, virtually regardless of their nature, can be transformed to autonomous biocomputing structures capable of implementing a functionally complete set of Boolean logic gates (YES, NOT, AND and OR) and of binding with a target as a result of the computation. The logic gating functionality is incorporated into self-assembled particle/biomolecule interfaces of the structures and is realized through their disassembly induced by an input. The use of magnetic nanoparticles (MP) as the basis for the assembly of biocomputing agents is very attractive due to biocompatibility of the iron oxide particles.

Beside drug delivery applications, the proposed approach for construction of the next-generation smart nanoagents is compatible with many *in vitro* diagnostics assay formats such as lateral flow, ELISA, homogenous and 3D-solid phase magnetic assays, etc. Cell targeting based on logic-gated biochemical analysis of cell's microenvironment is especially appealing for targeted drug delivery.

Theranostic potential of such MP-based agents can be further enhanced via their combination with our highly sensitive registration technique of magnetic particle quantification (MPQ), in which MP are magnetized by a magnetic field generated at two frequencies and their response is recorded at combinatorial frequencies [1,3]. The developed MPQ readers feature record limits of detection of 39 pg of MP in 0.2-ml volume and an extremely wide 7-order linear range [6]. MPQ can be used to detect magnetic agents in various formats both *in vitro* (e.g., in immunoassays and cytometry applications) and *in vivo* (real-time studies of pharmacokinetics, investigation of biodistribution and biodegradation).

1. M.P. Nikitin et al., Nat. Nanotechnol. (2014).
2. A.A. Tregubov et al., Chem. Rev. (2018).
3. M.P. Nikitin et al., Nanoscale (2018).

Design, production and intracellular application of semi-synthetic magnetic nanoparticles

Thursday, 11th July - 09:40: Invited Speech Session - Oral - Abstract ID: 251

Dr. Domenik Liße [1]

1. *Universität Osnabrück*

Dynamic remote control of cellular functions is still a major challenge in academical and biomedical research. Recently, we developed a technique, which we referred to as magnetogenetics. With this technique, we demonstrated magnetic control of the small Rho-GTPase Rac1 by exploiting magnetic microparticles acting as magnetically controllable carrier of a biological function.[1] Here, we present latest developments for magnetogenetic activation and probing of GTPases by exploiting semi-synthetic magnetic nanoparticles inside living cells. A ferritin-based nanobiomaterial was developed yielding **Mag**netic **I**ntra**c**ellular **S**tealth nanoparticles (MagIcS NPs).[2] These semi-synthetic NPs were not recognized by intracellular degradation machineries, which was a key pre-requisite for unbiased and specific application inside living cells. In addition, we developed an advanced magnetite core particle (MCP) coating strategy based on Mms6, an iron-binding protein derived from magnetostatic bacteria. This approach enabled one-step biofunctionalization of MCPs with mEGFP within 2h, yielding biocompatible mEGFP coated magnetic nanoparticless of 28nm in diameter. With these tools at hand, successful magnetic manipulation of targeted proteins on the surface of those particles could be demonstrated inside living cells. Furthermore, by exploiting re-engineered FRET-biosensors, those magnetic nanobiomaterials enabled site-specific and reversible activation of GTPases on a subcellular scale. Overall, magnetogenetic manipulation by exploiting magnetic nanobiomaterials provide a novel non-toxic tool for magnetic control of proteins inside living cells.

[1] Subcellular control of Rac-GTPase Signalling by Magnetogenetic Manipulation Inside Living Cells;F. Etoc, D. Liße, Y. Bellaiche, J. Piehler, M. Coppey, M. Dahan; (2013) *Nature Nanotechnology***8**, 193-198

[2] Engineered Ferritin for Magnetogenetic Manipulation of Proteins and Organelles Inside Living Cells;D. Liße, C. Monzel, C.Vicario, J. Manzi, I. Maurin, M.Coppey, J. Piehler and M. Dahan; (2017) *Advanced Materials **29 (42)***

Magneto- and photo-responsive nanoparticles in cell therapy, for tissue regeneration or for cancer treatment

Thursday, 11th July - 10:05: Invited Speech Session - Oral - Abstract ID: 156

Prof. Claire Wilhelm [1]

1. *CNRS / Université Paris Diderot, Laboratoire Matière et Systèmes Complexes UMR7057*

Magnetic nanoparticles bring multiple assets to the biomedical field, for therapeutic and/or diagnostic approaches. I will show some of the recent applications that we explored, adopting the materials angle from the outset. First, we developed magnetic-based methods to manipulate living cells, towards the goal to provide magnetic artificial tissue replacements [1,2], that can be stimulated on demand [3,4]. Second, we proposed combined and synergistic cancer solutions by applying multiple stimuli to the same magnetic nanoparticle [5]. In particular, we compared the heating potential of magnetic nanoparticles under magnetic hyperthermia or photothermia [6,7], with plasmonic nanoparticles under photothermia [8], or the combination of both [9-11]. Finally, we explored whether and how the properties of magnetic nanoparticles can be affected once achieving their therapeutic mission, as they journey within their cellular targets [12-14].

[1] Advanced Materials. 25, 2611-2616 (2013) [2] Acta Biomaterialia, 37, 101-110 (2016) [3] Phys Rev Lett, 114, 098105 (2015). [4] Nature Communications, 8, 400 (2017) [5] ACS Nano, 9, 2904-2916 (2015) [6] Advanced Functional Materials, 28, 1803660 (2018) [7] Journal of Controlled Release, 279, 271-281 (2018) [8] Advanced HealthCare Materials, 5, 1040- 48 (2016) [9] ACS nano 2016, 10, 2436-2446 (2016) [10] Nanoscale, 7, 18872-18877 (2015) [11] Theranostics, 9, 1288-1302 (2019) [12] ACS nano, 10, 7627-7638 (2016) [13] Advanced Functional Materials, 27, 1605997 (2017) [14] PNAS 10.1073/pnas.1816792116 (2019)

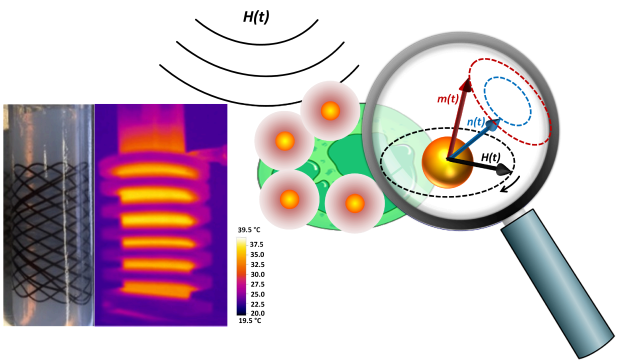
How ‘exciting’ and ‘relaxing’ is the environment of magnetic nanoparticles in hyperthermia applications?

Thursday, 11th July - 11:00: Plenary Speech Session - Oral - Abstract ID: 367

Mr. Ulrich Engelmann [1]***, Mr. Benedikt Mues*** [1]***, <u>Dr. Ioana Slabu</u>*** [1]

1. *Institute of Applied Medical Engineering, RWTH Aachen*

Magnetic fluid hyperthermia (MFH) enables the controlled release of therapeutical heat using magnetic nanoparticles (MNP) as heating agents. The MNP are excited in an externally applied alternating magnetic field (AMF). The excitation energy is transformed into heat via magnetic relaxation of the MNP. This heat is then dissipated into their immediate surroundings, e. g. a tumor, facilitating the therapy of organ-confined cancer. Treatment efficacy relies on MFH efficiency to generate heat, which is dependent on the MNP interaction with their environment. Here, different approaches of modelling this interaction well as corresponding *in vitro*studies are discussed with respect to two different applications: MFH after magnetic targeting of MNP to a tumor site and MFH through inductive heatable stents with incorporated MNP for treatment of endoluminal tumors. For these applications, MNP are restricted in their mobility and form clusters, which influences their magnetic relaxation and heating behavior. Using theoretical modelling techniques, sets of parameters are predicted which match field amplitude and frequency to MNP size and magnetic properties for optimized MFH efficiency. For the magnetic targeting application, the MNP interaction with tumor cells and its impact on heating efficiency is estimated by heating experiments on MNP immobilized in hydrogels, mimicking the settings in cellular environments such as binding to cell membranes and agglomeration inside lysosomes. Such hydrogels have tunable material properties that allow to quantify the effects of clustering and immobilization on particle heating. Further, the general feasibility of MFH is addressed with *in vitro* MFH experiments carried out with pancreatic tumor cells. Besides the obvious bulk temperature cytotoxic effect, the so-called nanoheating effect, i. e. heat developed up to 100 nm away from the MNP surface, is demonstrated. For the inductive heatable stents, different MNP are investigated concerning their concentration, immobilization and agglomeration effects on heating efficiency. The dipolar particle-particle interaction and the effective anisotropy energy increase for MNP agglomerates, directly influencing their non-linear dynamic magnetic susceptibility. Since hyperthermia and magnetic paticle imaging (MPI) rely on the non-linear dynamic magnetic susceptibility, the same behavior is observed in both techniques. So, the imaging performace of the stents is also presented.



Inductive heatable stents left and magnetic nanoparticle interaction effects on heating behavior right .png

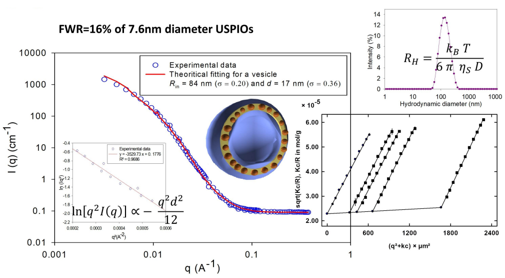
Embedding of USPIO nanoparticles into membranes of poly(ethylene oxide)-block-poly(ε-caprolactone) nanoscale magnetovesicles as ultrasensitive MRI probes of membrane degradation

Thursday, 11th July - 11:15: Plenary Speech Session - Oral - Abstract ID: 639

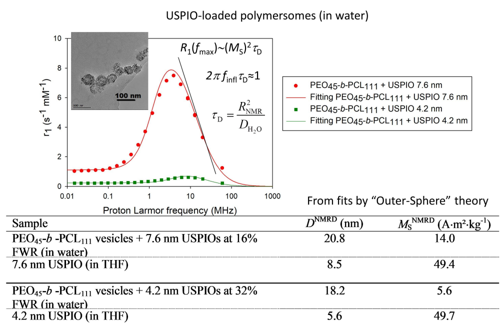
Dr. Adeline Hannecart [1], ***Dr. Dimitri Stanicki*** [1], ***Prof. Robert N. Muller*** [1], ***Prof. Luce Vander Elst*** [1], ***Dr. Annie Brûlet*** [2], ***Dr. Christophe Schatz*** [3], ***Prof. Sébastien Lecommandoux*** [3], ***Prof. Sophie Laurent*** [1], ***Dr. Olivier Sandre*** [3]

1. UMONS, 2. CEA/IRAMIS, CEA Saclay, 3. University of Bordeaux / CNRS

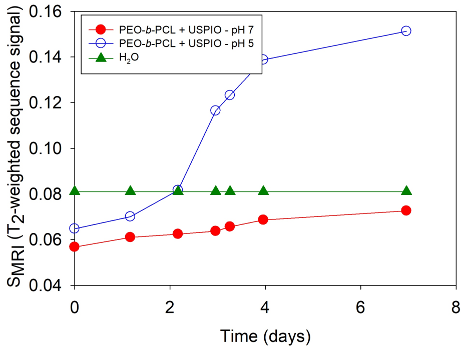
This communication will report the preparation of poly(ethylene oxide)-*block*-poly(ε-caprolactone) (PEO-*b*-PCL) polymer vesicles *via* a nanoprecipitation method and the loading of hydrophobically coated ultrasmall superparamagnetic iron oxide (USPIO) nanoparticles of two different core sizes (4.2 nm and 7.6 nm) into the membrane of these nanovesicles, whose thickness was measured precisely by small angle neutron scattering (SANS). Spherical nano-assemblies with a high USPIO payload and a diameter close to 150 nm were obtained as confirmed by dynamic light scattering (DLS), transmission electron microscopy (TEM) and cryo-TEM. Vesicular structure of these hybrid nano-assemblies was confirmed by multi-angle light scattering (MALS) measurements. Their magnetic properties (specific magnetization and relaxometric Outer Sphere diameters) were evaluated from their T_1 and T_2 water spin relaxation times measured at 20 and 60 MHz, (both at 37°C) and from the fitting of their nuclear magnetic relaxation dispersion (NMRD) profiles versus Larmor frequency (or field). The size of USPIO entrapped in the membranes of PEO-*b*-PCL vesicles has a strong impact on their magnetic properties. It affects both their longitudinal (r_1) and transverse (r_2) relaxivities and thus their magnetic resonance imaging (MRI) sensitivity, either as positive or negative MRI contrast agents. Acid-catalyzed hydrolysis of PCL membrane also influences their relaxivities as shown by measurements carried out at pH 7 *vs.* pH 5. The experimental r_2/r_1 ratio is a very sensitive property to monitor membrane hydrolytic degradation *in vitro*, as correlated with independent chromatographic analysis of the PEO-*b*-PCL copolymer chains. To conclude, this study brings a proof of concept of potential non-invasive monitoring of local drug delivery by nanomedicines, and will be highly suitable to help *in vivo* preclinical of potential MRI-guided nanotherapies under development.



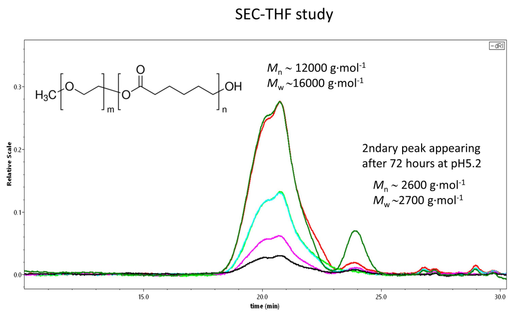
Uspio-loaded vesicles structural study.jpg



Uspio-loaded vesicles nmrd profiles.jpg



Predicted mri signal.jpg



Peo-b-pcl acidolysis gpc study.jpg

Cells targeting and protein denaturation through the use of magnetic protein imprinted polymers

Thursday, 11th July - 11:30: Plenary Speech Session - Oral - Abstract ID: 443

Mrs. Charlotte Boitard [1], Mrs. Aude Michel [1], Prof. Christine Ménager [2], Dr. Nebewia GRIFFETE [1]

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Molecularly imprinted polymers (MIP) are cross-linked polymer networks presenting very specific recognition sites for a template molecule. MIP presenting high adsorption capacity and high specificity toward biomacromolecules are of great interest for biotechnologies. Synthetic pathways were developed to obtain protein imprinted polymers (PIP), used for analytical purposes[1], but also to enhance nanoparticles stealth[2]. A great interest is nowadays focused on their use in nanomedicine, e.g. for in vivo protein targeting[3], because conventional methods employed to target cells have proved to be very effective but difficult to produce, requiring either animal hosts or expensive and time-consuming synthetic methods. Coupling PIP to magnetic nanoparticles[4]offer the possibility to detect and manipulate proteins *in vitro* or *in vivo*. It can also open a whole new field of application by taking advantage of their magnetic hyperthermia properties. Indeed, when submitted to an alternating magnetic field (AMF), maghemite nanoparticles (γ-Fe_2O_3) induce a local temperature increase that can be used to denature proteins trapped inside the coupled imprinted polymer (Fig. 1).

In this field, we developed a novel synthetic pathway, which was successfully employed to synthesize magnetic PIP[5]. Adsorption properties of the obtained nano-objects were carefully assessed and attention was paid to the fate of trapped proteins, before using γ-Fe_2O_3@PIP particles to target cells expressing green fluorescent protein (GFP) and induce cells fluorescence loss through the application of an AMF (Fig. 2).
Moreover, using this novel process, first results were obtained concerning the ability of magnetic CD44 imprinted polymer to target cells overexpressing CD44 (a glycoprotein overexpressed on the surface of circulating tumor cells) at their surface. We showed that the magnetic PIP targeted 80% of cells presenting CD44 when only 15% of cells were targeted with the same magnetic polymer without the CD44 imprints.

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5. C. Boitard, A.-L. Rollet, C. Ménager, N. Griffete, Chem. Commun. **53**, 8846–8849 (2017).

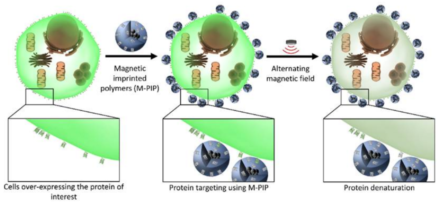

Figure 1: Representative scheme of the denaturation of green fluorescent proteins, overexpressed on the surface of cells, using magnetic GFP imprinted polymer after AMF application.

Figure 1.jpg

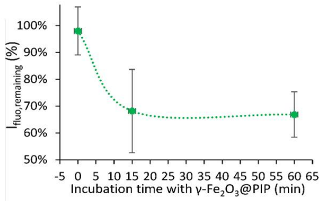

Figure 2. Remaining fluorescence intensity of GFP-expressing cells after incubation with magnetic protein imprinted polymer nano-objects and use of an AMF (335.1 kHz, 6.71 mT, 5 min).

Figure 2.jpg

Harvesting of Microalgal Cells Using Magnetic Nanoparticles

Thursday, 11th July - 11:45: Plenary Speech Session - Oral - Abstract ID: 284

Prof. Chen Guo [1]

1. Institute of Process Engineering, Chinese Academy of Sciences

Microalgae harvesting remains a challenge due to small cell size, low cell density in water, and large amount of water to remove. Among recent techniques for microalgae harvesting, magnetic separation with magnetic nanoparticles provides a promising method because of simple operation, fast separation, low running cost and energy saving. Here we report an efficient magnetic separation technology using Fe_3O_4 nanoparticles harvesting marine or fresh water microalgae from culture broth. Recovery capacity of these nanoparticles was affected by microalgal growth phase and reached the peak value when the microalgal growth reached its maximal biomass. The recovery efficiency of microalgal cells from the culture medium reached more than 95% within 4 min. Electrostatic attraction and cell aggregation was beneficial for harvesting the algal cells. Reuse of the culture medium obtained from magnetic separation gave similar biomass production in comparison with that from centrifugation separation after 5 recycles. A magnetic separator, which consisted of permanent magnet drum, separation chamber and scraper blade, was applied for efficient microalgae harvesting. The harvesting efficiency of Chlorella ellipsoidea cells reached more than 95% within forty seconds in each batch operation of microalgae harvesting. In the continuous operation of microalgae harvesting, the harvesting efficiency decreased with increasing the liquid flow rate through the separation chamber and remained more than 95% at the liquid flow rate less than 100 mL/min. The developed magnetic separator together with functional magnetic nanoparticles provided a promising method for efficient microalgae harvesting in practice.

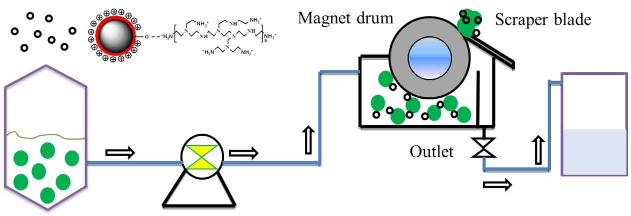

Figure 1.png

Investigating the dynamic magnetic behavior of nanoparticles in biological environments

Thursday, 11th July - 13:30: Invited Speech Session - Oral - Abstract ID: 449

Prof. Neil Telling [1], ***Dr. Maneea Eizadi Sharifabad*** [1], ***Dr. David Cabrera*** [1], ***Dr. Rémy Soucaille*** [2], ***Dr. Francisco Terán*** [3], ***Prof. Rob Hicken*** [2]

1. Keele University, 2. University of Exeter, 3. Unidad Asociada al Centro Nacional de Biotecnología (CSIC)

Understanding the dynamic magnetic behaviour of nanoparticles is crucial for developing techniques such as magnetic hyperthermia; an experimental thermal cancer treatment that uses magnetic nanoparticles to channel the energy from an external high-frequency AC magnetic field in order to kill cancer cells. As heating can only occur where nanoparticles are present, the technique provides a truly local effect and significant results can be obtained by accumulating nanoparticles within tumors. In principle the effects should occur at the cellular level, where the nanoparticles can heat the cells directly in order to trigger cell death. However, to date this approach has proved somewhat disappointing because it seems the dynamic magnetic properties and consequently heating power (specific absorption rate) of the nanoparticles can change once they are associated with cells [1].

In this talk I will discuss how developing a full understanding of the interactions of nanoparticles with their local environment is essential to achieve effective cellular level magnetic hyperthermia within real biological systems. Within this context I will describe the results of our recent work using inductive AC magnetic susceptometry and magnetometry to probe the high-frequency magnetic response of nanoparticles under different environmental conditions, including *in situ* measurements of nanoparticles associated with live cells. Here we found that the AC hysteresis loop area (and consequently SAR) of the nanoparticles, depended on their aggregation state due to a reduction in their effective anisotropy [2]. I will also discuss our development of a scanning magneto-optical system for high-frequency AC magnetometry and AC magnetic susceptibility measurement. The system configuration is based on modulation of the Faraday effect and measurement of Faraday rotation of the transmitted polarised laser light (488nm) using a balanced detector. The AC electromagnet can generate up to 50mT at frequencies up to 500MHz. This method opens up new possibilities for understanding dynamic magnetic response *in situ*.

[1] R. Di Corato *et al.*, Biomaterials 35 (2014) 6400-6411.

[2] D. Cabrera, *et al.*, *ACS Nano* 2018, 12, 3, 2741-2752.

Tailoring biocompatible hydrogels by embedded magnetic nanoparticles

Thursday, 11th July - 13:55: Invited Speech Session - Oral - Abstract ID: 139

Prof. Modesto T Lopez-Lopez [1]***, Prof. Luis Álvarez de Cienfuegos*** [1]***, Prof. Juan DG Duran*** [1]

1. *University of Granada*

Hydrogels are three-dimensional, hydrophilic networks of flexible polymer chains swollen by water or biological fluids. Due to their resemblance to the extracellular matrix of living tissues, hydrogels have been successfully used in many biomedical applications. Hybrid hydrogels can be prepared by combination of polymers with inorganic nanoparticles, which can endow them with new, intriguing properties. An example is the embedment of ferromagnetic nanoparticles within the hydrogel network, which results in magnetizable hydrogels that combine the typical flexibility of soft matter with a significant magnetic response, a unique characteristic that is not met by any natural material. What is more, the embedment of ferromagnetic nanoparticles within the hydrogel network also provides with a powerful tool to act on the microstructural and macromechanical properties of hydrogels. In particular, for fibrin-based hydrogels we found that the polymer precursors anchored on the nanoparticle surface, resulting in a perfect integration of the nanoparticles in the polymer network. This anchoring allowed actuation by magnetic forces during polymer assembly, which could be used to induce alignment of the polymer fibers along the desired direction, giving rise to anisotropy at the microscopic scale. For hydrogels based on fmoc-diphenylalanine (Fmoc-FF) peptides, we demonstrated that Fmoc-FF peptides adsorbed on the surface of the magnetic nanoparticles, and that application of a magnetic field during peptide assembly resulted in columnar structures aligned along the magnetic field direction, perfectly integrated within the hydrogel network. For both the fibrin-based and the peptide-based hydrogels, the observed changes in microstructure resulted in enhanced macromechanical properties with respect to nonmagnetic hydrogels. Finally, we used the fibrin-based hydrogels as scaffolds for the generation of artificial tissues. We did not find significant differences in cell proliferation in magnetic hydrogels with respect to nonmagnetic ones. However, the artificial tissues based on magnetic hydrogels demonstrated to be more resilient, in terms of mechanical strength, than those based on nonmagnetic hydrogels for the total duration (30 days) of the cell growth experiments.

Acknowledgements: project FIS2017-85954-R (Ministerio de Economía, Industria y Competitividad, MINECO, and Agencia Estatal de Investigación, AEI, Spain, cofounded by Fondo Europeo de Desarrollo Regional, FEDER, European Union).

Micro Magnetic Arrays for remote cell manipulation

Thursday, 11th July - 14:20: Plenary Speech Session - Oral - Abstract ID: 59

Dr. Koceila AIZEL [1]

***1.** Institut Curie*

Micro Magnetic Arrays, or MMAs, consist of a matrix of soft ferromagnetic elements that can be activated remotely using an external magnetic field. This technology was developed to overcome low throughput and reproducibility limitations of standard methods. MMAs were made using conventional micro fabrication techniques and subsequently carefully characterized using MOKE, Stokes and Magneto-optical measurements. In combination with magnetic fluids injected or uptaken by the cell population such technology can be used in a variety of in vivo and in vitro studies. Here we show an example of intracellular pathways activation and cell attraction using fluorescent coated magnetic nanoparticles.

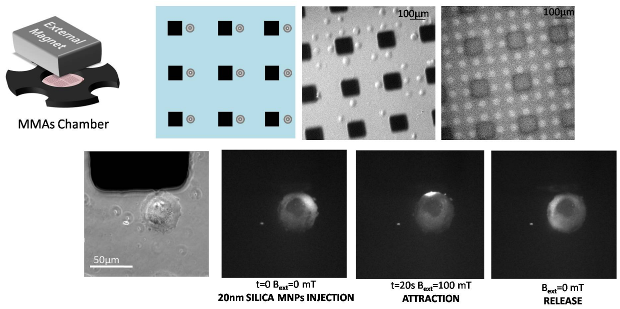

Image2.jpg

Silica-coated maghemite nanoparticles for biomedical applications

Thursday, 11th July - 14:35: Plenary Speech Session - Oral - Abstract ID: 484

Dr. Emilie Secret [1], Dr. Marie-Charlotte Horny [2], Mr. Elie Balloul [3], Dr. Domenik Liße [4], Mrs. Aude Michel [1], Dr. Jérôme Fresnais [1], Dr. Vincent Dupuis [1], Dr. Matthieu Coppey [3], Prof. Jacob Piehler [4], Prof. Christine Ménager [1], Dr. Jean Gamby [5], Dr. Jean-Michel Siaugue [1]

1. Physico-chimie des Électrolytes et Nanosystèmes Interfaciaux (PHENIX), Sorbonne Université, CNRS, Paris, France, 2. Centre de Nanosciences et de Nanotechnologies (C2N), CNRS, Univ. Paris-Sud, Université Paris-Saclay, Palaiseau, France / Physico-chimie des Électrolytes et Nanosystèmes Interfaciaux (PHENIX), Sorbonne Université, CNRS, Paris, France, 3. Laboratoire Physico-Chimie, Institut Curie, CNRS, PSL Research University, Sorbonne Université, Paris, France, 4. Division of Biophysics, Department of Biology, Osnabrück University, Osnabrück, Germany, 5. Centre de Nanosciences et de Nanotechnologies (C2N), CNRS, Univ. Paris-Sud, Université Paris-Saclay, Palaiseau, France

Magnetic nanoparticles are widely studied for biomedical applications, such as drug delivery, magnetic resonance imaging, biosensing or magnetogenetics. Among the diversity of magnetic nanoparticles, core-shell particles with a silica shell around a magnetic core are of particular interest, due to their biocompatibility, stability and their ease of functionalization. In this presentation, 2 examples of biomedical applications of γ-Fe_2O_3@SiO_2 core-shell nanoparticles will be presented.

In the first example, part of the MAGNEURON European project, we used magnetic nanoparticles that are biofunctionalized to trigger neurons' differentiation and growth along the direction of an applied external magnetic gradient. To this goal, maghemite (γ-Fe_2O_3) nanoparticles were synthesized by an inverse co-precipitation process and then used to synthesize γ-Fe_2O_3@SiO_2 core-shell nanoparticles. These particles were optimized in terms of size, charge and magnetization to obtain the optimal balance between colloidal stability and magnetic properties to facilitate intracellular motion. The magnetic γ-Fe_2O_3@SiO_2 nanoparticles were then functionalized either with a HaloTag ligand or with Green Fluorescent Protein (GFP) by click chemistry, in order to interact specifically with intracellular proteins able to trigger different pathways in the cell. For that purpose, MNPs were then microinjected in the cell (fig.1-b) and showed intra-cellular biased diffusion toward a micro-magnet (fig. 1-e). The magnet can then be used to displace target proteins, attached to the MNPs inside the cell (fig. 1-f,g)., and trigger signaling events.

In the second example, the same kind of nanoparticles were used in a lab on chip dedicated to microRNA detection. For a pre-concentration step, these colloidal particles were grafted with DNA probes that will allow a very fast capture of the aimed miRNA in the patient sample. Then, the confinement and the release of the extracted miRNA can easily be done thanks to the magnetic properties of the particles. In a model experiment, double-stranded DNA was grafted onto the nanoparticles surface. We demonstrated that by using mild magnetic hyperthermia conditions, without any elevation of the global temperature, dehybridation was as efficient as by global heating at 95 °C.

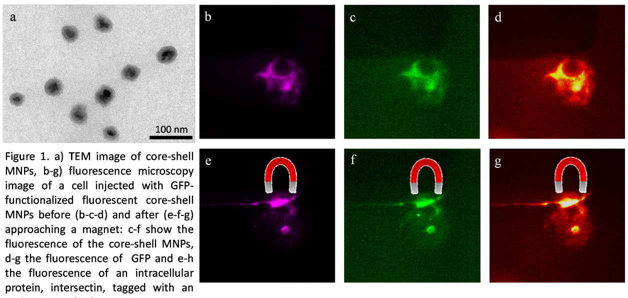

Figure 1. a) TEM image of core-shell MNPs, b-g) fluorescence microscopy image of a cell injected with GFP-functionalized fluorescent core-shell MNPs before (b-c-d) and after (e-f-g) approaching a magnet: c-f show the fluorescence of the core-shell MNPs, d-g the fluorescence of GFP and e-h the fluorescence of an intracellular protein, intersectin, tagged with an anti-GFP nanobody

Figure 1.png

Smart design of swimmers for selective penetration in 3D-cell spheroids

Thursday, 11th July - 14:50: Plenary Speech Session - Oral - Abstract ID: 395

Mr. Miguel Alexandre Ramos-Docampo [1]***, Ms. Essi M Taipaleenmäki*** [2]***, Dr. Ondrej Hovorka*** [3]***, Prof. Brigitte M Städler*** [2]***, Dr. Verónica Salgueiriño*** [1]

1. University of Vigo, 2. Aarhus University, 3. University of Southampton

Nano- and microswimmers are becoming a powerful and versatile option towards their use in biomedical applications. Among the mechanisms that swimmers may use to gain motion, one can distinguish between self-propulsion and external stimuli.[1] As for the former, enzymes have emerged as a convenient engine to sustain motion, due to their ability to perform specific reactions in biological conditions, and thus propel the swimmer. Additionally, magnetic nanoparticles have already shown their potential to be used as heat generators, and their capability to release heat in a controlled manner in biological environments.[2] Therefore, decorating nanoswimmers with magnetic nanoparticles may result in a clever strategy to locally heat up a specific area without damaging the surrounding tissue.

Hence, we herein present i) the assembly of a novel nanoswimmer that combines collagenase, as the enzyme able to promote motion, and manganese ferrite nanoparticles, because of their high saturation magnetization and low coercive field at room temperature; ii) the mobility analysis in collagen gel, as a proof-of-concept for guaranteeing its motion in a complex matrix; iii) the swimmer-cell spheroid interaction; and iv) the controlled heat delivery inside the cell spheroids, resulting in a decrease in cell viability (Figure 1).

Figure 1. Schematic illustration showing the swimmer internalization inside the cell spheroid through active cleavage of collagen fibres, to eventually release heat upon applying an alternating magnetic field (AMF).

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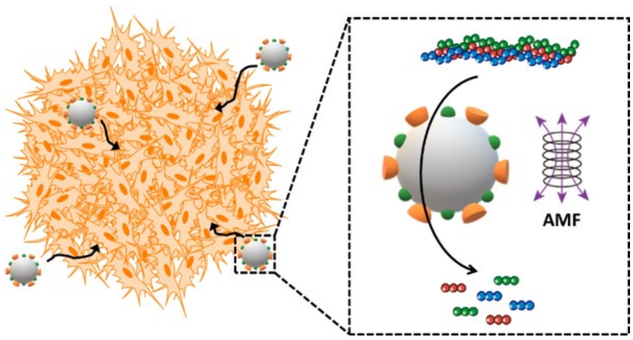

Scheme icmf-2019 mramos.jpg

Hyperthermia-triggered enhanced release of doxorubicin from polymer-coated magnetite nanorods

Thursday, 11th July - 15:05: Plenary Speech Session - Oral - Abstract ID: 295

Dr. Guillermo Iglesias Salto [1], *Ms. Blanca Luna Checa Fernández* [1], *Mrs. Felisa Reyes-Ortega* [1], *Dr. Ángel Delgado Mora* [1]

1. University of Granada

Magnetite nanoparticles (MNPs) have gained increasing interest in the last years because of their possible applications in the biomedical field, as they can be manipulated by an external magnetic field and at the same time functionalized as active drug transport vehicles. While there are many ways to prepare (quasi)spherical MNPs with controlled size and homogeneity [1], less attention and success has received the synthesis of particles with elongated shape (magnetic Nanorods, MNRs) which are homogeneous and well-stabilized in aqueous media. Nevertheless, it has been found that some advantages can be ascribed to MNRs for the applications mentioned. For instance, they show longer residence time in the gastrointestinal tract, greater capacity to overcoming rapid clearance by the reticuloendothelial system and higher bioavailability, as compared with spherical nanoparticles [2, 3].

In this work, two different synthesis methods (hydrothermal and co-precipitation) were used to obtain MNRs, as illustrated in Figure 1. The particles were coated with biocompatible polymers and loaded with the anticancer drug doxorubicin (DOX). In addition, they were used as magnetic hyperthermia agents, providing a multifunctional nano-tool for potential treatment of cancer.

The adsorption of the polymer and drug were carried out using the Layer-by-Layer technique. Evidence of the polymer coating and the drug loading will be presented. The DOX release rate was evaluated both in presence and absence of the ac magnetic field, that is, with or without simultaneous hyperthermia. It was found that DOX release was faster under magnetic field, as observed in Figure 2, demonstrating a clearly beneficial synergy between the two treatments.

Acknowledgements. Financial support from MINECO Ramón y Cajal Programme (RYC2014-16902) and Junta de Andalucía (PE2012-FQM694), Spain, is gratefully ackowledged.

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[2] Y. Zhao et al. Sci. Reports 7 (2017) 4131

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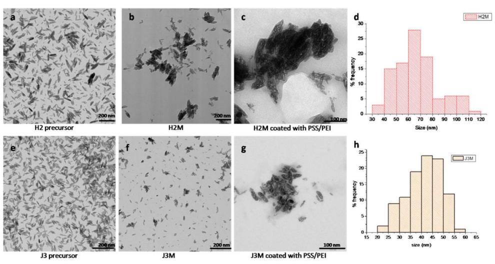


Figure 1. TEM images of the precursor particles, the bare and polymer-coated MNRs. Right panels: average size histograms.

Figure1.jpg

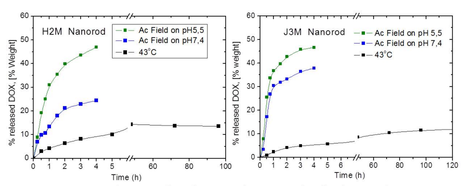


Figure 2. Release rate of DOX from H2 and J3 MNRs with and without simultaneous hyperthermia application

Figure2.jpg

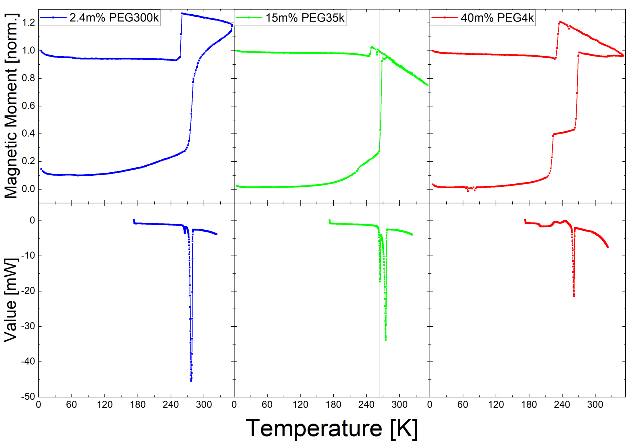
Effect of phase transitions in polymer matrices on the magnetic response of embedded nanoparticles

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 108

Ms. Samira Webers [1], ***Mrs. Melissa Hess*** [2], ***Dr. Joachim Landers*** [1], ***Prof. Annette Schmidt*** [2], ***Prof. Heiko Wende*** [1]

1. University of Duisburg-Essen, 2. University of Cologne

Magnetic nanoparticles embedded in complex materials can be used as tracer particles to investigate structural and magnetic transitions of the hybrid material. In temperature-dependent magnetization measurements, magnetic cobalt ferrite nanoparticles are shown to enable the detection of structural phase transitions in fluid environments by recording the thermomagnetic response under the influence of weak magnetic fields. Changes in the nanoparticle mobility, that are linked to structural changes in the particle environment, allow the examination of the melting and freezing behavior of a solution, as well as glass-like transitions. The results are crosschecked by differential scanning calorimetry (DSC).
In this work, various polyethylene glycol (PEG) solutions are studied. Starting with the investigation on non-entangled PEG, the complexity of the polymer solution is slowly increased by varying the polymer molar mass from 4.000 g/mol to 300.000 g/mol (see figure) and the polymer concentration from 2 m% to 25 m%. The cobalt ferrite particle content within the samples is tailored from 0.038 m% to 1 m% to be more sensitive to the glass transition. It was found that an increased particle content suppresses the glass-like transition, but higher applied magnetic fields highly accentuates the glass transition in temperature dependent magnetization curves. Furthermore, the high-temperature magnetization branch is fitted by the Langevin function and normalized to the particle concentration, providing information on the effective magnetic moment and the particle diameter, respectively.
By comparing the magnetization results to DSC results, a temperature shift and the limits of detecting second order phase transitions of the DSC method are observed. The melting and crystallization peaks in DSC curves are analyzed to examine the enthalpy change and the eutectic concentration of PEG300k.
This work is supported by the DFG (SPP1681, FOR1509).



The zfc-fc and complementary dsc curves of three polymer solutions with identical macropscopic viscosity.jpg

Preliminary In-Vitro Investigation of Magnetic Fluid Hyperthermia In Cervical Cancer Cells

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 138

Dr. Kinnari Parekh [1], *Mr. Anand Bhardwaj* [2], *Dr. Neeraj Jain* [3]

1. 1Dr. K C Patel R & D Centre 2P D Patel Institute of Applied Sciences, Charotar University of Science & Technology (CHARUSAT), Changa- 388 421, Anand, India, 2. Dr. K C Patel R & D Centre, Charotar University of Science & Technology (CHARUSAT), Changa- 388 421, Anand, India, 3. P D Patel Institute of Applied Sciences, Charotar University of Science & Technology (CHARUSAT), Changa- 388 421, Anand, India

Magnetic fluid hyperthermia (MFH) offers an alternate treatment option for fighting against cancer due to its potential biocompatibility, minimal side effects and efficient treatment modalities. It has gained scientific attention due to the flexibility of synthesizing chemically stable, inherently low toxicity, multifunctional particles that targets to different sites and optimum heat triggered modalities to kill the cancer cells without affecting healthy cells. Due to this, MFH has already reached to the clinical phase in last decade. Though few iron-based MNPs have reached up-to clinical trials for the treatment of glioblastoma and prostate cancer, in the present study auto-tunable temperature sensitive iron-based magnetic nanoparticles have been synthesized and their primary effects have been observed on cervical cancer cell line HeLa. The specific absorption of magnetic fluid was analyzed using induction heating at 350 kHz frequency applicator. The cytotoxicity of the optimized magnetic fluid was analyzed on HeLa with and without magnetic field applicator by performing MTT assay. The cytotoxicity assay after induction heating the magnetic fluids showed cell death up to 75% (Figure 1). The preliminary analysis revealed significant efficacy the synthesized magnetic fluid to caused cell death due to hyperthermia. In future such type of magnetic fluid can be used for localized treatment of cancer under magnetic field.

