82nd International Scientific Conference of the University of Latvia 2024

Section

Active, soft and magnetic matter

Abstract Book

UNIVERSITY
OF LATVIA

Magnētisku
Mīkstu
Materiālu
Laboratorija
LAB OF MAGNETIC SOFT MATERIALS

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Programme

Chair: Prof. Andrejs Cēbers		
12.00–12.05	*Opening*	
12.05–12.35	*Dr. Andris Pāvils Stikuts*	Motion of microparticles driven by electromagnetic fields
12.35–12.50	MSc student Mārtiņš Klevs	Dynamic mode decomposition of magnetic micro-convection
12.50–13.05	PhD student Māra Šmite	Cell magnetic moment measurement in an environmental sample
13.05–13.20	PhD student Bhagyashri Shinde	The dynamics of interacting ensembles of rotlets
13.20–13.35	Dr. Viesturs Šints	Nutrient flow in an Organ-on-a-Chip is non-Newtonian
13.35–14.00	Coffee break, discussions	
Vadītājs/Chair: Dr. Guntars Kitenbergs		
14.00–14.30	Msc. Jānis Hūns	Prospects for measuring the gyrogravitational ratio of intrinsic spin using a ferromagnetic gyroscope
14.30–14.45	Dr. Andrejs Tatuļčenkovs	Numerical simulation of the magnetic micro-convection with gravity in a Hele-Shaw cell
14.45–15.00	*Dr. Rūdolfs Livanovičs*	Smoothed profile – lattice Boltzmann methods for particle suspensions
15.00–15.15	*Dr.* Ivars Driķis	Hexagonal grain patterns of magnetic fluid concentrated phase droplets: formation and reorganization
15.15–15.30	*Dr.* Oksana Petričenko	Review of magnetic materials prepared in MMML Lab
15.30–15.55	Coffee break, discussions	
15.55–16.00	Conclusions, discussions	

Motion of microparticles driven by electromagnetic fields

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Periodic potential landscapes are commonly studied in collective particle transport. The motion of driven colloidal particles in a one-dimensional sinusoidal potential is one of the simplest such examples. When the number of particles exceeds the number of energy minima, clusters of particles can form that, like solitons, propel in the opposite direction of the driving force [1] (figure 1). Here we show how in an amplitude modulated potential such solitons themselves behave like quasi-particles slowing down their motion when “climbing uphill” the modulation and speeding up when “climbing down”.

It has been shown that bent rotating magnetic filaments due to the interaction with a surface suck in fluid in the rotation plane and push it out away from the surface [2]. In the same article the authors note that the filaments are rotating at different heights above the surface. Here we examine a rotating S shape that maximally deflects the flow toward itself in the plane of rotation and away from the surface. We characterize the resulting lift force using Lighthill’s slender-body theory.

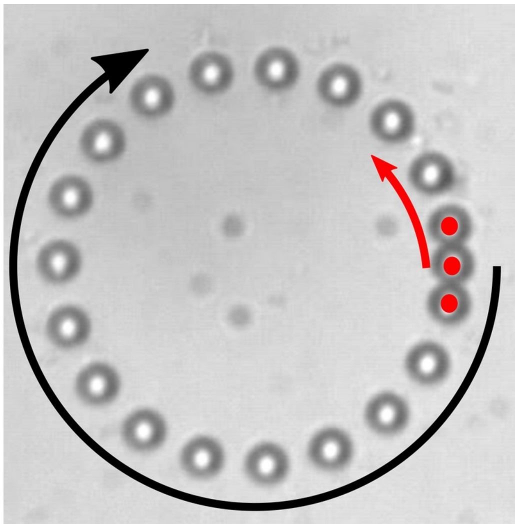

Figure 1. 20 spherical particles driven clockwise (the black arrow) by a circular arrangement of 19 optical traps. The 4 micron sized particles form a cluster propelling in the opposite direction (the red arrow).

