Magnetic Soft Matter

Abstract book

February 11, 2021

79th International Scientific Conference of the University of Latvia

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79th International Scientific Conference of the University of Latvia

Magnetic Soft Matter
February 11, 2021
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Programme

Times are given for Riga local time (GMT+2)

10:50 - 11:00 **Opening of seminar**

11:00 - 11:45 *Mahla Mirzaee-Kakhki, Adrian Ernst, Anna M. B. E. Rossi, Nico C. X. Stuhlmüller, Maciej Urbaniak, Feliks Stobiecki, Meike Reginka, Dennis Holzinger, Arno Ehresmann, Daniel de las Heras, Thomas M. Fischer*, **Applications of topological magnetic transport**

11:45 - 12:05 *Pietro Tierno, Antonio Ortiz-Ambriz, Helena Massana-Cid*, **Emergent colloidal currents generated via exchange dynamics in a broken dimer state**

12:05 - 12:25 *Mikhail Krakov, Arthur Zakinyan, Anastasia Zakinyan*, **Regarding the nature of the dependence of the critical wavelength on the magnetic field at the instability of interface of miscible magnetic/non-magnetic fluids**

12:25 - 12:45 *Armin Kögel, Alexandra Völkel, Reinhard Richter*, **Calming the waves, not the storm: measuring the Kelvin-Helmholtz instability in a tangential magnetic field**

12:45 - 13:05 *Carlo Rigoni, Bent Harnist, Grégory Beaune, Jaakko V. I. Timonen*, **Ferrofluidic Aqueous Two-Phase System with Ultralow Interfacial Tension, Instabilities and Pattern Formation**

13:05 - 13:20 **Break**

13:20 - 13:40 *Dmitry Chirikov, Andrey Zubarev, Pavel Kuzhir*, **Theoretical study of the flow of a ferrofluid in an oscillating magnetic field**

13:40 - 14:00 *Thiago Fiuza, Mitradeep Sarkar, Jesse C. Riedl, Andrejs Cēbers, Fabrice Cousin, Gilles Demouchy, Jérôme Depeyrot, Emmanuelle Dubois, Frédéric Gelebart, Guillaume Meriguet, Régine Perzynski, Véronique Peyre*, **Under-field thermodiffusion anisotropy in Ionic-Liquid-based ferrofluids**

14:00 - 14:20 *Ingo Rehberg, Reinhard Richter, Stefan Hartung*, **Graphical Magnetogranulometry**

14:20 - 14:40 *Alexey O. Ivanov, Olga B. Kuznetsova, Philip J. Camp*, **Dynamic magnetogranulometry of ferrofluids**

14:40 - 15:00 *Yuri Dikansky, Anna Ispiryan, Stanislav Kunikin*, **Susceptibility of water-based ferrofluid at various temperatures**

15:00 - 15:20 *Matus Molcan, Katarina Paulovicova, Milan Timko, Peter Kopcansky*, **Characterization of magnetic nanosystems with a focus on magnetic hyperthermia**

15:20 - 15:40 **Break**

15:40 - 16:00 *Andrey Yu. Zubarev, Dmitri Chirikov, Dmitry Zablotsky, Mikhail Maiorov, Slavko Kralj, Hans J. Herrmann*, **Viscoelastic properties of ferrofluids with multicore particles**

16:00 - 16:20 *Fereshteh Sohrabi, Tomy Cherian, Carlo Rigoni, Olli Ikkala, Jaakko Timonen*, **Electroferrofluids with Non-Equilibrium Voltage-Controlled Magnetism, Interfaces, and Patterns**

16:20 - 16:40 *Peter Kopcansky, Natalia Tomasovicova, Veromika Lackova, Milan Timko*, **Liquid crystals doped by magnetic nanoparticles**

16:40 - 17:00 *Martins Brics, Viesturs Sints, Andrejs Cēbers*, **Why do hematite cube chains contain kinks?**

17:00 - 17:20 *Artis Brasovs, Kostya Kornev*, **Magnetic Rotational Spectroscopy with Nanorods as a Tool for Characterization of Insect Blood**

17:20 - 17:40 *Andrejs Cēbers, Abdelqader Zaben, Guntars Kitenbergs*, **Ferromagnetic swimmers: experiment, theory and simulation**

17:40 - 18:00 *Andris P. Stikuts, Régine Perzynski, Andrejs Cēbers*, **Simulations of magnetic droplet dynamics in a rotating field**

18:00 - 18:20 *Aigars Langins, Andris P. Stikuts, Andrejs Cēbers*, **Rosensweig instability dynamics of magnetic fluid droplets in rotating field**

Applications of topological magnetic transport

Mahla Mirzaee-Kakhki[1], Adrian Ernst[1], Anna M. B. E. Rossi[1], Nico C. X. Stuhlmüller[1], Maciej Urbaniak[1], Feliks Stobiecki[2], Meike Reginka[3], Dennis Holzinger[3], Arno Ehresmann[3], Daniel de las Heras[1], Thomas M. Fischer[1*]

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Recently we have studied experimentally and withcomputer simulations the motion of magnetic nano-, micro-, and macro-particles placed above periodic mag-netic patterned substrates, see Fig. 1a). The particles aredriven by closed loops of a homogeneous time-dependentexternal magnetic field. The orientation of the externalmagnetic field changes during the loop. There exists special loops that after completion transport the particles byone unit cell of the pattern. The transport is topologically protected by topological invariants that depend on both the type of transported particle and the symmetry of the pattern. The robustness of the transport (due to itstopological nature) allows us to e.g. transport simultaneously and independently paramagnetic and diamagnetic particles in arbitrary directions [1], see Fig. 1b), and tomimic the electronic transport in topological insulators using a colloidal system [2], see Fig. 1c).

Here, we cover several new aspects and applications of such type of transport. In particular, we show (i) the simultaneous polydirectional transport of up to six classes of self assembled colloidal rods of different lengths [3], see Fig. 1d), (ii) a time crystal formed by the trajectories of three particles above an annulus, the (iii) motion of colloids above twisted bilayer patterns which shares similarities with the motion of electrons in twisted bilayer graphene, and (iv) the transition from topologically protected to geometrical transport by increasing the number of colloidal particles per unit cell of the pattern [4].