Figure 1: Cell viability of magnetic fluid with and without induction heating.

Acknowledgments

Authors would like to thank SERB, DST, Govt. of India for providing financial support through Project grant no. DST/SERB/EMR/2016/001000.

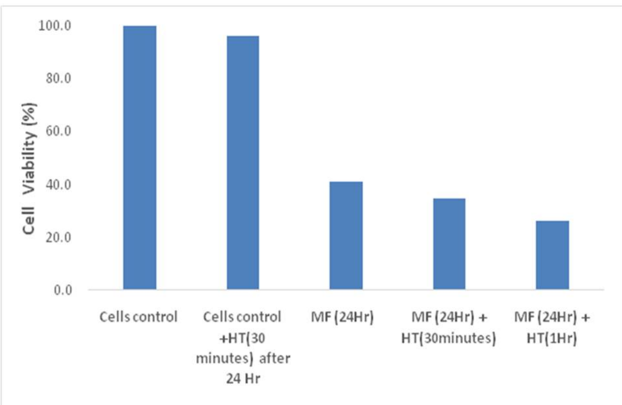


Figure 1.jpg

Exploring the static and dynamical behaviour of spherical exchange-biased Janus particles as a new tool for microfluidic biointeraction screening.

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 144

Mr. Rico Huhnstock [1], ***Ms. Meike Reginka*** [1], ***Ms. Andreea Tomita*** [1], ***Dr. Dennis Holzinger*** [1], ***Prof. Arno Ehresmann*** [1]

1. Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Heinrich-Plett-Str. 40, D-34132 Kassel

Janus particles (JPs) with engineered magnetic properties show significant potential for controlled motion in fluids by external dynamic magnetic fields. Previous work has mainly focused on JPs with either softmagnetic[1] or perpendicular to plane magnetized caps on non-magnetic particles[2], where it was demonstrated that they can be used, e.g., for catalytic self-propulsion in non-biocompatible media like H_20_2. Here, we introduce an exchange bias (EB) thin film system on spherical non-magnetic particles as functionalized JPs. In the caps of these JPs magnetic moments are aligned due to a competition between the unidirectional anisotropy originating from the EB and the shape anisotropy of the curved thin film. This paves the route towards a new class of anisotropic colloidal particles, in which the magnetic state of the hemispherical cap can be tailored by means of individually accessible anisotropy contributions.

The magnetic properties of the Janus particles were experimentally studied by magnetic force microscopy and MOKE magnetometry to investigate the magnetic moment arrangement within the cap. Hereby the formation of uncompensated magnetic net charges within the opposing equatorial regions along the anisotropy axis has been revealed. These experimental results were corroborated by micromagnetic simulations, in which further tailoring of the JPs' magnetic properties with respect to the strength of the EB field and the uniaxial anisotropy of the cap's ferromagnetic material was analysed. Probing the dynamics of the JPs by exposing them to a spatially and temporally shaped magnetic stray field landscape in a microfluidic environment resulted in a superposition of controlled translational and rotational movements. These findings emphasize the potential use of this particle type for biomolecular interaction analysis and yield the foundation for further research with respect to particle design and motion manipulation via external stimuli.

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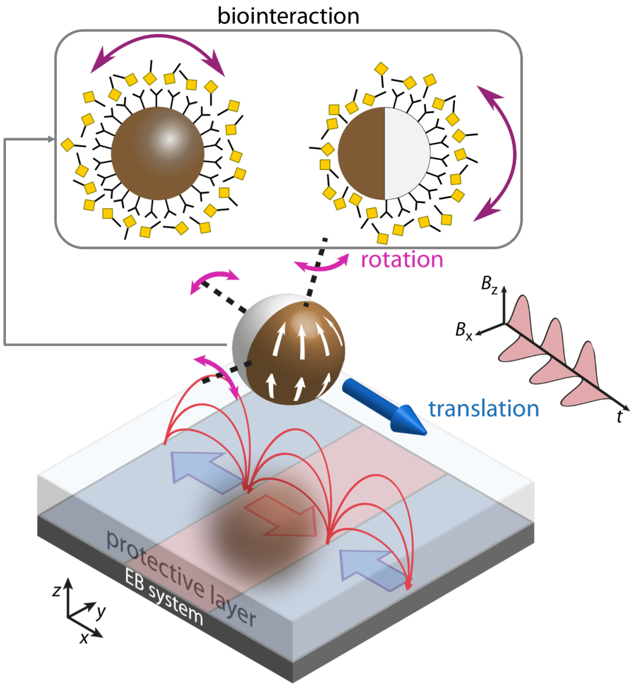
2. Baraban, L. *et al.* Catalytic Janus motors on microfluidic chip: Deterministic motion for targeted cargo delivery. *ACS Nano* **6,** 3383–3389 (2012).



Overview of exchange biased janus particles.png

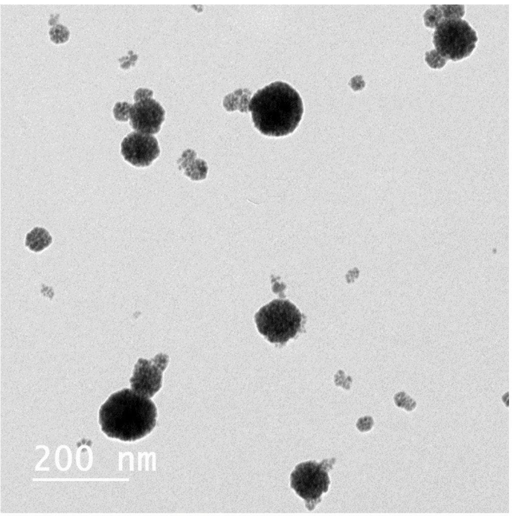
Magnetic Cationic Liposomes for Nucleic Acid Delivery

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 174

***Ms. Hai Doan DO* [1], Mrs. Aude Michel [2], Dr. Bich-Thuy Doan [3], Dr. Johanne Seguin [1], Dr. Corinne Marie [1], Prof. Christine Ménager [4], Dr. Nathalie Mignet [1]**

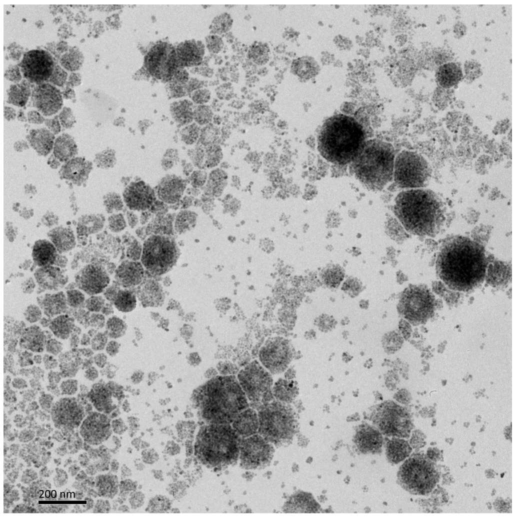
__1.__ Université Paris Descartes, Chemical and Biological Technologies for Health (UTCBS), CNRS UMR8258, INSERM 1022, __2.__ Sorbonne Université, Laboratoire PHENIX-CNRS UMR 8234, __3.__ Chimie ParisTech PSL, Institut of Chemistry for Life and Health Sciences i-CleHS, __4.__ Sorbonne Université, Laboratoire PHENIX UMR 8234 CNRS

Magnetic nanoparticles (MNPs) have been well studied and widely applied in many fields of science thanks to their unique properties and low toxicity. In nanomedicine, MNPs play several roles such as contrast agent for magnetic resonance imaging (MRI), targeting agent for drug delivery or heating agent for hyperthermia. In this work, nucleic acid delivery systems based on magnetic cationic liposomes (MCLs) were developed with an objective to fabricate a multifunctional non-viral vector for gene therapy. 10 nm citrated γ-Fe_2O_3 particles was used, and two different techniques, reverse phase evaporation and cosolvent sonication, were employed for liposome preparation. Characterization of the MCLs were carried out by dynamic light scattering, transmission electron microscopy image and relaxivity measurement at 7T. The cationic liposomes then were tested for their ability to make complex (lipoplex) with plasmid encoding luciferase (pFAR4-Luc). Lipoplex formation was monitored by gel retardation assay and Picogreen® assay. Results show that both strategies produced magnetic cationic liposomes of less than 200 nm with narrow size distribution and highly positive charge of more than + 60 mV. Enhancement of r_2 and r_2/r_1 was obtained with these two kinds of magnetic liposomes compared to free MNPs. Moreover, agarose gel electrophoresis and Picogreen®assay pointed out a high ability to make complex with pDNA of both formulations. These results suggest an opportunity for using these MCLs to integrate MRI and magnetically targeted gene delivery for theranostic strategy.



MCLs by cosolvent sonication technique

Cosolvent sonication mcls.jpg



MCLs by reverse phase evaporation technique

Reverse phase evaporation mcls.jpg

Magnetic fluid heat dissipation under 3D alternating and static excitation fields

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 212

Dr. James Wells [1], *Mr. Hendrik Paysen* [1], *Dr. Olaf Kosch* [1], *Dr. Uwe Steinhoff* [1], *Dr. Frank Wiekhorst* [1]

1. Physikalisch-Technische Bundesanstalt

Clinical translation of magnetic field hyperthermia (MFH) requires optimization and accurate characterization of magnetic nanoparticle (MNP) heating agents. Conversely, a research effort is underway to minimize heat dissipated by MNP during Magnetic Particle Imaging (MPI), to ensure patient safety.

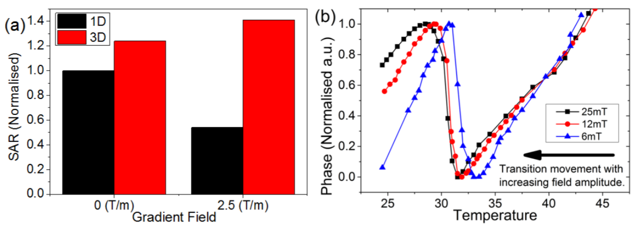
Macroscopic calorimetry of energy dissipation by liquid suspensions of MNP was conducted under different excitation fields (frequencies 23–177 kHz) and field amplitudes (0-16 mT). Additional calorimetry at 25 kHz was conducted with different excitation axis and static gradient field arrangements within a preclinical MPI scanner. The gradient induces a field-free-point (FFP) at the scanner's centre.

Non-zero SARs were recorded at all frequencies and field arrangements. Increasing the MPI scanner excitation to 2D and 3D excitations was associated with an increase in the SAR. For 1D excitations, introduction of static field gradients produced a focusing of the SAR at the FFP with an overall lowering of the SAR at all points, consistent with existing literature. For 3D excitations, a similar focusing was observed. However, the addition of a static field gradient produced an enhancement of the SAR at the FFP, creating more heat than in the gradient's absence.

Dilute MNP immobilized in gelatin were used to study localized effects, when the MNP concentration was too low for macroscopic heating. Temperature-dependent magnetic particle spectroscopy (MPS) measured the mobilization of MNP during gelatin melting. A trend towards particle mobilization at lower temperatures at larger MPS excitation amplitudes was interpreted as evidence of localized nanoscale heating effects in the absence of macroscopic heating.

Under certain conditions, complex multi-axis field excitations in the presence of static gradient fields can produce enhanced SARs. Our results provide intriguing possibilities for boosting the efficiency magnetic field hyperthermia therapy and suggest that significant care should be taken in the development of field sequences for non-damaging MPI field sequences. Furthermore, MPS measurements of MNP in gelatin suggest that localized hotspots may be a consideration for MPI safety, regardless of the macroscopic sample temperatures.

Figure (a) Comparison of SAR for 1D and 3D excitations (25 kHz, 12mT), with 0 and 2.5 T/m gradients. (b) MPS of gelatin melting with increasing excitation amplitudes.



Jameswells figuresaandb.png

Hybrid magnetic supramolecular hydrogels for regenerative medicine

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 213

Ms. Mari C. Mañas-Torres [1]***, Ms. Cristina Gila-Vilchez*** [2]***, Prof. Juan DG Duran*** [3]***, Prof. Modesto T Lopez-Lopez*** [3]***, Prof. Luis Álvarez de Cienfuegos*** [3]

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Supramolecular hydrogels are a particular type of gels formed by a low molecular weight solid (amino acids or peptides). These hidrogels are capable of self- assembly through non-covalent interactions, forming a three-dimensional reticular structure that immobilizes the macroscopic flow of water (up to 99% water) [1]. These hydrogels are of special importance because they possess biocompatibility, biodegradability and a high porosity, important characteristics for cell growth. In addition, thanks to its great versatility, they allow the introduction of different peptides, some of which, such as arginylglycyl aspartic acid, promote cell growth [2]. They also allow the introduction of magnetic nanoparticles (MNP), which stimulate the adhesion, proliferation and differentiation of cells [3].

Despite the clear advantages of peptide hydrogels, they have the disadvantage of their low mechanical strength, which limits the applications in clinical situations. This work focuses on overcoming this limitation; in order to do that, the peptide hydrogels have been combined with high molecular weight polymers, which allows benefiting from their advantages, avoiding their inconveniences. Furthermore, combining these hybrid hydrogels with MNP, their mechanical properties can also be modified.

To achieve the formation of these hybrid hydrogels, the peptide solution is prepared by the pH-switch method and then, the polymer solution (alginate or agarose) is added. Figure 1 shows an environmental electron microscope image of one of these hybrid hydrogels. The next step is the introduction of MNP. The final goal is to have hydrogels with physiological pH, for this, cell culture medium is diffused once the gel is formed.

Once prepared, hybrid hydrogels are studied as artificial matrices for cell growth both on the surface and in three dimensions. Its cytotoxicity, viability and cell proliferation are evaluated by several standard tests: analysis of cell morphology; permeability of the nuclear membrane by quantification of DNA release. The mechanical properties of hybrid hydrogels are studied by rheological measurements.

Acknowledgements: project FIS2017-85954-R (MINECO and AEI, Spain, cofounded by FEDER, European Union).

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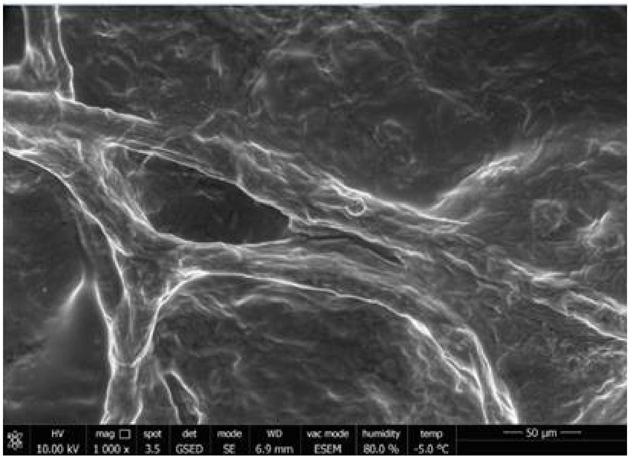

Figure 1 esem image of peptide hybrid hydrogel fmoc- phe-phe-oh with alginate.jpg

Morphogenesis of self-assembled bio-inorganic nanocomposite based upon interaction of lysozyme amyloid fibrils with magnetic nanoparticles and its application

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 218

***Dr. Natalia Tomasovicova** [1], **Prof. Po-Sheng Hu** [2], **Mr. Cyun-Lun Zeng** [2], **Dr. Jozefina Majorosova** [1], **Mrs. Katarina Zakutanska** [1], **Dr. Veronika Lackova** [1], **Dr. Andrzej Olejniczak** [3], **Dr. Kornel Csach** [1], **Dr. Peter Kopcansky** [1]*

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A variety of liquid crystals themselves are prominent examples of materials in which organized self-assembly forms spontaneously on different scales. Self-assembly of molecules is the fundamental basis of the morphogenesis of diverse and complex biological structure in all systems of living organisms. Structure of amyloid fibrils, a primary cause of many neurodegenerative disorder, for example, is an interesting model for elucidating liquid crystal phase behavior of biological anisotropic colloidal suspensions.

Development of bio-inorganic hybrid nanomaterials with advanced properties that improve functionality is receiving considerable interest due to the possibility of achieving biocompatibility and triggering novel nanotechnological applications. Much endeavor has been devoted to synthesizing biotemplated magnetic nanomaterials not only attributing to their potential use in medical diagnostics as contrast agents, biosensing and therapeutic agents, but also for their relevance in high-density data storage units. Particularly, magnetic hybrids offer potential capability to achieving high spatial order and alignment which is a highly desired feature in many applications.

In our study, hen egg white lysozyme, a well characterized monomeric protein homologous to human lysozyme, was chosen as a model of protein to prepare bio-inorganic hybrids formed by lysozyme fibrils doped with magnetic nanoparticles. The interaction between magnetic nanoparticles and lysozyme amyloid fibrils as well as their consequential structures were studied. Our results showed that the interaction depends on the size and concentration of particles [1] and that dendritic structures resembling microflower morphology are formed during drying process and its final structure is highly dependent on the size and shape of magnetic nanoparticles [2].

[1] N.Tomasovicova, P-S. Hu, C-L. Zeng, J. Majorosova, K. Zakutanska, P. Kopcansky, Dual size-dependent effect of Fe_3O_4 magnetic nanoparticles upon interaction with lysozyme amyloid fibrils“ Disintegration and adsorbtion, Nanomaterials 9 (2019) 37, doi:10.3390/nano9010037

[2] N. Tomasovicova, P. S. Hu, C. L. Zeng, M. Hurakova, K. Csach, J. Majorosova, M. Kubovcikova, P. Kopcansky, Dynamic morphogenesis of dendritic structures formation in hen egg white lysozyme fibrils doped with magnetic nanoparticles, Colloids and Surfaces B: Biointerfaces 161 (2018) 457-463, DOI:10.1016/j.colsurfb.2017.10.038

Enhancement in field induced heating efficiency of TMAOH coated superparamagnetic Fe3O4 nanoparticles by texturing under a static bias field

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 230

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Superparamagnetic iron oxide nanoparticles have been exploited for several bio-medical applications. Magnetic fluid hyperthermia (MFH) is one such application, where under a radio-frequency alternating magnetic field (RFAMF), superparamagnetic nanoparticles (SPM MNPs) generate heat due to Neel-Brown relaxation losses, thereby aiding in cancer therapy. However, in practical applications, magnetic nanofluids are to be injected into the cancerous tissues whose viscosity is several times higher than aqueous media, generally used for probing heating efficiency. This drastically modifies the heating efficiency due to partial or complete abrogation of Brownian relaxation, leading to a lowering of hyperthermia efficiency. As an alternative, we propose *in-situ* orientation of MNP for enhancing the heating efficiency.*Experiments were performed on tetramethyl ammonium hydroxide (TMAOH) coated SPM* Fe_3O_4 *MNP of size ~ 9 nm. To mimic tissue like environment, agar (concentration ~ 0.5-4 wt. %) was added to the aqueous magnetic nanofluids, which were then subjected to RFAMF induced heating under a fixed frequency of 126 kHz and three different RFAMF amplitudes. It was observed that specific absorption rate (SAR) decreased with increasing medium viscosity (from Fig. 1), after attaining a maximum at 1 wt. % agar concentration, where the product of circular frequency (ω) and effective relaxation time (τ) is nearest to the unity. This is accordance with Rosensweig's linear response theory and theoretical data obtained from dynamic hysteresis loop modelling also reveals similar behaviour. To mitigate the lowering of SAR at higher medium viscosity, we performed in-situ orientation of the MNP under a static bias field of 80 Gauss, which were then subjected to RFAMF induced heating (shown in Fig. 2). SAR was found to enhance by ~ 29 % at RFAMF amplitude of 33.1* kAm^{-1} *(MNP concentration = 8 wt. %). Under the action of the static magnetic field, the MNPs form linear chain like structure due to head-on aggregation along the direction of the external field, which leads to an increase in anisotropy energy density resulting in an enhancement of SAR, which was also verified from theoretical modelling based on dynamic hysteresis loops. This study will be immensely helpful for designing efficient candidates for MFH.*

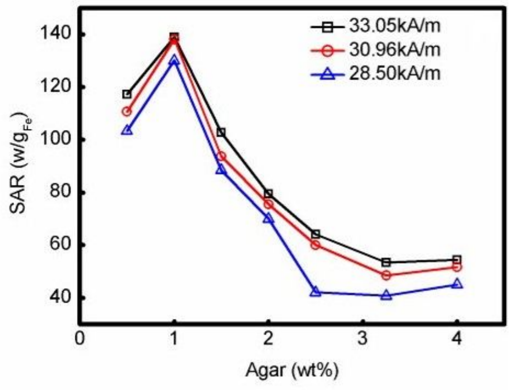

Fig. 1 Variation of SAR with agar concentration

Variation of sar fig 1.jpg

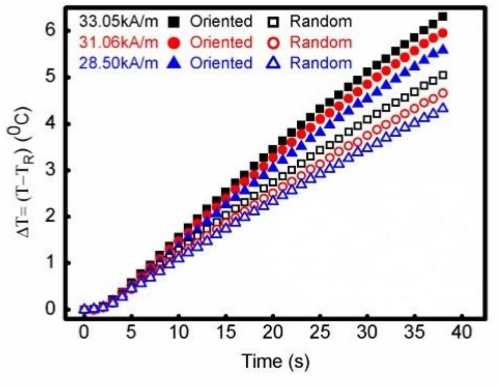

Fig. 2 Temperature rise as a function of time for magnetic nanofluids with oriented and random distribution of MNPs

Temperature rise fig 2.jpg

Magnetically meltable biopolymers with crosslinkable units for local polymerization

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 250

Ms. Natascha Kuhl [1], Dr. Robert Müller [2], Ms. Janna Kuchinka [1], Prof. Thomas Heinze [1]

***1.** 1 Institute of Organic Chemistry and Macromolecular Chemistry, Friedrich Schiller University of Jena, **2.** Leibniz-Institute of Photonic Technology (IPHT), Jena*

Meltable biopolymers are currently under research toward clinical applications. In a previous work, meltable biocomposites containing magnetic nanoparticles (MNPs) were prepared and could potentially find application as a magnetically remote controlled matrix for drug release[1]. Based on this, meltable biomaterials with different magnetic segments are desirable, which allow the melting of specific areas of the composite and, thus, make it possible to apply them in the field of microtechnological systems, such as actuators.
For this purpose, the polysaccharide dextran was chosen. In order to generate different magnetic microsections, a crosslinkable unit (coumarin) is attached to the dextran[2], which can create a kind of barrier in the material by means of photochemical reaction by irradiation with UV-light. The barrier should lead to an accumulation of MNPs in a magnetic field gradient that allows local melting in an AC magnetic field. The material was furthermore esterified with palmitic acid (Fig. 1) to adjust the melting temperature.
Precipitated MNPs were coated with oleic acid and mixed with the crosslinkable and meltable dextran ester. A MNP content of ca. 2% allows a magnetically heating above the melting temperature[1]. Hysteresis parameters are H_C=3.2 kA/m, M_R/M_S=0.07, M_S=1.2 Am^2/kg. The cross-linking behavior of dissolved dextran ester is shown by UV-Vis spectroscopy. Under UVA irradiation, a decrease of the typical absorption bands of coumarin (289 nm and 319 nm) was observed (Fig. 2). The further characterization of the composites is under progress.
Figure 1: Desired structure of the dextran, esteri-fied with palmitic acid and coumarin.
Figure 2: UV-Vis spectra of dextran ester dissolved in $CHCl_3$ during UV irradiation

Acknowledgments

The financial support of the German Science Foundation (SPP 1681, contracts HE2054/14-2, MU2382/5-1) is acknowledged.

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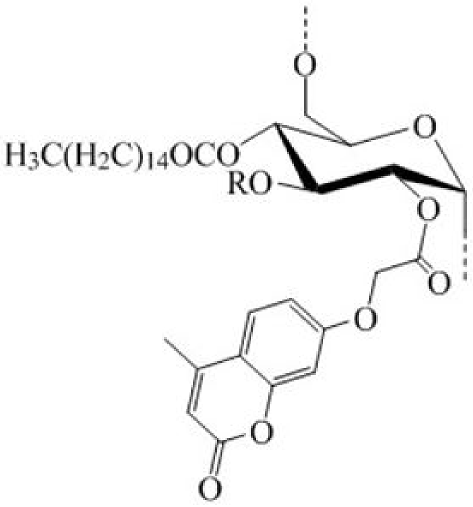


Fig1-dextranester-structure.jpg

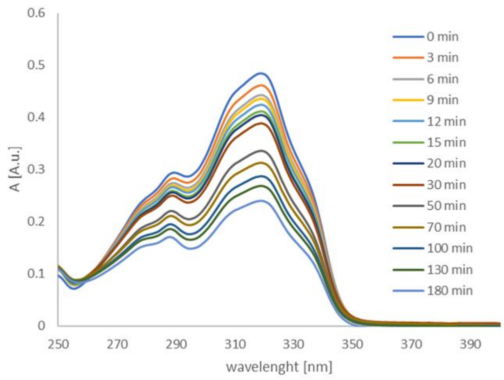


Fig2-uv-vis-spectra.jpg

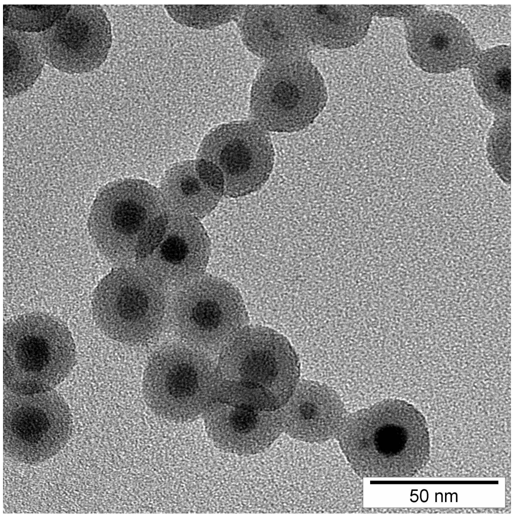
Silica coated Zn-substituted magnetite nanoparticles - Biocompatible contrast agents for MRI and their perspective use in MPI

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 279

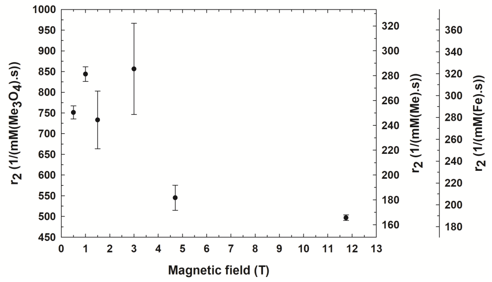
Ms. Denisa Kubániová [1], ***Prof. Jaroslav Kohout*** [1], ***Dr. Ondrej Kaman*** [2], ***Dr. Miroslav Maryško*** [2], ***Ms. Lenka Kubíčková*** [1], ***Mr. Petr Dvořák*** [1], ***Dr. Vít Herynek*** [3]

1. *Faculty of Mathematics and Physics, Charles University, V Holešovičkách 2, 180 00 Prague,* ***2.*** *Institute of Physics CAS, Cukrovarnická 10/112, 162 00 Prague,* ***3.*** *CAPI, First Faculty of Medicine, Charles University, Salmovská 3, 120 00 Prague*

We report the synthesis and characterization of $Zn_xFe_{3-x-\delta}\square_\delta O_4$ nanoparticles with *x* being 0, 0.05 and 0.36 with an application potential in theranostics as a contrast agent for T_2-weightened nuclear magnetic resonance imaging (MRI) and magnetic particle imaging (MPI), which exploits the nonlinear magnetization characteristics of superparamagnetic nanoparticles to localize their spatial position. The particles' morphology and size distribution as observed via transmission electron microscopy corresponds well to the log-normal distribution with mean diameters being ~11 nm. The distribution of cations in Zn-doped magnetite nanoparticles, ^{57}Fe hyperfine parameters and magnetic response is investigated in-depth by means of in-field Mössbauer spectroscopy (MS), XRD, XRF, AAS and SQUID magnetometry at various temperatures. The distribution of non-magnetic Zn cations within the tetrahedral (A) and octahedral [B] sites significantly influences the predominant A-B magnetic interactions, causing the change in magnetic structure and giving rise to novel magnetic properties. Regardless of the Zn preference to occupy A sites in bulk material, the synthesis of nanoparticles at temperatures below 300 °C by controlled two-step thermal decomposition, followed by rapid cooling, leads to metastable cation distribution. Based on the analysis of MS spectra, the Zn^{2+} cations evenly populates A and B crystallographic sites. The subsequent coating of magnetic cores (*x*=0.36) by diamagnetic amorphous silica shell of varying thickness (5-9 nm) provides colloidally stable particles whose transverse relaxivity (r_2) is analyzed with respect to the temperature and applied magnetic field (0.5-11.75 T). The encapsulation at higher temperatures takes advantage of NPs being in a superparamagnetic regime, leading to lower clustering and, consequently, preparation of single-core coated magnetic nanoparticles with homogeneous silica coating, which saturate in relatively low magnetic fields. The presence of zinc atoms in the structure led to an overall increase of saturated magnetization and transversal relaxivity compared to magnetite/maghemite NPs. The highest observed r_2 value of about 324 Fe $mM^{-1}s^{-1}$ at 3 T is slightly higher than those previously reported for other contrast agents with iron oxide cores. A preliminary attempt for MPI with these NPs has been made. The work is financially supported by Czech Science Foundation (grant number 19-02584S).



Representative tem bright field images of zinc-doped magnetite nanoparticles.jpg



Transversal relaxivity of zinc-doped magnetite nanoparticles with 6.9 8 nm thick silica-coating in dependence on the magnitude of external magnetic field.png

Bioactive properties of chitosan stabilized magnetic nanoparticles – focus on anti-amyloid and anti-cancer activities

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 286

***Mrs. Iryna Khmara* [1], *Dr. Matus Molcan* [2], *Dr. Andrea Antosova* [2], *Dr. Zuzana Bednarikova* [2], *Dr. Vlasta Zavisova* [2], *Dr. Martina Kubovcikova* [2], *Dr. Iryna Antal* [2], *Dr. Martina Koneracka* [2], *Dr. Zuzana Gazova* [2], *Dr. Peter Kopcansky* [2]**

***1.** Institute of Experimental Physics, Slovak Academy of Sciences, P.J. Safarik University in Kosice, **2.** Institute of Experimental Physics, Slovak Academy of Sciences*

Magnetic iron oxide nanoparticles (MNPs) are considered as a very interesting material due to their unique properties such as high surface/volume ratio, almost endless coating modifications, specific magnetic properties and low toxicity. Moreover, MNPs can generate heat in an alternating magnetic field (AMF) caused by the loss mechanisms. In this study, the MNPs were synthetized and stabilized by biodegradable, biocompatible and bioactive polymer chitosan (Chit). Complex physico-chemical characterization of chitosan coated MNPs (Chit-MNPs) dispersed in water was performed using various methods to determine their structure, morphology, magnetic and bioactive properties.

The nanoparticle heat production in the AMF is a promising feature used for hyperthermia cancer treatment. The experimental evaluation of the specific absorption rate (SAR) of both unmodified MNPs and modified Chit-MNPs was determined by calorimetric measurement. The SAR values reached approx. 5.1 Wg^{-1} for MNPs and 6.45 Wg^{-1} for Chit-MNPs, respectively at the highest applied field (7.8 kAm^{-1}) and frequency f = 190 kHz.

It was found that nanoparticles can affect the protein amyloid aggregation associated to amyloid diseases as Alzheimer´s disease or diabetes mellitus. Therefore, we focused on the investigation of the Chit-MNPs ability to disrupt α-lactalbumin amyloid fibrils (LAF) using ThT assay and AFM microscopy. It was observed that fluorescence intensity is substantially decreased in presence of Chit-MNPs (Fig. 1) suggesting their significant ability to reduce the amount of α-lactalbumin amyloid aggregates. The obtained results indicate their possible application in the treatment of diseases associated with protein amyloid aggregation.

Fig. 1. ThT fluorescence spectra of 10 μM native α-lactalbumin (red dotted line) and 10 μM α-lactalbumin fibrils (LAF) alone (red solid line) and LAF after 24 h incubation with Chit-MNPs at ratio Chit-MNPs: LAF = 7:1 (blue dashed line); 2:1 (green dash-dot-dashed line) and 1:2 (black dash-dot-dot-dashed line).

AcknowledgementsThis work was supported by the research grants Slovak Academy of Sciences, Slovakia – VEGA 2/033/19, VEGA 2/0145/17 and SAS-MOST JRP 2015/5, Ministry of Science and Technology – Taiwan MOST 105-2923-E-002- 010-MY3.

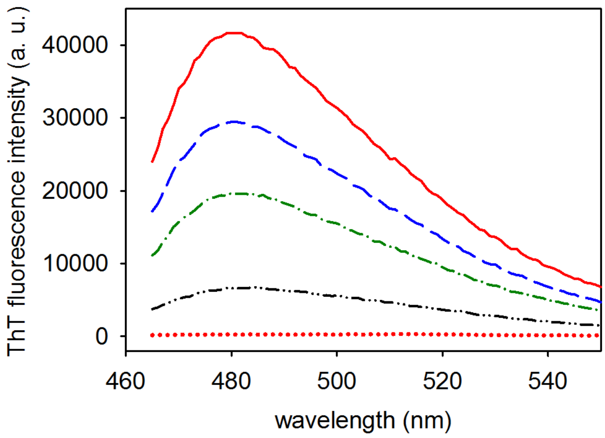


Fig. 1. tht fluorescence spectra.png

Investigation of therapeutic-like irradiation effect on magnetic hyperthermia characteristics of water based ferrofluids

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 297

Mr. Dragoslav Lazic [1], Prof. Iosif Malaescu [2], Prof. Madalin Bunoiu [2], Dr. Vlad Mircea Socoliuc [3], Prof. Catalin Nicolae Marin [4]

1. West University of Timisoara, Faculty of Physics and High Energy Radiotherapy Center, Timisoara, 2. West University of Timisoara, Faculty of Physics, 3. Romanian Academy Timisoara Branch, 4. West University of Timisoara

Treatment of cancer by magnetic hyperthermia is a complementary therapy that may accompany the standard surgical techniques, chemotherapy and radiation therapy. Following this reason, the paper presents the results of the effect of therapeutic-like irradiation of a water based magnetic fluid. The aim of the study is finding out whether the hyperthermia characteristics of the ferrofluids change after irradiation; in other words whether magnetic hyperthermia can be involved in the therapy plan, in the same period of time as the radiation therapy. The irradiation of the sample was done both with photon beam and with electron beam, using a linear accelerator (VARIAN 2100SC) [1], at the High Energy Radiotherapy Center Timisoara, at energy values of 10 MeV and 9 MeV, respectively.

The ferrofluid sample was introduced into the water phantom (simulating the insertion of the sample into the human body) and the exposure to radiation was similar to a real treatment plan (i.e. a dose of 50 Gy in 25 sessions). The experimental arrangement is shown in Figure 1 for photon irradiation.

Investigation of therapeutic-like irradiation effect on magnetic hyperthermia characteristics of the ferrofluid was done by specific loss power (SLP), heating rate (HR) and specific absorption rate (SAR) determination, both before irradiation and after irradiation. These parameters were computed from complex magnetic susceptibility measurements (in the 1 kHz to 2 MHz range). In addition, the heating rate was measured with a radiofrequency field heating system (with the amplitude of 8 kA/m and frequency of 100 kHz) [2].

Acknowledgments

This work was supported by a grant of the Romanian Ministery of Research and Innovation, CCDI-UEFISCDI, project number PN-III-P1-1.2-PCCDI-2017-0871/47PCCDI/2018-2020, within PNCDI III.

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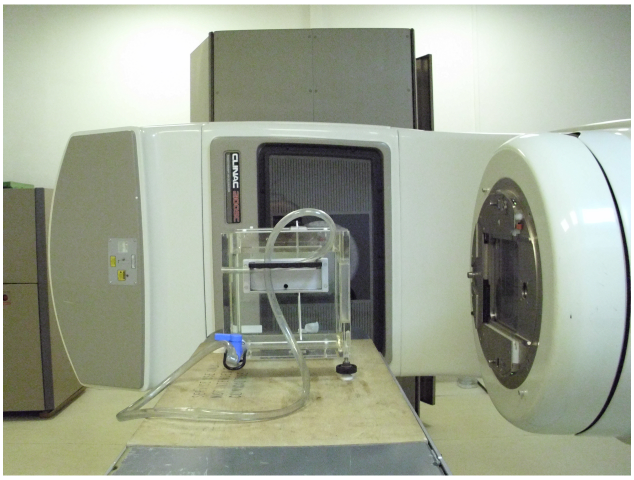


Figure1.jpg

Influence of tissue-mimicking phantom compressibility on effectiveness of magnetic nanoparticle hyperthermia

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 299

Ms. Katarzyna Kaczmarek [1], *Dr. Radosław Mrówczyński* [2], *Prof. Tomasz Hornowski* [1], *Prof. Arkadiusz Józefczak* [1]

1. Institute of Acoustics, Faculty of Physics, Adam Mickiewicz University in Poznań, Poland, 2. NanoBioMedical Centre, Adam Mickiewicz University in Poznań, Poland

During magnetic hyperthermia magnetic nanoparticles placed in AC magnetic field become the source of heat. It has been shown that in water suspensions (magnetic fluids) particles move freely and easily generate heat. However, high heating power in aqueous suspensions may not translate into efficient heating in the cellular environment. In tissues of different mechanical properties nanoparticles movement will be limited and generated heat will only slightly increase their temperature. Therefore it is crucial to conduct magnetic fluid hyperthermia experiments in conditions highly similar to human body.

The effect of tissue-mimicking phantom compressibility on effectiveness of magnetic hyperthermia was investigated on agar phantom. The mechanical properties of agar-gel on a large extent depends on the mesh-size network (pore size), which is related to the agar concentration. With increase in agar concentration, the pore size decreases. The mechanical properties of prepared phantoms were controlled by acoustic technique that allows to measure the compressibility.

In this study, we evaluated how the mechanical properties (compressibility) affect the magnetic losses in the alternating magnetic field. The heating effect was examined in particles suspension (magnetic fluid) and gel phantom with various compressibility. We demonstrated that environment in which nanoparticles are embedded affects the temperature increase during the magnetic hyperthermia. The lower the compressibility, the lower the thermal effect of magnetic hyperthermia. Specific absorption rate values (SAR) also proved our assumptions that tissue-mimicking phantom compressibility affects the magnetic losses in the alternating magnetic field.

This work was supported by a Polish National Science Centre grants: NCN/2015/17/B/ST7/03566 and NCN/2017/27/N/ST7/00201.