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Dynamic mode decomposition of magnetic micro-convection

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Magnetic micro-convection is a flow instability that causes spontaneous flow between a magnetic and non-magnetic fluid when an external magnetic field is applied. During this instability, ”fingers” start to grow at the boundary of the two fluids, which greatly contribute to the mixing of the two fluids, and their size and chaotic nature depend on the strength of the external magnetic field [1]. Understanding the shape of these ”fingers” is necessary to gain a better understanding of magnetic micro-convection.

This work uses an algorithm called dynamic mode decomposition (DMD), which decomposes numerical time series data into spatial modes that either oscillate, grow or decay over time [2]. Each dynamic mode is capable of containing information about different spatial and temporal scales. A modified version of the DMD algorithm is used to analyze numerical data of magnetic micro-convection systems to obtain additional information on the growth and shape of the ”fingers”.

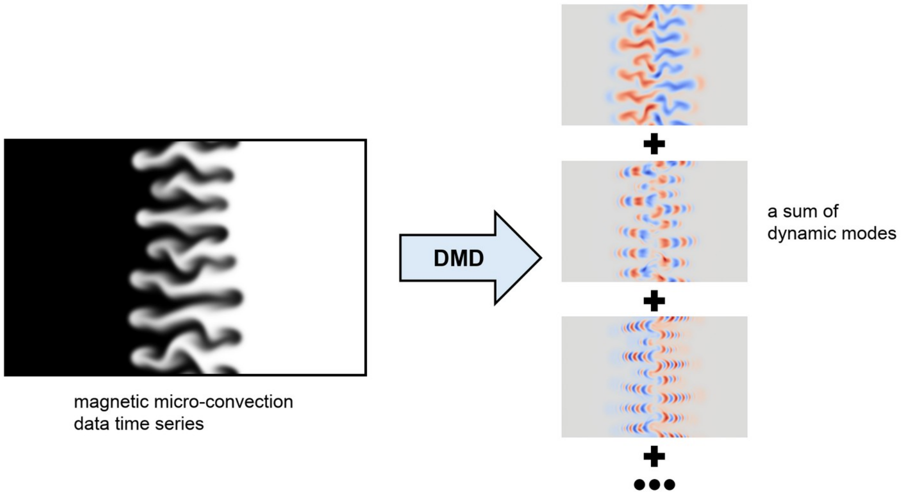

Figure 1. Schematic for the DMD algorithm. The concentration field time series is split into multiple spatial modes where each mode has its own frequency and growth/decay rate.

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This research has been funded by the Latvian Council of Science projects A4Mswim (project No. lzp-2021/1-0470) and BIMs (project No. lzp-2020/1-0149).

Cell magnetic moment measurement in an environmental sample

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Ogre River has been identified as a natural habitat for a considerable diversity of magnetotactic bacteria (MTB). Through two expeditions, we were able to collect samples containing live magnetic bacteria, and conduct morphological and genetic analyses, as well as perform motility measurements under an optical microscope.

Magnetotactic bacteria is a term that is used to characterize any bacteria able to produce magnetosomes and respond to magnetic field, therefore these bacteria can have a variety of cell shapes and motility mechanisms (Figure 1. a). Genetic analysis from a single Ogre River sample showed that it may contain up to four families of magnetotactic bacteria, which considerably complicates the process of distinguishing magnetic moment for each type, as the optical microscopy resolution only allows for the most basic morphotype determination (Figure 1. c-d).

The magnetic moment was found by fitting the experimental trajectory of bacterium at field inversion with the theoretical solution (Figure 1. e), instead of using the traditionally used time derivative. The magnetic moment was calculated for two distinct cell groups – cocci, which includes diplococcus and cocci clusters, and oblong, which includes rods, spirillum, and vibrio morphotypes (Figure 1. b).