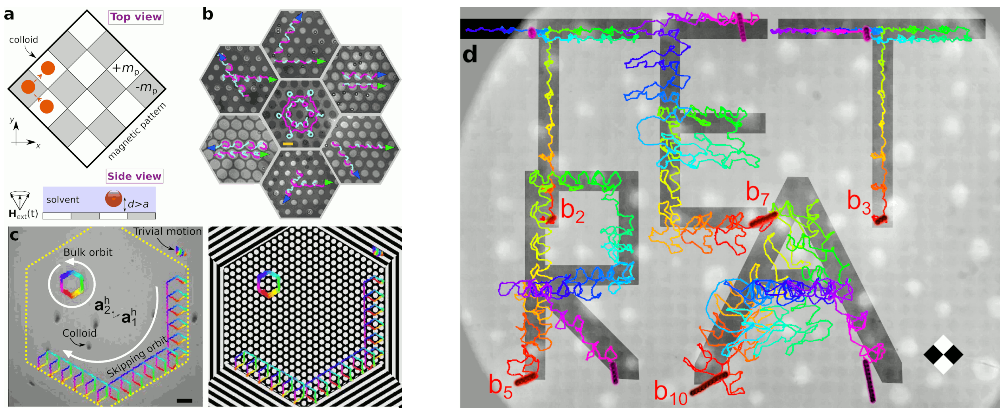

Figure 1 Schematics (top and side views) of the system: a colloidal particle (orange) is transported by one unit cell after completion of a loop. (b) Trajectories of diamagnetic (violet) and paramagnetic (blue) colloids above an hexagonal pattern. (c) Colloidal particles performing close (open) trajectories in the bulk (at the edges) of an hexagonal pattern surrounded by stripe patterns. (d) Five colloidal rods of different lenghts moving simultaneously and writting the word TETRA over a square magnetic pattern.

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References

[1] J. Loehr, M. Loenne, A. Ernst, D. de las Heras, and Th. M.Fischer, Topological protection of multiparticle dissipative transport *Nat. Comm.* **7**, 11745 (2016).

[2] Loehr, J., et al., Colloidal topological insulators. *Com-mun. Phys. Nature* **1**, 4 (2018).

[3] M. Mirzaee-Kakhki et al., Simultaneous polydirectional transport of colloidal bipeds *Nature Comm.* **11**, 4670, (2020).

[4] A. M. E. B. Rossi, J. Bugase, T. Lachner, A. Ernst, D. de las Heras, and Th. M. Fischer, Hard topological versus soft geometrical magnetic particle transport *Soft Matter* **15**, 8543 - 8551 (2019).

Emergent colloidal currents generated via exchange dynamics in a broken dimer state

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In this talk, I will describe a general strategy to assemble and transport polarizable microparticles in fluid media through a combination of confinement and magnetic dipolar interactions. We use a homogeneous magnetic modulation to assemble dispersed particles into rotating dimeric state and frustrated binary lattices and generate collective edge currents that arise from a novel, field-synchronized particle exchange process. The observed, net bidirectional current is composed of colloidal particles which periodically meet assembling into rotating dimers, and exchange their positions in a characteristic, "ceilidh"-like dance. We develop a theoretical model that explains the physics of the observed phenomena as dimer rupture and the onset of current, showing agreement with Brownian dynamic simulations. Our results demonstrate an effective technique to drive microscale matter by using a combination of confinement and homogeneous field modulations, not based on any gradient of the applied field.

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Regarding the nature of the dependence of the critical wavelength on the magnetic field at the instability of interface of miscible magnetic/non-magnetic fluids

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Earlier it was shown numerically and experimentally that in the case of the instability of miscible magnetic/non-magnetic fluids interface in a normal magnetic field, the critical wavelength decreases with an increase in the magnetic field inducing this instability [1]. This fact is not obvious, since a linear analysis of this instability gives the opposite result [2]. Besides, our numerical analysis showed that short waves disappear very quickly due to diffusion, i.e. long waves from the point of development of instability seem preferable. However, a numerical analysis of the growth rate of waves of different lengths made it possible to reveal the nature for the found dependence. The reasons are the non-exponential growth of the wave amplitude with time and the stabilizing effect of diffusion on the growth of instability. Waves with a short wavelength in the initial period of time grow faster, but their amplitude is limited by diffusion. Long waves grow more slowly at first, but their amplitude is large. Since the amplitude of short waves becomes larger with increasing field, they become competitive in comparison with long waves over a rather long period of time. If their amplitude becomes large enough, then long waves cannot become dominant. Therefore, at low fields, long waves dominate, and with an increase in the magnetic field, the critical wavelength shifts towards short waves.

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References

[1] M. S. Krakov, A. R. Zakinyan, A. A. Zakinyan, Instability of the miscible magnetic/non-magnetic fluids interface, *Journal of Fluid Mechanics*, 2021, in press.
[2] K. Erglis, F. Tatulcenkov, G. Kitenbergs, O. Petrichenko, F. G. Ergin, D. D. Watz, A. Cebers, Magnetic field driven micro-convection in the Hele-Shaw cell, *Journal of Fluid Mechanics*, 2013, 714, 33 612 - 633.

Calming the waves, not the storm: measuring the Kelvin-Helmholtz instability in a tangential magnetic field

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We measure the Kelvin-Helmholtz instability in-between a layer of a diamagnetic fluid, flowing in a channel, and a layer of ferrofluid, resting on top. When the diamagnetic fluid exceeds a critical flow velocity the interface in-between both fluids becomes unstable and waves develop. It has been predicted by Sutyrin & Taktarov (1975) that a homogeneous magnetic field, oriented horizontally, stabilises 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. From the measured growth and decay rates of the interface undulations we determine the critical flow velocity for various driving frequencies and applied magnetic fields. In this way we confirm quantitatively the stabilizing effect of the horizontal field. Moreover we measure the dispersion relation of the interfacial waves.