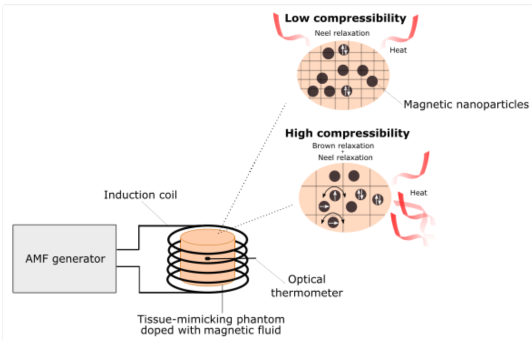


Fig abstract.png

The use of magnetic fluid in combined magneto-ultrasonic hyperthermia

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 301

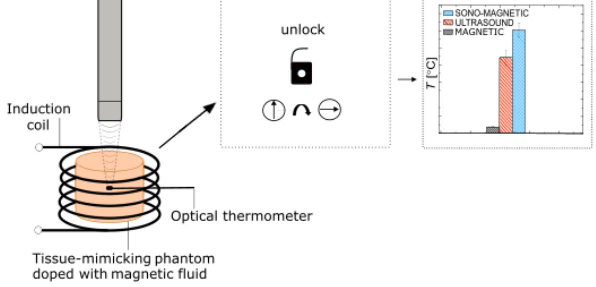
Ms. Katarzyna Kaczmarek [1]***, Prof. Tomasz Hornowski*** [1]***, Dr. Iryna Antal*** [2]***, Dr. Milan Timko*** [3]***, Prof. Arkadiusz Józefczak*** [1]

1. *Institute of Acoustics, Faculty of Physics, Adam Mickiewicz University in Poznań, Poland,* ***2.*** *Institute of Experimental Physics, Slovak Academy of Sciences,* ***3.*** *Institute of Experimental Physics*

Hyperthermia is a very promising anti-cancer medical treatment, that involves increase in tissue temperature up to 41–45˚C. Such generated heat exceeds physiological temperature of 36.6°C and in consequence leads to several changes in the tumor tissues. Weaken by the heat, cells are more susceptible for other cancer therapies like radiotherapy or chemotherapy. Temperature increase in the tissues can be applied through different mechanisms. It can be induced by ultrasounds, radio waves or alternating magnetic field. Magnetic fluids due to sensitivity to magnetic field are the source of heat in the magnetic hyperthermia. Moreover, magnetic fluids can be used as a sonosensitizing material in ultrasound hyperthermia. Magnetic nanoparticles are the cause of additional scattering of ultrasound wave which becomes the source of supplementary ultrasound attenuation. This additional attenuation consequently leads to higher increase in temperature during ultrasound hyperthermia.

The novelty of our research concerns combining the ultrasound sonication with magnetic hyperthermia. To investigate the magneto-ultrasonic thermal effect tissue-mimicking phantoms, doped with magnetic fluid, are simultaneously irradiated with the focused ultrasonic wave and the alternating magnetic field. During this magneto-ultrasonic heating, thermal effect of magnetic hyperthermia will be improved due to ultrasound sonication. Ultrasound impact will increase the size of pores in phantoms similarly as in sonophoresis treatment. This will enable activation of Brown thermal mechanism, responsible for heat generation in magnetic hyperthermia, beforehand blocked by the gel matrix of phantom. The preliminary results have shown that more effective thermal effect can be observed during magneto-ultrasonic heating than in magnetic or ultrasound hyperthermia. Therefore, coupling of magnetic and ultrasound hyperthermia gives possibility for developing new, innovative thermal therapy which can have an application potential in treating cancer at a lower magnetic fluid concentration and in shorter exposure time.

This work was supported by a Polish National Science Centre grants: NCN/2015/17/B/ST7/03566 and NCN/2017/27/N/ST7/00201.



Kaczmarek.png

Structure and dynamical properties of organoferrogels with mobile and weakly coupled magnetic nanoparticles

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 310

Dr. Hajnalka Nádasi [1], ***Prof. Alexey Eremin*** [1], ***Prof. Ralf Stannarius*** [1], ***Dr. Karin Koch*** [2], ***Prof. Annette Schmidt*** [2], ***Dr. Joachim Landers*** [3], ***Dr. Soma Salamon*** [3], ***Mr. Damian Günzing*** [3], ***Prof. Heiko Wende*** [3], ***Dr. Jing Zhong*** [4], ***Ms. Zhijun Wang*** [4], ***Prof. Frank Ludwig*** [4]

1. *Otto-von-Guericke-Universität Magdeburg,* ***2.*** *Universität zu Köln,* ***3.*** *University of Duisburg-Essen,* ***4.*** *TU Braunschweig*

Dispersions of magnetic nanoparticles in complex fluids such as polymers and gels is an exciting system in soft matter physics [1]. The coupling of viscoelastic properties of gels and magnetic properties of micro- or nano-size magnetic particles results in a magnetic field (MF) dependent mechanical response. Ferrogels represent a distinct class among magnetic stimuli-responsive materials.

Here, we investigate the structure, dynamics and the magneto-optical response of isotropic and anisotropic fibrillous organoferrogels with magnetic nanoparticles (MNPs). We use 12-HOA as a gelator known to form an LC phase with helical nanofilaments in mixtures with oils. In the gelator fibres, molecular dimers are packed in a fashion resulting in twisted layers as reported for bent-core mesogens. [2, 3]

We investigated two types of fibrillous ferrogels with a) mobile MNPs and b) with MNPs coupled to the gel network via hydrogen bonding. In the case of mobile particles, the gels exhibit a significant magnetooptical re-sposnse with complex temporal dynamics on the timescales ranging from microseconds to hours. The response is strongly affected by the anisotropy of the gel network structure. Mössbauer spectroscopy studies demonstrate the effect of the anisotropy on the mobility of single magnetic particles.

In contrast, the gels with weakly bound particles show suppressed magnetooptical response in magnetic fields below 300 mT and a yield behaviour in stronger fields. This behaviour is driven by the elastic response of the network and the diffusive dynamics of MNPs. We discuss the role of the anisotropy on the nanostructure and dynamical properties of the gels.

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Molecular weight versus heat production of dextran coated magnetite nanoparticles

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 343

Dr. Matus Molcan [1], Dr. Iryna Antal [1], Dr. Martina Kubovcikova [1], Dr. Michal Rajnak [1], Dr. Martina Koneracka [1], Dr. Vlasta Zavisova [1], Dr. Peter Kopcansky [1], Dr. Milan Timko [1]

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Recently, a huge quantity of studies of magnetic nanoparticles in the field of magnetic hyperthermia (MH) exists. In general, the principle of MH is very simple. Magnetic nanoparticles have permanent magnetic orientations. Due to the application of alternating magnetic field (AMF) the energy needed to magnetic moments reorientation is dissipated and converted to heat. The main effort is aimed to maximize the sample heat generation into the surrounding environment. This can be achieved by varying the applied magnetic field intensity and frequency, provided that different safety criteria are obeyed. The simplest way is to increase the concentration of magnetic particles in the sample. On the other hand, it is often counterproductive from the viewpoint of later elimination of the particles in the human body. In this study, we want to show how to improve the heat production of the sample in AMF at the same particle concentration. Magnetite superparamagnetic nanoparticles (MNPs) were modified by dextran coating with a different molecular weight ($DEX_{n,}$n = 40000, 70000 and 150000 Da) forming stable magnetic fluids. Dextran is a polysaccharide produced by bacteria well known in a variety of biomedical applications. Time-dependent temperature (T vs. t) measurements on the synthetized biocompatible magnetic fluids (DEX_n-MNPs) in AMF were conducted. As it is visible in Fig. 1 with increasing molecular weight the heat output of the sample was obviously higher. Magnetic particles with longer dextran molecules on the surface do not track the changes in the magnetic field and thus generate higher energy losses compared to MNPs with shorter DEX chain. Additionally, samples' magnetization on a cryogen-free superconducting magnet was measured. The obtained curves at room temperature (298 K) up to 5 T were well saturated, however with a different level of saturation magnetization (1.31 emu.g^{-1}, 1.48 emu.g^{-1} and 1.61 emu.g^{-1} for DEX_{150000}, DEX_{70000} and DEX_{40000}, respectively). Thus, it was found that the saturation magnetization decreases with increasing length of the DEX chain.

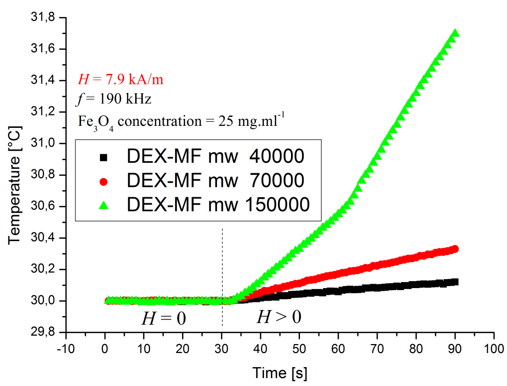

Fig1 molcan icmf 2019.png

Photothermally and Magnetically Controlled Reconfiguration of Polymer Composites for Soft Robotics

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 368

Ms. Jessica Liu [1], ***Prof. Joseph Tracy*** [1], ***Dr. Sumeet Mishra*** [1], ***Mr. Jonathan Gillen*** [1], ***Prof. Benjamin Evans*** [2]

1. North Carolina State University, 2. Elon University

Magnetic iron microparticles were embedded in shape memory polymer films through solvent casting.[1-2] These composites exhibit bifunctional responses because they can be actuated by both magnetic fields and light, which triggers photothermal heating and softens the polymer, thus modulating its magnetic responsiveness. Temporary shapes obtained through combined magnetic actuation and photothermal heating can be locked at room temperature by switching off the light and removing the magnetic field. Subsequent illumination over the transition temperature in the absence of the magnetic field drives recovery of the permanent shape and the structures can be reconfigured.[3] In cantilevers and flowers, multiple cycles of locking and unlocking are demonstrated. Scrolls show that the permanent shape of the film can be programmed, and they can be frozen in intermediate configurations. Bistable snappers can be magnetically and optically actuated, as well as biased, by controlling the permanent shape. Grabbers can pick up and release objects repeatedly by combining magnets to reset the grabber and light to drive release of the object. Simulations of combined photothermal heating and magnetic actuation are useful for guiding the design of new devices. Simultaneous reconfigurability and remote operation is an important capability for soft robotics, which enables untethered *in vivo* and space applications.

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Granular chute flows with magnetic particles

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 376

Mr. Caio Luke [1], ***Prof. Yuri D Sobral*** [2], ***Prof. Francisco Cunha*** [2]

1. *École Centrale de Lyon,* **2.** *University of Brasília*

In this study, we perform numerical simulations of granular chute flows in 2D in which some of the particles are magnetic and, therefore, interact among themselves through magnetic forces and torques. We change the volume fraction of the magnetic particles and compare the results with those obtained for similar flows without magnetic particles. We observe that the force chains on the initial (static) state are altered by the presence of the magnetic particles. However, our results indicate that the range of flow heights and inclinations for which we obtain a steady follow is not affected by the presence of magnetic particles. This can be attributed to the simulation protocol that was used. The influence of the volume fraction of magnetic particles on the steady-state velocity profiles different combinations of height and depth of the flow was analysed. Finally, segregation of magnetic particles happened for flows in which either the volume fraction or the strength of the dipoles of the magnetic particles was high. This Magnetic Brazil Nut Effect needs to be studied further.

Hyperthermia Efficiency Impact of Magnetic Nanoparticle Immobilization inside Hybrid Stents

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 380

Mr. Benedikt Mues [1], *Mr. Benedict Bauer* [2], *Ms. Jeanette Ortega* [2], *Prof. Thomas Gries* [2], *Prof. Thomas Schmitz-Rode* [1], *Dr. Ioana Slabu* [1]

1. Institute of Applied Medical Engineering, RWTH Aachen, 2. Institut für Textiltechnik, RWTH Aachen

Inductive heatable hybrid stents with incorporated magnetic nanoparticles (MNP) are developed for local hyperthermia treatment of endoluminal tumors. By application of an alternating magnetic field (AMF) a temperature of ca. 43 °C is generated at which tumor cell death *via* apoptosis is induced. In this way, tumor tissue in close vicinity to the stent can be destroyed.

In this study, we investigate the effects of MNP immobilization, concentration and agglomeration inside polypropylene (PP) matrices on hyperthermia efficiency. Two different PP matrices with incorporated MNP, compounds and fibers, are analyzed and compared to dispersed MNP and MNP immobilized in hydrogels. The compounds were produced by melt spinning PP pellets mixed with freeze-dried MNP and the fibers by melt spinning of these compounds. The synthesized MNP were stabilized with lauric acid and consist of iron oxide cores with a diameter of (10.2 ± 2.4) nm and a saturation magnetization of (99.4 ± 0.8) $Am^2/kg(Fe)$. All samples were exposed to an AMF at H = 14 kA/m and f = 100 kHz and the intrinsic loss power (ILP) was determined.

We analyzed the ILP values for dispersed MNP in water compared to MNP immobilized in polyacrylamide hydrogel as well as for incorporated MNP in PP compounds and PP fibers with various MNP concentrations. The results show an ILP decrease of approx. 20 % for the immobilized MNP in hydrogel, of approx. 65 % for the compounds and of approx. 73 % for the fibers. This can be explained by partial blocking of Brownian relaxation of MNP for the hydrogels and a full blocking for the PP matrices. Further, larger agglomerates formed during the freeze-drying and melt spinning process may have an influence on the heating efficiency. Figure 1 shows a linear ILP decrease and temperature rise increase with MNP concentration in the PP fibers, which would allow a controlled adjustment of therapeutical heat.

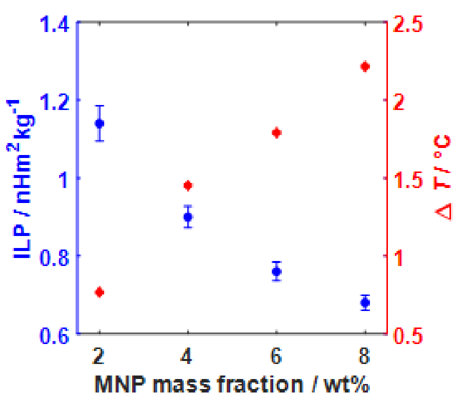

Figure 1: Intrinsic loss power (ILP) values and temperature rise ΔT vs. MNP concentration in the PP matrices.

Ilp values and temperature rise vs mnp concentration in the pp matrices.png

Aggregation Patterns in Magnetic Granular Systems composed of Few Magnetic Particles

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 381

Mr. Jorge Augusto Cassis Modesto [1], ***Prof. Yuri D Sobral*** [1], ***Prof. Francisco Cunha*** [2]

1. *University of Brasília - UnB,* ***2.*** *University of Brasília*

In this work, we present a simplified model problem to study particle agglomeration in magnetic granular material (MGM). We study magnetic and mechanical interactions in systems composed by 2 and 3 magnetic particles in 2D, and analyse the influence of various factors on the dynamics of the systems. The key parameters are those associated to the particles propreties (mass, radii and dipole strength) and to geometric configuration of initial conditions (particles radii and distance ratio, initial configuration). Our models are mostly based on soft-sphere models, and magnetic interactions are modelled considering particles as perfect point-dipoles. We analyse the formation of aggregates, study their configurations and obtain a surprise fractal aggregation diagram on particles initial configuration space.

Magnetic hydrogels as new materials for individual implants

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 399

Ms. Charis Czichy [1]***, Ms. Janina Spangenberg*** [2]***, Dr. Stefan Günther*** [1]***, Prof. Michael Gelinsky*** [2]***, Prof. Stefan Odenbach*** [1]

1. *Chair of Magnetofluiddynamics, Measuring and Automation Technology, TU Dresden, 01069 Dresden, Germany,* ***2.*** *Centre for Translational Bone, Joint and Soft Tissue Research, University Hospital Carl Gustav Carus and Faculty of Medicine, TU Dresden, 01307 Dresden, Germany*

Additive manufacturing processes have become increasingly more important for the manufacturing of individual implants over the last years [1, 2]. A new approach in this field is the utilization of hydrogels compounded with stem cells and magnetic micro-particles [3]. By applying an alternating external magnetic field, these hydrogel structures will be deformed cyclically. This cyclic deformation stimulates the cells to divide and differentiate [2], whereby a healing should be encouraged. Our research is focused on the interactions between matrix, particles, cells and magnetic field. A key challenge in this study is to establish a correlation between macroscopic deformation and microscopic particle structures. We use X-ray micro computed tomography (μCT) to determine the macroscopic geometry and the deformation of hydrogel samples as well as the particle structures and particle motions on a microscopic scale. Model samples with a simple and defined geometry like scaffolds (fig. 1) or like beams are placed in a specially designed magnetic field setup that is scanned in a laboratory μCT system in two consecutive measurements with and without a magnetic field. The three-dimensional μCT data can alternatively be used for a purely macroscopic analysis. The mechanical and magnetic properties of the magnetic hydrogels depend, among other things, on the matrix material, the particle size and the particle concentration. We performed tensile tests, showing that higher particle concentration increases the Youngs modulus. Furthermore a higher particle concentration increases the saturation magnetization, wherefore stronger magnetic forces are acting on the sample in a magnetic field. These partly opposing effects are investigated in parametric studies, to optimize material composition and magnetic field configuration. Preliminary results of our studies will be presented. Financial support by the SAB and the ESF for the project ESF-NFG IndivImp is gratefully acknowledged.

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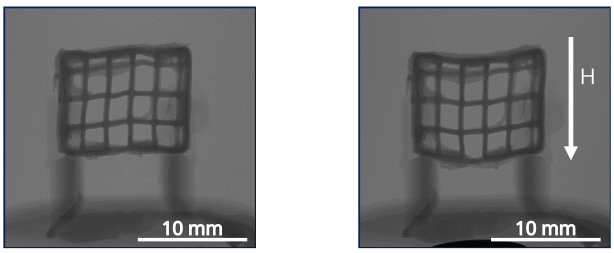

Figure 1 x-ray images of a magnetic hydrogel scaffold without a and with b in an inhomogeneous magnetic field h top 44 kam h bottom 51 kam .jpg

Gel point determination on the nanoscale of viscoelastic hydrogels by rotating magnetic nanowires

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 403

Mrs. Katinka Kohl [1], ***Prof. Stefan Odenbach*** [2], ***Mr. Philipp Mehner*** [1], ***Prof. Bethanie Stadler*** [3]

1. Technische Universität Dresden, 2. Chair of Magnetofluiddynamics, Measuring and Automation Technology, TU Dresden, 01069 Dresden, Germany, 3. University of Minnesota

We present a novel and simple technique to measure the gelpoint of Nanocomposite (NC) hydrogels based on poly(N-isopropylacrylamide) (PNIPAm) and inorganic clay (Laponite® XLS) nanoparticles for mechanical stiffness and loaded with nanowires (ø = 120-200 nm, length: 1- 20 μm) for detecting the phase transition. It is already known to use tracer particles for micro rheological examinations [Backes 2015]. Tschöpe et al utilized nanorods for magneto-optical measurements to determine viscosities and shear moduli and compared them with macroscopic values obtained by conventional shear rheometry [Tschöpe 2014]. Nanowires - visualized by electro-microscopy in Figure 1 - are produced by template-assisted electrodeposition. The gelation is based on a free radical polymerization with potassium persulfate (KPS) and N,N,N',N'-Tetramethyl-ethylenediamine (TEMED). We propose a novel measurement technique to determine the phase transition by using a laser (λ= 650 nm), a digital detector and a rotating magnetic field (Figure 2). Due to the external magnetic field, the nanowires rotate in the monomeric solution, reflect the laser beam and cause a visual laser pulse in the beaker. In the experiments, a 120 rpm rotation speed of the stir plate allows a setup which is sensitive enough to viscosity changes through the dag force of the fluid, but also slow enough to be detectable with a digital detector at 240 Hz frame rate. The images from the detector are analysed and detect the area change of the laser pulse. During gelation, the laser pulse weakens until a continus laser beam is visual. In Figure 3, the peak-area-change of the laser is shown which highlights a zero peak-area-change in the solidified gel.The intensity of the signal, respectively the signal quality, depends on the nanowire concentration.The gelation times obtained from the measurements were compared to macroscopic values obtained by conventional rheometry [Borin 2009]. Characteristic features were found for both measuring methods, but with differences in the gelation time due to the lower mechanical influence of the nanowires.

Financial support by DFG in the RTG 1865/1 is gratefully acknowledged.

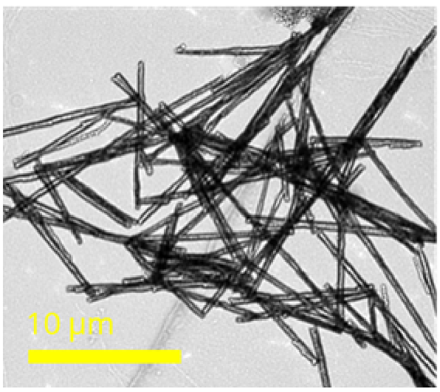

Figure 1 transmission electron microscopy image of the nanowires used.png

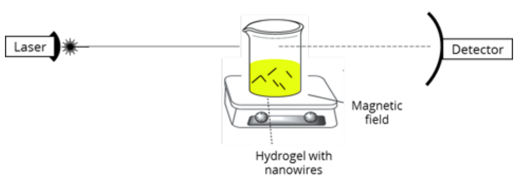

Figure 2 test setup laser left 650 nm magnetically stirring plate middle and detector right .png

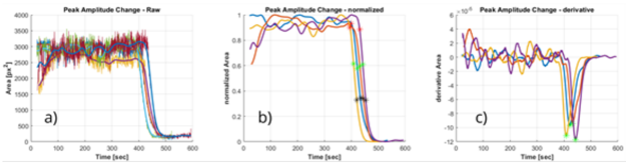

Figure 3 in a the peak change raw data is smoothed for 3 experiments on which in b the starting point red the turning point green and the rise time black are marked. c shows the first deriv.png

Using cell penetrating peptides to improve the cellular uptake of magnetic nanoparticles

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 414

***Ms. Mathilde Le Jeune* [1], *Dr. Emilie Secret* [2], *Dr. Jean-Michel Siaugue* [2], *Prof. Sandrine Sagan* [3], *Mrs. Aude Michel* [2], *Mrs. Françoise Illien* [4], *Dr. Fabienne Burlina* [3], *Prof. Christine Ménager* [5]**

***1.** Sorbonne Université, **2.** Sorbonne Université, Laboratoire PHENIX-CNRS UMR 8234, **3.** CNRS, Sorbonne Université, Laboratoire des biomolécules, **4.** Sorbonne Université Laboratoire des Biomolécules, **5.** Sorbonne Université, Laboratoire PHENIX UMR 8234 CNRS*

The development of nanobioscience has highlighted remarkable properties of nanoparticles (NPs) to better control and understand intracellular processes with direct consequences on migration, division or cell death. Magnetic nanoparticles (MNPs) have singular properties that are powerful tools at the cell scale. However, one of the drawbacks to use MNPs at the cellular level is their trapping in endosomes, following their internalization by endocytosis due to the size of these objects. This internalization path is not specific to MNPs, it has been described for a large number of nanoparticles regardless of their composition, charge or surface functionalization. The trapping of MNPs in endosomes is a limit for their applications as vectors of drugs and for their use in the recruitment of proteins of interest.

Besides, cell-penetrating peptides (CPPs) are able to vectorise in cells bioactive compounds, such as peptides, proteins, or nanoparticles. These peptides are able to go through biological membranes by endocytosis pathway, but also by translocation pathway.

Poly-Arginine peptide, first CPPs examined in this study, was synthesized on a solid support using Fmoc solid-phase method and the final product was purified with a reverse phase HPLC and the correct mass was verified using MALDI-TOF mass spectrometer. Maghemite nanoparticles (g-Fe_2O_3) were synthesized by co-precipitation. Stability and physical size of the MNPs were analysed using dynamic light scattering (DLS) and transmission electron microscopy (TEM).

These magnetic nanoparticles were incorporated into two magnetic nanoplateforms of different size and composition: core-shell particles (Fe_2O_3@SiO_2,diameter, 40 nm) and liposomes (phospholipid vesicles made of DDPC/DSPC/DSPE-PEG encapsulating MNPs, 250 nm) (Figure 1). They were functionalized with DBCO (dibenzocyclooctyne) to allow grafting of the CPPs-azide at their surface by click chemistry (Figure 2).

This project use the ability of CPPs to penetrate by translocation to promote direct MNPs access to the cytosol. The cell localization studies will be made by fluorescence optical microscopy under a magnetic field gradient where MNPs present in the cytosol will have a mobility in the field and could be visualized.

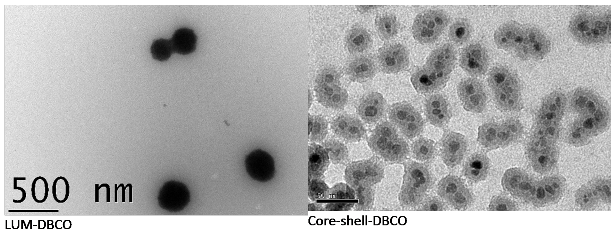

Figure 1 : transmission electron microscopy (TEM) of liposomes encapsulating MNP (left) and core shell particles (right)

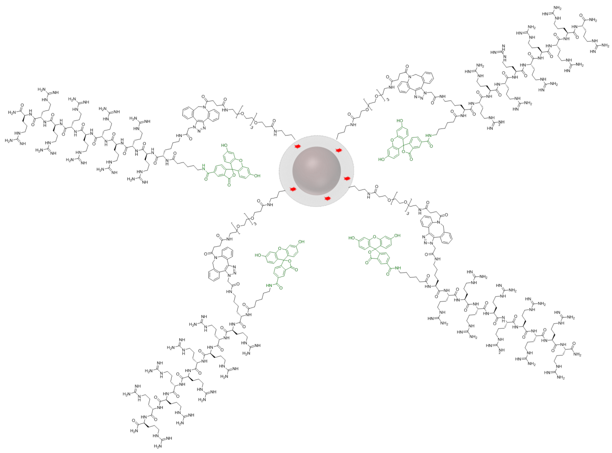

Figure 2: Scheme of magnetic nanoparticles (core-shell or liposomes) with CPP grafted at their surface by click chemistry

Mlj image icmf.png

The design and the study of protein coatings on magnetic iron oxide nanoparticles for biomedical applications

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 415

Dr. Anna Bychkova [1], Ms. Mariia Lopukhova [1], Mr. Alexander Shalupov [1], Dr. Anton Kolotaev [2], Dr. Luybov Wasserman [1], Dr. Elizaveta Kostanova [1], Ms. Eleonora Sadykova [1], Dr. Yevgeniy Degtyarev [1], Prof. Alexander Kovarski [1], Dr. Pavel Pronkin [1], Dr. Derenik Khachatryan [2]

1. N.M. Emanuel Institute of Biochemical Physics, Russian Academy of Sciences, 2. Institute for Chemical Reagents and High Purity Chemical Substances of NRC «Kurchatov Institute» (NRC «Kurchatov Institute» – IREA)

Magnetic nanoparticles (MNPs) are considered promising components of the systems designed for targeted drug delivery, magnetic resonance imaging, hyperthermia, separation of biological fluids (particularly, for the diagnosis of various pathologies in vitro).

The goal of this study was to fix protein macromolecules on the surface of MNPs and adapt modern instrumental physicochemical methods (ferromagnetic resonance (FMR), differential scanning calorimetry (DSC), dynamic light scattering, UV / visible spectrophotometry, fluorescence measurements, etc.) to study of the heterogeneous systems containing particles of different sizes and composition, which are involved in interactions with biological molecules or other particles in various media.

In this work, particles with sizes ranging from tens to hundreds of nanometers were synthesized by coprecipitation of iron (II) and (III) salts in alkaline medium or by partially reducing iron (III) to (II) at elevated temperatures in ethylene glycol. The particles were modified by serum albumin using the free radical approach presented in [A.V. Bychkova, et al., Free-radical cross-linking of serum albumin molecules on the surface of magnetite nanoparticles in aqueous dispersion, Colloid J., 2013, Vol. 75 (1), pp 7–13. DOI: 10.1134/S1061933X13010031] and immunoglobulin G. The effect of pH and buffer composition on the protein adsorption on the surface of MNPs has been studied. The thermodynamic description of the interaction of proteins with MNPs in liquid dispersion media was carried out. New approaches based on competitive adsorption processes induced by other blood proteins (fibrinogen and immunoglobulin G) were developed to assess the stability of the protein coatings. The study of these interactions and the coating thickness on individual MNPs is important when creating artificial functional systems and predicting their behavior in biological fluids.The work was funded by the Russian Science Foundation project No. 18-73-00350. The part of research devoted to the development of DSC and other methods applications to the competitive adsorption processes was carried out within the framework of the government task (themes 0084-2014-0001, State reg. No 01201253311, and 0084-2014-0005, State reg. No 01201253307). For FMR measurements we used the devices of the Core Facility of N.M. Emanuel Institute of Biochemical Physics, Russian Academy of Sciences "New Materials and Technologies".

Magnetic nanoparticles (La,Sr)MnO3 with the perovskite structure as promising inducers of magnetic nanohyperthermia

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 436

Dr. Yuliia Shlapa [1], ***Dr. Sergii Solopan*** [1], ***Prof. Anatolii Belous*** [1]

1. V. I. Vernadskii Institute of General and inorganic Chemistry of the NAS of Ukraine

Due to the unique properties, magnetic nanomaterials are of particular interest concerning their promising application in medicine. One of the possible directions for their application is magnetic nanohyperhtermia (MH) – local heating oncological tumors with previously injected magnetic nanoparticles (NPs) under the action of an alternating magnetic field (AMF) to 43 – 45°C. At present, magnetite Fe_3O_4 NPs are actively studied as promising inducers of MH since they satisfy the main requirements to such materials. However, Fe_3O_4 has a significant drawback – high Curie temperature value (585°C), which can lead to the uncontrolled heating NPs in AMF. In this case, $(La,Sr)MnO_3$ manganite (LSMO) with the perovskite structure is one more alternative material. Interest to LSMO is caused by the dependence of its Curie temperature on the chemical composition that can allow controlling the heating temperature of NPs without any additional means of thermoregulation.

In this study, LSMO NPs were synthesized by sol-gel method. Application of such method for obtaining LSMO NPs can provide uniform distribution of metal ions in polymer matrix that is important for obtaining single-phased crystalline product in one stage. By means of ^1H NMR spectroscopy it was established that LSMO precursor forms through formation of metal complexes with citric acid and ethylene glycol used for synthesis. According to X-ray diffraction data, an amorphous non-magnetic powder was formed after synthesis; obtaining crystalline structure requires the additional heat treatment. It was established that crystalline perovskite structure of LSMO begins to form at 600°C and NPs become completely crystalline after treatment at 800°C.

Morphology of NPs was investigated by TEM microscopy. It was established that NPs are weakly agglomerated with average size of 30 – 35 nm and narrow size distribution. To estimate the heating efficiency of NPs in AMF, magnetic fluids based on LSMO NPs and aqueous solution of dextran were prepared. It was found that LSMO NPs effectively heat up in AMF (specific loss power is 38 W/g) and heating temperature becomes stable in some time. Obtained results have significant value since they allow recommending LSMO NPs for further investigations as the inducers of MH treatment.

Swarming of micron-sized hematite cubes in a rotating magnetic field - Experiments.

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 473

Dr. Oksana Petrichenko [1], Dr. Guntars Kitenbergs [1], Prof. Régine Perzynski [2], Prof. Andrejs Cebers [1]

1. University of Latvia, MMML lab, 2. Sorbonne University, CNRS, PHENIX lab.

Energy input by under-field rotation of particles drives the systems to emergent non-equilibrium states. Here we consider the suspension of rotating magnetic particles interacting by cohesion and lubrication forces [1]. Cohesion forces are due to time averaged dipolar interactions. Estimates show that the suspension of hematite particles because of their modest magnetic properties is especially interesting for observing different bifurcations in non-equilibrium states. Experiments with the suspension of hematite cubes are carried out in a rotating field (frequency range [0.5 –100] Hz; field strength 23 Oe). Particles with size [1.5 – 2] µm are synthesized according to the method [2]. At 0.5 Hz, we observe the formation of rotating swarms of magnetic particles (Fig. 1a) with angular velocity less than that of the individual particles, which are single cubes or chains of several cubes. Swarms near to each other merge due to the action of cohesion forces similarly to liquid droplets.

Increasing the frequency up to 10 Hz, at constant magnetic field (H = 23 Oe), the swarms shrink to smaller circular shapes with cubes tightly packed inside them (Fig.1b), while some individual cubes begin to separate from the swarms. Further increasing the frequency up to 20–50 Hz, the swarms break apart (Fig. 1c). For a field rotating at 100 Hz, swarms totally dissolve. Closer observation of the dynamics of swarms show the development of edge currents on the surface of swarms as predicted in [1]. Measured angular velocity of swarms is in quantitative agreement with the theoretical model of [1]. It is interesting to note that hematite particles with peanut or ellipsoidal shapes do not form the swarms.

The work is financially supported by PostDocLatvia project no. 1.1.1.2/VIAA/1/16/018 (for O. Petrichenko) and no. 1.1.1.2/VIAA/1/16/197 (for G. Kitenbergs), French-Latvian bilateral program OSMOSE project no. LV-FR/2018/5 and by Grant No.1.1.1.5/ERANET/18/04 of the European Regional Development Fund.

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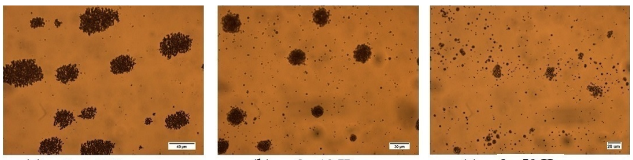

(a) f = 0.5 Hz (b) f = 10 Hz (c) f = 50 Hz

In fig. 1a to 1c bars are respectively 40µm, 30 µm, 20 µm.

Swarms in a rotating magnetic field. h is constant 23 oe . optical microscopy images magnification is 40x .jpg

From microscopic to macroscopic interaction: Nickel-particle doublet movement in an elastomer matrix under exertion to magnetic field

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 501

***Mr. Henrik Schmidt* [1], Dr. Mate Puljiz [2], Mr. Dirk Sindersberger [3], Mr. Benedikt Straub [1], Dr. Andreas M. Menzel [2], Dr. Günter K. Auernhammer [4]**

1. Max Planck Institute for Polymer Research, 2. Heinrich-Heine University, 3. Ostbayerische Technische Hochschule Regensburg, 4. Leibniz-Institute for Polymer Research Dresden

To obtain strong magneto-rheological effects, the particles inside Magnetorheological elastomers (MREs) have to rearrange in position and orientation under the action of an applied magnetic field. Strong magneto-rheological effects require a high volume fraction of the magnetic material, resulting in particle distances below one particle diameter.

Particles in distances close to contact experience a magnetic interaction deviating from the dipole approximation. Even small particle displacements then can locally generate high deformations of the matrix.

To study the interaction and movements of magnetic particles in distances close to contact we reduced the system to a small number of superparamagnetic nickel particles embedded in a cross-linked PDMS-matrix. As the magnetic forces not only depend on the distance between the particles but also on their position relative to the external field, a slowly rotating magnetic field is used.

Extending previous studies [1], we resolve particle attachment and detachment (Fig. 1) and measure the angles between the particle axis and external field for every position. These jumping events depend on parameters like the elastic modulus, equilibrium distance, and particle size. In agreement with the theoretical prediction of comparable particle systems, the dipole approximation lacks to describe the experimental results. Higher order multipoles seem to play a role [1,2,3]. For a quantitative picture, we use the same particles and elastic modulus of the matrix and place the particles at different equilibrium distances. We extract the angle at which magnetic forces are zero (Fig. 2). These angles decrease with decreasing equilibrium distance.

In addition, we investigate the influences of a third particle. There are similarities to the two particle systems. But the hysteresis loop is altered due to matrix mediated crosstalk of the attachment and detachment events. Small variations for the ideal geometry play here an important role in the movement of the particles (Fig. 3).

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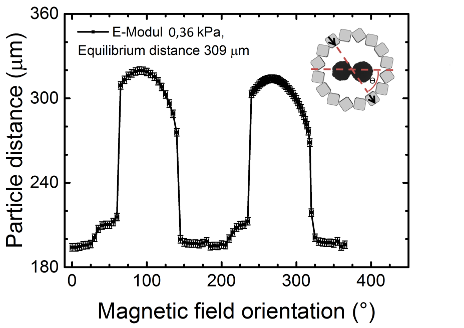

Fig. 1 Particle distance over external magnetic field orientation. Distance center to center of the particles in undisturbed state is 309 micrometer. Inset shows the definiton of the magnetic field orientation.

14 pdms 316 micro insert nur magnetfeld und beschriftung.png

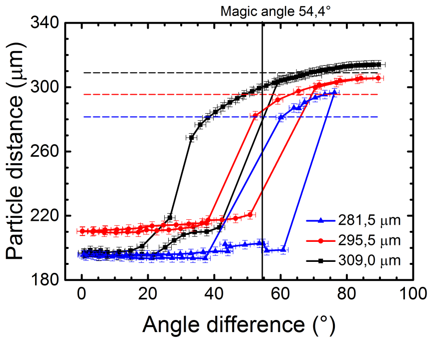

Fig 2. Particle distance over the angle difference between magnetic field and particle axis. Dashed lines mark the distance without magnetic field. The magic angle of 54,4° indicates the change of sign of the dipole-dipole force.

Mit fehlerbalken abstandabh ngigkeit mit beschriftung.png

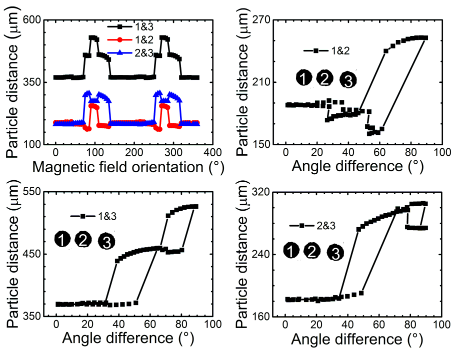

Fig. 3
Particles jump into contact when field is directed along the particle axis. Particle 1&2 show a clear hysteretic trend. Due to small variations from the ideal geometry hysteresis of particle 2&3 shows intermediate states. Effective three particle interaction.

14 1partikelkette mit beschriftung.png

Controlling human blood clot dynamics with magnetic nanoparticles

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 558

Dr. David Cabrera* [1], Mrs. Karen Walker [1], Dr. Sandhya Moise [2], Prof. Neil Telling [1], Dr. Alan Harper [1]

***1.** Keele University, **2.** Bath University*

Heart attacks and strokes triggered by unwanted blood clotting remain one of the leading caused of mortality and morbidity in Europe. Current pharmacological treatments involve the administration of anti-platelet therapies to control thrombus growth, and in severe cases, the application of thrombolytic enzymes to try to break down the clot in. However, both approaches lack specificity, leading to major bleeding events in some patients. Upon blood vessel damage, blood platelets activate by adhering to the subendothelial matrix. This initial stage is characterised by a significant rise in the platelet's cytosolic calcium concentration, which triggers their activation. Platelets contain a complex series of tunnels called the open canalicular system (OCS) which are formed by infolding of the plasma membrane. We have previously suggested that the OCS lumen may provide a transient calcium store that promotes platelet aggregation by maintaining cytosolic calcium rises. Here we demonstrate that iron oxide nanoparticles coated with the known calcium chelator, citrate (Cit-IONPs), can act as selective calcium nanochelators. These nanochelators buffer the calcium accumulations that occur in the OCS and control clotting dynamics. Transmission electron microscopy revealed that Cit-IONPs are exclusively taken up by activated platelets into the OCS (Figure 1). Pretreatment of human platelet suspensions with Cit-IONPs inhibits thrombin-evoked cytosolic calcium rises to 41.8 ± 4.0 % of control (Figure 2; $n = 6$, $P < 0.05$) and impairs platelet aggregation ans clot retraction (Figure 3).