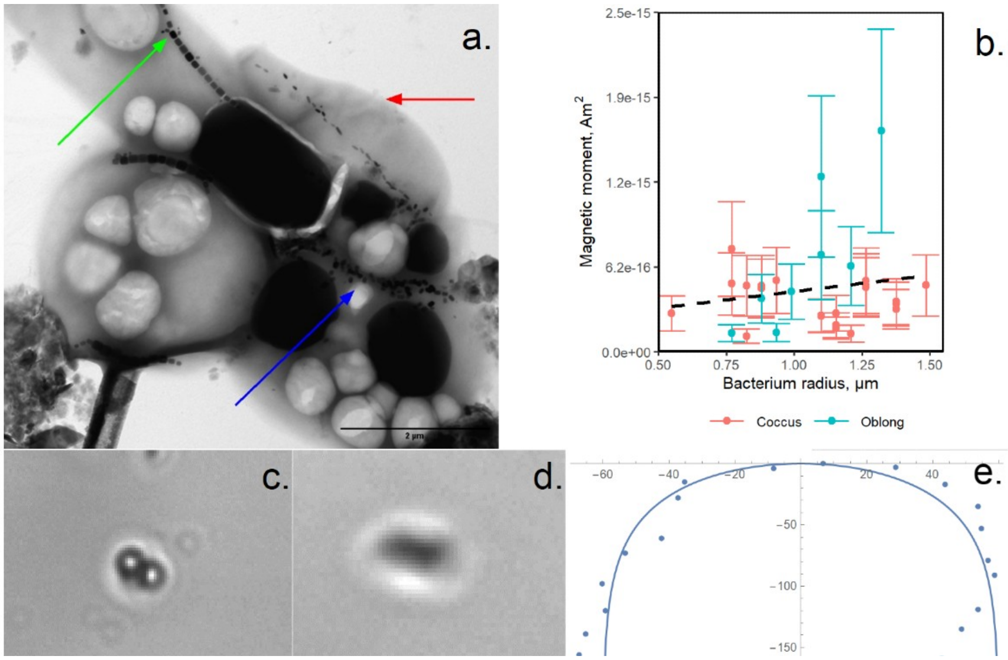

Figure 1. *a* - TEM image of the diverse MTB found in Ogre River, arrows point to different cell morphotypes. *b* - cell magnetic moment. *c-d* cell shapes as seen with an optical microscope, used for magnetic moment calculation, *e* – trajectory fit.

This research has been funded by the Latvian Council of Science, project A4Mswim, project No. lzp-2021/1-0470 and the French-Latvian bilateral program "Osmose", project No. LV-FR/2023/3.

The dynamics of interacting ensembles of rotlets

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Research on the dynamics of interacting swarms has gained great attention owing to its interesting applications in biology, physics, and robotics [1]. Examples observed in nature are from colonies of bacteria to swarms of insects and many more, and in inanimate objects from ensembles of magnetic particles to swarms of robots and many more. We are particularly interested in the dynamics of two interacting ensembles of magnetic particles, motivated by experiments on the ensemble of magnetic droplets rotating under an external field [2]. In interacting ensembles, the pre-and post-merging processes are crucial to understanding the mechanism behind merging.

We present a two-dimensional numerical simulation to study the behavior of two ensembles of rotlets. The repulsive force between the rotlets is incorporated into the model along with hydrodynamic interactions. In this system, the two ensembles initially rotated around each other. Over time, they merge, resulting in a single-ordered rotating structure. The eventual configuration obtained depends on the initial condition parameter, which is the distance separating the ensembles: either a stable hexagonally ordered structure or a disordered structure. We demonstrate the embedding of one ensemble into another to determine the level of complexity when both ensembles merge and form a single-ordered structure. We also studied the dynamics of a single particle when merged with a large ensemble.

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Nutrient flow in an Organ-on-a-Chip is non-Newtonian