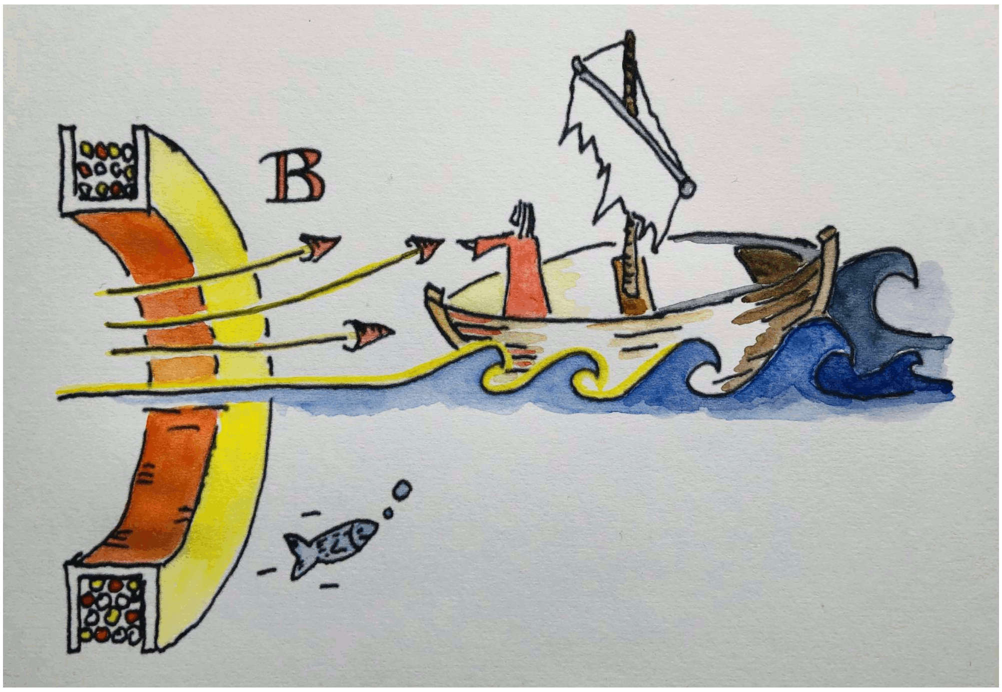

Figure 1 Calming the waves on the Sea of Galilee, not according to the gospel of Mark (about 70 AD), but according to Sutyrin & Taktarov (1975) by means of a tangential magnetic field.

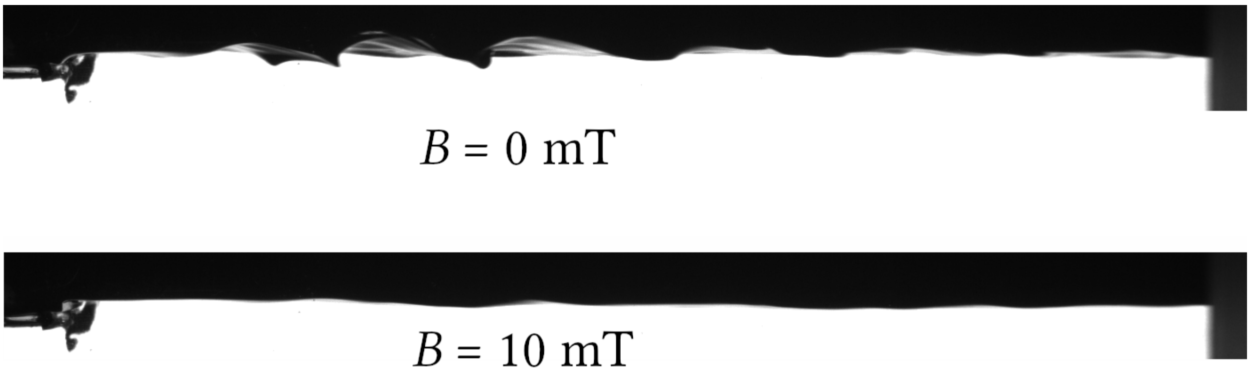

Figure 2 Experimental work.

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Ferrofluidic Aqueous Two-Phase System with Ultralow Interfacial Tension, Instabilities and Pattern Formation

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Ferrofluids are strongly magnetic fluids consisting of magnetic nanoparticles dispersed in a carrier liquid. Besides their various technological applications, they have a tendency to form beautiful and scientifically important patterns when subjected to external static and dynamic magnetic fields. Many of the patterns occur at the thermodynamic interface between two immiscible fluids, one ferrofluidic (magnetic susceptibility $\chi > 0$) and one essentially non-magnetic ($\chi \sim 0$). The interfacial tension γ between the two phases is usually large, tens of mN/m, restricting the observation of patterns to strongly magnetic systems and large pattern periodicities that are linked to the interfacial tension. In this presentation we show that it is possible to greatly reduce the interfacial tension by designing a ferrofluid two phase system that has the same carrier liquid in both phases. We realize this by utilizing phase separation of dissolved polymers (dextran and polyethylene glycol) in water and spontaneous asymmetric partitioning of superparamagnetic citrate coated maghemite nanoparticles between the two aqueous phases. Our continuous aqueous system has an ultralow interfacial tension, $\gamma \sim 1\,\mu Nm$. The iconic normal-field instability (Rosensweig instability) can be observed in the system in various geometries with significantly smaller length scale ($\sim 200\mu m$) compared to classic systems with immiscible fluids ($\sim 10mm$). The measured periodicities are in agreement with approximative theoretical models. Our ferrofluidic system paves way towards interesting physics enabled by the ultralow interfacial tension, such as the coupling between magnetic instability patterns and thermal capillary waves.

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Theoretical study of the flow of a ferrofluid in an oscillating magnetic field

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Most common method of the treatment of brain stokes consists in injection of tissue of plasminogen activator to dissolve the blood clots and restore the blood flux. However, the thrombolytic drug diffuses very slowly toward the blood clots through the blocked vessels.

We present theoretical modeling of macroscopic flow induced in a cloud of ferrofluid by oscillating running magnetic field. The aim of this work is development of a theoretical basis for a progressive method of address drug delivery to thrombus clots in blood vessels with the help of the magnetically induced circulation flow.

The cloud is placed in a cylindrical channel filled with a non-magnetic liquid (water or blood). Diameter of the channel is about 1mm; that corresponds to the brain blood vessels. We suppose that the channel is placed into two coaxial solenoids with the distance about $10\,cm$ between them; the ferrofluid cloud is in the middle between the solenoids; which create a running oscillating magnetic field with the angular frequency $\omega = 15\,s^{-1}$ and the amplitude, inside the cloud, $H = 20\,kA/m$.