These magnetic nanoparticle-based calcium nanochelators could potentially provide additional clinical functions beyond those offered by traditional anti-platelet therapies. Use of a magnetic nanoparticle core would allow their recovery using external magnetic gradients in a technique known as blood magnetic filtration. Additionally, these magnetic nanoparticles could be used as contrast agents to facilitate the imaging of blood clots and the filtration of emboli from the peripheral circulation as well as enable the adjuvant use of magnetic hyperthermia to disrupt blood clots. Therefore, citric acid coated nanoparticles deliver a promising wide-available, low-cost prototype for the development of new multi-functional clinical tools to diagnose and treat acute cardiovascular events.

Smart model of intrinsic loss power of SPIONs in hyperthermia treatment

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 560

***Ms. Marco Alberti* [1], *Prof. Adriele Prina Mello* [1]**

1. Trinity College Dublin

Smart model incorporates *computational modelling* and *computational testing*. Starting from guidelines design, the simulation methodology involves model building and testing, up to real experimentation for data comparison and final implementation of new patterns.

This modelling technique is applied to determine the heating profile of *SPIONs* injected into *ex vivo* tissues forming clusters, under the application of an external alternating-magnetic-field. *In vitro* experiments are carried out in parallel to obtain nanoparticles data, to strengthen model validation and to provide real comparison terms for the computational simulation.

A physical characterization of SPIONs has been provided, exploiting the Rosensweig's model of Intrinsic Loss Power, combined into Pennes' bioheat equation. This allows for a complete description of the thermal exposure to which the body is subjected during hyperthermia treatment. Image processing, performed through *MATLAB Image Processing Toolbox* on mice liver sections, guaranteed to define the working geometries from where to start the investigation of real injection scenarios.

Experimental work was carried out adopting solutions and phantom samples of 1% Agarose gel as hosting media for SPIONs, allowing to explore different features of the two families of single-core nanoparticles under investigation. Through COMSOL Multiphysics, a *FEM analysis* was performed, to apply the bioheat equation dynamically over the entire simulation environment. The smart model was developed and tested, performing high-profile and deep-level studies of heat diffusion spectrum, potential thermal ablation and damage estimation (*CEM_{43} analysis*).

SPIONs with different hydrodynamic diameter, hosted in different media are considered in this work. Results show, for each sample, the correlation coefficient evaluated between the in vitro measurement versus the value obtained through the computational simulation. Agarose samples coefficients showed a strong agreement, with correlation coefficient values in the range [0.934÷0.975], while solution samples showed a very strong correlation, with values in the range [0.972÷0.989].

The set of analysis performed would provide an evaluation of the spectrum of best operational conditions for hyperthermia treatment. The intrinsic-value of a smart model approach lies in its large applicability: it can be extended to a wide and diverse range of experiments and constantly empowered with new data.

Correlation analysis between *in vitro* experiment and *in silico* model			
Hydrodynamic diameter	***Hosting media***	***SPIONs concentration***	***Correlation coefficient***
70 nm	Water	5 mg/ml	0.986
100 nm	Water	5 mg/ml	0.989
70 nm	Water	10 mg/ml	0.972
100 nm	Water	10 mg/ml	0.982
70 nm	Agarose 1%	5 mg/ml	0.934
100 nm	Agarose 1%	5 mg/ml	0.944
70 nm	Agarose 1%	10 mg/ml	0.975
100 nm	Agarose 1%	10 mg/ml	0.966

Correlation analysis results.png

Life cycle of iron oxide nanoparticles in human stem cells: the case of magnetosomes assimilation, from degradation to neosynthesis

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 563

Dr. Alberto Curcio [1], ***Dr. Aurore Van de Walle*** [1], ***Dr. Anoucka Plan*** [1], ***Dr. Aida Serrano*** [2], ***Dr. Sandra Preveral*** [3], ***Dr. Christopher Lefèvre*** [3], ***Prof. Nicolas Menguy*** [4], ***Dr. Ana Espinosa*** [2], ***Prof. Claire Wilhelm*** [5]

1. *Laboratoire Matière et Systèmes Complexes (MSC), UMR7057, Université Paris Diderot,* ***2.*** *Instituto de Ciencia de Materiales de Madrid (ICMM-CSIC), Consejo Superior de Investigaciones Científicas, Cantoblanco,* ***3.*** *Institut de biosciences et biotechnologies d'Aix-Marseille, UMR7265, CEA - CNRS - Aix-Marseille Université,* ***4.*** *Institut de Minéralogie de Physique des Matériaux et de Cosmochimie (IMPMC), UMR7590, Sorbonne Université / CNRS / MNHN / IRD,* ***5.*** *CNRS / Université Paris Diderot, Laboratoire Matière et Systèmes Complexes UMR7057*

The magnetosomes, magnetic nanoparticles biosynthesized by the magnetotactic bacteria, are made of a magnetite core with high levels of crystallinity and surrounded by a lipid bilayer that protects as well as stabilizes them. Their versatile and biocompatible nanostructure has found many possible applications in nanomedicine (MRI contrast agent, magnetic hyperthermia, photothermal therapy, drug delivery), while their intracellular stability and toxicity has been poorly reported, especially in the long-term. After implementing their use in tumor-targeted photothermal therapy,[1] we investigated their fate upon internalization in human mesenchymal stem cells using magnetic measurements, high-resolution electron microscopy, and synchrotron-based X-ray absorption spectroscopy for a direct and quantitative assessment of the magnetosomes transformations *in cellulo*.[2] Remarkably, all measurements converge to the demonstration that intracellular magnetosomes experience an important dose-dependent biodegradation over time, with up to 70% of their initial content degraded within the first days upon incorporation. Surprisingly, two scenarios then emerged following this degradation, depending on the stem cells physico-chemical environment. In 3D spheroids, with the addition of growth factors stimulating the chondrogenic differentiation, the magnetosomes degradation is associated with an extensive magnetite to ferrihydrite phase transition. In contrast, in 2D monolayers, a *de-novo* biosynthesis of magnetic nanoparticles is observed, based on the iron released over the magnetosomes degradation and associated with the magnetization recovery. We recently demonstrated this remarkable capacity of human stem cells to biosynthesize magnetic nanoparticles upon degradation of chemically-synthesized iron oxide nanoparticles,[3] it can now be extended to magnetosomes.

We thus evidence for the first time that magnetosomes can have a true intracellular cycle in human cells, where they are first degraded, then either assimilated in the physiologic iron metabolism and stored as ferrihydrite, or transformed into magnetic nanoparticles.

1. Plan Sangnier, A. *et al.* Targeted thermal therapy with genetically engineered magnetite magnetosomes@RGD *J. Control. Release* 279, 271–281 (2018).

2. Curcio, A. *et al.* Magnetosomes intracellular degradation in human stem cells results in iron state transition from magnetite to ferrihydrite. *Submitted* (2019).

3. Van de Walle, A. *et al.* Biosynthesis of magnetic nanoparticles from nano-degradation products revealed in human stem cells. *Proc. Natl. Acad. Sci.* 116, 4044 LP-4053 (2019).

Superparamagnetic microdevices assembled from controlled arrays of micromagnets

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 582

***Dr. Joseph Tavacoli* [1], *Mr. Christoph Pauer* [1], *Mr. Mihir Dass* [1], *Dr. Julien Heuvingh* [2], *Dr. Olivia Du Roure* [2], *Prof. Tim Liedl* [1]**

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The controlled fabrication of nanoscale and micronscale objects is without doubt one of today's central goals in science and technology, key to the fabrication of advanced industrial and consumer goods, building technologies and optical devices. [1]
A convenient fabrication methodology at such dimensions is self-assembly, that is, the spontaneous creation of ordered structures from individual components. [2] In this presentation we detail how superparamagnetic microdevices with precise actuation characteristics can be fabricated from the magnetic-field induced assembly of superparamagnetic microshapes held in preprogrammed arrays.
Starting from said arrays that hold a single shape designwe use two parameters to manipulate assembly: the array pitch and the angle of an applied homogenous magnetic field in relation the array axis. We demonstrate the effect of these parameters by producing a range of assemblies which we tabulate in 'phase diagrams'. [3] In doing so, we derive a set of design rules from which to assemble specific structures that can be remotely actuated with external magnetic fields – such as swimmers and beaters – and demonstrate how their design can be rigorously controlled by the assembly method. Finally, we detail our attempts to engineer polymer links between our microshapes to enhance the flexibility and actuation performance of their assembled architectures in response to oscillating magnetic fields.

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Demonstration of vessel constriction in a numerical model of magnetic drug targeting for a branched artery model

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 601

Ms. Veronica Carla Gonella [1], ***Prof. Stefan Odenbach*** [2], ***Prof. Daniel Baumgarten*** [1]

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Introduction

Magnetic drug targeting is a promising approach in cancer therapy. Therapeutic substances bound to magnetic nanoparticles are concentrated in a target region by manipulating the particles with an external magnetic field. However, the accurate control of ferrofluids motion still represents a challenge. Mathematical models are a powerful tool to predict flow-mediated ferrofluid mass transport to support patient-specific therapy planning. We present a computational fluid dynamic model to predict the transport of a ferrofluid concentration in a steady fluid flow under the influence of an external magnetic field. By reproducing the setup of experimental investigations[1], the model is verified by comparing the outcome of the simulation to the experimental results.

Methods

In our model, developed in COMSOL Multiphysics, the advection-diffusion equation was implemented to describe the ferrofluid mass transport and coupled to the Maxwell equations to describe the magnetic field. A two-way coupling approach[2] has been employed to consider the fluidic drag on the particles as well as the magnetic momentum transfer from the accelerated nanoparticles towards the fluid. A setup comprising a steady flow through a Y-branched tube and a permanent magnet in specific positions[1] was emulated in the model. The time-dependent ferrofluid behaviour was simulated and the targeting efficiency, i.e. the fraction of ferrofluid attracted to the branched tube by the magnet, was computed for selected magnet positions.

Results

Simulation results (*Fig. 1*and*2*) reproduced the uptake pattern described for the experiments mentioned above. We observed that the targeting efficiency increased with the magnetic fluid volume force on the ferrofluid determined by the distance of the magnet. However, bringing the magnet too close to the tube leads to a drop in the efficiency due to obstruction of the branched tube by ferrofluid being kept below the magnet.

Conclusion

The presented numerical model proved to be representative for the experimental observations. Quantitative deviations to the experimental results can be explained by the neglection of particle scale phenomena, e.g. particle-particle interaction, particle clustering acting as additional local magnetic field sources.

References

[1] Gitter et al., J Mag Magn Mat 323, 2011

[2] Fratzl et al., Soft Matter 14, 2018

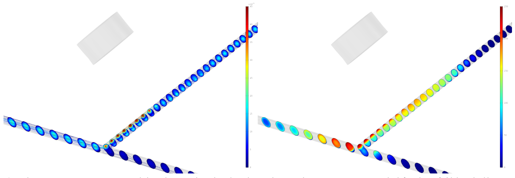

Fig. 1 The permanent magnet is positioned along the target branch and results are shown at the same time instant. On the left: velocity field described by slices and streamlines coloured by velocity magnitude (in m/s) . On the right: ferrofluid molar concentration distribution (in mol/m^3). It can be noticed how the flow streamlines are locally influenced by the magnetic field and how the ferrofluid concentration moves according to the magnetic field gradients.

Permanent magnet along the target branch.png

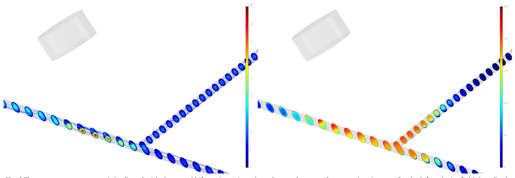

Fig. 2 The permanent magnet axis is aligned with the vessel bifurcation axis and results are shown at the same time instant. On the left: velocity field described by slices and streamlines coloured by velocity magnitude (in m/s). On the right: ferrofluid molar concentration distribution (in mol/m^3). The magnetic field shapes again the flow streamlines and dictates the ferrofluid distribution into the fluid domain.

Permanent magnet aligned with the vessel bifurcation axis.png

Chains of ferromagnetic nanoparticles in biological shear flows

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 604

Dr. Nina Podoliak [1], ***Dr. Giles Richardson*** [1], ***Dr. Ondrej Hovorka*** [1]

1. *University of Southampton*

Magnetic nanoparticles have shown significant potential in biomedicine for applications such as targeted drug delivery, magnetic resonance imaging and magnetic hyperthermia [1]. Development of these applications requires understanding the behaviour of magnetic nanoparticles in vasculature and biological tissue. It was shown that the nanoparticles in vascular flow subject to external magnetic field form stable chain-like aggregates [2]. Their hydrodynamic behaviour in biological fluids depends on the chain orientation, which result from a competition between the particle-fluid and particle-magnetic field interactions.

We investigate the orientational stability of magnetic nanoparticle chains in a static magnetic field and under shear flow. We consider a chain of ferromagnetic uniaxial particles coupled by dipolar interactions. The particles may have a layer of non-magnetic surface coating. The stable orientations of magnetic chains in the flow result from the competition between the magnetic field and fluid torques. The magnetic torque is calculated numerically in a self-consistent manner, accounting for the magnetic hysteresis which, given that particles are ferromagnetic, is essential. The torque produced by the shear flow is evaluated using a slender-body theory approach [3], which is shown to be more accurate than using Stokes drag formula for individual particles. The orientational and mechanical stability of chains is then determined the balance condition between particle dipolar attraction force and the fluid force.

We calculate the stable chain orientation for arbitrary strength of the applied magnetic field, biologically relevant shear rates, chain length and particle properties, and the thickness of non-magnetic surface coating. By considering the chain stability condition, we evaluate the critical shear rate that destroy the chain, as well as the critical chain length.

The present model can be used for modelling the magnetic nanoparticle chains in more complex biological flows. It can be also relevant for other magneto fluidic problems, which rely to particle chain formation.

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Magnetometer Based Sensing for Magnetic Fluid Control in Biomedicine and Drug Delivery

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 609

Mr. Michael Colella [1], Ms. Skylar Eiskowitz [1], Mr. Jacob Maarek [1], Prof. David Trubatch [2], Mr. Haoran Wei [1], Prof. Philip Yecko [3]

1. The Cooper Union, 2. Montclair State University, 3. Cooper Union

Magnetic drug delivery has been shown to carry drugs to tumors in both shallow areas just beneath the skin and in hard-to-reach areas, such as the back of the eye or inner ear. Less effort has been put into realistically implementing a control system that moves magnetic fluid regions to a specified, possibly deep, location within the body. In particular, most practical control systems rely of some form of sensing (i.e. to locate the magnetic fluid) yet most current studies have relied on the use of videocameras for sensing and to validate magnetic fluid control strategies. In transitioning these systems for use on cancer patients and in opaque regions of the body, non-visual sensing and control systems are needed.

In this paper, we create an innovative method of passively imaging carriers in real time using low cost readily available magnetometers in a geometric array and without using visual feedback. An algorithm is developed to use the magnetometers data to track the position of a permanent magnet and a ferrofluid droplet in real time, validating the approach. Our sensing system could be easily developed into a handheld medical device. Moreover, our device bridges the gap between the research done on magnetic drug therapy in idealized settings and the more realistic conditions found in vivo.

Figure 1 shows the 4 magnetometer array used for sensing the location of a ferrofluid droplet within the central petri dish; a single external (control) magnet is also shown. In figure 2 we show an example field due to a magnetized drop of ferrofluid in the presence of the field of one magnet. Figure 3 shows the visual sensing system used as a baseline for development of magnetometer sensing and control.

To close the loop, data obtained from the magnetometer sensing algorithm will next be integrated into the magnetic field control algorithm. In addition, the magnetometer array can be redesigned to locate the magnetometers on different planes to restrict the localization solutions even more, while the algorithm and controls can both be extended easily to three-dimensional space.

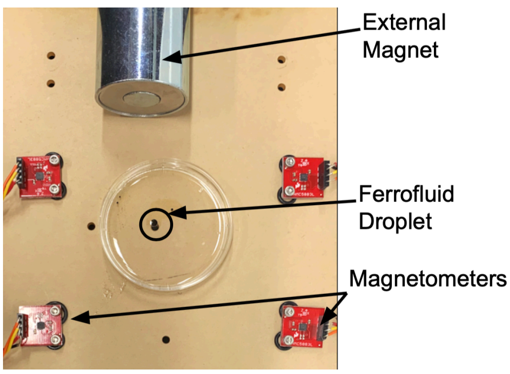


Figure1.png

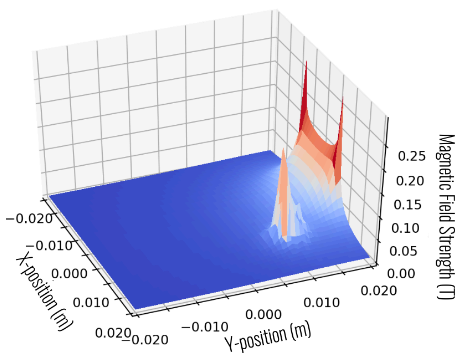


Figure2.png

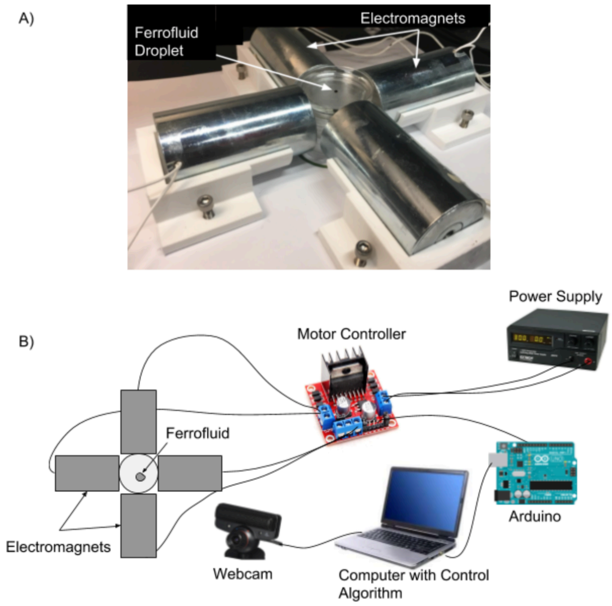

A)
Ferrofluid
Droplet
Electromagnets
B)
Motor Controller
Power Supply
Ferrofluid
Arduino
Electromagnets
Webcam
Computer with Control
Algorithm

Figure3.png

Field-induced Deformation of Nanorod-Hydrogel-Composites

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 624

Ms. Kerstin Birster [1]***, Mr. Rouven Schweitzer*** [1]***, Mr. Daniel Schmid*** [1]***, Dr. Andreas Tschöpe*** [1]

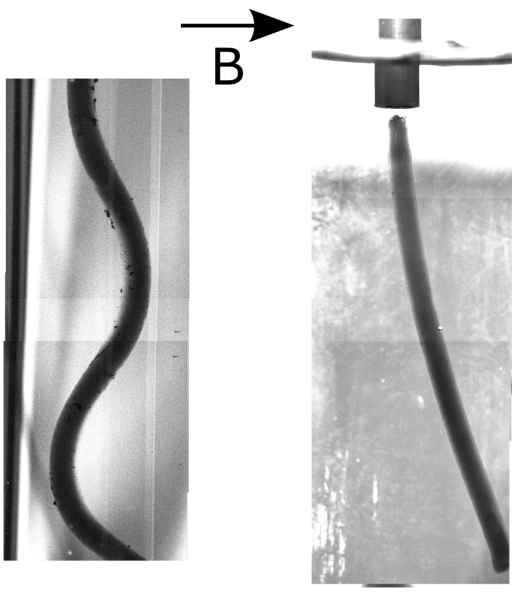
1. *Saarland University*

Shape-changing smart materials are able to reversibly deform in response to an external stimulus such as temperature, pressure, or electric and magnetic fields. An evident application is their use as active components in soft microactuators.

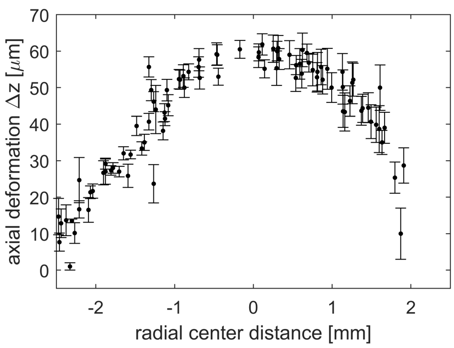
In the present study, we used ferromagnetic single domain nanorods as magnetic phase in cylindrical shaped polyacrylamide hydrogel composites. During polymerisation a magnetic texture was imprinted by alignment of the anisotropy axes in magnetic fields of predefined geometry. If the nanorods are directed perpendicular to the long cylinder axis, the composite is forced to a torsional deformation [1]. Composites with a magnetic texture component parallel to the long axis, perform a bending deformation in a transversal magnetic field. Both deformation patterns were measured by video microscopy and data were analyzed assuming a continuum model with volume-distributed torques.

Aiming at a high volume fraction of isolated magnetic nanoparticles, we used a magnetic gradient field to collect core-shell nanorods with adsorbed gelatin in a thin 2D layer. The magnetic texture inside the layer is tunable by the geometry of the permanent magnet setup. A coaxial configuration of a NdFeB cylinder inside a hollow cylinder of reverse magnetization was investigated as a particular example. The geometry of the stray field was determined experimentally by optical transmission measurements with linearly polarized light and was compared with a finite elemente simulation. With the field-guided assembly, we realized a nanocomposite layer with circular texture of the magnetic anisotropy. Application of a homogeneous magnetic field perpendicular to the surface of the sample generated a bowls like deformation which was measured by video microscopy.

[1] Schopphoven, C. et al, Arch Appl Mech, Issue 1, pp 119–132.



Bending deformations of 1d composites.png



Axial deformation of a 2d gelatin-nanorod composite layer.png

Magnetic Anisotropy Due to Self-Assembled Particle Chains Enhances Magnetic Heating and Torques

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 627

Prof. Benjamin Evans [1], ***Ms. Kayla Pieri*** [1], ***Mr. Robert Feather*** [1], ***Ms. Jessica Liu*** [2], ***Prof. Joseph Tracy*** [2]

1. *Elon University,* ***2.*** *North Carolina State University*

Magnetic-particle/polymer composites have been developed for applications ranging from magnetic nanoparticle hyperthermia (MNH) to magnetic actuation. In many cases, the microenvironment of the magnetic particles may have a dramatic effect on performance. In nanoparticle hyperthermia, for example, it is becoming increasingly apparent that interparticle magnetic interactions in concentrated ensembles may dominate the individual attributes of constituent nanoparticles [1]; similarly, in magnetic actuators, interactions between magnetic particle pairs may influence the direction and magnitude of applied magnetic torques.[2] In this work, we investigate the effects of self-assembled chains of magnetic nano- and microparticles in magnetic-particle/polymer composites. Magnetic nanocomposites were composed of magnetite particles (7-nm) dispersed in a polydimethylsiloxane-co-aminopropylmethylsiloxane matrix [3] and ordered into chain-like structures under the influence of a uniform 300-G magnetic field prior to crosslinking. Subsequent exposure to RF magnetic fields (80-460 kHz, 164-300 G) resulted in substantial improvement in heating rates relative to unchained materials. Likewise, self-assembled chains of 4 to 100-um iron particles in thin films of polyurethane and polydimethylsiloxane resulted in a directionally-dependent enhanced heating as well as enhanced magnetic torques leading to more facile actuation. In both nano- and microparticle composites, magnetic anisotropy due to particle chaining was quantified with torque magnetometry, and measured anisotropy energy was shown to correlate well with enhanced RF heating and enhanced performance of actuators.

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Characterization of conjugated of poly(succinimide)-carboplatin anticancer drug

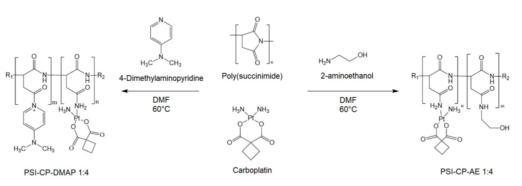
Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 645

Ms. Petra Bankó [1], Prof. Dong Hyu Cho [2], Dr. David Juriga [3], Prof. Miklós Zrínyi [3], Dr. Judit Berta [4], Prof. CHANG HOON CHAE [3]

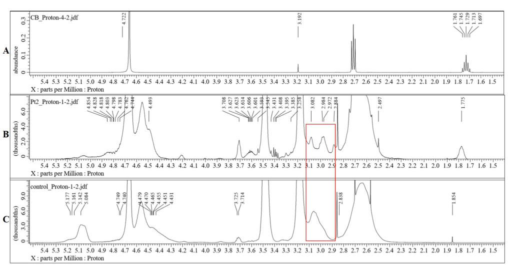
1. Budapest University of Technology and Economics, 2. Chonbuk National University Hospital, 3. Semmelweis university, 4. National Koranyi Institute of Pulmonology

Our study is to report the in vitro characteristics, cell viability and activity of iNOS gene in when carboplatin is added in a conjugated to PSI (polysuccinimide). PSI is a biodegradable and biocompatible polymer and has promising properties as a drug delivery material. We have examined the expression of the iNOS gene, because it has shown to play an important role in both cancer cell survival and inhibition. We synthesized PSI and conjugated it with carboplatin to create a modified chemotherapeutic agent. We were able to confirm that the carboplatin was successfully conjugated to the PSI through NMR experiment. In order to achieve a water-soluble modified anticancer agent, we conjugated further modifying groups (Ae) to the PSI-carboplatin conjugate. To confirm the biological characteristics of the conjugated carboplatin, SKOV-3 cell and CHO cell were treated with the conjugate alone and in combination with paclitaxel and topotecan, which are used in conventional chemotherapy. The cell viability, carboplatin conjugated polymer showed less cytotoxic effect than carboplatin. However, when we examined the cell survival rate, paclitaxel in combination with the carboplatin conjugated polymer treatment showed inhibition in the growth of ovarian cancer cells. Cytotoxicity tests on normal ovarian cancer cell showed no effect on the growth in the group treated with paclitaxel in combination with carboplatin conjugated polymer. In the mRNA expression study of INOS, there was no expression when treated with paclitaxel alone in cancer cells, but it was confirmed that the combination of carboplatin conjugated polymer with paclitaxel resulted in overexpression. Expression studies of the INOS protein showed normal expression of the protein in all groups, but in the case of the combination of carboplatin conjugated polymer with paclitaxel, there was no protein expression compared to the mRNA.

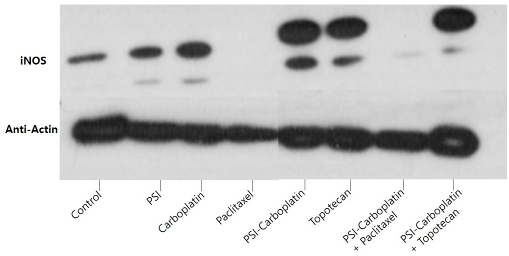
In conclusion, it is possible to confirm the possibility of a newly synthesized compound through the conjugating of the polymer and the inorganic compound platinum. The carboplatin-polymer conjugate and the paclitaxel treatment displayed anticancer activity on ovarian cancer cell and no toxic effects on normal ovarian cancer cells, resulting in the development of candidate anticancer drug that remains effective while eliminating severe side effects.



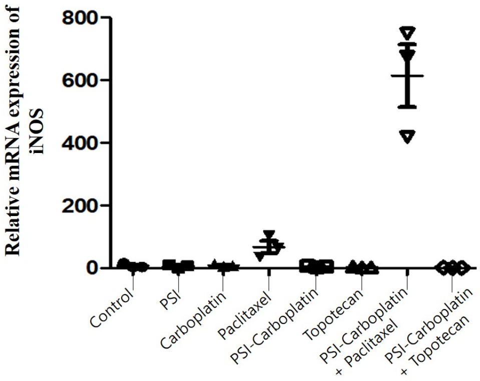
Synthesis of psi-carboplatin conjugat.jpg



1h nmr spectroscopy.jpg



Western blot.jpg



Mrna expression.jpg

Combined magneto-optical and fluorescence microscopy instrument for broadband AC susceptibility and magnetometry on nanoparticles

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 653

Dr. Maneea Eizadi Sharifabad [1], ***Dr. Rémy Soucaille*** [2], ***Prof. Rob Hicken*** [2], ***Prof. Neil Telling*** [1]

1. *Keele University,* ***2.*** *University of Exeter*

Hyperthermia cancer treatment exploits the lowered heat resistance of cancerous tissues compared to normal tissues [1]. Nanoparticles-mediated hyperthermia treatment is a promising cancer therapy that enables selective heating of cancerous tissues to slow or stop tumour growth whilst also increasing tumour sensitivity to chemotherapy and radiotherapy [2]. Importance of magnetic hyperthermia determines the growing interest in development of various magnetic nanocomposites and consequently necessitate the need for development of efficient characterisation tools capable of assessing nanoparticles at relevant clinical conditions.
Generally, magnetic characterization of magnetic nanoparticles is performed using inductive coil-based setups. However, such measurements are limited to lower frequencies where the heating of the sensing coils can be minimised. Further, coil based methods provide only averaged measurements and information on local environmental factors is lost.
Here we present a new magneto-optical and fluorescence microscopy capable of performing high-frequency magnetometry and susceptibility measurements of magnetic nanoparticle colloids in hyperthermia condition. The added fluorescence lifetime feature allows us to simultaneously measure magnetisation dynamics, temperature and biological changes in the cellular environment independent of the dye concentration. This could advance our understanding of magnetisation dynamics, heat generation and relaxation mechanisms in cellular environments upon exposure to alternating magnetic fields which in turn lead to optimisation of nanoparticles' design for magnetic hyperthermia cancer treatment.
We use the same laser (wavelength: 488 nm) to excite the fluorescent dye and measure the magnetization dynamic. The laser intensity is modulated at high frequency (20-40MHz) to measure the fluorescence lifetime and the polarization axis is modulated at the frequency of the applied magnetic field through the Faraday effect. The rotation of the polarization is proportional to the projection of the magnetic nanoparticle magnetization along the direction of the light propagation. Our electromagnet can generate magnetic fields relevant for magnetic hyperthermia, with an amplitude as high as 50 mT up to 500kHz and frequencies up to 1 MHz for low amplitude AC susceptibility measurement while keeping an optical access to the sample.

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Hyperthermia and cell uptake properties of manganese and zinc ferrites magnetic nanoparticles

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 661

***Dr. Cristian Iacovita** [1], **Dr. Adrian Florea** [1], **Dr. Roxana Dudric** [2], **Ms. Lavinia Scorus** [1], **Dr. Emoke Pall** [3], **Prof. Romulus Tetean** [4], **Prof. Rares Stiufiuc** [1], **Prof. Constantin Mihai Lucaciu** [1]*

***1.** Iuliu Hatieganu University of Medicine and Pharmacy Cluj-Napoca, **2.** Babes Bolyai University Cluj-Napoca, **3.** University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, **4.** Babes-Bolyai University Cluj-Napoca*

The remarkable magnetic properties of spinel ferrite magnetic nanoparticles (MNPs) make them suitable for a broad spectrum of biomedical applications [1]. In particular, manganese and zinc ferrites are nowadays thoroughly investigated as both hyperthermia and magnetic relaxation enhancement agents.
Multicore manganese and zinc ferrites MNPs with a diameter around 80 nm were synthesized by means of a polyol method, using chloride magnetic precursors, sodium acetate and ethylene-glycol (figure a) [2]. X-ray diffraction patterns clearly reveal the formation of spinel phase cubic ferrites, while the position of all diffraction peaks ascribe to $MnFe_2O_4$ and $ZnFe_2O_4$ MNPs. However, a small percent (10%) of ZnO is detected in the case of $ZnFe_2O_4$ MNPs. Both types of MNPs exhibit a ferrimagnetic behavior at room temperature, the $MnFe_2O_4$MNPs displaying a higher saturation magnetization (figure b). The evolution of specific absorption rate (SAR) on the external alternating magnetic field amplitude of both types of MNPs presents a sigmoidal shape (figure c) [2, 3]. Upon dispersion in water, $MnFe_2O_4$MNPs exhibit a remarkable saturation SAR value of 1000 $W/g_{Fe\text{-}Mn}$, while $ZnFe_2O_4$MNPs display only 650 $W/g_{Fe\text{-}Zn}$. SAR values depend on the concentration of MNPs and considerably decrease when both MNPs are dispersed in highly viscous/solid PEG8000. Toxicity assays (standard MTT) performed on four cell lines revealed almost no toxicity for both MNPs up to a concentration of 0,05 mg/ml. Upon an increase in the concentration (up to 0,2 mg/ml), a significant drop in the cell viability is recorded: 15% for $MnFe_2O_4$MNPs and 35% for $ZnFe_2O_4$ MNPs. The cellular uptake experiments show that both types of MNPs penetrate the cells through endocytosis, in a time dependent manner and escape the endosomes (figure d). It was also observed the biodegradation of the MNPs inside cells, while some cells were found to be dead.
This research was supported by the Romanian Ministry of Research and Innovation, CNCSIS-UEFISCDI, through research projects No. PN-III-P1-1.1-TE-2016-0967 and No. PN-III-P4-ID-PCCFF-2016-0112, NanoTEX.

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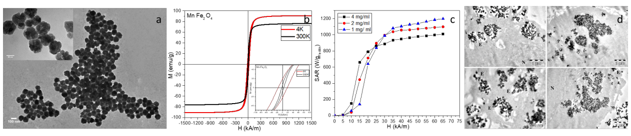

Figure abstract lucaciu.png

Induction heating studies of Fe-Mn ferrite nanoparticles for magnetic fluid hyperthermia

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 407

Ms. Jyoti Dhumal [1], *Mr. Sushil Bandgar* [1], *Dr. Kisan Zipare* [2], *Dr. Guruling Shahane* [1]
1. DBF Dayanand College of Arts and Science, Solapur, 2. C.B. Khedgi's B. Sci., R.V. Comm. and R.J. Arts College, Akkalkot

Magnetic nanoparticles of transition metal ferrites (MFe_2O_4, M = Mn, Co, Ni etc.) having a spinel structure are of great interest for their properties, which are novel in comparison with the corresponding bulk materials. In particular, they exhibit superparamagnetic behavior attributable to the nanometric size of the particles. They find applications in miniaturized devices such as magnetic storage devices, photomagnetic materials and in biomedical applications such as site specific drug delivery, hyperthermia treatments, MRI, etc. Many preparation technologies of manganese ferrites such as sol–gel, auto-combustion, thermal decomposition, chemical co-precipitation, hydrothermal, ball milling, reverse micelle synthesis, solid-phase reaction, thermally activated solid state reaction and pulsed laser deposition have been developed to prepare the single-domain Fe-Mn nanoparticles. Among these methods chemical co-precipitation method has the advantage of better control on particle size and size distribution. We have synthesized Fe-Mn ferrite nanoparticles with composition $Fe_{1-x}Mn_xFe_2O_4$, (x=0, 0.3, 0.5, 0.7, 1) by chemical co-precipitation method.
The nanoparticles have good crystallanity with average crystallite size of the order of 10-12nm. From TEM analysis it is seen that the sample contains nanoparticles with the average particle size of 10nm. Formation of the spinel Fe-Mn ferrite was also supported by Fourier Transform Infrared Spectroscopy. The VSM study reveals superparamagnetic nature of the sample with negligible remanence and coercivity. The saturation magnetization (Ms) values are in the range of 30emu/g to 45emu/g. The Fe-Mn nanoparticles exhibited specific absorption rate (SAR) of about 78.85W/g at physiological safe range of frequency 289 KHz and amplitude 15kA/m. In vitro biocompatibility study of $Fe_{0.3}Mn_{0.7}Fe_2O_4$ nanoparticles was carried out using L-929 mouse fibroblast cell line MTT assay purchased from APT Research Foundation, Pune, India. The study showed dose-dependent cell viability. The synthesized nanoparticles are found suitable for hyperthermia application.

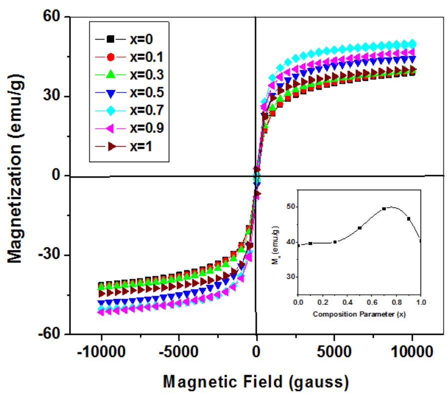

Fig. 1: Magnetization curves of $Fe_{1-x}Mn_xFe_2O_4$ nanoparticles with different compositions

Fig 1.png

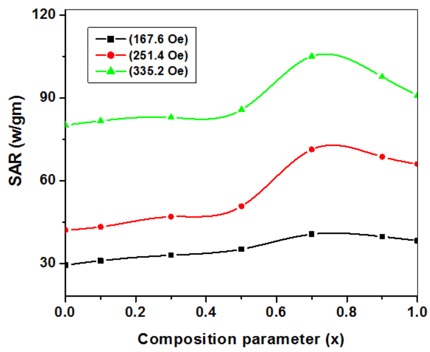

Fig. 2: Variation of SAR as a function of composition parameter.

Fig 2.png

Anisotropic nanocomposites ureasil-PEO-maghemite for drug release

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 592

Dr. Bruno Caetano [1], Prof. Christine Ménager [2], Prof. Celso Santilli [3], Prof. Leila Chiavacci [4], Dr. Alba Marcellan [1], Prof. Dominique Hourdet [1], Dr. Sebastien Abramson [2]

1. Sorbonne Université, PSL, ESPCI, CNRS Laboratoire SIMM UMR 7615, 2. Sorbonne Université, Laboratoire PHENIX UMR 8234 CNRS, 3. Chemistry Institute, UNESP, 4. São Paulo State University (UNESP), School of Pharmaceutical Sciences

The development of platforms for controlled drug release has generated the development of different materials as liposomes, micelles and organic-inorganic hybrids (OIHs). Among the OIH used as drug delivery, siloxane cross-linked macromers known as ureasil-polyether (U-PEO) are an emerging option. These materials present good thermal stability, exhibits hydrophilic characteristics and present different chemical group [1]. Due to these properties, U-PEO has a high capacity to encapsulate ionic species, polar molecules and nanoparticles. Magnetic nanoparticles (MNP) such as maghemite y-Fe_2O_3 or magnetite Fe_3O_4 are a class of highly suitable nanomaterials for use in biomedical applications, due to their biocompatibility and superparamagnetic properties. The combination of both materials has led to U-PEO/y-Fe_2O_3 nanocomposites, with a high potential for applications in drug release [2].

Here, we report the synthesis of nanocomposites formed by the conjugation of U-PEO matrix loaded with curcumin (CUR) and y-Fe_2O_3. These syntheses were realised with or without the application of a magnetic field inducing the orientation of the nanoparticles, to control the rate and direction of the CUR diffusion.