Viesturs Šints, Jānis Cīmurs, Guntars Kitenbergs

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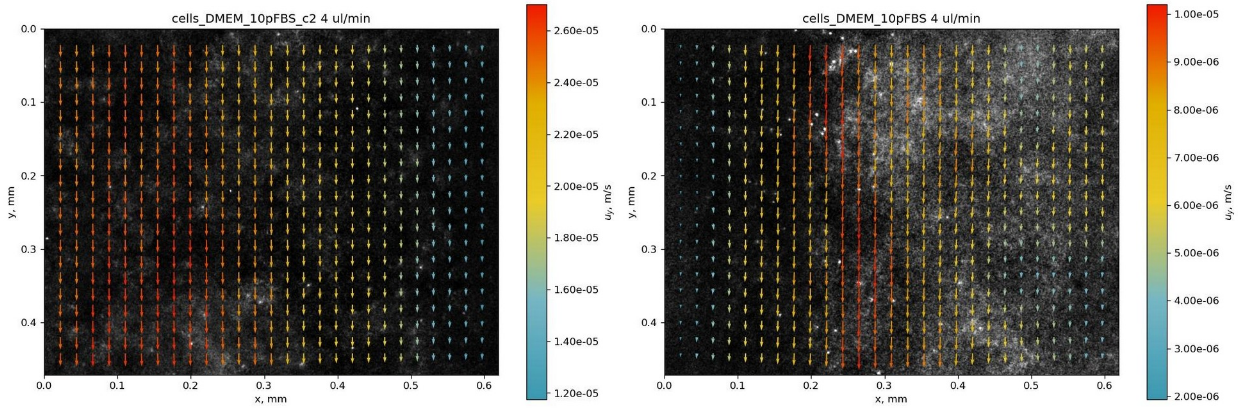
Organ-on-a-Chip (OoaC) technology endeavors to replicate human organ functionality in microfluidic devices. In the OoaC devices involved in this study, human organ tissue is grown on a membrane between two flow channels. Here, we investigate nutrient solution flow in an OoaC channel by two methods – non-Newtonian characteristics of the solution are obtained by rheometric measurements, while the flow itself is observed via Particle Image Velocimetry (PIV), performed in the OoaC device itself.

Measurements of nutrient solution viscosity depending on flow rate ascertain that it is a non-Newtonian fluid. Describing this dependency with a power law allows us to use actual viscosity values in description of the flow. The impact of information on flow within the channel that is provided by the PIV measurements is two-fold. One of the results is a shear stress profile for the cell growth area of the channel – this is of importance due to a role played by shear stress in the cell growth[1]. The other notable result is information on shape of tissue structures revealed by flow velocity field (Fig.1).



velocity distribution at wall

velocity distribution at cell layer

Figure 1. Flow velocity field in nutrient flow channel: undisturbed (left) and affected by presence of tissue matter (right)

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Prospects for measuring the gyrogravitational ratio of intrinsic spinusing a ferromagnetic gyroscope

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The Lense-Thirring (LT) precession and de Sitter (dS) precession have been observed both in astrophysical settings and in in-orbit experiments [1] for objects carrying mechanical angular momentum. Several theories of gravity predict this precession to be faster for intrinsic spin. This is expressed through the gyrogravitational ratio - akin to the gyromagnetic ratio in magnetism Measuring these effects for intrinsic spin could constitute the first experimental test of these theories.

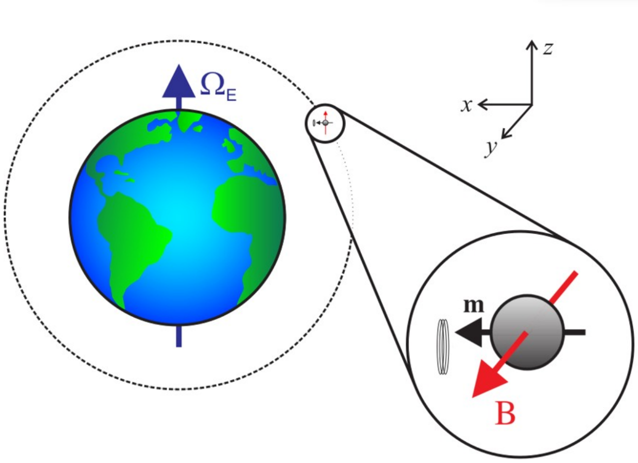

Figure 1. Schematic of the proposed experiment. The magnetic field creates Larmor precssion of the magnetic moment, which is synchronised with the orbit to amplify the Lense-Thirring effect. Figure adapted from [2].