Our results show that the concentration profile of the ferrofluid is blurred over time; the running field can induce, inside and near the cloud, specific circulating flows with the velocity amplitude about several millimeters per second. These flows can significantly increase the rate of transport of the molecular non-magnetic impurity (the thrombolytics) in the channel.

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Under-field thermodiffusion anisotropy in Ionic-Liquid-based ferrofluids

Thiago Fiuza[1,2], Mitradeep Sarkar[1], Jesse C. Riedl[1], Andrejs Cēbers[3], Fabrice Cousin[4], Gilles Demouchy[1,5], Jérôme Depeyrot[2], Emmanuelle Dubois[1], Frédéric Gelebart[1], Guillaume Meriguet[1], Régine Perzynski[1*], Véronique Peyre[1]

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Ferrofluids (FFs) based on Ionic Liquids (ILs) are new materials, recently developed for thermoelectric low-grade energy harvesting [1,2]. In the IL model-system, 1-Ethyl-3-methylimidazolium bistriflimide (EMIM-TFSI), they can be stabilized in a wide range of nanoparticle volume fractions ($0.2\,vol\% \leq \Phi \leq 15\,vol\%$) and temperatures ($295\,K \leq T \leq 473\,K$), the charged NPs ($\approx 9\,nm$) being hydroxyl-coated with SMIM±-TFSI- counter-ions [3,4].

A Forced Rayleigh scattering experiment under an applied magnetic field [5,6] allows to probe the anisotropy of the NP Soret coefficient and their diffusion coefficient at various Φ and T. As in [5] for aqueous ferrofluids at room temperature, the results are here analysed according to the model developed in [7].

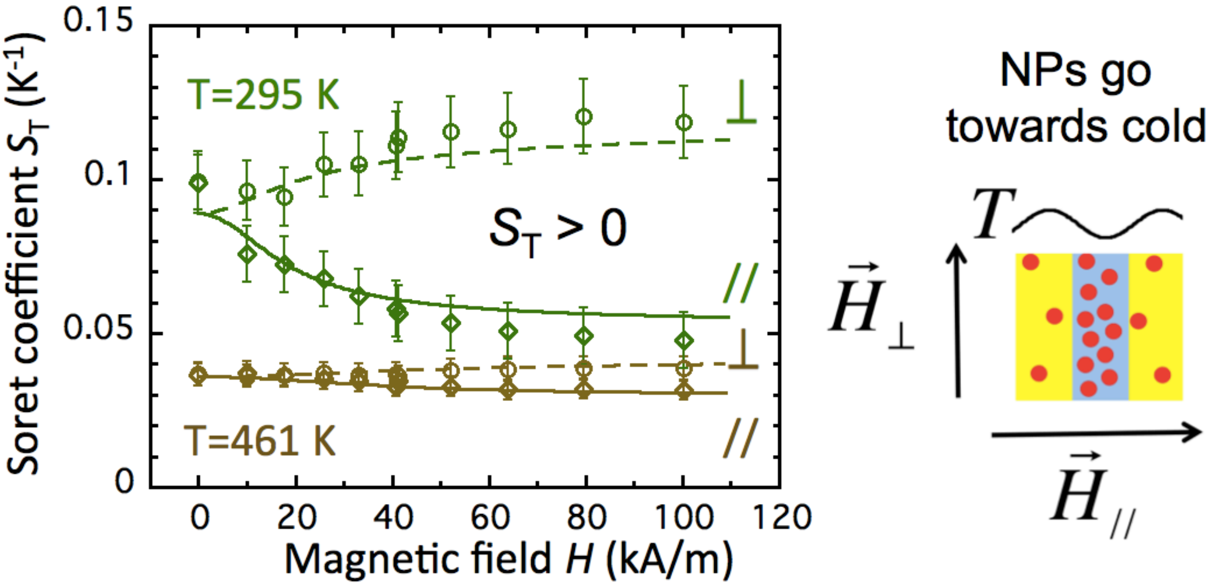

Figure 1 Anisotropy of Soret coefficient at 295K and 461K in the ferrofluid based on EMIM-TFSI, adjusted with the model of [5,7]

Support by the Brazilian agency CNPq, the bilateral programs PHC OSMOSE 2018 no 40033S & CAPES-COFECUB no Ph 959/20 and the European Union's Horizon 2020 research and innovation programme under grant agreement no 731976 (MAGENTA) is acknowledged.

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References

[1] T.J. Salez et al, *Phys. Chem. Chem. Phys.* **19** (2017) 9409-9416
[2] K. Battacharya et al, *Chemical Engineering* **4** (2020) 1-25
[3] J.C. Riedl et al, *Nanoscale Advances* **2** (2020) 1560 - 1572
[4] J.C. Riedl et al, *(to be submitted)*
[5] M. Kouyaté et al, *Phys. Chem. Chem. Phys.* **21** (2019) 1895-1903
[6] M. Sarkar et al, *Eur. Phys. J E* **42** (2019) 72 1-10
[7] T.J. Salez et al, *Entropy* **20** (2018) 405 1-27