SEM images of the samples synthetized in presence of the magnetic field present parallel lines with length of several micrometers. EDX analysis showed that these lines are due to the chaining of the y-Fe_2O_3inside the matrix (Figure 1). Nevertheless, it was not possible to observe the presence of lines in the SEM images of the nanocomposites prepared without magnetic field, indicating that the y-Fe_2O_3were well-dispersed (Figure 2). The 2-D SAXS images for a sample synthetized with a magnetic field displayed an anisotropic structure (Figure 3), while the 2-D SAXS images for a sample prepared in absence of field showed isotropic characteristics (Figure 4), thus confirming the SEM results. The next steps of the work are to perform CUR diffusion assays to investigate that the anisotropy generated by the presence of the nanoparticles plays an important role in the diffusion process.

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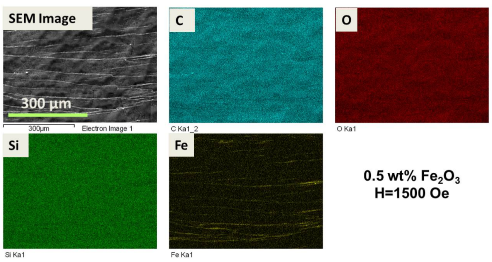

Figure 1 icmf bc.jpg

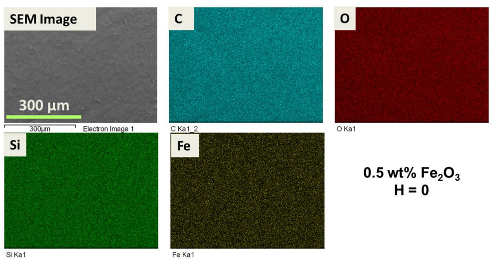

Figure 2 icmf bc.jpg

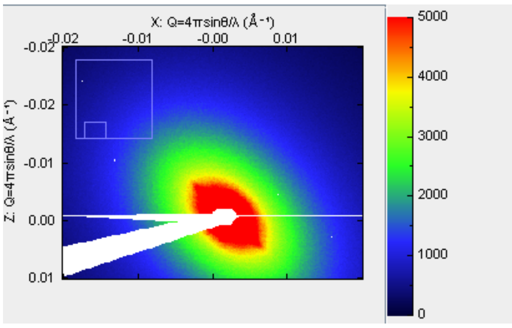

Figure 3 icmf bc.png

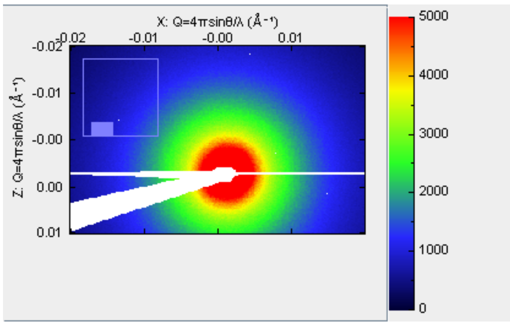

Figure 4 icmf bc.png

Iron oxide nanoflower @ copper sulfide spiky core-shell nanohybrids designed to combine photothermal, magnetic hyperthermia and photodinamic therapy

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 623

Dr. Sonia Cabana [1], *Dr. Alberto Curcio* [2], *Prof. Claire Wilhelm* [3], *Dr. Ali ABOU-HASSAN* [1]

1. Sorbonne Université, Laboratoire PHENIX-CNRS UMR 8234, 2. Paris Diderot University, 3. CNRS / Université Paris Diderot, Laboratoire Matière et Systèmes Complexes UMR7057

Herein we report the design of an optimized nanohybrid for cancer tri-therapy featuring a maghemite (γ-Fe_2O_3) nanoflower-like multicore nanoparticle conceived for efficient magnetic hyperthermia (MHT) and a spiky copper sulfide shell (IONF@CuS) with a high near infra-red (NIR) absorption coefficient suitable for photothermal (PTT) and photodynamic therapy (PDT) (Curcio et al., 2019). The unprecedented spiky-like IONF@CuS nanohybrids were obtained through a template sacrificial synthesis method by tuning polyvinylpyrolidone (PVP) concentration during the synthesis leading to increased IR absorption (Wu et al., 2015). Their structural properties were characterized by combining complementary UV-Vis-IR absorption, TEM, SEM, HR-TEM, EELS, XRD, and NTA. Tests carried out for nanohybrid aqueous dispersion demonstrated the impressive efficiency of IONF@CuS nanohybrids to convert light (conversion coefficient » 42%) and magnetic stimulation (SAR » 350 W g-1) into heat as well as to induce concurrent reactive oxygen species (ROS) formation upon laser irradiation. Such capabilities were also confirmed in cellular environment by in vitro tests and at the organism level by in vivo tests in a murine tumor model. Notably, complete tumor regression was obtained for the PTT mode at low Cu concentration. Overall, these results allowed determining windows of applicability for each therapy individually or in combination. Altogether, the obtained data evidence the successful synthesis of a unique tri-therapeutic nanoparticle introducing prospective of clinical relevance such as reduced nanoparticle administered dose, reduced magnetic field frequency, reduced laser power exposure, possibility of serial heating cycles and therapy monitoring by photoacoustic (PA) and magnetic resonance imaging (MRI).

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Effect of surfactant amount on surfaced ferrofluid thermophoresis

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 309

Mr. Viesturs Sints [1]**, *Dr. Mitradeep Sarkar*** [2]**, *Mr. Jesse Riedl*** [2]**, *Dr. Gilles Demouchy*** [3]**, *Prof. Régine Perzynski*** [2]**, *Dr. Emmanuelle Dubois*** [2]**, *Dr. Gunars Kronkalns*** [1]**, *Dr. Elmars Blums*** [1]

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Experimental research on surfaced ferrofluid thermophoresis in a porous medium has revealed an influence of excess surfactant on surfaced nanoparticle thermal transport.[1] A ferrofluid with magnetite nanoparticles surfaced with oleic acid is used. Increasing concentration of excess surfactant, unbound to the particles, results in a decrease of Soret coefficient, corresponding to a decrease in the tendency of particles to move away from higher temperatures. With sufficient surfactant concentration, particle transport direction is inverted, Soret coefficient changing from positive to negative and the particles now moving towards higher temperatures.

In order to investigate the nature of of this phenomena, series of experiments to characterize the ferrofluid's behaviour in non-isothermal conditions have been performed. The effects are originally observed within a porous layer subjected to a temperature difference but isolated to mass transport. Ferrofluid flow with various surfactant concentrations through an analogous porous layer, but allowing for mass transport through the layer has been investigated. In order to determine the effects of a porous environment, nanoparticle thermophoresis in a free fluid outside of a porous environment is measured using Forced Rayleigh scattering.

The results of ferrofluid flow through the porous layer agree with the decrease of Soret coefficient observed in a closed layer. Soret coefficient measurements in free fluid don't show such a change, suggesting that the observed effect are related to the presence of porous material. Dependence of Soret coefficient on temperature has emerged as an important effect in both cases.

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Exploring the Water Memory hypothesis in a new model of medical device for biomedical applications of Electromagnetic Fields – The “Aubento” new setting.

Thursday, 11th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 463

Mr. Joao Gaspary [1], ***Prof. Fernanda Gaspary*** [2], ***Prof. Eder Simão*** [2], ***Mr. Marcos Ferreira*** [3], ***Mr. Paulo Garcia*** [4], ***Mr. Arnaldo Walty*** [5], ***Prof. Rosane Schlatter*** [1], ***Prof. Fernanda Oliveira*** [1]

1. *Hospital de Clínicas de Porto Alegre,* ***2.*** *Universidade Franciscana,* ***3.*** *Universidade Federal de Santa Maria,* ***4.*** *Universidade Regional do Noroeste do Estado do Rio Grande do Sul,* ***5.*** *Soul Sul Produções*

BACKGROUND: The Water Memory (WM) hypothesis was first suggested by Benveniste in 1988 and it generated a great number of controversial scientific reactions. Since then, several publications have begun to explore the memory capacity of water based on its capacity to store energy. Posteriorly, it was concluded that water has the capacity to store and release substantial amounts of charge. The Fourth Phase of Water theory explains that it stores energy by order and charge separation. It was also demonstrated that the collective dynamics can arise in colloidal systems subjected to electromagnetic fields (EMF). The majority of in vitro research of therapeutic action of EMF are performed with cells immersed in aqueous colloidal solutions. This scenario is not repeated in clinical use.

AIM: To analyze if WM hypothesis can be used for biomedical applications of EMF the first step was to perform a design experience of a new medical device for clinical use.

METHODS: The project was conducted as part of a Master’s Dissertation in Clinical Research at Hospital de Clínicas, Porto Alegre, Brazil. An interdisciplinary team of professionals composed by biologist, clinicians, architect, physicist and design engineer, who were part of the design experience that generated a patent “AuBento”.

RESULTS: The new device acts as a camera where the patient comes in full contact with the pre-defined colloidal aqueous solution. These solution is prepared by receiving a pre-defined charge of EMF in a personalized manner according to the set of patient’s symptoms. During the session, the patient is not directly influenced by a new source of EMF. He is floating in the liquid and listening to music. The fluid flow is produced by a low-frequency active sonar, to stimulate patient relaxation. When the session ends, the solution is discarded. With each new patient, the process restarts.

CONCLUSIONS: This study explores the hypothesis that EMF can also be stored in water and it can be used for medical applications. Future research for proper clinical validation of this new device may allow the demonstration of the possible benefit of this nanotechnology to increase quality of life and symptom control in patients.

Long distance heat transport device using temperature sensitive magnetic fluid

Thursday, 11th July - 16:50: Plenary Speech Session - Oral - Abstract ID: 272

Prof. Hiroshi Yamaguchi [1], *Dr. Takeshi Bessho* [2]

1. Doshisha University, Kyoto, Japan, 2. Toyota Motor Corporation, Aichi, Japan

The most unique feature of temperature-sensitive magnetic fluid (TSMF) is that the thermal flow behavior is actively controlled by means of magnetic field. In view of transporting thermal energy, there exists a heat pipe. With modern technology applying to heat pipes the technical challenge is actively under way. The conventional heat pipe (with wick structure), however, has a limitation that maximum heat transport distance is approximately 10 m for an advanced heat pipe. With this aspect the device using TSMF has not only a great potential of high performance heat transport ability, but also long distance energy (heat) transporting capability. Taking into account of the advantages of thermo-magnetic properties, a prototype heat transport device using TSMF is newly designed for recovering low to high temperature available heat. In the present study, a closed loop heat transport device is newly constructed for transport thermal energy in long distance as schematically shown in the first figure. From measurements, it was shown that volumetric flow rate Qm increases as heat source temperature T is increased as show in the second figure. It is also verified that the heat transport device transports heat with self-driving pressure for a channel length of more than L = 10 m. In order to examine self-driving capability the self-driving pressure ΔPm is also estimated by measured magnetic field strength, which is approximated by a fitting function. When the applying magnetic field strength is altered with the function, the predicted self-driving pressure ΔPm can well predict the data gained in the experiment, and suggests higher heat transporting capability, as shown in the third figure.

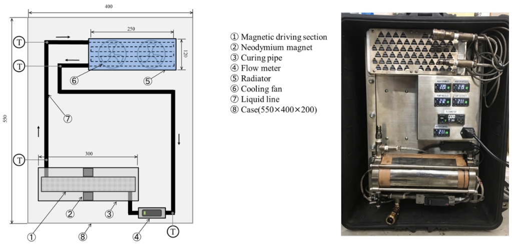

Fig. 1.png

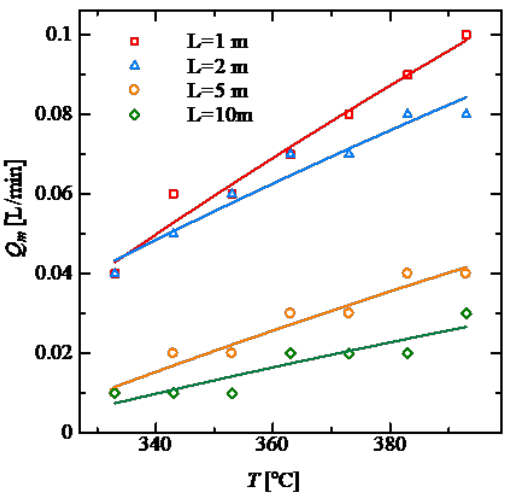

Fig. 2.png

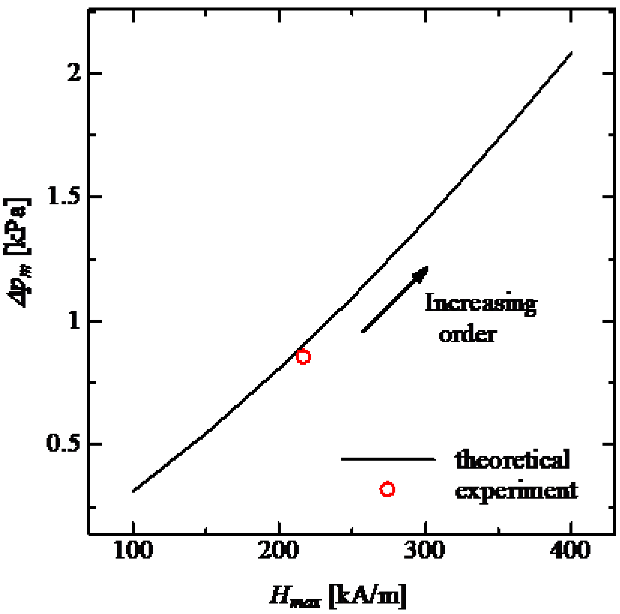
2
1.5
1
0.5
Δp_m [kPa]
100
200
300
400
H_max [kA/m]
Increasing order
theoretical
experiment

Fig. 3.png

Induction Heating Properties of Ferromagnetic Composite for Varicose Veins Healing

Thursday, 11th July - 17:05: Plenary Speech Session - Oral - Abstract ID: 187

Ms. Ziyin XIANG [1]***, Mrs. Minh-quyen LE*** [1]***, Mr. Pierre-Jean COTTINET*** [1]***, Mr. Benjamin DUCHARNE*** [1]

1. *LGEF Lab INSA LYON*

Key words

Ferromagnetic composites, hysteresis loss, low-frequency induction heating, varicose veins healing.

Abstract

In this study, we investigate ferromagnetic composites made of ABS thermoplastic matrix fulfilled with iron oxide particles (Fe3O4). The low frequency induction heating effect (LFIH) in such composites is mainly due to the hysteresis losses linked to the magnetic domain's wall motions under low frequency alternating magnetic excitation fields [1]-[3]. Therefore, LFIH can be used as varicose veins treatment. In the future, the LFIH method will probably outclass the existing treatment methods as its performances in terms of precision, cost and applicability seem much better [4].

For the hysteresis characterization of the magnetic properties and validation of the LFIH method, samples with different shapes and particle volume fractions were built. Magnetic properties such as hysteresis cycles, permeability, remnant inductions, and coercive fields … were measured using the experimental test bench illustrated in Fig. 1. For the validation of the LFIH method, a specific experimental test-bench was developed. This new set-up is shown in Fig. 2. An alternative magnetic field with significant amplitude under a frequency range varying from a few hundred Hz to 2.5 KHz was generated by an inductor made of 8 strong permanent magnets located on a high speed electric motor rotating output shaft.

A significant temperature increase of the ferromagnetic composite was observed by the thermal camera after 5 minutes, as illustrated in Fig. 3 a). To highlight the ferromagnetic composites induction heating effect, a comparison with electrically conductive but non-ferromagnetic samples was performed. In Fig. 3 b), as opposed to the ferromagnetic composite, the conductive sample exhibited a very weak response to the magnetic field excitation and no temperature variation was observed.

The temperature variations of the ferromagnetic composites confirmed their potential as local heating and healing treatment for medical applications. Characterizations under simultaneous magnetic and thermic excitation also revealed very stable magnetic properties (stable permeability can been achieved on a very large temperature range) confirming the reliability of the developed composite magnetic properties.

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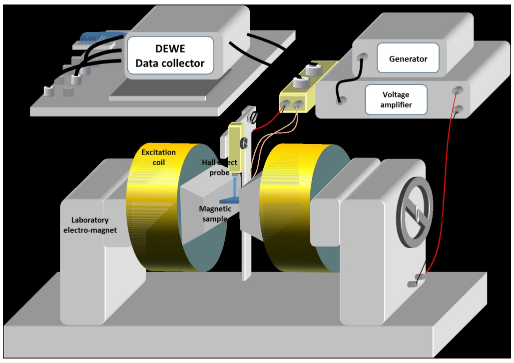

Figure 1. experimental setup for the magnetic characterization of the magnetic composites..jpg

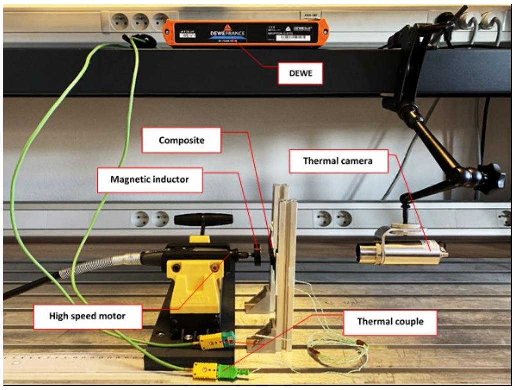

Figure 2. experimental setup for the induction heating effect..jpg

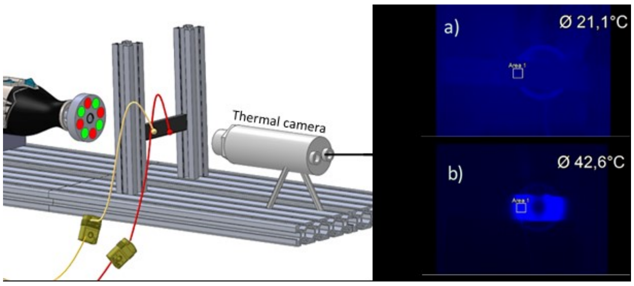

Figure 3. lfih thermal camera observation under steady ac magnetic field excitation. a conductive composite. b ferromagnetic composite..jpg

Bidisperse Magneto-Rheological Fluids

Thursday, 11th July - 17:20: Plenary Speech Session - Poster - Abstract ID: 224

Ms. mona nejatpour [1], *Prof. Havva Yagci Acar* [1], *Prof. uğur Unal* [1]
1. KOÇ UNIVERSITY

The aim of this study was to prepare bidisperse magnetorheological fluids (MRFs) with reduced sedimentation, oxidation, and improved chemical stabilities. For this purpose, carbonyl iron was subjected to surface modification and combined with surface active nano-scale iron oxide nanoparticles. Particles and the MRFs were analyzed by transmission electron microscopy (TEM), scanning electron microscopy (SEM), vibrating sample magnetometer (VSM) and FTIR. The magnetorheological properties of bidisperse MRFs were examined under an applied magnetic field using a tween-gap parallel-plate-type Rheometer both in rotational and oscillatory modes. In addition, the yield stress behavior of the prepared samples was examined in various temperatures. Obtained results were compared with 140-CG MRF from Lord Corp. as the benchmark. Results showed that the synthesized bidisperse MRFs represent a comparable rheological behavior when compared to 140-CG MRF but with improved stability.

Key words: Magnetorheological fluids, superparamagnetic iron oxide, bidisperse MRFs, yield stress

Bidisperse MRFs	Code
140-CG MRF LORD	140-CG
83wt%(CI_LA+12wt%SPION_PAA+3wt%PVA of total oil gram) in hydraulic oil	MRF-8
83wt%(CI_LA+12wt%SPION_PAA+3wt%PVA of total oil gram) in mineral oil	MRF-9
83wt%(CI_LA+12wt%SPION_PAA+3wt%PVA of total oil gram) in paraffin	MRF-10
84wt%(CI_LA+9wt%SPION_PAA) in hydraulic oil	MRF-11
84wt%(CI_LA+12wt%SPION_PAA+3wt%PVA of total oil gram) in hydraulic oil	MRF-12

Table.png

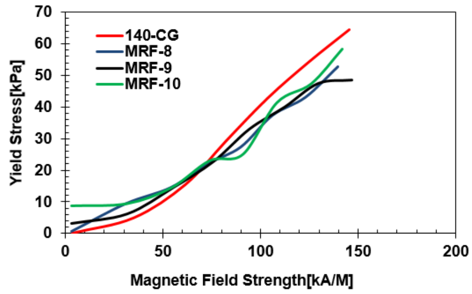

Figure 11. Yield Stress vs. Magnetic field strength.

3.png

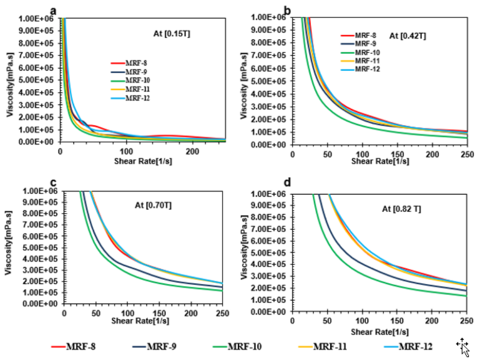

Figure 8. Viscosity under applied Shear rate for MRFs using lauric-acid coated carbonyl Iron in four different magnetic flux density.

2.png

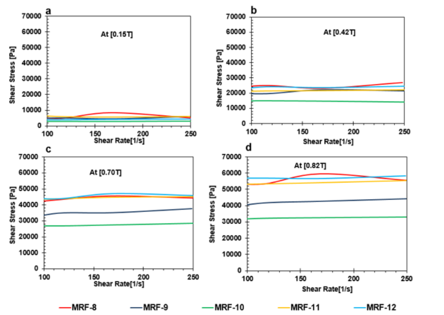

Figure 6. Shear Stress under Shear rate for MRFs using lauric-acid coated carbonyl Iron.

1.png

Magnetorheology of ferrofluids – effects beyond suspensions in newtonian carrier liquids

Thursday, 11th July - 17:50: Invited Speech Session - Oral - Abstract ID: 452

Prof. Stefan Odenbach [1]

1. *Chair of Magnetofluiddynamics, Measuring and Automation Technology, TU Dresden, 01069 Dresden, Germany*

One of the most outstanding changes that can be produced with magnetic fields in magnetic suspensions is the change in their viscosity. Two different processes have to be distinguished. On the one hand, the so-called rotational viscosity where the magnetic field hinders the rotation of the particles in a shear flow through the alignment of the magnetic moment of magnetic hard particles, resulting in an increase in viscosity. This effect, theoretically described by Shliomis, can achieve a maximum percentage viscosity increase equal to one and a half times the volume concentration of the magnetic particles.

The viscosity changes can be much greater if the magnetic particles interact and form large structures such as chains. This effect is well known from magnetorheological suspensions in which micrometer sized particles are suspended and effects can be generated that can easily be used for technical applications like damping systems or clutches.

Also in ferrofluids changes of viscosity by structure formation have been proven. The formation of chains not only leads to a significantly increased viscosity change but also to non-Newtonian effects such as visco-elasticity or normal stress differences. However, the effects here are orders of magnitude smaller than in magnetorheological fluids and they are extremely sensitive to mechanical loads, which means that they can only be detected at very low shear rates.

A question that has always been of interest in this context concerns suspensions of magnetic particles where the carrier liquid is a non-Newtonian liquid. Especially when such carrier media contain larger structures such as non-magnetic particles, liquid crystal molecules or cells, the question arises what the interaction between these objects and the structures formed by the magnetic particles looks like.

Using the example of mixtures of blood with magnetic nanoparticles it will be shown that the viscosity increase is many times higher than in pure ferrofluids and that shear stability increases significantly. For the medical application of ferrofluids, this is a significant change in the overall situation. The increase in viscosity in the magnetic field changes the flow processes and thus the efficiency of biomedical applications.

Self-assembly, trapping and manipulation of nonmagnetic microobjects with magnetic fields

Friday, 12th July - 09:00: Keynote Speech Session - Oral - Abstract ID: 234

Prof. Bartosz Grzybowski [1]

***1.** UNIST*

Magnetic fields can manipulate non-magnetic/diamagnetic objects provided these objects are immersed in a medium of significantly higher magnetic susceptibility (e.g. solution of a paramagnetic salt or suspension of magnetic nanoparticles). Besides levitating a frog (for which an Ig-Nobel was once given to a future Nobel laureate), this phenomenon has been used in the assembly of macroscopic components as well as formation of colloidal arrays of various compositions. Along these lines, the first part of my talk will focus on the use of micropatterned static magnetic fields to drive formation of both mono-component and multi-component colloidal arrays, colloidal molecules, three-dimensional assemblies, and even arrays of bacteria and colloid-bacteria hybrids. These assemblies can comprise up to hundreds of millions of regularly positioned components. In the second part of the talk, I will focus on using magnetic fields to trap and manipulate *individual* non-magnetic microobjects. In the system we have recently developed, the microobjects (colloids or live cells) are immersed in a high-susceptibility solution ($HoNO_3$ or Fe_3O_4/dextran nanoparticles, respectively) subject to a uniform magnetic field (~ 20 mT) produced by an external electromagnet. A sharp coaxial "pen" comprising tungsten core surrounded by a layer of Ni/Fe supermalloy is the working element of the system – when the external field is on, the pen creates a local minimum in the magnetic fluid beneath its tip, thus creating a trap for nonmagnetic objects; when the external filed is off, the trap vanishes. What is remarkable about this trapping mode is that the strength of the trap can be regulated by the electromagnet's field, and its shape, by the cross-section of the magnetic pen. Capitalizing on these advantages, I will show how to address not only individual colloids or living cells, but also create traps with which entire colloidal formations (e.g., lines of particles) can be manipulated or traps in which colloidal clusters can be controllably crystallized. Many of the capabilities of our electromagnetic traps cannot be realized with optical trapping approaches.

How investigations of detailed crystalline structure can help to improve the magnetic properties of core/shell ferrite nanoparticles?

Friday, 12th July - 09:40: Invited Speech Session - Oral - Abstract ID: 447

Dr. Rafael Cabreira Gomes [1], Dr. Fernando Henrique Martins da Silva [1], Dr. Vanessa Pilati [1], Prof. Fabio Luis Oliveira Paula [1], Dr. Franciscarlos Gomes da Silva [2], Prof. Renata Aquino [3], Prof. Alex Campos [1], Dr. Florence Porcher [4], Prof. Régine Perzynski [5], Prof. Jerome Depeyrot [6]

***1.** University of Brasília - UnB, **2.** Uni, **3.** Universidade de Brasília, **4.** Laboratoire Léon Brillouin, **5.** Sor, **6.** Instituto de Física - Universidade de Brasília*

Among the nanomaterials, magnetic nanoparticles (NPs) have gained a considerable attention because of their applicability in several areas such as catalysis, biomedicine and environmental applications [1,2]. Using heterogeneous nanostructures as core/shell bimagnetic NPs, different characteristics can be combined in a unique object, which may contribute to the fine tuning of their physical and chemical properties. Then, it may lead to improvement of the whole of their performances [1,2]. As magnetic anisotropy and magnetization are structure-dependent for both core and shell, satisfactory knowledge of the detailed structure in such NPs has become the subject of primary interest for understanding their behavior in biomedical and technological applications [3]. In this talk, we will review the details of the local structure of core/shell NPs made of Zn ferrite, Mn ferrite and mixed Zn-Mn ferrites cores recovered by a thin layer of maghemite [4, 5]. By crossing synchrotron X-ray diffraction and absorption with neutron diffraction and magnetization measurements, we will show how the structure of bimagnetic core/shell NPs influences their magnetic features. Perspectives about the challenges to improve the applications in several fields will be finally reported.

Acknowledgments: this work was supported by Brazilian agencies CNPq (INCT-FCx, 465259/2014-6), CAPES and FAPDF (PRONEX, 0193-001194/2016) and by contracts CAPES/COFECUB n°714/11 and PICS n°75939 from CNRS

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Nonlinear optical properties of magnetite ferrofluids: anisotropy of the magnetic susceptibility and hyperpolarizability

Friday, 12th July - 10:05: Invited Speech Session - Oral - Abstract ID: 42

Prof. Antonio Martins Figueiredo Neto [1]***, Mr. Daniel Espinosa*** [1]***, Mr. Cristiano Oliveira*** [1]***, Mr. Eduardo Gonçalves*** [1]***, Mr. Ruben Fonseca*** [1]***, Mr. Leonardo De Boni*** [1]

1. *University of São Paulo*

Magnetic fluids or ferrofuids (FF) are colloidal suspension of magnetic nanoparticles in a liquid carrier. When a material is illuminated with a high-intensity light, typically nanosecond, picosecond and femtosecond pulsed laser beam, its refractive index n_2 and absorption coefficient β depend on the light intensity I. The Z-Scan (ZS) nonlinear optical and the Small-Angle X-Ray Scattering (SAXS) techniques are used to investigate the structure and nonlinear optical properties of magnetite nanoparticles dispersed in a colloid and trapped in thin films. The nonlinear refractive index (n_2) and the two-photon absorption coefficient (β) were measured as a function of the intensity of an external applied magnetic field **H**. Different relative orientation of the field with respect to the light-polarization direction were investigated. When the external magnetic field is applied to the colloidal sample (**H** parallel to the light-polarization direction), the two-photon absorption coefficient increases with the field, ranging from β= 1.5 cm/GW (without field) to β= 2.4 cm/GW (2700 Oe). For the field direction perpendicular to the light polarisation direction, β decreases to β= 1.0 cm/GW (2700 Oe) and after remains stable. These values allowed us to evaluate some elements of the third-order nonlinear optical susceptibility tensor $\chi^{(3)}$. The SAXS experiments revealed that when the field is applied, small linear aggregates are formed in the direction of **H**. Considering that the nanoparticles rotate to align their magnetic moment parallel to the applied field direction, and the particle's magnetic moment is aligned along the ⟨111⟩ lattice direction of the nanoparticle's crystalline structure, our results indicate an optical anisotropy in magnetite. The calculated third-order nonlinear optical susceptibility, along the ⟨111⟩direction, is $Im\chi^{(3)}_{xxxx}=2.0(3)\times10^{-20} m^2/V^2$, while its average along the other two orthogonal directions is $(Im\chi^{(3)}_{yyyy}+ Im\chi^{(3)}_{xxxx})/2 = 0.9(3)\times10^{-20} m^2/V^2$. For the thin-film sample, however, the n_2 and β values do not change when the field of 1600 Oe is applied. Within the experimental error, n_2 does not seem to change with field for the colloidal samples [1,2]. **Support:CNPq, FAPESP, CAPES, INCT-FCx and NAP-FCx**

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[2] E.S. Gonçalves et al., JOSA B 35 (2018) 2681-2689.

Integrated permanent magnets prepared by magnetic alignment of highly concentrated Co nanorod suspension

Friday, 12th July - 11:00: Plenary Speech Session - Oral - Abstract ID: 632

Prof. Lise-Marie Lacroix [1], ***Mr. Pierre Moritz*** [2], ***Prof. Guillaume Viau*** [1], ***Mr. Fabrice Mathieu*** [3], ***Dr. Liviu Nicu*** [3], ***Mr. David Bourrier*** [3], ***Dr. Thierry Leichlé*** [3]

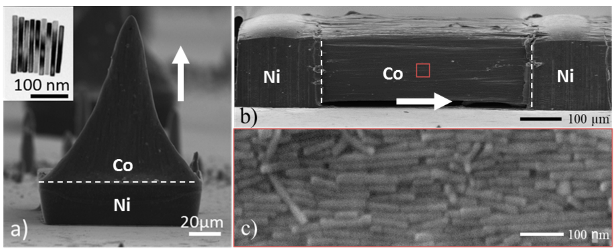
1. University of Toulouse, LPCNO, 2. University of Toulouse, LPCNO, LAAS, 3. LAAS, Toulouse

The fabrication of micrometric magnetic materials and their integration into portable devices reveal great interests for telecommunications, automotive, biomedical and space applications, but still remain highly challenging. These compact systems being fabricated through multistep technological processes, the permanent magnet (PM) integration should be implemented without altering the complex architecture of the device. The present state-of the-art is not satisfactory due to technological and material limitations.

The bottom-up approach for nanostructured permanent magnets is an interesting alternative route to the classical rare earth metallurgy. Indeed, the recent progresses in the magnetic nanoparticle synthesis allow a good control of the particle size, shape and chemical composition. Co NRs presenting a diameter in the range of 10-30 nm and an aspect ratio varying between 5 and 20 were synthesized by the polyol process (inset Figure 1a) [1]. Dense assemblies of aligned Co NRs were prepared by the controlled evaporation of a concentrated suspension under an external magnetic field [2], leading to performant magnets competing in the permanent magnet panorama [3].

Taking benefits of this know-how, micrometric magnets were fabricated at predefined location by a magnetophoresis process. Highly concentrated Co NR suspensions were magnetically aligned on a patterned substrate presenting pairs or arrays of electrodeposited Ni blocks. The soft ferromagnetic Ni blocks effectively serve as flux concentrators, inducing local magnetic field gradients which drive the Co NR assembly. This process leads to individual micrometric Co NR magnets and magnet networks exhibiting in-plane or out-of-plane magnetization depending of the applied magnetic field direction (Figure 1). Multiple scientific issues raise from this new approach, which was recently patented [4], especially concerning the drying of ferrofluids where magnetic and capillary forces are competing.

In-plane Co NR assemblies of length and thickness comprised in the range of 50-500 µm were prepared. These hybrid magnets generate sufficient magnetic stray field to actuate by Laplace force a Si microcantilever containing an AC current loop.



Micrometric co nr assemblies with out-of-plane or in-plane magnetization.png

Enhanced heat transport properties of Mn-Zn-Dy ferrofluid

Friday, 12th July - 11:15: Plenary Speech Session - Oral - Abstract ID: 406

Dr. Guruling Shahane [1], *Mr. Sushil Bandgar* [1], *Dr. Kisan Zipare* [2]

1. DBF Dayanand College of Arts and Science, Solapur, 2. C.B. Khedgi's B. Sci., R.V. Comm. and R.J. Arts College, Akkalkot

Dispersion of nanoparticles of different materials in a carrier fluid has been a subject of intensive investigations over decades due to their potential applications in heat transfer and electronic cooling systems. A possibility to induce and control the heat transfer process by means of an external magnetic field opened a window to a spectrum of promising applications including enhancement of heat transfer for cooling of high power electric transformers, and magnetically controlled heat transfer in energy conversion systems. Mn-Zn ferrites are among the most widely used electromagnetic materials for a broad category of applications including heat transfer enhancement and energy conversion devices. This paper describes the synthesis and characterization of oleic acid coated Mn-Zn-Dy ferrite nanoparticles for temperature sensitive ferrofluid and their application in heat transfer device. The effect of rare earth cation substitution on structural and magnetic properties of Mn-Zn ferrite is investigated.

In the present study, the chemical route was used to synthesize oleic acid coated $Mn_{0.5}Zn_{0.5}Dy_xFe_{2-x}O_4$ (x=0, 0.05, 0.1, 0.15 and 0.2) nanoparticles. The XRD study reveals the single crystalline phase of all samples with size between 6 to 8 nm. The lattice parameter increases with increase in Dy concentration. The observed particle sizes from TEM analysis are in good agreement with XRD values. From the magnetization studies it is observed that the saturation magnetization and Curie temperature decreases with increase in Dy-concentration and can be correlated to modifications in the A-B exchange interactions as a result of the structural modifications due to Dy-substitution. An experimental set up (prototype) is developed for the investigation of heat transport. A considerable enhancement in heat transfer is observed with the application of magnetic field. The better results are obtained for the composition $Mn_{0.5}Zn_{0.5}Dy_{0.1}Fe_{1.9}O_4$. Reduction in the Curie temperature and higher values of pyromagnetic coefficient makes them suitable for the preparation of temperature sensitive ferrofluid for heat transfer applications.

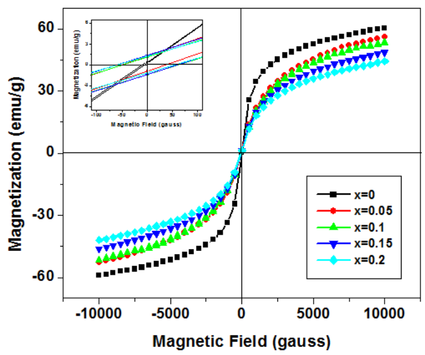


Fig. 1 Magnetization curves of $Mn_{0.5}Zn_{0.5}Dy_xFe_{2-x}O_4$ nanoparticles.

Fig 1.png

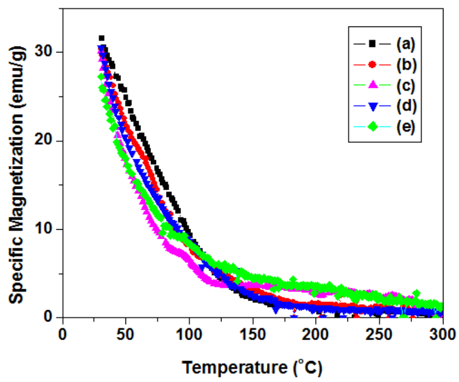


Fig. 2: Temperature dependence of magnetization for $Mn_{0.5}Zn_{0.5}Dy_xFe_2O_4$ nanoparticles: a) x=0, b) x=0.05, c) x=0.1, d) x=0.15 and e) x=0.2.

Fig 2.png

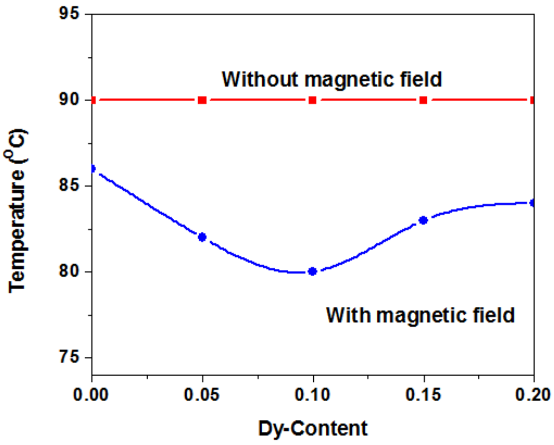


Fig 3: Variation of maximum temperature of the hot object as a function of composition of ferrofluid

Fig 3.png

Design and Fabrication of Micro-Transformer based on Ferrofluids

Friday, 12th July - 11:30: Plenary Speech Session - Oral - Abstract ID: 293

***Mrs. Vinayasree Sreedharan* [1], *Prof. Anantharaman M R* [1]**

***1.** Cochin University of Science and Technology*

The micro miniaturization techniques such as CMOS and MEMS/NEMS fabrication technology paved the way of on-chip transformers on a silicon wafer. Therefore realization of micro-transformers on a chip which can be fully integrated with other electronic circuits such as, DC/DC converters, RF MEMS, biosensors and mobile power delivery applications are crucial. Also miniaturization of switched mode power supplies (SMPS) has become the main focus for developing future generation power supplies, which uses micro transformers, also known as power supply in package (PSiP) and power supply on chip (PwrSoC). This investigation is an attempt to fabricate on-chip ferrofluid core transformers without using conventional electroplating and wire bonding used for the construction of coils in micro transformers. Transformer losses negatively affect the performance of the transformers especially at high frequencies. Among all the transformer loss, core loss is the major contributing factor and substantially interrupts the coupling between primary and secondary winding. Core losses due to eddy currents and hysteresis loss can be considerably reduced by employing superparamagnetic material as core. Ferrofluid exhibit superparamagnetism, with zero remanence and coercivity, and marked as a good thermal management liquid. The transformer design adopted here consists of two overlapped coils on top of each other around a hollow core chamber. In the middle of the internal coil, there is a thin hollow chamber core of thickness 0.5µm sandwiched between two insulation layers. Contact pads are given at the two ends of the coils for external circuitry connections. The top view of the micro-transformer is presented in figure 1. The process include 9 levels of lithography corresponds to 9 separate optical masks. The optical images of one device after each level of fabrication is shown in figure 2 and 3. The transformer performance with an aqueous ferrofluid, synthesized in the lab, is evaluated and compared with that of a transformer with an air core. The inductance and quality factor measurement is done in the low frequency regime using a precision impedance analyzer. The details involving the fabrication steps along with initial results will be presented here.