An in-orbit experiment has been proposed to measure the LT or dS precession of intrinsic spin using a ferromagnetic gyroscope (FG) [2]. We aim to improve the proposed experimental setup. By synchronising the Larmor precession of the FG in a magnetic field with double the orbital frequency the LT or dS effects can accumulate into a constant tilting rate. Owing to recent developments in magnetometer technology [3] this could, in principle, discern various theories of gravity after just a few hours of continuous measurement.

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Numerical simulation of the magnetic micro-convection with gravity in a Hele-Shaw cell

Andrejs Tatuļčenkovs, Lāsma Puķina-Slava, Andrejs Cēbers, Guntars Kitenbergs

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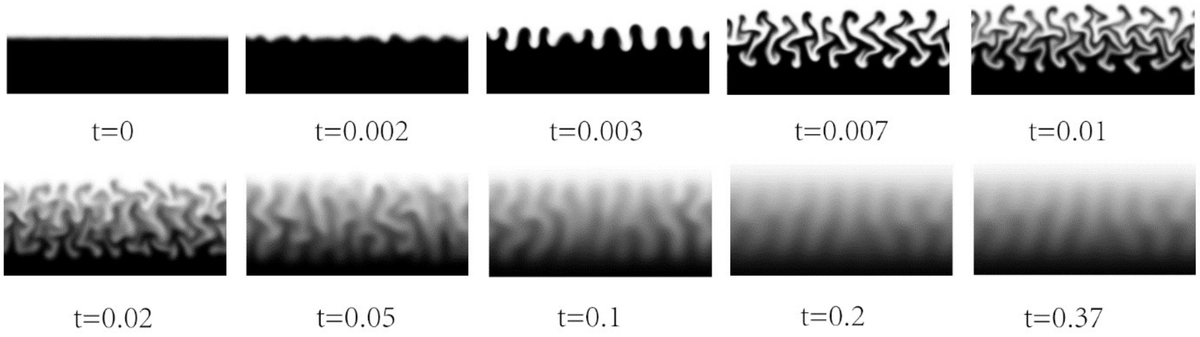
The phenomenon of magnetic micro-convection occurs at the interface between magnetic and non-magnetic fluids when exposed to an external magnetic field. The characteristics of this instability can be easily controlled by adjusting certain experimental parameters, making it an intriguing subject for fundamental research due to undiscovered behaviors and contributing factors. Additionally, magnetic micro-convection can improve mixing in microfluidics and lab-on-a-chip devices, where laminar fluid flows are typical.

This investigation focuses on studying magnetic micro-convection between non magnetic and magnetic fluids in a vertical cell (Hele-Shaw cell), utilizing numerical simulation method to observe the nonlinear regime of the micro-convection and linear stability analysis to explore the impact of magnetic and gravitational fields on the stabilization of magnetic micro-convection [1]. The linear stability analysis involves a three-layer system of fluids with varying concentrations of magnetic particles.


$t=0$ $t=0.002$ $t=0.003$ $t=0.007$ $t=0.01$

$t=0.02$ $t=0.05$ $t=0.1$ $t=0.2$ $t=0.37$

Figure 1. Numerical simulation concentration plots of the magnetic micro-convection dynamics for Ram = 2000 and Rag = 3031 at dimensionless time moments for initial smearing parameter t_0 = 0.0033.

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Smoothed profile – lattice Boltzmann methods for particle suspensions

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Numerical simulation of relatively dense suspensions of rigid particles is a well studied problem in computational fluid dynamics. Nonetheless, constructing computationally efficient, accurate and numerically stable models of dense suspensions with bidirectional fluid-particle coupling remains a challenge. Due to the advent of highly parallel computing architectures, lattice Boltzmann methods have gained considerable popularity as fluid solvers with low parallelization overhead and relative ease of implementation across a diverse range of computer hardware. In this context, a class of immersed boundary methods are usually employed for coupling with particle models, however, this approach often presents a myriad of numerical challenges.

Recognizing that many of the numerical issues observed stem from the need to enforce boundary conditions on sharp interfaces across relatively coarse Cartesian grids, a smoothed profile approach, which allows for continuous interface boundaries, has been introduced [1]. This approach maintains the benefits of explicit direct forcing methods while avoiding the complex force density interpolations between Eulerian and Lagrangian representations that characterize immersed boundary methods and often lead to numerical instability or computational inefficiency.