Graphical Magnetogranulometry

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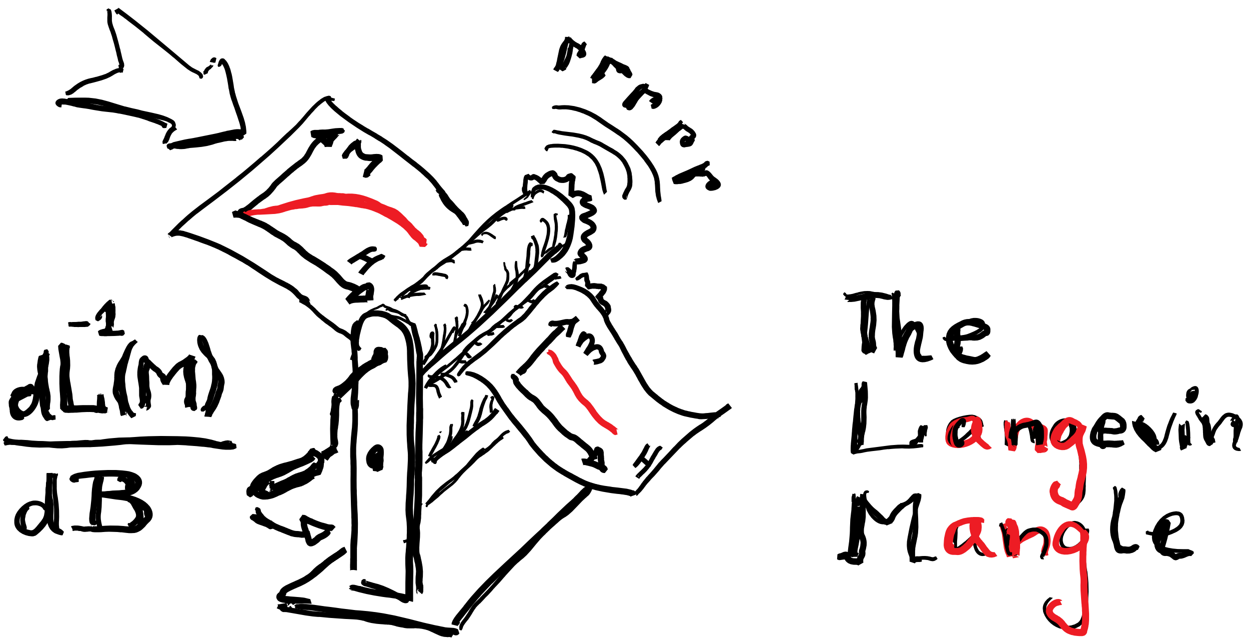
The dipole strength m of the magnetic particles in a colloidal suspension is obtained by a graphical rectification of the magnetization curves. This method [1,2]

- does not rely on assuming a particular distribution function $f(m)$,
- yields the arithmetic and the harmonic mean of $f(m)$,
- provides an estimate of the relative standard deviation of $f(m)$.



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References

[1] Ingo Rehberg, Reinhard Richter, Stefan Hartung, Niklas Lucht, Birgit Hankiewicz, and Thomas Friedrich, Measuring magnetic moments of polydisperse ferrofluids utilizing the inverse Langevin function, *Phys. Rev. B* **100** 134425 (2019)
[2] Ingo Rehberg, Reinhard Richter, Stefan Hartung, Graphical Magnetogranulometry of EMG 909, *JMMM* **508**, 166868 (2020)

Dynamic magnetogranulometry of ferrofluids

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Magnetogranulometry involves analyzing the magnetic properties of a material in order to determine the microscopic composition. For ferrofluids, this means determining the number of magnetic particles of particular size and magnetic dipole moment. Previous work has focused on analyzing the static initial magnetic susceptibility, using an accurate theory for how it depends on the Langevin magnetic susceptibility, which is a function of the concentration and dipole moment of each particle fraction. Herein, the application of similar techniques to the frequency-dependent magnetic susceptibility is examined with the assumption of the Brownian rotation mechanism. The usefulness of the analysis relies on the accuracy of the underlying theory. Ignoring interparticle interactions gives the Debye theory. Interactions are taken into account using a modified mean-field theory and a modified-Weiss theory. Using computer-simulation results for known compositions as model "experimental" data, it is shown that it is essential to take interactions into account, and that the modified Weiss theory provides the most accurate results.

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Susceptibility of water-based ferrofluid at various temperatures

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Present the results of water-based ferrofluid investigation. Significant differences in the magnetic susceptibility temperature dependencies of water-based magnetic fluids established compared to magnetic fluids based on hydrocarbons.

We studied the profile of magnetic susceptibility temperature dependencies of water-based magnetic colloids, which undergo crystallization upon freezing.

Initially, temperature studies of the real part of the magnetic susceptibility were carried out by sequential heating; the samples were frozen in liquid nitrogen. Temperature dependences of the magnetic susceptibility for water-based samples showed features not characteristic for magnetic liquids based on hydrocarbons. For instance, at the temperature of the transition ($273\,K$), the curve $\chi(T)$ underwent a sharp minimum, not observed for dependences of other kinds of magnetic fluids.

Further susceptibility studies were carried out in conditions of sequential decrease in temperature. It was found that the temperature dependencies of χ obtained in this case shows some differences from the previous dependencies. There was no significant change in the magnetic susceptibility when the temperature was decreased from 298 to $265\,K$. However, at $T = 264.5\,K$, the temperature of the system increased rapidly to a value close to $273\,K$, while the magnetic susceptibility decreases stepwise. Further cooling of the system led to a monotonous decrease in its temperature, which determined the further course of the temperature dependence of the susceptibility.

It was found that the process of crystallization of water leads to an inhomogeneous distribution of the fine particles, the formation of regions with dense packing, and an increase in interaction.

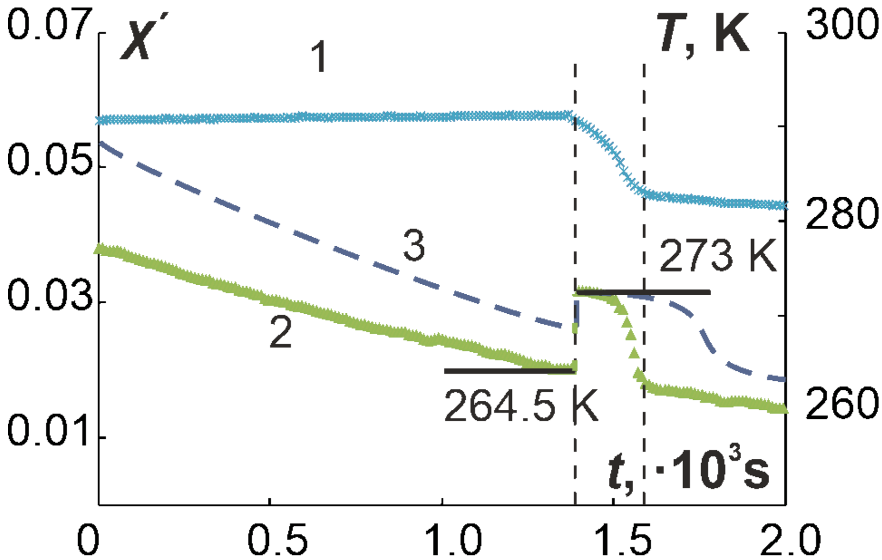

Figure 1 Evaluations of Sample in thermostatic conditions during cooling. Dependence of the real part of the dynamic magnetic susceptibility on time for Sample 1 (1)