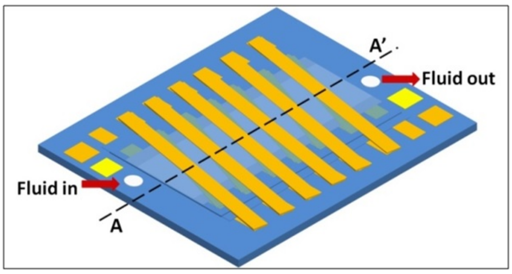


Figure 1.jpg

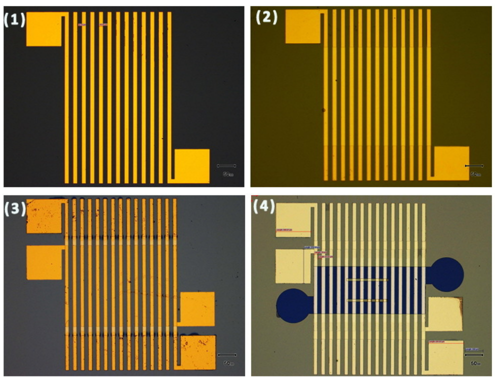


Figure 2.jpg

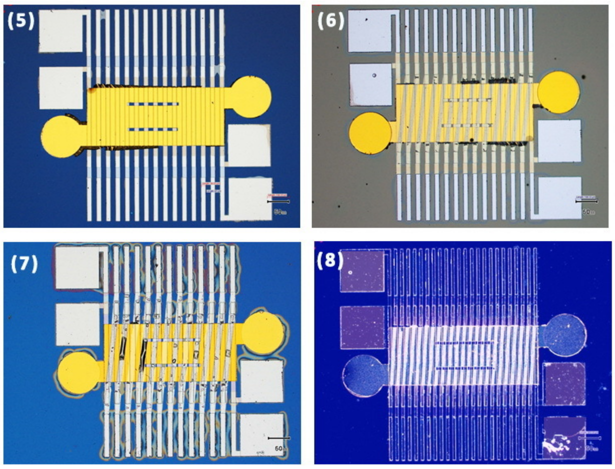


Figure 3.jpg

Thermodiffusion of charged nanoparticles dispersed in Ionic Liquids.

Friday, 12th July - 11:45: Plenary Speech Session - Oral - Abstract ID: 356

Dr. Mitradeep Sarkar [1]***, Mr. Jesse Riedl*** [1]***, Mr. Thiago Fiuza*** [2]***, Dr. Gilles Demouchy*** [3]***, Mr. Frédéric Gélébart*** [1]***, Dr. Fabrice Cousin*** [4]***, Prof. Jerome Depeyrot*** [2]***, Dr. Guillaume Mériguet*** [1]***, Dr. Veronique Peyre*** [1]***, Dr. Emmanuelle Dubois*** [1]***, Prof. Régine Perzynski*** [1]

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Ionic liquids (ILs) are a wide class of solvents, purely constituted of ions, which can be liquid at room temperature. They strongly differ from classical molecular solvents. Our work aims at developing new thermoelectric materials based on IL-ferrofluids that are versatile, cost-effective and non-toxic to assist the economically and environmentally sustainable energy transition [1]. We first present a simple model-system of IL-ferrofluid based on citrate-coated maghemite nanoparticles (NPs) dispersed in ethylammonium nitrate [2]. Then more complex Il-based systems are studied varying parameters such as IL-anions or IL-cation [3], NP coating and temperature. Simultaneous Dynamic Light Scattering and Small Angle Neutron Scattering measurements are performed at PAXY spectrometer in ORPHEE-LLB-Saclay-France in a controlled oven at 295K<T<473K to study the colloidal stability and the interparticle interaction in the dispersions.

Thermoelectric applications [4,5] require precise determination of several transport coefficients of the NPs under a thermal gradient, namely Ludwig-Soret (thermodiffusive) and Seebeck (thermoelectric) effects which are interlinked in such ionic systems. On applying a temperature gradient ∇T on the dispersions, Soret effect induces a volume fraction gradient of the NPs (Soret coefficient defined as $\Phi S_T \nabla T=-\nabla\Phi$) and Seebeck effect induces an internal electric field E (Seebeck coefficient defined in stationary conditions as $S_e^{ST} \nabla T=E$) . By forced Rayleigh scattering [6], we determine the mass diffusion coefficient D_m and the Soret coefficient S_T of the NPs as a function of temperature (295K<T<461K) for the IL-ferrofluids.

Acknowledgements :

The authors deeply thank F. Clement and A. Helary for their help during the experiments in LLB-Saclay, A. Anfry for her help in sample characterizations and SOLVIONIC for providing us with the Ionic Liquids. This work has been supported by the Brazilian agency CNPq and the European Union's Horizon 2020 research and innovation programme under grant agreement n° 731976 (MAGENTA).

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Low-grade thermal energy harvesting using magnetic ferrofluids

Friday, 12th July - 12:00: Plenary Speech Session - Oral - Abstract ID: 277

Dr. Kakoli BHATTACHARYA [1]***, Mr. Jesse Riedl*** [2]***, Dr. Mitradeep Sarkar*** [2]***, Dr. Veronique Peyre*** [3]***, Dr. Emmanuelle Dubois*** [3]***, Dr. Marco Bonetti*** [1]***, Prof. Michel Roger*** [1]***, Prof. Régine Perzynski*** [3]***, Dr. sawako nakamae*** [4]

1. *Service de Physique de l'Etat Condensé (DSM/IRAMIS/SPEC) - CNRS/UMR 3680,* ***2.*** *UPMC,* ***3.*** *Sorbonne Université,* ***4.*** *Commissariat à l'Energie Atomique et aux Energies Alternatives*

Development of advanced technologies for better waste-heat management is an important key step for the sustainable energy production. Thermogalvanic cells containing liquid electrolytes are emerging as promising candidates for low-grade thermal energy harvesting as they provide a cheap and scalable route for directly converting heat into electricity without producing harmful emissions or consuming toxic materials. In fact, liquid thermogalvanic cells are known to produce thermoelectric voltage (often called the Seebeck voltage) that is one to two order of magnitude larger than the solid thermoelectric modules for a given heat input. Today, the particularly challenging aspect of thermogalvanic cells is achieving a power performance. To this end, ionic-liquids with high ionic conductivity and/or nanofluids containing highly charged colloidal particles are actively studied.

In this work, ionic liquid based ferrofluids are studied as novel electrolytes in thermogalvanic cells. We have investigated the influence of the thermodiffusion of magnetic nanoparticles (charge stabilized) under a temperature gradient on the open-circuit output voltage as well as power output of the thermogalvanic cells. Further insight into achieving higher thermoelectric conversion efficiency by tuning the concentration of magnetic nanoparticles is reported.

This work is supported by European Union's Horizon 2020 research and innovation programme under the grant agreement No 731976 (MAGENTA).

Effect of the nanoparticles coating on the colloidal stability of ferrofluids

Friday, 12th July - 13:30: Invited Speech Session - Oral - Abstract ID: 433

Dr. Kalliopi Trohidou [1]***, Dr. Nikolaos Ntallis*** [1]***, Dr. Marianna Vasilakaki*** [1]***, Dr. Dino Fiorani*** [2]***, Dr. Davide Peddis*** [3]

1. *NCSR "Demokritos",* ***2.*** *Struttura della Materia-CNR,* ***3.*** *Univ. Genoa, Dept. Chem. & Ind. Chem. and Struttura della Materia-CNR*

Ferrofluids consisting of ultra-small magnetic nanoparticles offer a potential breakthrough as next-generation heat transfer fluids. A drawback for using ferrofluids in practical applications is the difficulty in maintaining colloidal stability [1].

In our effort to obtain colloidal stability and dispersibility of nanoparticles in liquids, we study the effect of ligands bonding [2] on their charge distribution and their magnetic properties, using a multi-scale modeling approach. We performed DFT electronic structure calculations using the VASP package [3] for the charge distribution and their microscopic magnetic parameters. The DFT results were used as input in our mesoscopic model of an assembly of interacting nanoparticles [2,4]. Two examples will illustrate the new possibilities offered by the coatings of the magnetic nanoparticles in ferrofluids for applications.

First ultra-small spherical $CoFe_2O_4$ nanoparticles coated with Oleic acid (OA) [2] were studied. Our results compared with those for the uncoated nanoparticles show that: (a) the charge distributions obtained for the coated particles result to a slower reduction of the electric field with the distance, (b) the saturation magnetization and the blocking temperature increases whereas the coercive field decreases, in the OA sample. Our results are in very good agreement with recent experimental findings [2].

Next, we study ultra-small $MnFe_2O_4$ nanoparticles covered by albumin. Our calculations show that the albumin coating enhances the charge and reduces the saturation magnetization and the surface anisotropy in the nanoparticles leading to lower values of the coercive field from the uncoated ones, in agreement with the experimental findings [4]. The albumin coated clusters, formed during the coating process, give high irreversibility temperatures and they exhibit a super spin glass (SSG) behavior. Remarkably the magnetisation curves provide evidence that the strength of the dipolar interactions is not affected by the albumin coating.

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Enhancing microfluidic separation of magnetic nanoparticles by molecular adsorption

Friday, 12th July - 13:55: Invited Speech Session - Oral - Abstract ID: 20

Mr. Jordy Campos [1], Ms. Luna Checa Fernandez [2], Dr. Charlotte Hurel [1], Dr. Claire Lomenech [1], Dr. Agnès Bée [3], Dr. Delphine Talbot [3], Dr. Pavel Kuzhir [4]

***1.** University Côte d'Azur/ INPHYNI, **2.** University of Granada, **3.** Sorbonne Université, **4.** University of Côte d'Azur / Institute of Physics of Nice*

Microfluidic manipulation of magnetic nanoparticles is a smart tool for various environmental and biomedical applications, such as water remediation from pollutant molecules (heavy metals, pesticides, …), high-sensitivity immunoassays, cancer treatment by controlled drug delivery, hyperthermia or mechanical destruction of cells, protein purification, gene transfection, etc. In most of these applications, magnetic nanoparticles bear on their surface adsorbed molecules (either pollutants or biomolecules), which should either be delivered to the target site (drug delivery, gene transfection) or be extracted from the solvent (immunoassays, protein purification, water remediation). Unfortunately, these technics have strong limitations related to low efficiency of the magnetic manipulation of nanoparticles because of their strong Brownian motion and low efficiency of their separation from the suspending fluid (magnetic separation) under flows in microfluidic devices. However, molecules adsorbed on the nanoparticle surface often reduce repulsive colloidal interactions between nanoparticles and provoke a weak agglomeration of nanoparticles. Such agglomeration in the absence of applied magnetic field leads to an increase of the effective size of nanoparticles (or rather primary aggregates) and, once the magnetic field is applied, the magnetic force acting on primary aggregates is strongly amplified as compared to the situation of single non-aggregated nanoparticles. In this case the adsorbed molecules not only fulfill their function in water remediation or biomedical applications but allow a drastic enhancement of nanoparticle manipulation by magnetic fields, thereby broadening the application fields of nanoparticles.

In the present work, we consider two different systems which follow the aforementioned behavior: iron oxide nanoparticles (of an average size of 8 nm) with either methylene blue (MB) dye adsorbed on their surface or monoclonal antibodies (AB) grafted on their surface and destined for realization of immunoassays. Dynamic light scattering (DLS), zeta-potential measurements along with experiments on kinetics of primary (at zero field) and secondary (field-induced) aggregation and microfluidic magnetic separation allow assessing the quantitative effect of the surface coverage of nanoparticles by MB or AB on the efficiency of nanoparticle clustering and magnetic separation in the presence of external magnetic fields as low as ~5-10 mT.

Design of superparamagnetic nanoreactors as heterogeneous catalysts for oxidative degradation of organic pollutants by Fenton-like reaction

Friday, 12th July - 14:20: Plenary Speech Session - Oral - Abstract ID: 370

Mr. Alvaro Gallo Cordova [1], ***Prof. Maria del Puerto Morales*** [1], ***Dr. Eva Mazarío Masip*** [2]

1. *Institute of Materials Science of Madrid,* ***2.*** *Universidad Autónoma de Madrid*

The discharge of highly coloured wastes from effluents of textile, paint, ink and cosmetic industries, could be extremely hazardous for the environment and human health [1]. For example, this contaminated water can be very harmful for the aquatic environment due the obstruction of light, causing distress of biological processes, and also these pollutants can be degraded into toxic compounds with hazardous aftermaths to human health [2]. Therefore, the need to eliminate them is a great concern nowadays and magnetic nanoparticles have been proposed as good candidates to be used as catalyst or adsorbents in these water remediation processes. These materials offer the advantages of high surface area, easy separation by means of a magnet and high heating capabilities under an alternating magnetic field for the improvement of reaction yields in catalytic processes [3].

In this project, the design and assembly of superparamagnetic nanoreactors (NRs), with high surface area, were successfully performed and they were evaluated as magnetic heterogeneous Fenton catalyst. The NRs were fully characterized and the morphology and properties of the material were obtained by X-ray diffraction, transmission electron microscopy, Fourier transform infrared spectroscopy, vibrating sample magnetometry, thermal gravimetric analyses and Brunauer-Emmet-Teller measurements. Azo dye methyl orange (MO) was used as the selected organic pollutant for the batch experimentation and its equilibrium adsorption capacity with the NRs was analysed. The decolorization rate of as prepared aqueous solutions of MO was measured after performing the reaction with H_2O_2 and with NRs as catalyst. The magnetic magnetite ($Fe^{2+}Fe^{3+}{}_2O_4$) core of the NRs allowed the formation of non-selective oxidants hydroxyl radicals for the MO oxidation. The decolorization yield as well as the oxidation efficiency were calculated by analysing the data obtained in the reaction batch experimentation.

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Fundamental characteristics of diesel particulate removal using a ferrofluid and nonthermal plasma discharge

Friday, 12th July - 14:35: Plenary Speech Session - Oral - Abstract ID: 68

Prof. Takuya Kuwahara [1]

1. *Nippon Institute of Technology*

Energy conversion devices are indispensable for our life. Among the energy conversion devices, diesel engines have advantages such as high energy density of fuels, low fuel consumption, and relatively low CO_2 emission. Therefore, diesel engines are most popularly used in various applications. Instead of the advantages of diesel engine, emission of diesel exhaust gas is one of serious environmental issues. Diesel particulates in the emission cause the respiratory disease and air pollution such as $PM_{2.5}$ issue in recent years. One of the removing technologies of diesel particulates, which is widely used for automobiles, is a diesel particulate filter (DPF). However, its pressure loss degrades the engine performance, and the fuel consumption becomes higher.

In the present study, a plasma-based ferrofluid filter for removing diesel particulates from exhaust gas are proposed to solve the issue. The principle of diesel particulate removal is provided and discussed. The proposed technology uses both of the Brownian diffusion and the electrostatic force, which are effective for the collection of sub-micron particulates. In addition, the use of a ferrofluid overcomes the essential problem of re-entrainment that emerges in collection of low-resistive particulates such as diesel particulates. The plasma-based ferrofluid filter has little pressure drop, which is the main problem with conventional DPFs, in the diesel particulate removal.Prior to the development of the plasma-based ferrofluid filter, fundamental characteristics of diesel particulate removal using a ferrofluid and nonthermal plasma discharge are investigated. A model plasma-based ferrofluid filter and its evaluation system are established. **Figure** shows the plasma-based ferrofluid filter. The nonthermal plasma discharge is dielectric-barrier discharge (DBD) with the discharge voltage of 9 kV. Equations for evaluating the collection efficiency are provided. In the present paper, the experimental results and discussion on the performance of the proposed ferrofluid filter are reported. The removal efficiencies are evaluated in different particulate diameters, which are 0.3, 0.5, 1.0, 2.0, 5.0, and 10.0 μm. The results confirm the feasibility of diesel particulate removal, and reveals that the removal efficiency is higher than 85% for particulates having a diameter more than 0.5 μm.

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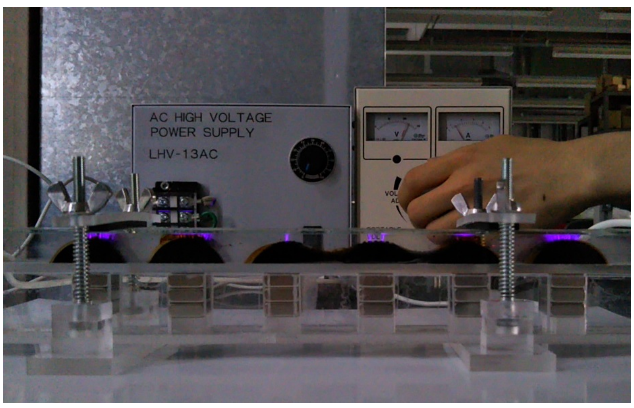

Plasma-based ferrofluid filter.jpg

Flocculation and settlement of clay platelets and maghemite nanoparticles : a model for magnetically assisted flocculation processes in water treatment

Friday, 12th July - 14:50: Plenary Speech Session - Oral - Abstract ID: 586

Dr. Sebastien Abramson [1], ***Dr. Sofia Housni*** [1], ***Dr. Laurent Michot*** [1], ***Prof. Pierre Levitz*** [1]

1. Sorbonne Université, Laboratoire PHENIX-CNRS UMR 8234

Flocculation is a physicochemical process during which colloidal particles in suspension agglomerate and form bigger particles called flocs. Thanks to their large size, the flocs are characterized by an appreciable settlement rate, which allows their separation from the liquid phase. This method is especially used in water treatment. However, this process is generally limited by the relatively slow decantation of the flocs under gravity, due to their low density. Our work consists in studying the replacement of conventional flocculating agents by magnetic nanoparticles, to facilitate the decantation step. The objective was first to treat model colloidal aqueous suspensions composed of beidellite platelets by maghemite nanoparticles, the obtained magnetic flocs being recovered using a magnet.

Our work has been carried out according to the following procedure (figure 1). First, maghemite nanoparticles (NPs) were synthesized, sorted into different sizes, and dispersed in acidic solutions. Those dilutions were then added to suspensions of size-sorted beidellite platelets. The flocculation was immediately observed due to the electrostatic interactions between the positively charged nanoparticles and the negatively charged clay lamellae. The flocs were then left to settle in presence of a Nd-B-Fe magnet (figure 1). In comparison to gravity, the settlement rate of the flocs resulting from the magnetic field gradient was up to 100 times faster.

First, we will describe our results about the physicochemical conditions (pH, concentration and sizes of the nanoparticles and clays…) allowing the formation of the flocs. We will also give an estimation of the settlement rates of the flocs, depending on the way of decantation (magnet or gravity), and on the various parameters varied during the flocculation. Afterwards, we will present our experiments to determine the multiscale structure of the flocs. A first description of their organization has been obtained by cryo-TEM (figure 2), SAXS (figure 3), SANS and Small Angle Scattering curves recomputed by analysis of the optical micrographs.

Finally, we attempted to apply this method to natural waters originating from the Seine River. We evaluated the evolution of turbidity (figure 4), iron concentration and total organic carbon after addition of the maghemite nanoparticles and settlement using a magnet.

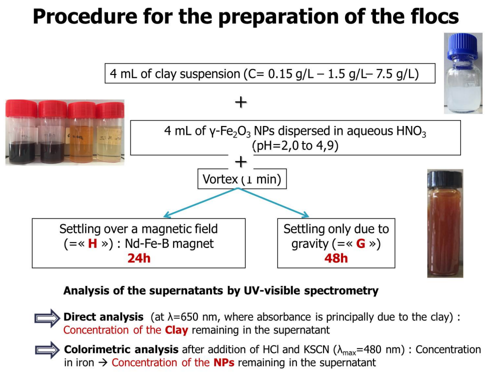

Fig 1 icmf.jpg

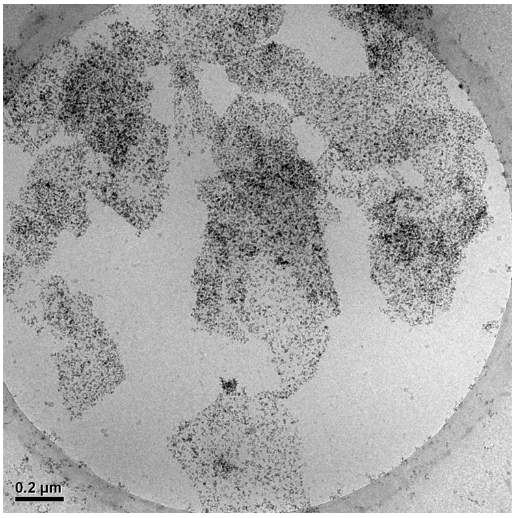

Fig 2 icmf.png

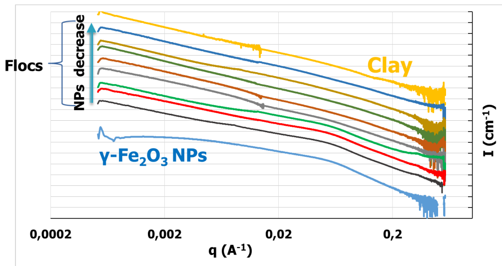

Fig 3 icmf.png

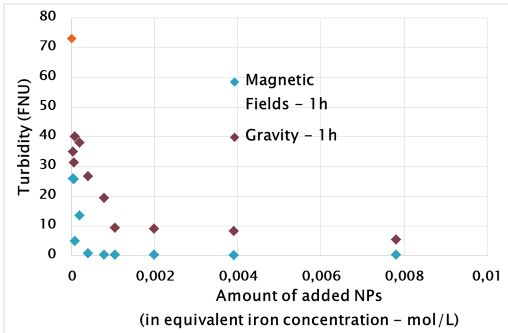

Fig 4 icmf.png

Development of water electrolysis using magnetic buoyancy force in water-based magnetic fluids

Friday, 12th July - 15:05: Plenary Speech Session - Oral - Abstract ID: 503

Prof. Yuhiro Iwamoto [1], ***Mr. Kotaro Chimura*** [1], ***Mr. Hitoshi Miyao*** [1], ***Prof. Yasushi Ido*** [1], ***Prof. Yosuke Ishii*** [1], ***Prof. Kawasaki Shinji*** [1], ***Prof. Shigeru Takagi*** [1], ***Prof. Jeyadevan Balachandran*** [2]

1. Nagoya Institute of Technology, 2. The University of Shiga Prefecture

A combination of renewable energies and water electrolysis has been attracting much attention as an environmentally-friendly method to produce hydrogen, which has been expected as promising future energy storage and carrier media. In the present study, a new method which has the potential to dramatically enhance the water electrolysis efficient was proposed by utilizing the magnetic buoyancy. Using water-based magnetic fluids as an electrolyte and directly electrolyzing them in the presence of inhomogeneous magnetic fields should enhance the desorption of gas-bubbles absorbed on electrodes. We investigated the effect of magnetic field strength on the water electrolysis process by a dynamic impedance method. Figure (a) shows the Nyquist plot obtained by the dynamic impedance method. The tested electrolyte was a water-based magnetic fluid adding Na_2SO_4 with 0.1 mol/L. When the magnetic field intensity increases (decreasing the distance between a permanent magnet and the working electrode, L), Z_{Re} decreases, which represents that the resistance in the water electrolysis becomes smaller. The equivalent circuit in Figure (b) fits the experimental data well, resulting in that it is possible to divide the whole resistance into the charge-transfer and solution resistances. The charge-transfer resistance dramatically decreases with the magnetic field strength, while the solution resistance doesn't change. This phenomenon explains that the magnetic buoyancy sufficiently enhances the bubble desorption, resulting in the water electrolysis enhancement.

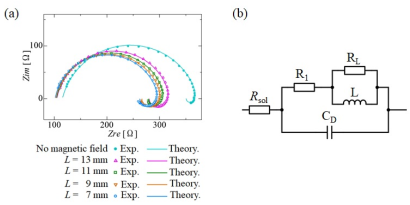

Figure.jpg

Non-contact manipulation of nonmagnetic materials using a uniform magnetic field

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 39

Mr. Xiang Li [1], ***Prof. Peng Yu*** [1], ***Prof. Xiaodong Niu*** [2], ***Prof. Hiroshi Yamaguchi*** [3]

1. *Southern University of Science and Technology,* ***2.*** *Shantou University,* ***3.*** *Doshisha University*

Magnetic field induced dynamic self-assembly (MFIDSA) can be regarded as one of non-contact manipulation method under special category of micro-scale or nano-scale fabrication technique, which is confined to magnetic materials. This study is focused on MFIDSA process of nonmagnetic materials in inverse magnetic fluids by using the experimental technique and numerical method. To explore the controllability of MFIDSA process, a series of experiments by using the inverse magnetic fluids comprising of nonmagnetic polystyrene spheres with different particle-size distributions were carried out. The relations of the strength of external magnetic field, the average length of self-assembled chain-like structure, and the particle-size distributions of nonmagnetic polystyrene sphere were investigated experimentally. Meanwhile, to reveal the interaction mechanisms behind the self-assembling behaviors of nonmagnetic materials, an immersed boundary lattice Boltzmann method has been applied to simulate the multi-physical field coupled multiphase flows in MFIDSA process. The present work shows that the average length of self-assembled chain-like structure is mainly determined by the strength of external magnetic field, irrespective of the particle-size distribution of nonmagnetic materials. The coincident results of the experiments and numerical simulations provide a guidance on how to manipulate the nonmagnetic materials to form the chain-like structures by magnetic field.

In-Field Colloidal Stability of Aqueous Ferrofluids for Magnetic Density Separation

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 96

Mr. Alex van Silfhout [1], *Dr. Ben Erne* [1]

1. Van 't Hoff laboratory for Physical and Colloid Chemistry, Debye Institute for Nanomaterials Science, Utrecht University

The recycling of waste materials is essential for society's transition to a circular economy, and a novel recycling technology based on magnetic density separation is being developed in a Dutch nation-wide program (NWO-TTW Perspectief program P14-07 [1]). Nonmagnetic solid materials dispersed in a ferrofluid will levitate in external magnetic field, reaching specific floatation heights that depend mainly on the buoyant mass densities of the materials and the precise height dependence of the magnetic field strength. Using a well-engineered and well-characterized magnetic field, materials with a large range of densities can be separated with high precision, see Figure a. In such an application, it is crucial for the ferrofluid to have excellent colloidal stability in external magnetic field, and it must be aqueous if the objective is to separate plastics.

In this research, the colloidal stability of aqueous ferrofluids in external magnetic fields is evaluated from time-dependent transmission profiles of X-rays [2,3] and visible light. Sedimentation rates and equilibrium concentration profiles of the colloidal iron oxide nanoparticles were determined on a neodymium magnet and up to 25 T at the High Field Magnet Laboratory in Nijmegen [4], at different gradients from 0 to >100 T/m. For the most stable ferrofluids, both the time-dependent and final equilibrium profiles agree with numerical simulations that take into account the spatial dependent magnetic field and nanoparticle polydispersity. Less stable ferrofluids phase separate within seconds, see Figure b, as expected from the formation of large dipolar structures [5].

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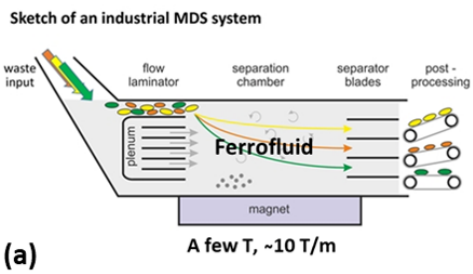
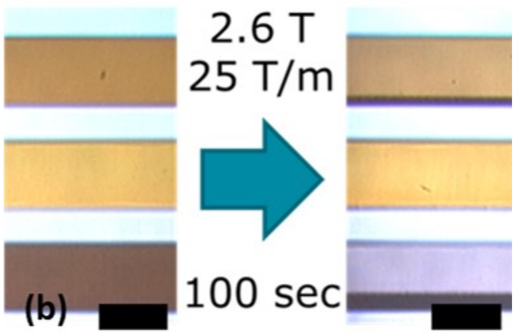


Industrial setup.png



Ferrofluids in field.jpg

Shape Designed (Nonspheric) Polymeric Particles Functionalized with an Exchange Bias Layer System

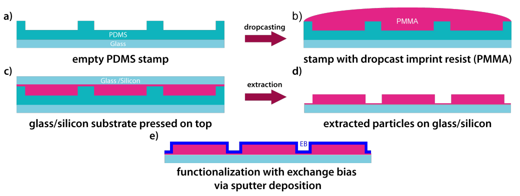
Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 116

***Ms. Andreea Tomita* [1], *Mr. Burhan Kaban* [2], *Mr. Uh-Myong Ha* [2], *Ms. Meike Reginka* [1], *Prof. Hartmut Hillmer* [2], *Prof. Arno Ehresmann* [1], *Dr. Dennis Holzinger* [1]**

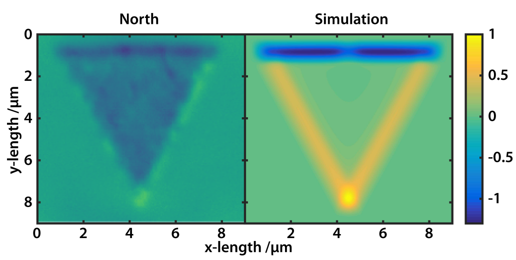
1. Universität Kassel, Institute of Physics, 2. Universität Kassel, Institute of Nanostructure Technologies and Analytics

During the past decades, the use of magnetic micro- and nanoparticles for microfluidic applications, e.g. lab-on-a-chip devices with particles acting as structure materials for 3D assembly, molecular transporters, microsensors or contrast agents in medical diagnostics has seen an ever-evolving interest. While most of these magnetic particles are colloidal, mainly spherically shaped particles, either because of synthesis simplicity, or because they attempt to imitate living organisms found in nature, more diverse shapes remain largely unexplored. However, when it comes to hydrodynamic behaviors e.g. transport in a liquid environment, varying the particles' geometries introduces a well of untapped potential for control of motion characteristics. Here, a major challenge is to individually address the particles' shape and magnetic properties, since the latter is usually influenced by the former. Thus, being able to tune the magnetic texture of the particles becomes crucial. To achieve a desired magnetic functionality with respect to the particles' remanent magnetization, independent on their geometry, surface functionalization with magnetic thin films was employed. Here however, energy minimization typically hinders the presence of arbitrary patterns for deliberate particle sizes and geometry. Our approach is, therefore, to introduce an exchange bias (EB) system since that enables us to control the strength and the direction of this additional unidirectional anisotropy. The resulting particles have a defined remnant magnetic state that can be exploited to control their spacial orientation, as well as their rotational and translational behavior when in a magnetic environment.

Here, we introduce nonspherical shape-designed particles with extruded 2D shapes, molded from polymethyl methacrylate via reverse nanoimprint lithography and subsequently coated with an EB thin film system via sputter deposition. The particles' properties were characterized by Kerr magnetometry and MFM to unravel the strength of the EB effect and their magnetostatic charge distribution pattern. The latter relates on how well the anisotropy is preserved along the particles' shape. Corroborated by micromagnetic simulations, we observe that, although the magnetic texture wraps itself along the borders of the particle geometry, the anisotropy is generally aligned along the imposed unidirectionality which produces a large remanent magnetic moment and therefore, the opportunity for precise particle actuation.



Reverse nanoimprint lithography sputter deposition.png



Oommf vs mfm 120 1tri 7.5 5nm.png

Measurement of Thermomagnetic Convection Effect in a Cooling Process

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 152

Mr. Sleimane NASSER EL DINE [1], ***Prof. Xavier MININGER*** [1], ***Prof. Caroline NORE*** [1], ***Prof. Frédéric Bouillault*** [1], ***Mrs. Sophie NEVEU*** [2]

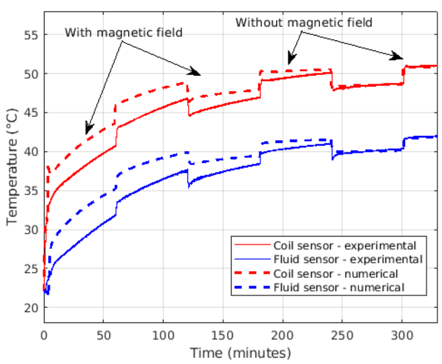
1. Université Paris Saclay, 2. Sorbonne Université

An experiment is performed to measure the thermomagnetic convection effect in a prototype immersed coil. A magnetic fluid (Midel vegetable oil - $CoFe_2O_4$ Cobalt ferrite magnetic fluid) with nanoparticles volume fraction of 5% is used as a coolant for this purpose. The test cell consists of a copper coil, in the form of a two-wire conductor, chosen to obtain two identical coaxial resistors. The coil entirely immersed in ferrofluid is set into an Aluminium tank closed at the top by a PVC cap. When the directions of the currents flowing in the two resistors of the coil are opposite, the generated magnetic fields are compensated in the device and the thermomagnetic convection effect is deactivated. On the other hand, if the current directions are the same, a magnetic field is applied in the test cell and the thermomagnetic convection effect is activated. In both configurations, the same amount of heat is dissipated by the Joule effect at the solenoid.

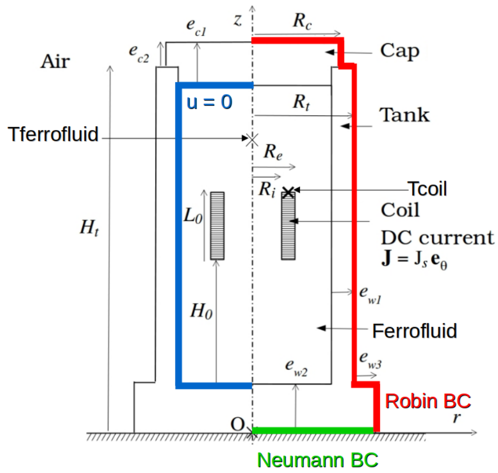
Two sensors are inserted in the fluid and at the coil respectively, to show temperature evolution during experiment progress. The current direction in each resistor is initially the same, then reversed every 60 minutes to activate/deactivate the magnetoconvection. The results corresponding to the time evolution of the coil temperature show reproducible crenelations with equal amplitude of 2,2°C approximately. Hence, when the thermomagnetic convection is active, the coil temperature decreases, revealing the impact of the thermomagnetic convection in the cooling operation.

The same process is numerically tested, with a 2D axisymmetric model of the setup, using the finite element method. We use the magnetic fluid properties deduced from the experiment to improve the cooling efficiency of the coil. Due to the presence of an additional magnetic force, the fluid flow around the coil is modified. As a result, a new convection cell arises in the ferrofluid, and cools down the heated coil. Experimental results in agreement with numerical ones prove that the proposed model and the applied boundary conditions are appropriate for the modelling of the actual setup.

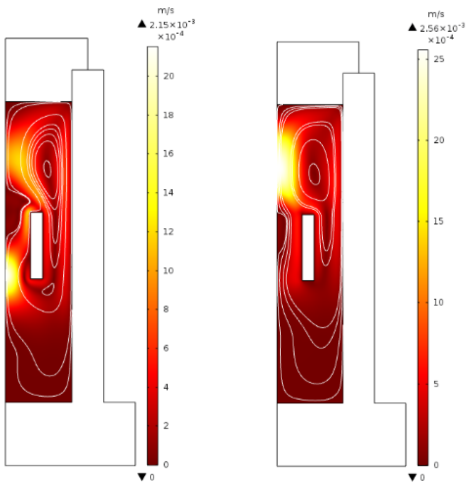
Index Terms—Cooling, Ferrofluid, Finite Element Method, Electromagnetic Device, Thermomagnetic Convection, Magnetic Body Force



Magnetoconvection effect.png



Setup.png



Velocity intensity with magnetic force at t=280 min

Velocity intensity without magnetic force at t=330 min

Velocity.png

Size Effects of Nanocrystalline GdVO4 on Magnetocaloric Properties

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 159

Prof. Chunghee Nam [1], ***Mr. Sung-Myung Ryu*** [1]
1. *Hannam University*

Vapor-compression refrigeration system (VCRS) technology has practical limitations to improve against environmental destruction such as destruction of ozone layer and global warming. Recently, proposals and researches on new cooling technologies to replace these past cooling technologies have been underway. Magnetocaloric effect (MCE) is a magneto-thermodynamic phenomenon where the temperature changes when material is exposed to changing magnetic fields. These properties can be combined with cooling technology. The cooling technology with MCE has been used in a variety of cryogenic applications, such as cryogenic technology in space science, liquefaction of hydrogen or other fuel gases. In this study, we investigated the MCE properties of antiferromagnetic $GdVO_4$ with nanostructures synthesized by a microwave-assisted hydrothermal method. The magnetic transition temperatures (Neel Temperature, T_N), effective magnetic moment, *magnetic entropy changes, and relative cooling power (RCP) were obtained from MPMS measurements. It was found that* $GdVO_4$ *nanocrystals have an intrinsic antiferromagnetic-paramagnetic second-order phase transition for* $GdVO_4$*, indicating that they can be applied for cryogenic magnetic cooling materials such as hydrogen gas liquefaction [1].*

Acknowledgements

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF- 2019R1D1A3A03017434).

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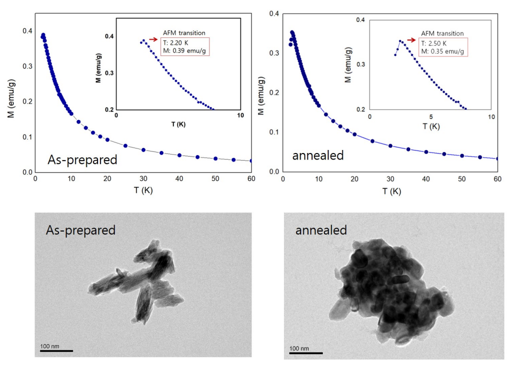


Fig. 1 (a, b) M-T of as-prepared and annealed samples, respectively. (c, d) TEM images of as-prepared and annealed samples, respectively.