We present a coupled smoothed profile – lattice Boltzmann solver and discuss the challenges associated with its implementation on modern GPU architectures, showcasing initial benchmarks to illustrate its suitability for efficiently calculating the many body dynamics of rigid particles immersed in an incompressible Newtonian fluid.

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Hexagonal grain patterns of magnetic fluid concentrated phase droplets: formation and reorganization

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A numerical method for the simulation of the concentration domain structures of liquid magnetics in plane layers was formulated in [1,2]. There we present the results of long-term calculations that illustrated structural behavior of hexagonal patterns built by magnetic fluid concentrated phase droplets. We detect pairs of neighbor droplets that has exactly 5 and 7 neighbors. Initially they forms quite random pattern. Later large part of them annihilates and rest of them form the boundaries of droplet pattern grains that differs by inclination of hexagonal pattern. When whole pattern contains both small and large gains, small gains melts and pattern simplifies.

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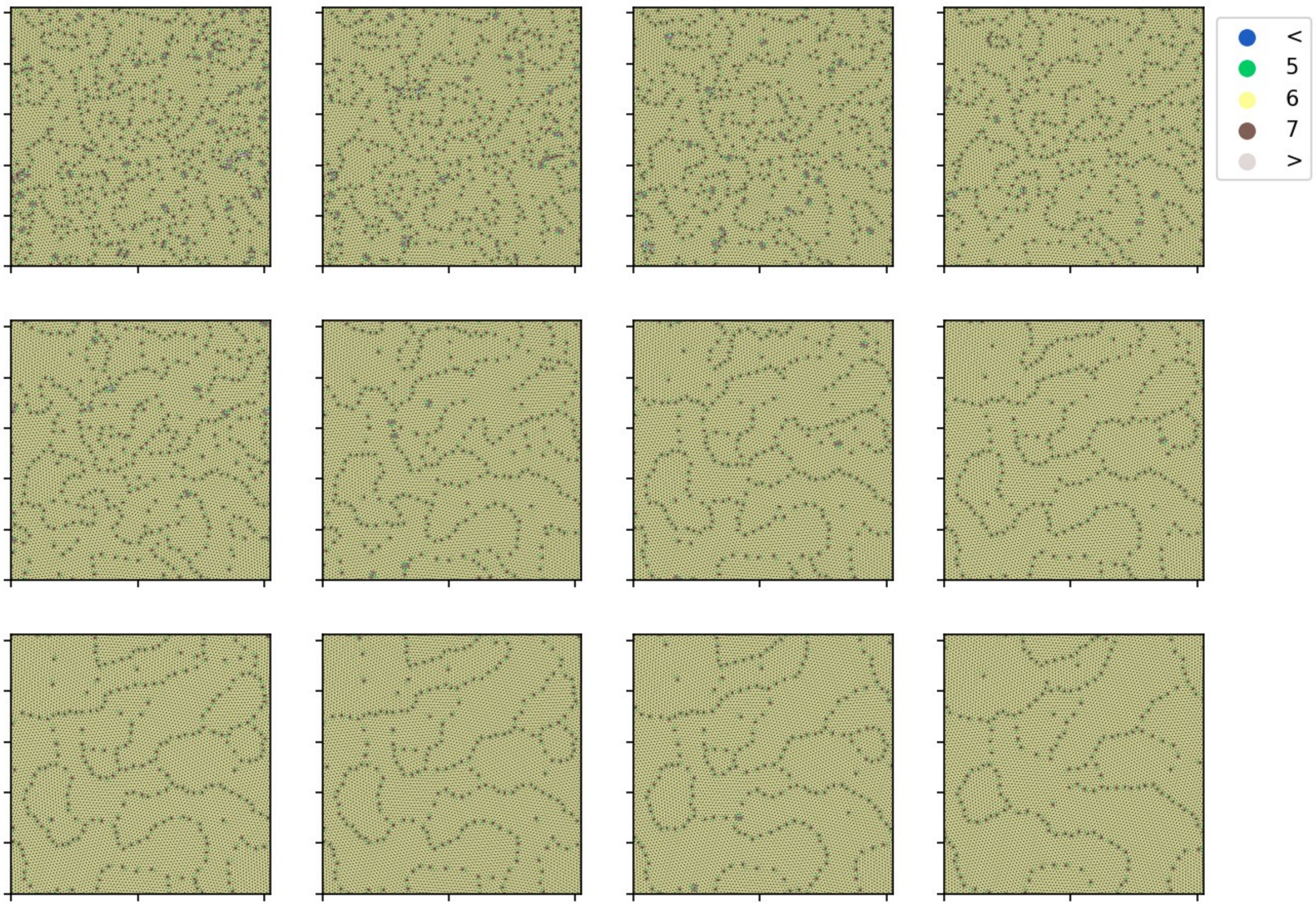