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Characterization of magnetic nanosystems with a focus on magnetic hyperthermia

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The contribution deals with magnetic nanosystems in colloidal form, providing their basic physico-chemical analysis as well as measurements of magnetic hyperthermia. The response to the applied external alternating magnetic field is studied on samples of bio-origin: magnetosomes and magnetoferritin. In the case of magnetosomes, the experiments were conducted and compared on samples in the form of a colloidal suspension (i.e. in magnetosomes dispersed in a liquid buffer) as well as on samples where the magnetosomes were fixed in the agar structure. The motivation was to compare the particles heat development in conditions simulating human tissue. It has been shown that at higher applied AC magnetic field intensities, there is a significant difference between the increase in temperature for the suspension and the agar phantom. In the other work, the measurement of the real and imaginary part of the magnetosome chains magnetic susceptibility showed a different nature of the frequency dependence. The so-called "Flexible rod model", was introduced, which describes the asymptotic behavior of complex magnetic susceptibility at high frequencies. In the case of magnetoferritin, this is one of the first experiments on this type of sample in the field of magnetic hyperthermia. It was shown that magnetoferitin could be considered as a potential magneto-farmaceutical nanomaterial.

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Viscoelastic properties of ferrofluids with multicore particles

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Magnetic fluid, consisting of multi-core particles, attract considerable interest because they look very promising for various technical and biomedical applications. The typical size of the composite particles ranges from tens to few hundred nanometers, whereas the individual single-domains ferroparticles, they consist of, vary in the range 5 to 20 nm.

Rheological phenomena in the fluids (high magnetorheological effect; slow viscoelastic relaxation; shear thinning effects) are determine by the particles aggregation in the applied field; dynamics and rupture of the aggregates under the macroscopic deformation flow. From our best knowledge, the micro/mesoscopic nature of the macroscopic rheological phenomena has not been sufficiently investigated yet.

We present results of experimental and theoretical study of the non-linear viscoelastic effects in the multicore ferrofluids and effect of applied magnetic field on these properties.

In the experiments volume concentration of the composite particle varied in the range of several per cent. The experiments demonstrate strong dependence of both, the storage G' and loss G'' fluid moduli on the applied field, global shear rate and frequency of the flow oscillations as well. Time of the viscoelastic relaxation of the fluid is about 1 sec; that is several orders more than that for the ferrofluids with individual ferromagnetic nanoparticles.

A theoretical model, based on the idea of the particles unification in the linear chain-like aggregates, is suggested. Theoretical results are in quantitative agreement with the experiments.

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Electroferrofluids with Non-Equilibrium Voltage-Controlled Magnetism, Interfaces, and Patterns

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An increased interest in dissipative materials has emerged due to exhibiting functionalities, such as self-repairing and high adaptivity, that cannot be achieved in thermal equilibrium. However, designing such materials and quantifying the dissipation is challenging. We propose that a systematic steady-state nanoparticle concentration gradient can emerge and be sustained by continuous energy dissipation in a colloidal mixture of electrically active superparamagnetic nanoparticle, i.e. electroferrofluid. For the nanoparticles to be responsive to electric fields, we added a charge controlling agent, bis(2-ethylhexyl) sulfosuccinate sodium salt (Aerosol OT, AOT), that forms charged inverse micelles that can charge the nanoparticles. We fill planar interdigitated microelectrode indium tin oxide (ITO) electrodes with the mixture and drive the mixture out of thermodynamic equilibrium by applying an electric field. A reversible non-equilibrium nanoparticle concentration gradient is formed near the positive electrodes and is sustained as long as the electric field is applied. The concentration gradient is dependent on the applied voltage. Moreover, since the magnetic response of the colloidal dispersion depends on nanoparticle concentration, we can achieve dissipative voltage-controlled magnetism in the system. By applying magnetic fields in parallel or perpendicular directions to microelectrode cells, instabilities with well-defined spacing emerge above a threshold. We also quantified the energy dissipation in electroferrofluid pattern formations. Consequently, we introduce electroferrofluids with voltage-controlled magnetism and diffuse non-equilibrium interfaces, instead of classic ferrofluids with thermodynamic phase boundaries. This opens a new horizon in designing tunable responses of nanoparticles out of thermodynamic equilibrium.

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Liquid crystals doped by magnetic nanoparticles

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Suspensions of magnetic nanoparticles (MNPs) in nematic liquid crystals (LC)ie special class of soft matter and the so-called ferronematics (FNs), have become a promising material with enhancing sensitivity of LCs to magnetic field. Assuming that a stable, optically transparent, and homogeneous FNs are synthetized, it would give a strong push for the development of many kinds of new magnetically controlled LC-devices. As an illustration, this is the way to obtain magnetovision camera with the possibility of mapping the magnetic field in space. The variety of physical processes in magnetic suspensions, complexity of the system and potential applications encourage scientists to continue studies of these materials, despite the fact that the main features of the magnetic LC suspensions were established 50 years ago. In presentation will be illustrated basic theory of FNs as well as the recent experimental works that reflect the modern trends of the FNs research with a special attention to understanding of major physical mechanisms responsible for the influence of various type of nanoparticles on the properties of LCs.The influence of magnetic nanoparticles on sensitivity of FNs in low magnetic field will be presented as well as influence on the nematic isotropic transition. Nematic isotropic transition can used for the realization of ferromagnetic fluid too.

FNs can be also realized on the base of lyotropic LCs (biological e.g.) and MNPs. The possible formation of nematic LC phase in solutions containing lysozyme amyloid fibrils (LAF) and MNPs will be presented too.

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Why do hematite cube chains contain kinks?

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Hematite is a weak ferromagnetic material with three orders of magnitude smaller permanent magnetization than magnetite. Thus, hematite colloids allow us to explore different physical particle interaction parameter range compared to ordinary ferromagnetic particle colloids. In the presence of a weak static external magnetic field ($B < 0.1\,mT$) the particles of hematite with cubic shape tend to align and form straight chains along the direction of the applied field. An increase in the strength of the applied magnetic field causes an additional rearrangement of the chains. Chains reorganize in the kinked structures. In this presentation we explain why such kinked structures are formed. To achieve this goal we examine the most energetically favorable configurations of hematite cube chains and observe what changes if thermal fluctuations are taken into account. We calculate distributions for angle between the orientation of a chain and the direction of the external magnetic field. Obtained results we compare with experiments.