Fig1.jpg

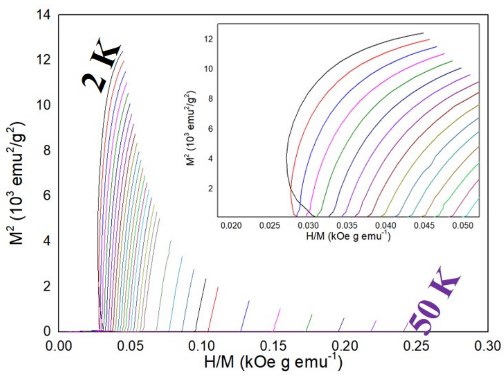


Fig. 1 Arrott plot of the annealed samples, showing a first-order magnetic transition

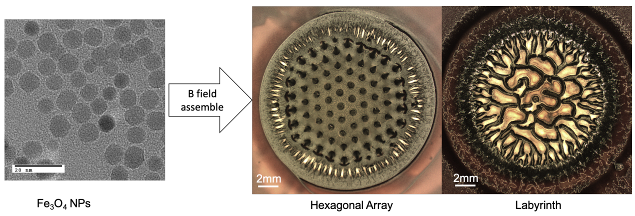
Fig2.jpg

Magnetically-assisted pattern formation: directed self-assembly of magnetic nanoparticles into hierarchical structures

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 163

Mr. Tianyu Zhong [1], *Prof. Mark Andrews* [1]
1. McGill University

Ferrofluids are colloidal fluid suspensions of superparamagnetic nanoparticles. Under certain conditions, ferrofluids undergo symmetry-breaking transitions that manifest themselves in extraordinary patterns in the presence of magnetic fields. These include hexagonal, square array, labyrinth and so forth. These patterns collapse upon removal of the magnetic field. In our work, we establish methods to make permanent patterns from ferrofluidic media. We show that pattern formation depends on the magnetic nanoparticles, solvent media and surface energy of the substrates. The as-assembled spike-like structures exhibit hierarchies of patterns over length scales spanning nanometers to millimeters. We theorize how magnetic nanoparticles assemble into macroscopic spike-like structures under magnetic fields. We explore magneto-chemo-mechanical controlover soft magnetic media to create new kinds of functional matter.



Field-directed pattern formation from magnetic nanoparticles.png

Electro-controlled processes in the near-electrode layer of magnetic fluid

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 182

Mr. Vladimir Chekanov [1]

1. *Russian Technological University*

In this paper we research a new active medium, which electrophysical and optical properties can be controlled by a weak electric field. This medium is a nanoscale near-electrode layer of a concentrated magnetic fluid.

- Experimental methods for calculating the thickness and refractive index of the ITO electrode and a thin electrode layer of a concentrated magnetic fluid by the interference of reflected rays were developed.
- The influence of the formation of near-electrode layers on the electrical properties of a cell with a magnetic fluid was established. Since the thickness of the layers depends on the voltage on the electrodes, the charge, capacity, and resistance measured in the cell, as measured by the discharge current, depend on the voltage on the electrodes.
- It is shown that the near-electrode layer is an excitable active medium capable of forming an impulse in response to an external effect. An excitable medium consists of a large number of individual elements (elementary areas of the electrode layer or particle ensembles), each of which is an autonomous source of energy
- In the studied medium we researched self-organization — an autowave process and propagation modes of autowaves in the near-electrode layer of magnetic fluid: “fast” and “slow” autowaves, relaxation self-oscillations. (Figure 1)
- The propagation of autowaves in a medium with local heterogeneity is researched. It is shown that the region around the local heterogeneity has a refractory period R_1, which differs from the refractory period R_2 of the medium. Therefore, the wave front reaches the section with refractoriness R_1 and gets broken. An arrhythmia occurs in the oscillations between the whole surface of the cell and the area around the local heterogeneity.
- The autowave synchronization in the near-electrode layer of a magnetic fluid was experimentally researched for the first time. The possibility of practical application of this phenomenon for modeling the operation of a cardiac pacemaker is shown. (Figure 2)
- A mathematical model of the autowave process is constructed. The model is implemented as a computer simulation in the software for modeling physical processes COMSOL Multiphysics 5.2.

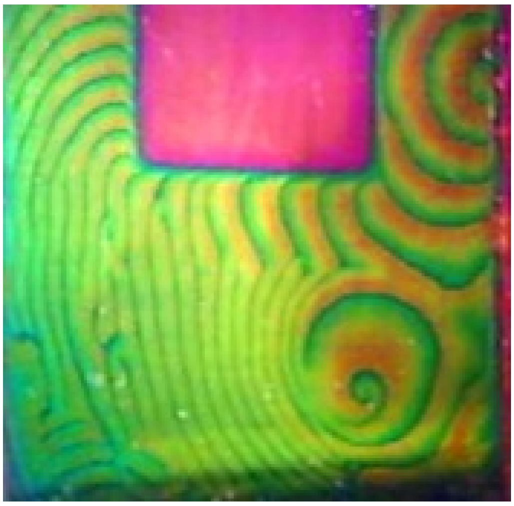


Figure 1.jpg

Figure 2.jpg

Field-induced phase separation of a magnetic colloid under AC fields

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 194

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This work is devoted to an experimental study of kinetics of phase separation of a magnetic colloid under AC rotating magnetic fields. To this purpose, we use citrate-coated maghemite nanoparticles (medium size 8 nm) dispersed in distilled water and slightly destabilized by either adsorption on their surface of a methylene blue molecules or addition of salts, both screening electrostatic repulsion between nanoparticles and leading to primary aggregates of a medium size of about 100 nm. In the presence of a DC magnetic field or an AC unidirectional sinusoidal magnetic field, of an intensity 5-10 kA/m, the primary isotropic aggregates are attracted to each other and form long needle-shape aggregates of a typical length of 0.1-0.5 mm during a timescale related to a translational diffusivity of nanoparticles and the suspension supersaturation. Once they reach a maximal length related to homogeneity of the chemical potential across the suspension, some aggregates coalesce with each other in order to decrease the surface energy but the coalescence is strongly slowed down by repulsive magnetic dipolar interactions, such that in practice the phase separation is not accomplished during a few hours. However, when a rotating sinusoidal magnetic field of the same amplitude is applied, the needle-like aggregates (appearing a few minutes after switching on the field) coalesce very quickly due to their collisions as they synchronously rotate with the field and form circular gear-like aggregates of a millimetric size with a relatively weak internal volume fraction of nanoparticles. We focus on fundamental understanding of this phenomenon tuned by Mason and Péclet numbers, as well as by magnetic nanoparticle concentration and suspension supersaturation. From the practical point of view, the obtained results open new perspectives for controlling the field-induced aggregation which may be applied in co-operative magnetophoresis, immuno-agglutination assays and magnetically assisted thrombolysis.

Dynamic behavior of gas bubble released from single orifice in magnetic fluid

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 195

Dr. Haruhiko Yamasaki [1], ***Mr. Taro Kishimoto*** [2], ***Mr. Takuya Tazawa*** [2], ***Prof. Hiroshi Yamaguchi*** [2]

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Bubble behavior in the magnetic fluid is one of the most important issues to understand characteristics of gaseous-liquid two-phase flow for basic fluid science such as often found in energy transport device, in which boiling-bubble in magnetic fluid affects the heat transport efficiency significantly. Among many applications of magnetic fluid with gaseous phase, knowledge of gas bubble in magnetic fluid is essential. However, no detailed dynamic behavior of bubble have yet fully verified and discussed due to the difficulty of visual observation.

In the present study, in order to understand the dynamics behavior of gas bubble in magnetic fluid, bubble released from single orifice in magnetic fluid is investigated by using near infrared light source with long wavelength of 800-1000 nm as shown in Fig. 1. Surface tension of magnetic fluid, which is key factor to determine the bubble characteristic, is also investigated by a maximum bubble pressure method. Based on the visualization measured, it is found that the detached frequency of bubble increases and the bubble diameter decreases by applying magnetic field. This is caused by the magnetic body force, so called the magnetic ejection force, acts on growing bubble in the same direction as buoyancy force. The measurement of the surface tension and contact angle of magnetic fluid show that the surface tension and contact angle increase simultaneously with increase of applied magnetic field. This is caused by that the Maxwell stress which acts on the interface surface of magnetic fluid, and resultantly gaseous-phase affects to increase the apparent surface tension. From the results of the visualization, it is found that a bubble released from single orifice in magnetic fluid is largely promoted by not only the magnetic ejection effect, but also the change of the surface tension.

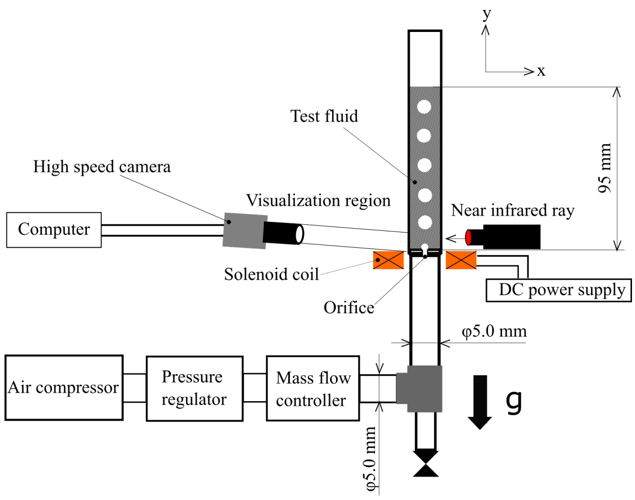

Figure 1.png

Effect of an External Magnetic Field on the Heat and Mass Transports in Silicon - Germanium Melt at High Temperature

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 200

Dr. Farid MECHIGHEL [1], ***Prof. Sadik DOST*** [2]

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Numerical simulations were carried out to explain the behavior exhibited in experimental work on the dissolution process of silicon into a germanium melt. The axisymmetric model equations, namely the equations of conservation of mass, momentum balance, energy balance, and solute transport balance were solved numerically. Measured concentration profiles and dissolution height from the samples processed with and without the application of magnetic field show that the amount of silicon transported into the melt is slightly higher in the samples processed under magnetic field, and there is a difference in dissolution interface shape indicating a change in flow structure. This change in flow structure was predicted by the present model. In the absence of magnetic field a flat stable interface is observed. However, in the presence of an applied field the dissolution interface remains flat in the center but curves back into the silicon source near the edge of the wall. This indicates a far higher dissolution rate at the edge of the silicon source.

Thermal conductivity of flake-shaped iron particles based magnetorheological suspension: Influence of nano-magnetic particle concentration.

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 227

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The tunable rheological properties like yield stress, viscosity, etc., under the magnetic field in magnetorheological fluids were utilized to exploit their use in different applications. The detail, understanding of thermal transport properties of this fluid and influence of particle shape, size, and other parameters, remains limited. There are few studies in the literature on thermal conductivity of iron-based MR suspensions. In this work, non-spherical shape (flake-shape) iron particles based magneto-rheological (MR) fluid thermal conductivity is experimentally investigated using the hot-wire method. The data is compared with the commercially available Lord's MRF-122EG MR fluid. Under the magnetic field, thermal conductivity increased by 20% compared to spherical shape commercial MR fluid having nearly 20% higher volume fraction of iron particles. This enhancement results from the larger contact area of flake-shape particles when they form a chain, which helps to transport heat quickly. The magnetic nanoparticles of size 6.5 nm were added to this MR fluid in varying magnetic weight fractions and studied for their influence on thermal conductivity.

The increase of magnetic nanoparticle concentration enhances the thermal conductivity and increases field reversibility. To analyze the variation of torque with the magnetic field, an empirical relation has been developed based on the variation of yield stress with the field.

k (H) = k(H=0) Tanh (H/H_c) + k(constant) . . . . (1)

Here the H_c is a critical value of the field, above which the TC starts showing the constant value and k is a constant. The line in Figure 1 represents fit to the equation (1). The observed increase in TC and low hysteresis losses attributed to the friction reduction in flake-shaped iron particles in the presence of nanoparticles.

Figure 1. Variation of thermal conductivity with the field for 122EG (left) and Flake shaped particles (right). The filled symbol is for decreasing field. The line is fit to equation (1). For lord sample, the H_c

is 60kA/m while for Flake shaped particles it is 29 kA/m

Acknowledgment: Authors are thankful to CHARUSAT for providing research support.

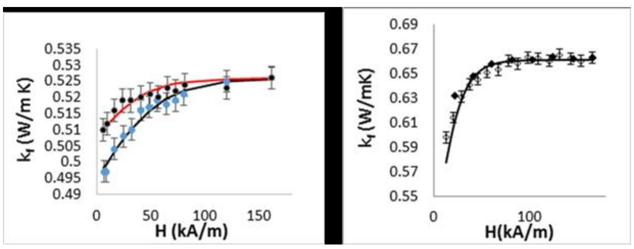

Figure 1.jpg

Flow characteristic of Magneto-viscoelastic Fluid in Sudden Expansion and Contraction Channel

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 256

Mr. Takuya Tazawa [1]***, Prof. Hiroshi Yamaguchi*** [1]

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There are much demands to control viscoelastic properties by external means. Magneto-viscoelastic fluid which can be substantiated by mixing polymeric material into magnetic fluid as a model fluid, is a premising functional fluid whose viscoelastic properties can be controlled by magnetic field. In order to gain fundamental knowledge, in view of examining the effect of chancing viscoelastic properties to the flow characteristics, the flow of magneto-viscoelastic fluid is investigated in sudden contraction and expansion channel. experiments are conducted by measuring pressure difference between the contraction and expansion section, under applying magnetic field at the contraction section as shown in Fig. 1. As in this report, the numerical analysis for considering the influence of the internal flow mode on the pressure loss is performed by the VOF method. The governing equations of system are continuity equation, momentum equation including effect of magnetic field and constitutive equation of viscoelastic fluid. It was known that the pressure loss varies with size of the vortex region around sudden contraction part and sudden expansion part, and it is strongly affected by applying magnetic field.

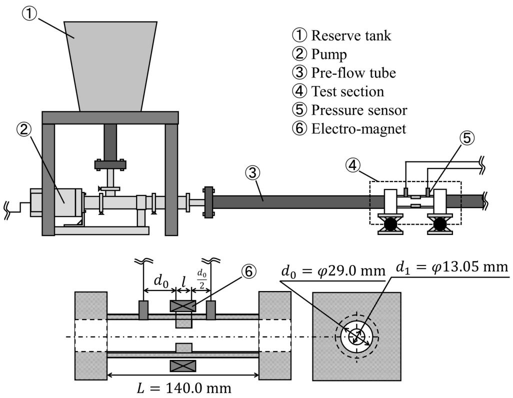


Figure 1.jpg

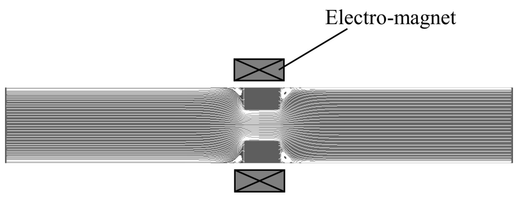


Figure 2.jpg

Spherical magnetizable body partially immersed in a magnetic fluid in a uniform magnetic field

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 276

Dr. Daria Pelevina [1]***, Ms. Olga Sharova*** [1]***, Mr. Dmitriy Merkulov*** [1]***, Dr. Vladimir Turkov*** [1]***, Prof. Vera Naletova*** [1]

1. *Lomonosov Moscow State University*

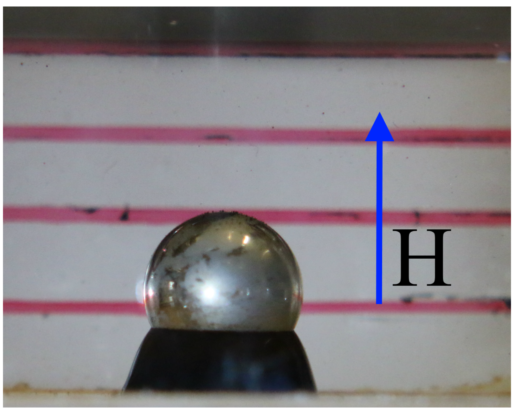
The deformation of a magnetic fluid in an applied magnetic field can be used to create directional motion. In this work, the statics and motion of a spherical body with magnetizable material (body), partially immersed in a magnetic fluid (MF) with a free surface, on a horizontal plane in a uniform vertical applied magnetic field H are considered experimentally and theoretically.

The statics experiments are made with water-based MF and the body in a non-magnetic medium in a rectangular vessel. The vessel with fluids is placed in a uniform vertical magnetic field H of Helmholtz coils. The maximum H is turned on, and the body levitates in the MF (see Fig. 1). Then the field value H is decreased by some step. The dependencies of the levitation height of the body on H are plotted.

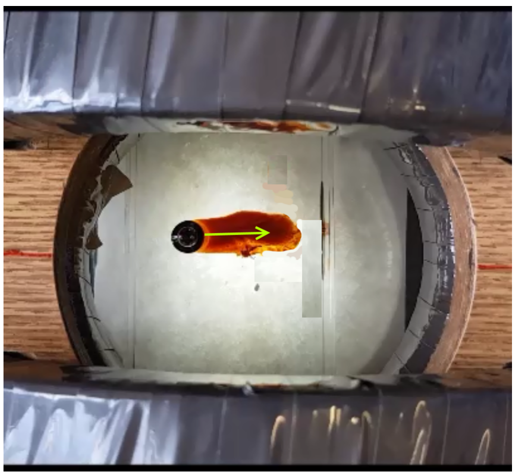
The dynamic experiment is carried out as follows: the body, which levitates in the MF drop (~ 0.01 ml) in uniform vertical H, is displaced for some distance from the initial position. A thin MF layer remains behind the body (see Fig. 2). Then we free the body and observe a horizontal motion along the layer.

The problem of the equilibrium of the spherical magnetizable body in the MF drop is solved, considering the gravity, the dependence of the magnetization on the magnetic field, without surface tension. An analytical expression for the magnetic force acting on the body in a non-inductive approximation is found. A program for calculation of this force and the MF shape is written. The dependence of the levitation height on the applied field H is plotted numerically. The expression for the horizontal component of the magnetic force acting on the body from the thin rectangular MF layer is obtained analytically. Using this expression, the motion of the body along a MF layer is calculated taking into account the viscous force. A comparison of theoretical and experimental results is made.

This work was supported by the RFBR grants 18-31-00066 (experimental and numerical investigations), 18-501-12011.



1 spherical magnetizable body in a magnetic fluid drop.png



2 spherical magnetizable body and a thin magnetic fluid layer.png

Experimental Study on Contribution of Clustering Structure to Surface Tension Change of Magnetic Fluid under Magnetic Field

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 280

Mr. Soichiro ISHII [1], *Dr. Masaaki MOTOZAWA* [1], *Prof. Mitsuhiro FUKUTA* [1]

1. Shizuoka University

When magnetic field is applied to a magnetic fluid (MF) for long time, inner magnetic particles form clustering structure, and this clustering structure grows from time by time. Therefore, surface tension of MF is possible to change with the influence of growth of clustering structure. For long time use of MF application, it is important to clarify the contribution of clustering structure to surface tension change of MF after application of magnetic field. In this study, we measured surface tension of water-based and kerosene-based MF by maximum bubble pressure method (MBPM) to investigate the contribution of growth of clustering structure and by Wilhelmy method to consider the influence of magnetic field direction.

Figures 1 and 2 show the experimental apparatus of MBPM and one result of water-based MF by applying 68mT measured by MBPM, respectively. To argue the contribution of growth of clustering structure, magnetic field is applied for 2, 60, 120 and 600 min to MF before the measurement. We defined this time as T_{cl}(cluster growing time).

In MBPM, surface tension can be determined every generation of the bubble. Therefore, in the case of no magnetic field, the surface tension of MF does not change naturally with elapsed time except for first few seconds as shown in Fig.2. On the contrary, the surface tension gradually decreases with elapsed time in case of T_{cl} = 60 and 120 min, but hardly changes forT_{cl} = 2 min. This indicates that the clustering structure grows largely for T_{cl} = 60 and 120 min by applied magnetic field and it breaks down by generated bubble. This means that it is possible to evaluate the contribution of clustering structure to the surface tension change by MBPM. On the whole, when a magnetic field is applied to MF, the surface tension increases. The increase of surface tension compared withT_{cl} = 2 min indicates the contribution of clustering structure to surface tension changes of MF as shown in Fig. 2. However, entirely different result was obtained for T_{cl}= 600 min. Further detailed discussion and other results will be held in the presentation.

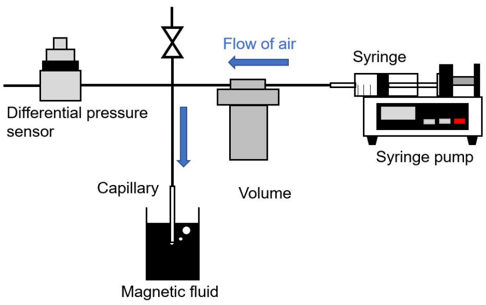


Fig1.jpg

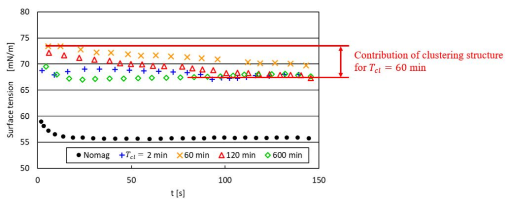


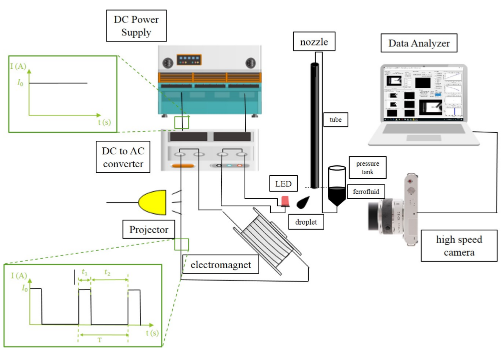
Fig2.jpg

Ferrofluid droplet formation from a nozzle using alternating magnetic field with different angles

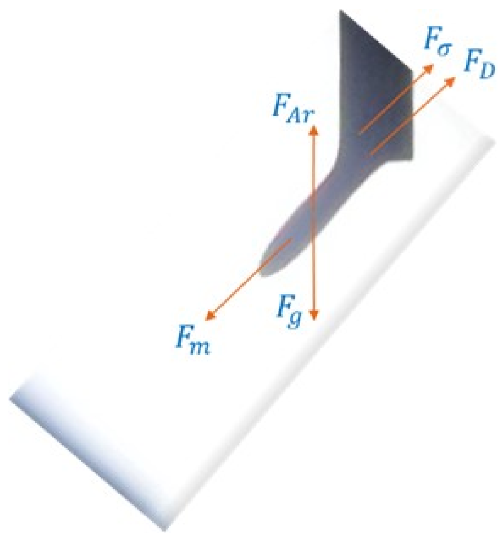
Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 292

Mr. Amirhossein Favakeh [1], *Mr. Mohamad Ali Bijarchi* [1], *Prof. Mohammad Behshad Shafii* [1]
1. *Sharif University of Technology*

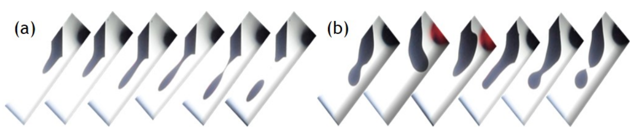
Ferrofluid has been used in many fields, such as microfluidics, droplet formation, and heat transfer, due to its potential to be attracted in the presence of a magnetic field. Droplet formation, itself has many applications such as emulsions, 3D micro-printers, MEMS, and electro-sprays. In this study, the mechanism of ferrofluid droplet formation from the nozzle in the presence of an alternative magnetic field has been investigated. Also, the magnetic field was applied at different angles with respect to gravity. The effect of the alternating magnetic field and the angle on the produced droplet volume, satellite droplet, and droplet formation frequency have been studied for the first time. The results showed that with increasing magnetic flux density, the volume of droplets in both DC and AC cases decreases, while the droplet formation frequency increases. It was also observed that by using a DC magnetic field for all angles, the droplets formation accompanied by a satellite droplet, while in the presence of the AC magnetic field the satellite droplet was omitted. So, a new regime of droplet formation was observed. Also, by tuning the alternating magnetic field, a larger droplet with respect to DC magnetic field was detected. Besides, by increasing duty cycle droplet volume decreases while by increasing applied magnetic frequency, droplet volume increases. Interestingly, it was shown that by increasing the angle from zero to 90 degrees the volume of the produced droplet has a minimum in 45 degrees.



Experimental setup schematic.jpg



The forces applied to the ferrofluid droplet.jpg



The process of droplet formation in a dc and b ac magnetic field for the angle of 45 degrees.jpg

Magnetic convection inside a thin enclosure: new insights based on numerical and experimental analysis

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 339

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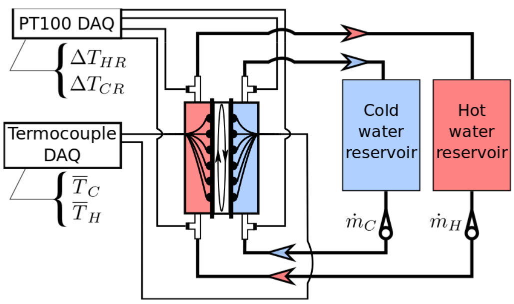
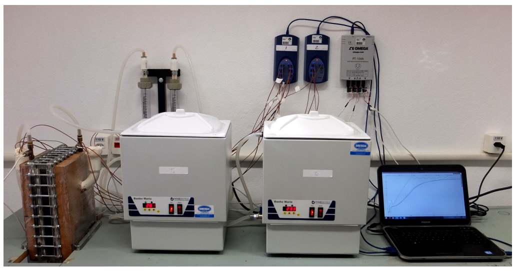
1. University of Campinas, 2. University of Brasília - UnB

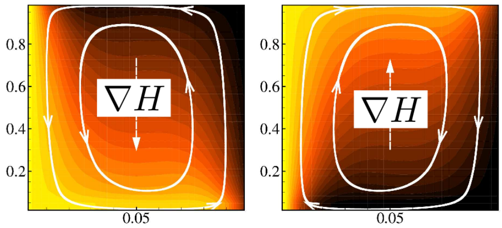
In this work we explore the physics of an elliptic flow of a magnetic fluid subjected to a temperature gradient. The flow is produced by density stratification promoted by the imposed thermal boundary conditions. The geometry in which the fluid is bounded is a narrow rectangular cavity. When an external magnetic field gradient is imposed, secondary currents appear due to magnetic susceptibility stratification. When combined with magnetic field gradients this setup leads to an equivalent magnetic buoyancy mechanism. This phenomenon, known as magnetic convection, modifies the flow´s convective heat transfer rates. We explore this problem using scaling arguments and numerical simulations. We also present a conceptual design of an experimental bench, which is being assembled by our Research Group in order to experimentally investigate this problem. Both, numerical code and experimental bench, were designed, implemented and operated by the authors. Our results report a controllable increase on the convective heat transfer rates due to the application of the magnetic field. We also validate previous scaling analysis done by members of our group. This heat transfer increase due to magnetic effects could be applied in numerous engineering process, specially those regarding optimization of heat exchangers. However, the focus of our work lies on the physical discussions regarding the mechanisms behind the observed heat transfer increase and on the quantification of those rates. Particularly, we argue that a vorticity production mechanism, related to magnetic susceptibility gradients induced by thermal stratification seems to be the primary cause of the observed phenomenon.



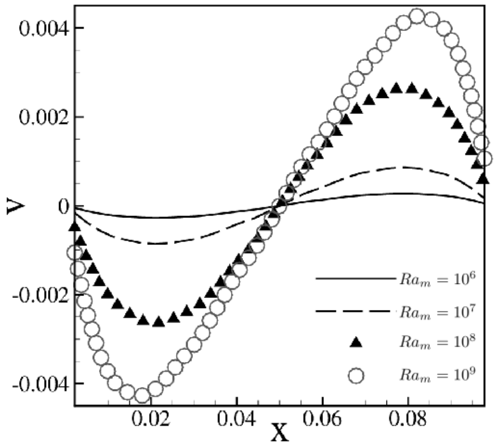
Experimental schematic diagram.png



Experimental setup.jpg



Numerical convective cell rotation inversion.png



Numerical velocity profiles.png

Gravity limited mixing with magnetic micro-convection

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 351

Ms. Lāsma Puķina-Slava [1], *Dr. Guntars Kitenbergs* [1], *Dr. Andrejs Tatulcenkovs* [1]

1. University of Latvia, Lab of Magnetic Soft Materials

Mixing remains an important problem for development of successful microfluidic and lab-on-a-chip devices. Due to the low Reynolds numbers laminar flows are typical in microfluidic devices, therefore mixing happens only because of the slow diffusion process. One possible way how to accelerate diffusion in microfluidics is by generating magnetic micro-convection, an instability happening on the interface of miscible magnetic and non-magnetic fluids in a Hele-Shaw cell under applied magnetic field.

In this study the fluids are brought together in a microfluidics chip, that has a specific rectangular shape with two inlets and one outlet. The experimental system (Fig.1.) is made so, that the microfluidics chip stands vertically and the denser magnetic fluid is under the water in order to exclude the parasitic convection.The fluids are pumped in and out of the microfluidics chip using two synchronized syringe pumps, that can be quickly stopped. This allows to obtain a sharp and motionless interface, which is a novelty comparing to our previous work [1] where micro-convection at different flow-rates was studied and the critical field for motionless regime could only be extrapolated. The density difference of two fluids changes gravitational influence, while coil system allows to change external magnetic field. The study is conducted both- experimentally and by simulations.

Experimental image series of the instability development for various field strengths can be seen in FIG.2. We can see both how finger-like instability develops over time and that the mixing length of two fluids increase by increasing the external magnetic field.

Both simulations and experiments confirm the mixing length of both fluids is limited by gravity and can be expanded by increasing magnetic field. We quantify dependence of mixing length and address its origins.

[1] G.Kitenbergs, A.Tatulcenkovs, L.Pukina, A.Cebers, EPJE, 41,138 (2018)

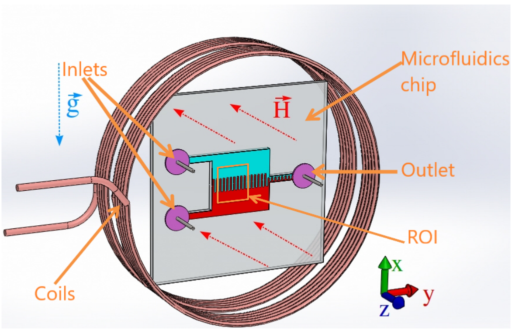


Fig.1. experimental setup.png

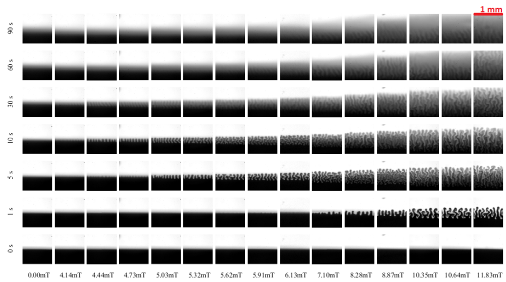


Fig.2. the development of instability over time.png

Characterization of performance map of magnetic pumping for magnetocaloric refrigerator application

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 382

Mr. Luca Granelli [1], ***Mr. Keerthivasan Rajamani*** [1], ***Dr. Mina Shahi*** [1]

***1.** University of Twente*

Magnetocaloric refrigeration is considered as a viable environmentally-friendly alternative to vapour compression refrigeration system. By suspending nanoparticles of the magneto-caloric material in a heat transfer fluid, a magnetic refrigerator can be built with no moving parts by utilizing magnetic pumping. The present study investigates such a system by using space and time varying magnetic fields (in the order of 100 mT) to pump magnetic fluid (for example - a flow rate of 0.13 ml/s at 20 mT is obtained over a height difference of 17 mm). The performance map of such a magnetic pump is characterized for different profiles of the varying magnetic field created by direct current coupled to a pulse generator, and by alternating current at frequencies less than 50 Hz. The usage of higher frequencies is restricted due to heating effect caused by viscous dissipation between nanoparticle chains and the suspended fluid, which is detrimental to the cooling effect produced by the magneto-caloric effect.

Magnetic fluid seals working in liquid environments: factors limiting their life and solution methods

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 487

Dr. Yoshinori MITAMURA [1], ***Dr. Kazumitsu SEKINE*** [2], ***Prof. Eiji OKAMOTO*** [3]

1. Graduate School of Information Science and Technology, Hokkaido University, 2. Institute of Biomedical Sciences, Tokushima University, 3. Graduate School of Science and Engineering, Tokai University

A magnetic fluid (MF) seal enables mechanical contact-free rotation of a shaft and hence has excellent durability. The performance of an MF seal, however, decreases in liquids. We developed an MF seal that has a "shield" mechanism. Factors limiting the seal life and their solution methods were studied.
(a) Factor limiting seal life: MF flowing away. Three types of MF seal were installed in a rotary pump (Fig. 1). Seal A was a conventional seal, and seal C was a seal with a shield. Seal A failed after 6 and 11 days. Seal C showed long-term durability (217 and 275 days). The shield prevented MF from flowing away with fluids and hence prolonged seal life.

(b) Factor limiting seal life: mixing of MF and liquids. Mixing of MFs and water was studied (Fig. 2). Six mL of an MF and 50 mL of distilled water were poured into a beaker. The liquids were stirred for 5 days (Group B) and for 10 days (Group C). The saturated magnetization of the MFs decreased by−7.4% (Group B) and−15.5% (Group C). These results suggested mixing of MF and water and deterioration of the MF, which would reduce seal life.

Two types of shield were placed in MF seals installed in rotary pumps (Fig. 3). One shield (Seal D) had a small cavity space and the other shield (Seal E) had a large cavity space. Seal D showed a longer life (110+ days, ongoing), while Seal E failed after 28, 31 and 32 days.

When a rotary pump is connected to an afterload, water flows into the shield space until air pressure in the shield space reaches the afterload pressure. The volumes of water that flowed into the shield space were estimated to be almost zero in the case of Seal D and about 0.12 μL in the case of Seal E. Less water in contact with the MF prolonged the seal life (Seal D).

In conclusion, a shield mechanism prolongs an MF seal life by preventing the MF from flowing away and mixing with liquids.

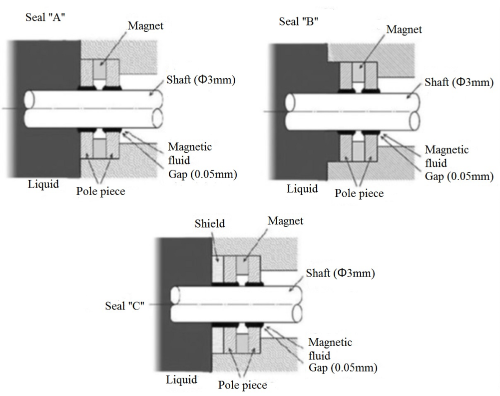


Fig. 1 three types of magnetic fluiud seal.jpg

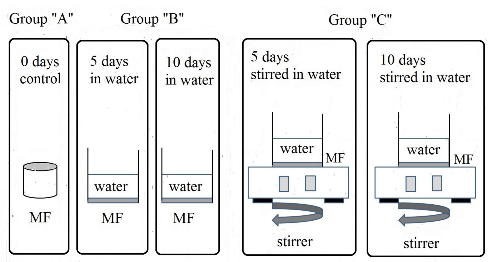


Fig. 2 three sets of experiments..jpg

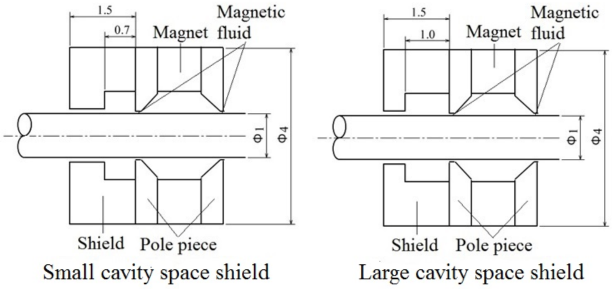


Fig. 3 two types of shield..jpg

Evaporation of superparamagnetic colloid droplets under constant, oscillating and rotating magnetic fields

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 513

Prof. Geoffroy Lumay [1]***, Mr. Alexis Darras*** [2]***, Ms. Florence Mignolet*** [1]

1. *University of Liege,* ***2.*** *Unieversity of Liege*

Evaporation of sessile droplets is a way to organize suspended particles and create surface coating. Many studies have demonstrated that suspensions with various compositions can give rise to qualitatively different dried patterns.

An external and constant magnetic field applied to superparamagnetic colloidal suspensions induces the formation of chains. These chains are the result of the competition between Brownian motion and magnetic interactions. We have shown that these chains can form ribbons due to lateral aggregation between long chains [1]. In oscillating or rotating fields, a panel of structures (rotating chains, aggregates, …) can be observed due to the superimposed effect of hydrodynamic interactions.

In this presentation, we combine magnetic interaction and evaporation process to obtain several dried patterns with superparamagnetic colloids. We show the various patterns obtained with zero, constant, rotating, and oscillating magnetic fields [2]. Moreover, we identify different flow stages during the evaporation thanks to particle image velocimetry analysis.

[1] A. Darras, J. Fiscina, M. Pakpour, N. Vandewalle, and G. Lumay, Ribbons of superparamagnetic colloids in magnetic field, European Physical Journal E 39, 47 (2016)

[2] A. Darras, F. Mignolet, N. Vandewalle, and G. Lumay, Remote-controlled deposit of superparamagnetic colloidal droplets, Physical Review E 98, 062608 (2018)

The behaviour of gas inclusions in a magnetic fluid in a non-uniform magnetic field

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 526

Dr. Petr Ryapolov [1]***, Prof. Vyacheslav Polunin*** [1]***, Dr. Eugene Postnikov*** [2]***, Prof. Viktor Bashtovoi*** [3]***, Prof. Aliaksandr Reks*** [3]

1. *Southwest State University, Kursk, Russia,* ***2.*** *Kursk State University, Russia,* ***3.*** *Belarusian National Technical University*

Gas-liquid systems of various kinds can be found in many technological processes and devices in industry, energy and instrument engineering. The use of magnetic fluid as a liquid medium opens up broad prospects for fairly simple control over the processes of the formation and dynamics of gas-liquid systems and the processes of heat and mass transfer in such systems. In this paper, the installation used in [1] is upgraded by using a transparent channel and video recording system with special software developed in LabView. A concentration series of MFs based on kerosene was studied. The concentrations of MF-1□MF-4 samples are 10.56%, 6.32%, 3.93%, 2.08%, respectively. Figure 1 shows the result of video recording of the air cavity in MF-1 in a flat channel. It can be seen from the figure that the upper part of the gas-MF interface intersects the isolines of the magnetic field intensity modulus of 35 kA/m.

Figure 2 shows a graph of the dependence of the air cavity volume on time; the time when the air cavity touches the bottom of the flat channel is taken as a reference point. Vertical segments on the graph reflect the moment of a sharp change in the volume of the gas cavity, associated with the separation of the gas bubble. It can be seen from the graph that a small number of gas bubbles of large diameter is formed in the low concentrated MFs, the bubble detaches earlier. On the contrary, concentrated MFs are characterized by the formation of a large number of bubbles of small diameter. The data obtained for MF-1 sample coincide with the data obtained in [1] using acoustic-magnetic method for experimental setup with a cylindrical tube filled with MF. This system has prospects as a basis for creating new types of gas meters.

This work was supported by the grant of the President of the Russian Federation MK-1393.2019.8 and the basic part of the state assignment of the Ministry of Education and Science of the Russian Federation No. 3.8949.2017/BP.