Review of magnetic materials prepared in MMML Lab

Oksana Petrichenko

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MMML research interests cover various aspects in the field of magnetic soft materials, magnetism and soft matter, including material synthesis, characterization and rheology, investigation of different phenomena connected with these materials and development of new methods and applications for use in biotechnology. Due to their biocompatibility, iron oxides are mostly studied magnetic materials.

In the Laboratory of soft magnetic materials five different magnetic materials were synthesized and prepared. The first material is maghemate (γ-Fe_2O_3) magnetic nanoparticles (MNPs) in water medium (ferrofluid, FF) with different surface coating.

The second material is micro-sized hematite (α-Fe_2O_3) particles with different shapes (see Fig. 1)

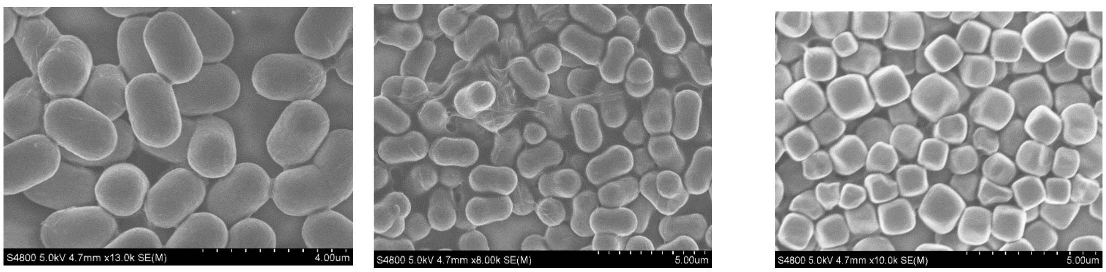

Figure 1. α-Fe_2O_3 particles SEM (Hitachi S-4800) images (K.Buks, Institute of Chem.Phys.)

The third material is aqueous two-phase magnetic systems – ferrofluid (ATPS-FF). ATPS are composed of two polymers: PEG and dextran [1].

The fourth material is magnetic liposomes. If the internal volumes of liposomes are filled with a FF, these liposomes become magnetic. The physicochemical properties of the new original heterocyclic compounds synthesized in the Laboratory of Membrane active compounds and β-diketones (MAC) of the Latvian Institute of Organic Synthesis were studied. We determined the influence of compound structures on the formed liposomes properties. The physicochemical properties of liposomes that determine the efficacy of a liposome formulation include size, surface charge, composition, and surface modifications [2, 3].

The fifth material is magnetic polymer material with incorporated magnetic NPs. The material was produced by electrospinning in collaboration with the Laboratory of optical biosensors and functional nanomaterials (R.Viter, Y.Tepliakova, V.Zabolotnii).

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About

The main organization of this section is done by the MMML lab (Lab of Magnetic Soft Materials) of the University of Latvia. More information about our activities and research interests can be found on our website https://mmml.lu.lv. You can also follow our twitter account @MMML_LU.

Conference session organizer is Dr. Mārtiņš Brics and section chairs are Prof. Andrejs Cēbers and Dr. Guntars Kitenbergs.

For the technical support we thank the Faculty of Physics, Mathematics and Optometry.

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