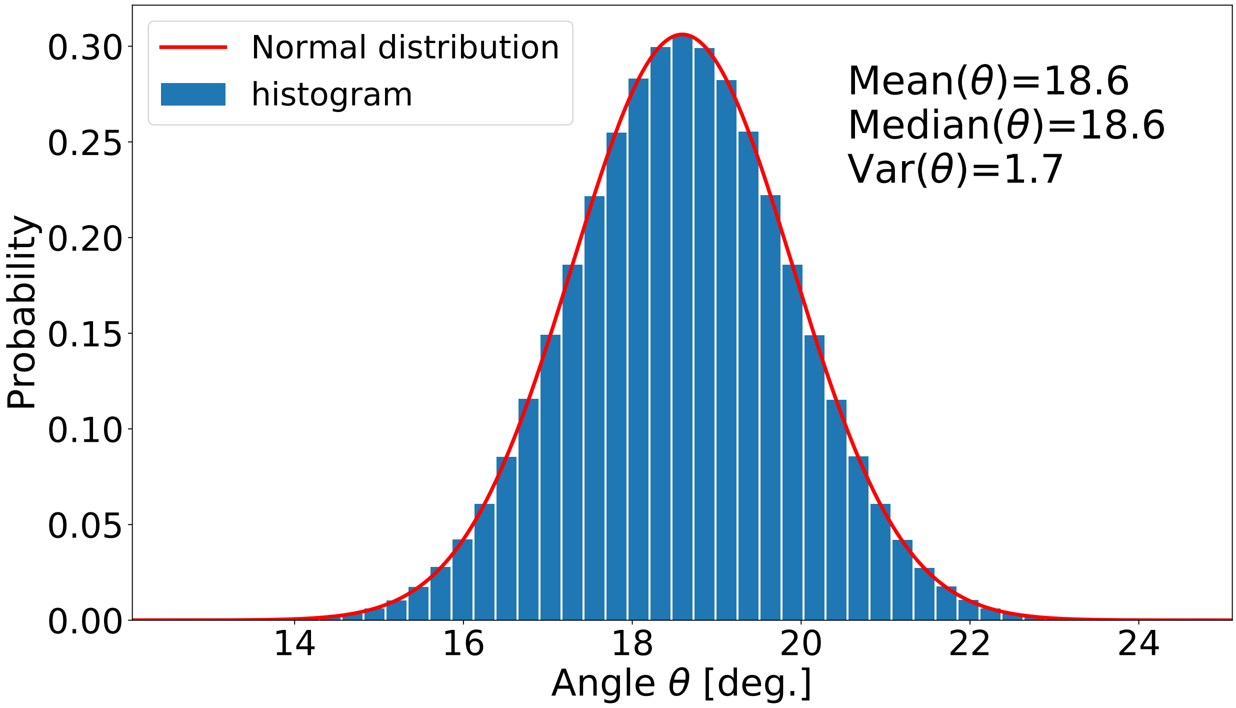

Figure 1 From MD simulations at room temperature calculated histograms of angle between the orientation of a chain and the direction external magnetic field for straight four cube chains at $B = 0.7\,mT$.

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Magnetic Rotational Spectroscopy with Nanorods as a Tool for Characterization of Insect Blood

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Magnetic nanorods are attractive materials enabling assembly, ordering, control, and reconfiguration of different magnetic lattices within milliseconds. MilliTesla magnetic fields are sufficient to manipulate with these nanorods. In this talk, we will discuss remote controlled rotation of magnetic nanorods providing a new nanoscale tool to probe different properties of liquids at the micrometer scale. Magnetic Rotational Spectroscopy (MRS) will be introduced and specific features of rotating nanorods will be explained. Then we will experimentally demonstrate that MRS provides rich physicochemical information on properties of insect blood. We illustrate this methodology by studying viscosity and correlating it with surface properties of blood of hawk moth Manduca sexta.

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Ferromagnetic swimmers: experiment, theory and simulation

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Flexible rods with permanent magnetic moments are created linking functionalized ferromagnetic microparticles by biotinized DNA fragments.These filaments in an applied field have the characteristic buckling instabilities leading to the S-like and U-like shapes. Applying the time dependent magnetic field it is possible to initiate periodic U-like deformations of rods which due to broken symmetry propel. Time dependence of the displacements illustrating the characteristic forth and back motion is shown in Fig. 1. Numerically calculated velocity of the propulsion is compared with experiments and the good agreement is obtained. Both in experiments and simulations propulsion may cease due to the development of S-like deformations. The final stages of this process are interpretated by the analysis of the Floquet multipliers of the bending modes.