[1] Polunin V M, Ryapolov P A, 2018 MHD 54 211-224

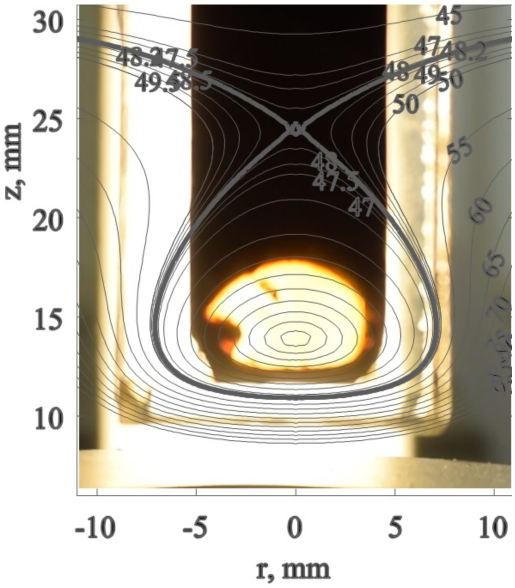


Figure 1

Figure 1.jpg

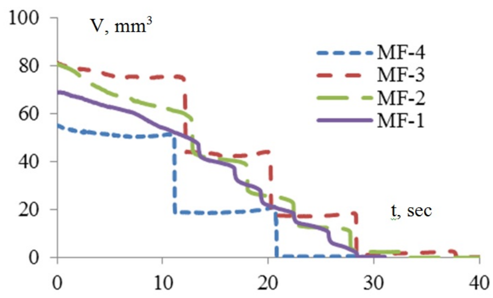


Figure 2

Figure 2.jpg

Controlling the Motion and Stopping of Ferrofluid Droplets Using Surface Tension Gradients and Uniform Magnetic Fields

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 551

Dr. Khalid Eid [1]

1. *Birzeit University*

We will present our work on controlling the motion and stopping of individual water-based ferrofluid droplets due to a wedge-shaped surface tension gradient and a uniform magnetic field.[i]
Uniform DC magnetic fields applied parallel to the surface tension gradient direction allow the droplets to spread freely in the direction of the gradient regardless of the strength of the field. However, weaker uniform magnetic fields are enough to pin a droplet and prevent it from spreading down the surface tension gradient direction when the magnetic field is applied perpendicular to the gradient. This combined effect can be thought of as a 'valve' that can be used to control the flow and stopping of individual ferrofluid droplets on horizontal surfaces, as seen in the Fig. 1 below.
Fig. 1: Uniform magnetic fields applied perpendicular to a surface tension gradient prevent a ferrofluid droplet from moving down the gradient, while parallel magnetic fields almost have no effect on the motion.
Furthermore, our studies show that t*he contact angle varies substantially around the perimeter of ferrofluid droplets* placed on unpatterned horizontal surfaces in a uniform magnetic field. The contact angle variation depends on the direction relative to the magnetic field and on the wetting properties of the surface. This is in sharp contrast with the behavior of nonmagnetic liquids as well as magnetic liquids in the absence of a magnetic field. We will present our results, offer possible explanations/models of this behavior and discuss the possible interplay between the effects of magnetic fields and surface tension gradients on ferrofluid droplets' contact angles.

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Motion of ferrofluid drops on magnetically patterned surfaces

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 559

Prof. Mistura Giampaolo [1], ***Dr. Carlo Rigoni*** [2], ***Dr. Davide Ferraro*** [1], ***Prof. Matteo Pierno*** [1], ***Dr. Delphine Talbot*** [3], ***Dr. Ali ABOU-HASSAN*** [4]

1. *University of Padova,* ***2.*** *Aalto University,* ***3.*** *Sorbonne Université,* ***4.*** *Sorbonne Université, Laboratoire PHENIX-CNRS UMR 8234*

The motion of liquid drops on solid surfaces is attracting a lot of attention because of its fundamental implications and wide technological applications. Here we present a comprehensive experimental study of the interaction between gravity driven ferrofluid drops on very slippery oil impregnated surfaces and a patterned magnetic field. The shape of ferrofluid drops can be significantly deformed by the application of a magnetic field [1]. This magnetic interaction may eventually lead to the division of the drop [2]. From a dynamic point of view, the drop speed can be accurately tuned by the magnetic interaction and, more interestingly, drops are found to undergo a stick-slip motion whose contrast and phase can be easily tuned by changing either the strength of the magnetic field or the ferrofluid concentration [3]. This motion is the result of the periodic modulation of the external magnetic field and can be accurately analyzed because the intrinsic pinning due to chemical defects is negligible on oil impregnated surfaces.

1. C. Rigoni, M. Pierno, G. Mistura, D. Talbot, R. Massart, J.C.Bacri, A. Abou-Hassan, Static magnetowetting of ferrofluid drops, Langmuir 32, 7639-7646 (2016).

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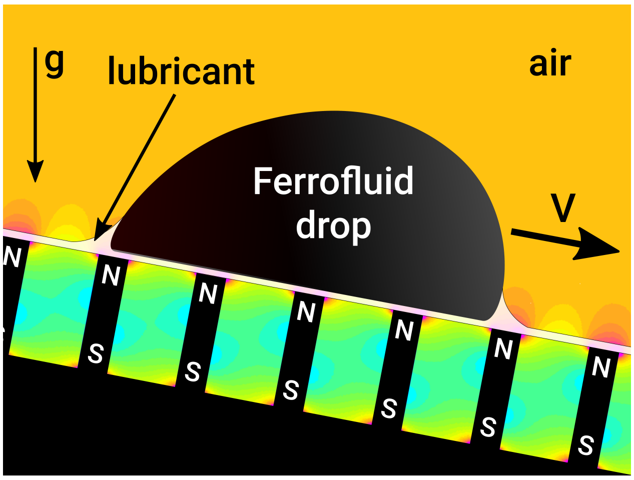

Magnetic liquid drop sliding.png

Absorbtion processes of gases in liquids: new perspectives from ferrofluids?

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 576

Mr. Thibault Plays [1], *Dr. Paolo Stringari* [1], *Dr. Philippe Arpentinier* [2]

1. Mines Paristech, 2. Air Liquide

Absorption is one of the fundamental unit operations in industrial processes; it is particularly used for gas purification. Absorption is a phenomenon of dissolution of a gaseous compound into a liquid solvent. Constant research is carried out for finding and characterizing new absorption fluids with higher absorption capability and selectivity, less energy requirements for regeneration, and lower environmental impact. In the present work, the potential use of ferrofluids as absorption means for separating gaseous mixtures of paramagnetic and diamagnetic components has been investigated for the first time. The effect of an external magnetic field has been investigated to understand how it can enhance the absorption capability of the ferrofluid.

The solvation of ferromagnetic particles into a solvent changes its magnetic and thermodynamic properties (density, viscosity...). The purpose of this work has been studying the variation of the solubility of gaseous oxygen, a paramagnetic molecule, in a ferrofluid in the presence of an external applied magnetic field.

An experimental apparatus (Fig. 1), based on the static-analytic method, has been designed and built for measuring the oxygen solubility in organic solvent with and without an external magnetic field. Samples of the liquid phase have been withdrawn using a ROLSI® sampler and analyzed through a gas chromatographic technique. The experimental apparatus has been validated by comparison of the measured solubility of gaseous oxygen in liquid n-octane with literature data (Fig. 2).

The apparatus allowed to study the system within a large range of pressure (3-60 bar) and temperature (5-80°C). The magnetic field was produced by a magnetic coil settled around the equilibrium cell. The ferrofluid used in this study was composed of n-heptane, as solvent, (99.5% purity) and ferromagnetic nanoparticles. Two types of nanoparticles were studied; the EMG1200, with a fatty acid coating, and the EMG1300, with a dispersant polymer coating, both supplied by the company FerroTec. Preliminary tests on the solubility of gaseous oxygen in the ferrofluid composed of n-heptane and EMG1200 have revealed no influence of the magnetic field on the solubility.

The experimental developments will be applied in the future to different ferrofluids and extended temperature and pressure conditions.

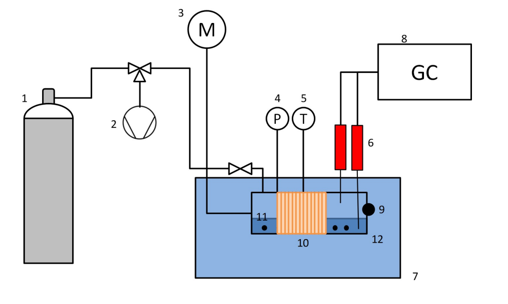

Figure 1. Scheme of the experimental apparatus.

(1): Oxygen cylinder; (2): vacuum pump; (3): driving motor; (4): pressure transducer; (5): temperature probe; (6) ROLSI® sampler; (7): thermostated bath; (8): gas chromatograph; (9): pivot; (10) electromagnetic coil; (11): polymer beads; (12): equilibrium cell.

Fig 1 - scheme of the experimental apparatus.jpg

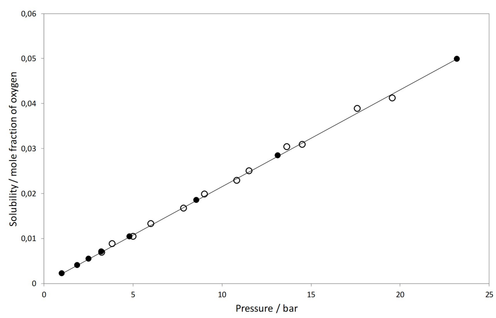

Figure 2. Solubility measurements of oxygen in n-octane at 298.15 K at various pressures.

(●): literature data [1]; (○): this work.

Fig 2 - solubility of o2 in n-c8.jpg

Studies of thermal lens effect of magnetic fluid caused by Gaussian laser beam

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 581

Ms. yanan gao [1]***, Mr. Xiangpeng Yang*** [1]***, Prof. Zhili Zhang*** [1]***, Prof. Decai Li*** [1]

1. *Beijing Jiaotong University*

As a new type of material, the nonlinear optical property of magnetic fluid (MF) presented under Gaussian laser beam (GLB) has caused attention. The theoretical study and application about this are however, still at the beginning. This paper studies the thermal lens effect of MF under Gaussian laser beam. GLB passes through the MF sample and forms the diffraction ring in the far field, indicating that the MF sample behaves like a thermal lens. The laser beam passing through the MF sample causes a radial temperature change in the sample and thus a radial refractive index change, which makes the MF sample a thermal lens. According to the experimental result, we do the numerical simulation based on the Fresnel-Krichhoff integral and the heat transfer equation, analysis different far-field diffraction patterns that might present when laser beam passes through nonlinear medium, which in this case, the MF sample. This nonlinear optical property of MF could be applied on optical instruments like filter and grating.

Thermodiffusion of ionic colloidal dispersions in water/DMSO mixtures

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 606

***Dr. Gilles Demouchy** [1], **Dr. Mitradeep Sarkar** [2], **Mr. Thiago Fiuza** [3], **Mr. Jesse Riedl** [4], **Mr. Frédéric Gélébart** [4], **Dr. Guillaume Mériguet** [4], **Dr. Veronique Peyre** [3], **Prof. Jerome Depeyrot** [5], **Dr. Emmanuelle Dubois** [3], **Prof. Régine Perzynski** [3]*

***1.** University of Cergy-Pontoise, **2.** UPMC, **3.** Sorbonne Université, **4.** Sorbonne Université - CNRS - Lab. PHysico-chimie des Electrolytes et Nanosytèmes InterfaciauX (PHENIX), case 51- 4 place Jussieu, F-75005 Paris, France, **5.** Instituto de Física - Universidade de Brasília*

Thermodiffusion, observed in aqueous salt solutions by Soret and Ludwig 140 years ago, is a process of (ionic) mass flow induced by a temperature gradient. Previous works [1-4] have shown that the Soret coefficient (ST) of maghemite nanoparticles (NPs) dispersed in polar media depends on all the details of the NP/solvent interface and that charged NPs induce a Seebeck contribution to ST. In particular, at room temperature, positively charged NPs, thermophilic in water (ST<0), become thermophobic (ST>0) when dispersed in Dimethylsiloxane (DMSO) at similar ionic strength.
Using Forced Rayleigh Scattering the temperature-dependence of thermodiffusion properties of charged maghemite NPs dispersed in water/DMSO mixtures at different proportions xw of water is studied. These optically-absorbing NPs dispersed at volume fractions □≤2.5% are submitted to a temperature gradient by imaging a 2D grid in the colloid which induces a concentration grating owing to Ludwig-Soret effect [4]. These two arrays can be decoupled due to different characteristic response-times and are studied by diffraction of a non-absorbing laser beam. ST of the NPs is measured in stationary conditions and mass diffusion coefficient (Dm) is obtained by suppressing the temperature modulation.
Whatever □, xw and T, Dm is ruled by interparticle interaction (determined by X-ray scattering), and solvent viscosity, while ST depends on interparticle interaction, the NP/solvent one (ŜNP, Eastman entropy of transfer) and on Seebeck contribution. In solvent mixtures with high proportions of water or DMSO and for T close to room temperature, ST is dominated by ŜNP. ŜNP>0 whatever T for xw<0.3, and changes its sign from negative to positive at T≈45°C for xw>0.8. Adding DMSO molecules in water and/or increasing temperature induces huge changes in the H-bond organization of the molecular solvent.
The authors thank F. Clement, A. Helary, A. Anfry for their help in experiments. This work is supported by the European Union's Horizon 2020 research and innovation programme under grant agreement no 731976 (MAGENTA).
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Magnetic nanomaterials for removal of pollutants in water

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 612

Dr. Agnès Bée [1], ***Dr. Sebastien Abramson*** [2], ***Dr. Nebewia Griffete*** [1], ***Dr. Vincent Dupuis*** [3], ***Dr. Laurent Michot*** [2], ***Mrs. Ibtissam Boussouf*** [4], ***Dr. Sofia Housni*** [5], ***Dr. Nassira Ferroudj*** [6], ***Dr. Layaly Obeid*** [2], ***Dr. Delphine Talbot*** [7]

1. *Sorbonne Université,* ***2.*** *Sorbonne Université, Laboratoire PHENIX-CNRS UMR 8234,* ***3.*** *so,* ***4.*** *Université 20 Août 1955 Skikda,* ***5.*** *Sorbonne Université, Laboratoire PHENIX UMR 8234 CNRS;,* ***6.*** *Université 20 août 1955-Skikda,* ***7.*** *Sorbonne Université, Laboratoire PHENIX UMR 8234 CNRS*

Today, the removal of pollutants from effluents is always a challenge in the environmental field. Among the methods used for the water treatment, we focus here on adsorption and advanced oxidation processes whose efficiency strongly depends on the chosen materials and on the way to recover them after the depollution process. Magnetically assisted solid-liquid separation has been applied to water treatment processes for a long time, since this technique allows an easy separation and recycling of the waste solids resulting from the depollution step, through the simple use of a magnet or electromagnet[1].

In this framework, we present here few examples illustrating how the composition of magnetic nanomaterials can be tuned for obtaining an efficient removal of organic or inorganic pollutants followed by a fast and complete separation of the resulting waste solids from the effluent.

We showed how magnetic-silica microspheres and nanospheres obtained by sol-gel in water-in-oil emulsions (figure 1) can be applied as heterogeneous catalysts in Fenton and photo-Fenton processes for the oxidation of organic micropollutants in water or solid-liquid slurries.

We have also developed a wide range of magnetic adsorbents by encapsulation of magnetic nanoparticles in a biopolymer matrix. The biopolymer and the compound coencapsulated with the magnetic nanoparticles are chosen according to the targeted pollutant. For example, the encapsulation of a magnetic Molecularly Imprinted Polymer (MIP) in an alginate matrix led to a magnetic adsorbent, which could selectively adsorb p-nitrophenol (PNP), an industrial pollutant. Before being introduced in the millimetric alginate beads, MIP are prepared in presence of PNP, which acts as a template that serves as a mold for the formation of pollutant binding sites (Figure 2).

To investigate the efficiency of our different magnetic nanomaterials for the removal of pollutants, batch experiments were carried out to show the effects of different parameters such as initial pollutant concentration, contact time, pH…

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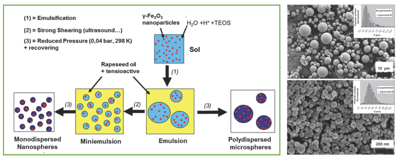

Figure 1: Schematic representation of the synthesis of the magnetic microspheres and nanospheres and their SEM images with size-distributions in inset

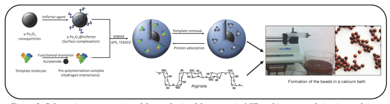

Figure 2: Schematic representation of the synthesis of the magnetic MIP and its encapsulation in an alginate matrix

Figure 1.jpg

Figure 2.jpg

Examination of contact angles of magnetic fluid droplets on different surfaces in uniform magnetic field

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 618

Mr. Sándor Guba [1]***, Dr. Barnabás Horváth*** [1]***, Dr. István Szalai*** [1]

1. *University of Pannonia*

Magnetic fluids significantly change their properties when they interact with magnetic field. This phenomenon can be utilized in several ways (microfluidics, bioanalysis, magnetic actuators), but in most cases the interactions between magnetic droplets and its environment should also be considered.

The interactions between liquid-solid and liquid-gas phases can be characterized by measuring the contact angle between the surface and the magnetic liquid droplet. It is important to know the properties of the surface and the conditions of the measurement (temperature, humidity).

In our research we used water based magnetic fluids containing nanosized (~10 nm) magnetite particles (Ferrotec EMG700). We investigated the magnetic field induced deformation of droplets containing different concentration of magnetite nanoparticles on different surfaces. The contact angle measurements were conducted on droplets placed on hydrophobic (silicone rubber coated silicon wafer) and hydrophilic (uncoated silicon wafer) surfaces. The maximum field strength was 73 kA/m. The droplets were photographed using a microscope camera and the contact angles were determined by LabVIEW software. The measurements were made in a closed system with temperature and humidity sensors. The experimental data are discussed in the framework of perturbation theory.

Experimental method for determining the stability of magnetic fluids based on ultrasound

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 622

***Ms. Ainara Gomez* [1], *Dr. Joanes Berasategui* [1], *Dr. Tomas Gomez Alvarez-Arenas* [2], *Dr. M. Mounir Bou-Ali* [1]**

1. Mondragon Unibertsitatea, 2. Consejo Superior de Investigaciones Científicas - CSIC

In this work, an experimental method based on ultrasound has been developed for determining the stability of magnetic fluids. The development of this procedure implies the choice of the optimal set-up; the acquisition and processing of data; and the correlation of the ultrasonic physical quantities (flight time and attenuation) with magnetic fluid stability parameters. Through the new technique, the stability of different formulated MR fluids has been evaluated, and likewise, this technique has been compared with other techniques already known to determine the stability of magnetic fluids. The results show that the new procedure has advantages over other techniques, since it is less sensitive to the adjustment parameters of the set-up, and the induced disturbance is insignificant.

Rosensweig instability studies of hydrocarbon based ferrofluid under uniform magnetic field

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 657

Mrs. Nimisha O K [1]***, Dr. Reena mary A P*** [1]***, Mr. Shubhadeep Pal*** [2]

1. *university of calicut,* ***2.*** *TIFR, Autonomous*

Magnetically controllable fluids paved way to the new branch of Ferrohydrodynamics. To investigate the Rosensweig instability on a horizontal free surface of a ferrofluid under the influence of a normal uniform magnetic field is very interesting. The instability mechanism occurs when the applied magnetic field exceeds the stabilizing forces such as surface tension and gravitational forces. When the applied magnetic field greater than the critical field a static periodic pattern appears on the free surface of a ferrofluid. When the applied field was increased in a quasistatic way the flat surface changed to ridges. Further increase in the magnetic field resulted in a transition to a hexagonal pattern, the wave number remains constant and amplitude grows when the field exceeds the critical field throughout the first threshold. When the applied magnetic field reaches a second threshold value the hexagonal pattern disappears and square pattern appears. But when the applied magnetic field reduced to obtain a hexagonal pattern, the comeback of the hexagons occurs at a higher field than before due to the inverse hysteresis. The hexagonal pattern is a stable state and square pattern is a metastable state induced by compression of the hexagonal pattern.

In the present work Fe_3O_4nanoparticles are synthesized by controlled chemical co- precipitation. Structural studies were carried out by X- ray diffraction. The DLS method is employed to determine the hydrodynamic radius of the colloidal particles. The FTIR spectra indicate coating of surfactant on the particles. Surface tension of the fluid is measured by Pendant drop method (a) and is correlated with instability measurement as shown in Fig. 1.

ACKNOWLEDGEMENTS

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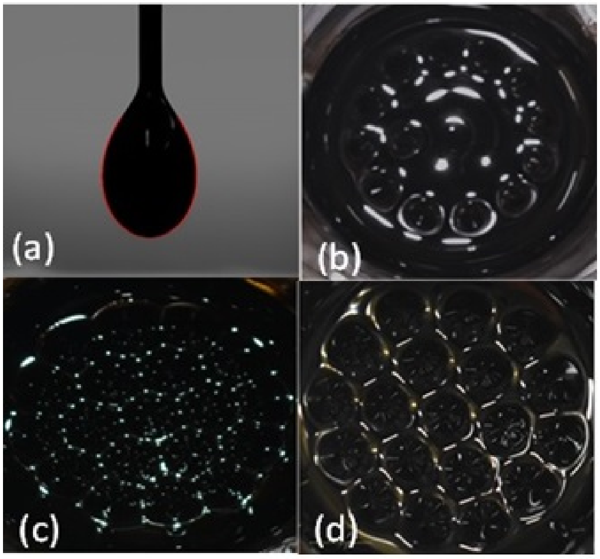

Fig. 1 a pendant drop of the fluid b onset of instability c fluid under 130 gauss d fluid under 155 gauss.jpg

Benchtop ferrofluid lithography of micron size cone-shape pillars

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 658

Mr. Vahid Nasirimarekani [1]***, Dr. Peter Dunne*** [2]***, Prof. Bernard Doudin*** [2]***, Dr. Fernando Benito López*** [3]***, Prof. Lourdes Basabe Desmonts*** [1]

***1.** university of Basque Country, **2.** IPCMS UMR 7504, **3.** Univeristy of Basque Country*

Lithography as a way to write a pattern on a substrate has wide range of applications in micro and Nanofabrication. A patterning process usually requires designing and printing out a photomask which adds complexity and increases the fabrication cost and time. Mask free lithography can tackle this drawback. Magnetizing a ferrofluid by external field and favoring from dipole-dipole interactions trigger spontaneous self-assembly and formation of cone-shape pillars known as Rosenweig instabilities [1], these patterns can be used for lithography. Ferrofluid lithography has been previously introduced to mold cone-shape ferrofluid pillars for modification of polymeric surfaces such as PDMS, but has not been fully discussed and optimized [2,3]. Moreover, we have observed that introducing a polymeric viscous liquid on self-assembled ferrofluid increases surface tension, which plays an important role on energy minimization and as the result increasing the pattern irregularity and size of pillars.

Herein, we describe an approach to improve ferrofluid lithography, avoiding the surface tension effect of liquid polymer by drying the ferrofluid pattern. A drop of 5 mL ferrofluid (EMG900) was dropped on top of a glass slide kept at 2 mm from a permanent magnet (1cm cubic NdFeB magnet with 450 mT magnetization) and let it dry at room atmosphere. Subsequently a UV curable liquid polymer was poured on top of the pattern and cured for 30 minutes by 365 nm wavelength UV light. Afterwards, the glass slide was removed, and the residual ferrofluid was washed out to obtain a mold of cone-shape cavities. Dried ferrofluid showed enough mechanical stability and the volume and size of the pillars decreased in some extent. Additionally, by positioning a second permanent magnet above the ferrofluid pillars they were tilted 40 degree from the vertical axis. In this way lithography of titled pillars could be done which is not easy to do with conventional lithography techniques. This technique does not require any complex tools and skills and it is highly cost effective.

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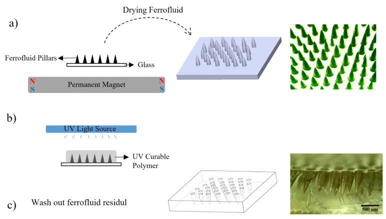
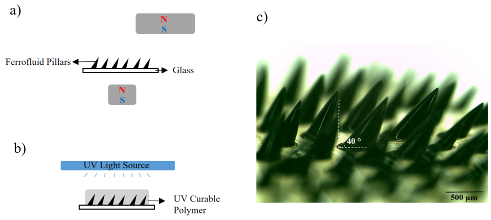


Fabrication of polymeric mold by ferrofluid lithography.png



Polymeric mold of tilted pillars.png

Laccase Immobilization on Functional Magnetic Nanocomposites for Efficient Degradation of Industrial Contaminants

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 271

Prof. Chunzhao Liu [1]

1. Institute of Process Engineering, Chinese Academy of Sciences

In the recent decades, massive industrial revolution of textile dyes brought a serious environmental pollution, especially for water. Synthetic dyes gave warning not only for the environment but also for human health because of their existence in wool, textiles, papers, and leathers. As environmentally friendly biocatalysts, laccases can degrade a broad range of industrial toxic contaminants. However, the industrial applications are limited due to the low stability and poor reusability of free laccases.

Enzyme immobilization can reduce the restrictions by increasing the stability, durability and realizing continuous operations. Up to now, laccase has been successfully immobilized on various kinds of carriers, such as microspheres, nanoparticles, nanofibers and membrane. Among these carriers, the specific magnetic particles can be produced by immobilization of an affinity ligand on the surface of prefabricated magnetic beads, which can be quickly separated from the reaction medium and controlled by applying a magnetic field; then the catalytic efficiency and stability properties of the enzyme can be greatly improved.

In the current study, functionalized magnetic graphene oxide (MGO) support attached with Nα,Nα-Bis (carboxymethyl)-L-lysine hydrate (NTA-NH_2) and chelated with Cu^{2+} were synthesized for laccase immobilization (Figure 1). The Cu^{2+}-chelated MGO (MGO-NTA-Cu^{2+}) exhibited the highest adsorption capacity of 177 mg/g-support for CotA laccase among all synthesized nano-composites. The maximum activity recovery of laccase using MGO-NTA-Cu^{2+} was 114%. The catalytic properties of MGO-NTA-Cu-CotA laccase were significantly improved in comparison with those of free laccase. MGO-NTA-Cu-CotA laccase showed efficient decolorization rate for Congo red (CR) reached 100 % after 5 h reaction at 60 °C and pH 8. MGO-NTA-Cu-CotA laccase retained 89.4 % of its initial activity after 10 consecutive cycles. These MGO-NTA-Cu^{2+} supports provide promising potential for large-scale laccase immobilization in practice.

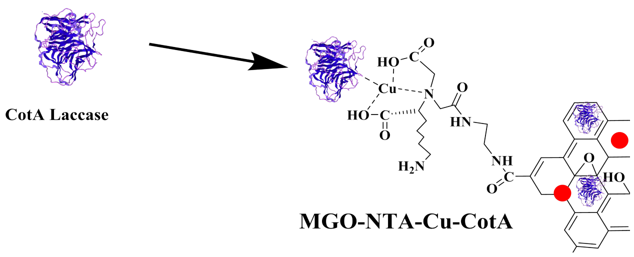


Figure 1.png

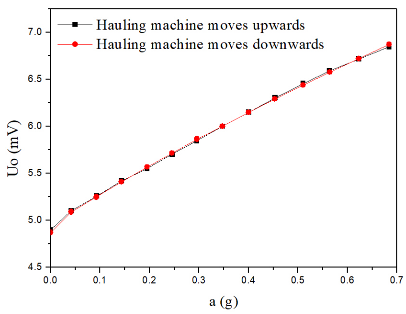
Study on single bubble in acceleration sensor with magnetic fluid

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 244

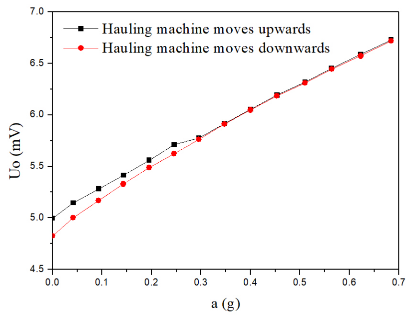
Mr. Rui Sun [1], **Prof. Decai Li** [1]

1. Tsinghua University

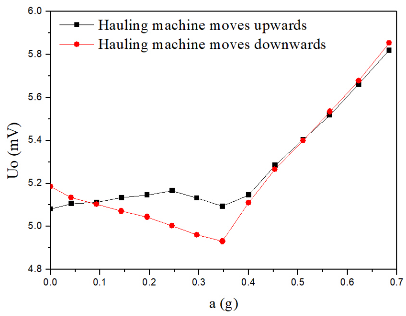
Problems caused by bubble are always inevitable in acceleration sensor with magnetic fluid (ASMF) and influence the performance of the sensor. In this paper, the behavior of single bubble in ASMF is investigated. The relationship between output voltage (U_0) and acceleration (a) of the sensor without bubble is studied theoretically, and it can be clearly found that the linear law is obeyed approximately. Moreover, the formula of total force of the single bubble in ASMF is derived. To analyze the force on the bubble, simulation analysis is utilized by emulating the normal magnetic field strength on the boundary of the bubble. Finally, experiments are presented with different volume fractions of bubble (ranging from 0 to 0.135). Experimental results show that U_0 is linear to a when there is no bubble or the bubble is relatively small. It also shows that bubble greatly influences the linearity of the sensor. The difference between experimental results and the theoretical analysis is less than 6.25%.



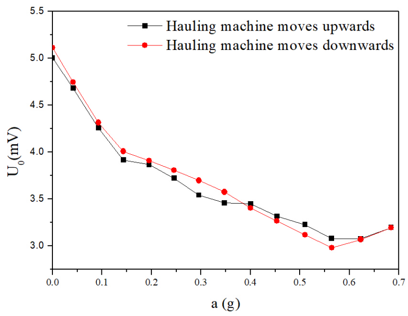
No bubble.jpg



Volume fraction of bubble is 4.5 .jpg



Volume fraction of bubble is 9 .jpg



Volume fraction of bubble is 13.5 .jpg

A 3D BEM algorithm for simulations of magnetic fluid droplet dynamics

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 626

Mr. Aigars Langins [1]***, Mr. Andris P. Stikuts*** [2]***, Prof. Andrejs Cebers*** [2]

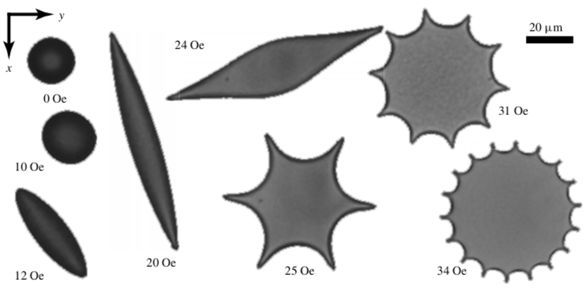
1. *University of Latvia, MMML lab.,* ***2.*** *University of Latvia, MMML lab*

Magnetic droplets are known to exhibit various interesting configurations under the influence of external magnetic fields. As these phenomena are described by a simple model of a magnetic fluid that cannot in general be solved analytically, in recent years some 3D boundary integral equation solutions for magnetic droplet of such configurations have been explored [1], however the question of the droplet dynamics is still a wide field to explore, in particular, for arbitrary fluid viscosity ratios and non-equilibrium shapes in time-varying magnetic fields.

In this paper, we present an algorithm for simulating 3D magnetic droplet dynamics in external magnetic fields by solving boundary integral equations for arbitrary liquid viscosity ratios. This approach relies on multiple mesh stabilization mechanisms and integral equation regularization schemes. The algorithm is tested against a variety of benchmark cases, for example relaxation of an ellipsoidal droplet, stretching in a shear flow and deformations of a spherical droplet in a homogeneous magnetic field.

[1] J. Erdmanis, G. Kitenbergs, R. Perzynski, A. Cēbers (2017) Magnetic micro-droplet in rotating field: numerical simulation and comparison with experiment. Journal of Fluid Mechanics, 821, 266-295.

Figure from Ref. 1. Magnetic droplet configurations in a rotating magnetic field.



Magnetic droplet configurations.png

Deformation of flexible ferromagnetic filaments under a rotating magnetic field

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 566

Mr. Abdelqader Zaben [1], ***Dr. Guntars Kitenbergs*** [1], ***Prof. Andrejs Cebers*** [1]

1. *University of Latvia*

Research on magnetic particles dispersed in a fluid medium, actuated by a rotating magnetic field, is becoming increasingly active for both lab-on-chip and bio-sensing applications [1]. In this study, we experimentally investigate the behaviour of ferromagnetic filaments in a rotating field which are interesting for possible applications as mixers in microfluidics. Filaments are synthesized by linking micron-sized functionalized by streptavidin ferromagnetic particles with biotinized DNA strands.

The experiments are carried out by using different filaments lengths, magnetic field strengths and frequencies. The deformed shapes are characterized by the angle between the tangent at the filament center (ϑ) and magnetic field (H). It has been shown that longer filaments tend to deform having 'S' like shape compared with shorter ones, hence are more flexible as expected. An example of filament deformation can be seen in figure 1. Figure 2 shows the experimental results for the angle ϑ as a function of the frequency at different field strengths. Increasing the frequency for fixed field strength increases ϑ until reaching an angle of 90 degrees before the transition to asynchronous regime. It is found that the slope coefficient in the angle ϑ linear dependence on the frequency is proportional to 1/H as shown in figure 3. The effect of the filament size was investigated and it is found that the longer filaments have larger ϑ with respect to the magnetic field direction for a given frequency. Hence, a lower critical frequency fc is required for the transition to asynchronous regime. Above the transition to asynchronous regime the shape of the filaments becomes three dimensional.

References

[1] - Moerland, C., van IJzendoorn, L. and Prins, M. (2019). Rotating magnetic particles for lab-on-chip applications – a comprehensive review. Lab on a Chip, 19(6), pp.919-933.

Effect of magnetophoresis and Brownian diffusion on thermomechanical processes in magnetic fluids.

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 143

Prof. Viktor Bashtovoi [1]***, Prof. Aliaksandr Reks*** [1]***, Dr. Pavel Kuzhir*** [2]***, Prof. Andrey Zubarev*** [3]***, Dr. Olga Volkova*** [4]***, Mrs. Victoria Moroz*** [1]

1. Belarusian National Technical University, 2. University Côte d'Azur, 3. Ural Federal University named after the first President of Russia B.N. Yeltsin, 4. Université Côte d'Azur, CNRS, Inphyni,UMR7010

Magnetophoresis and Brownian diffusion are natural processes taking place in magnetic fluids in the presence of inhomogeneous magnetic field. As a result, the concentration of magnetic particles Φ does not remain homogeneous and concentration gradients appear. One of the main criteria determining the behavior of these processes is the ratio *U* of the magnetic energy of a particle to its thermal energy.

On the other hand, the magnetic and thermophysical properties of the magnetic fluid depend on the concentration of particles, such that the following phenomena can appear:

1) the dependence of the magnetic fluid magnetization on Φ leads to a change of the magnetic volume force F_m acting on volume;

2) the dependence of the fluid viscosity η on Φ (which can be described by the approximation of Krieger-Dougherty $\eta=\eta(\Phi=0)(1-1{,}35\Phi)^{-1{,}85}$) leads to a change of the viscous stresses in the fluid and the forces of viscous friction F_τ on the solid boundaries;

3) the dependence of the effective thermal conductivity of the magnetic fluid λ_e on Φ (which can be described by the Maxwell's formula

$\lambda_e(\Phi)= \lambda_f[2+\varepsilon-2\Phi(1-\varepsilon)]/[2+\varepsilon+\Phi(1-\varepsilon)]$, where ε is the ratio of thermal conductivity of a base fluid λ_f to the thermal conductivity of solid particles) leads to a change of heat fluxes Q in a non-isothermal fluid.

These changes can be characterized by coefficients representing the ratio of the above quantities to their values in a fluid with a uniform concentration of particles Φ_0: $k_m=F_m(\Phi)/F_m(\Phi_0)$, $k_\tau=F_\tau(\Phi)/F_\tau(\Phi_0)$, $k_q=Q(\Phi)/Q(\Phi_0)$.

On the basis of the diffusion equations, and taking into account phase transitions in magnetic fluid, calculations of the particle concentration distribution and of the above coefficients for the finite volume of magnetic fluid held by a locally inhomogeneous magnetic field in the gap between rotating coaxial cylinders with different temperatures (see picture in figure 1) have been carried out. The results of calculations as a function of the energy ratio U are presented in the figure 1.

The results of an experimental study of diffusion processes in a thin layer of magnetic fluid are also presented (see figure 2).

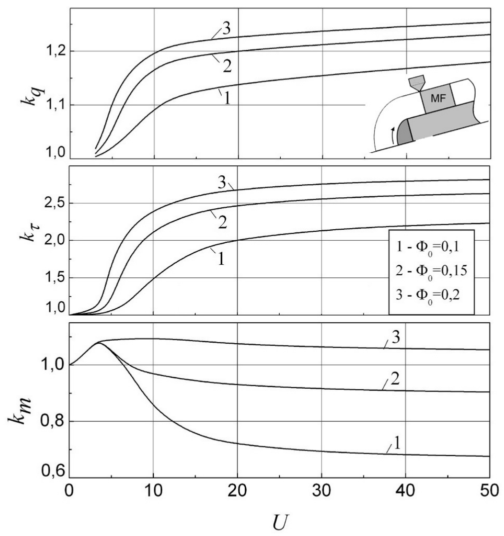


Figure 1

Bashtovoi figure1.jpg

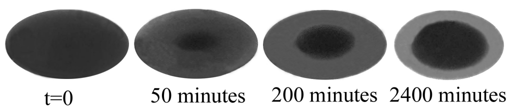


Figure 2

Bashtovoi figure 2.jpg

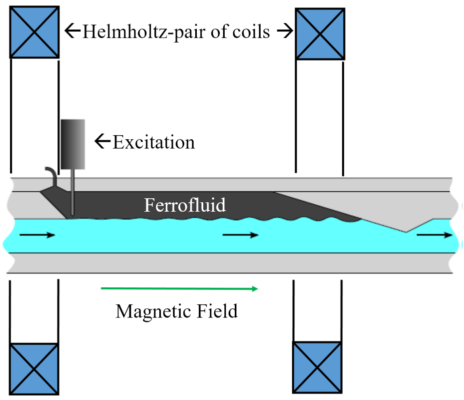
Magnetic Wave Calming

Friday, 12th July - 15:20: Poster Session & Coffee Break - Poster - Abstract ID: 173

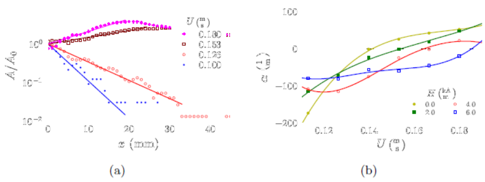
Mr. Armin Kögel [1]***, Mrs. Alexandra Völkel*** [1]***, Dr. Reinhard Richter*** [1]

1. University of Bayreuth, Experimentalphysik 5

We measure the Kelvin-Helmholtz-Instability in between a resting layer of ferrofluid and a laminar flow of magnetically neutral fluid. It has been predicted by Rosensweig (1985) that a homogeneous magnetic field, oriented horizontally, is stabilizing the liquid interface. To test this prediction we apply in a closed flow channel a local periodic perturbation of the interface by magnetic or mechanic means (see Fig. 1, KHI_setup). From the measured growth and decay rates of the interface undulations (see Fig.2a, KHI_growth_rate) we determine the critical flow velocity for various driving frequencies and applied magnetic fields (cf. Fig. 2b). In this way we confirm quantitatively the stabilizing effect of the horizontal field. Moreover we measure the dispersion relation of the interface.



Khi setup.png



Khi growth rate.png

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Conferences, Events & Workshops