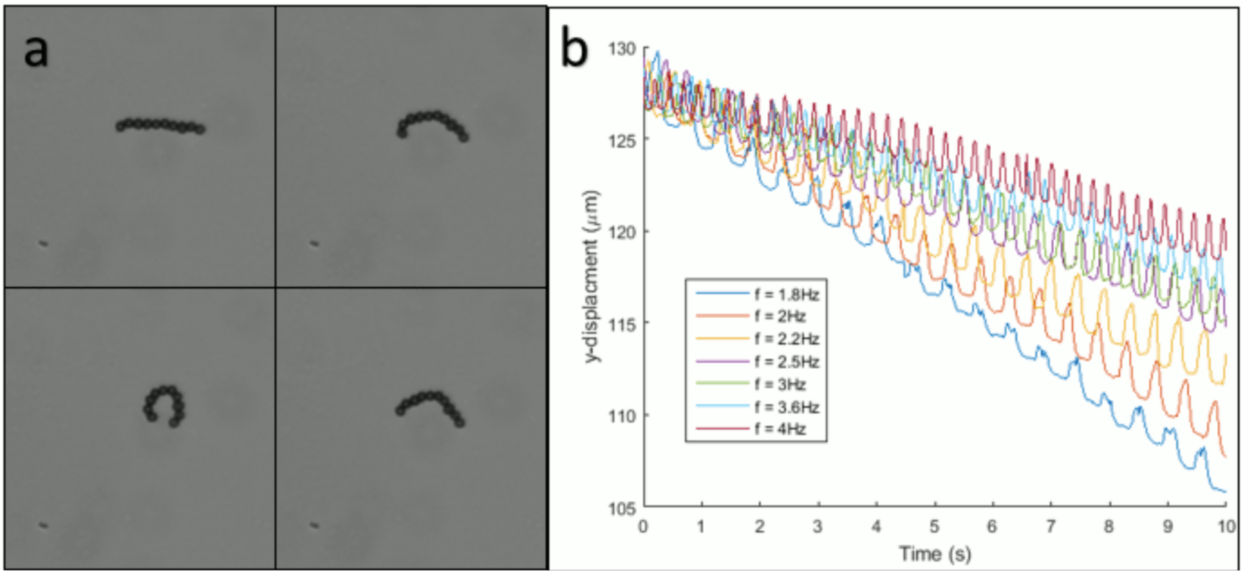

Figure 1 (a) - Example of experimental filament configuration showing U-deformations, under the application of square field profile in the x-direction (field strength $H = 4.3\,Oe$, field frequency $f = 3\,Hz$ and filament length $L = 60\,\mu m$). (b) -Time dependence of the displacements for filament operating at different f, $L = 69\,\mu m$ and $H = 4.3\,Oe$)

The work was funded by M.era-net project FMF No.1.1.1.5/ERANET/18/04 and Horizon 2020 research and innovation program grant agreement MAMI No.766007.

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Simulations of magnetic droplet dynamics in a rotating field

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Microscopic magnetic droplets are useful in microfluidic applications since their motion can be relatively simply induced with an external magnetic field without complex integrated components like pumps or valves [1].

Such droplets can be described by a model of a magnetic fluid. Analytic solution of the dynamics of such droplets are feasible only in the simplest geometries such as the droplet being an ellipsoid. However, experiments show a rich variety of shapes being taken up by the droplets in rotating fields [2]. To calculate the motion of a magnetic droplet in a rotating magnetic field, we have developed a numerical algorithm based on the boundary element method.

In the talk we show the dynamics of a magnetic droplet in a rotating field and characterize the resulting motion in dependence on the frequency of the rotating field and the field strength. We show that for small to medium frequency of rotation, the shape of the droplet is not axisymmetric, and it oscillates as the droplet moves with the magnetic field (see fig. 1).

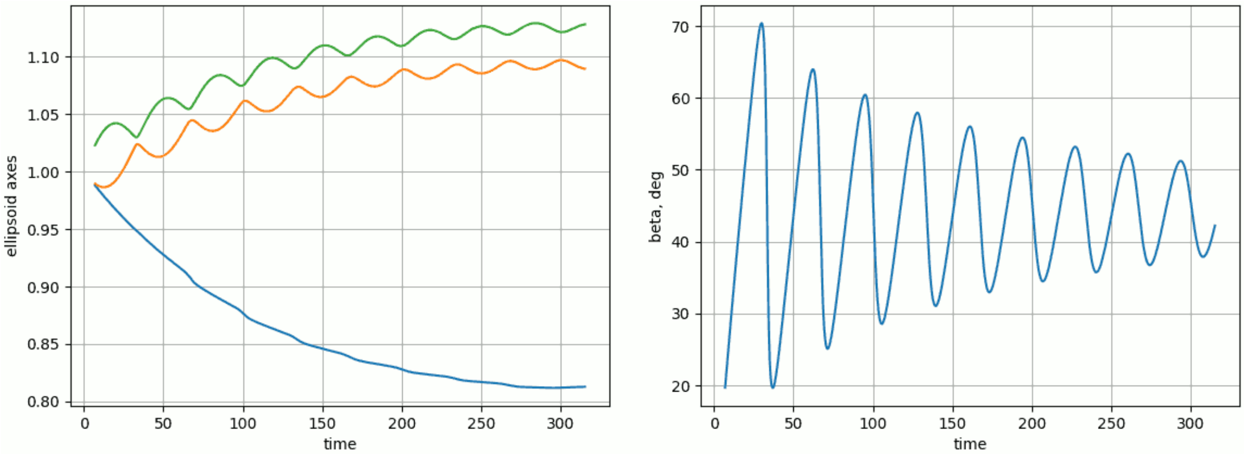

Figure 1 The motion of a magnetic droplet with permeability μ=10 and viscosity $\eta = 100\eta_{H_2O}$ subjected to a rotating magnetic field with a magnetic Bond number $Bm = (R_0H_0^2)/\gamma = 10$ and a frequency of $\omega t_0 = 2\pi f t_0 = 0.1t_0$, the time is scale is chosen to be $t_0 = (R_0\eta_{H_2O})/\gamma$. R_0 - the radius of an undeformed droplet, here taken to be unity, H_0 - the applied field magnitude, γ - the surface tension, η_{H_2O} - the viscosity of the surrounding fluid. The left side shows the evolution of the ellipsoid's that best describes the droplet semiaxes over time. The ride side shows the angle that the largest axis makes with the magnetic field direction.

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References

[1] E. Al-Hetlani and M. O. Amin, Continuous magnetic droplets and microfluidics: generation, manipulation, synthesis and detection, *Microchim Acta*, vol. 186, no. 2, p. 55, Feb. 2019, `doi:10.1007/s00604-018-3118-6`.

[2] E. Janiaud, F. Elias, J.-C. Bacri, V. Cabuil, R. Perzynski, Spinning ferrofluid microscopic droplets, *Magnetohydrodynamics*, vol. 36, no. 4, p. 365-378, 2000.

Rosensweig instability dynamics of magnetic fluid droplets in rotating field

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Magnetic fluid droplets are known to exhibit various interesting configurations in external magnetic fields. These phenomena cannot in general be described by analytical solutions, so numerical methods are required. Some three-dimensional boundary integral equation (BIE) algorithms have been proposed, however, in droplet dynamics there still remain many problems to investigate.

In this presentation, we present our 3D BIE algorithm for solving full dynamics of magnetic droplets in arbitrary viscosity ratios. In particular explore the onset of the normal field or Rosensweig instability of magnetic fluid droplets in rotating magnetic fields and the tempo-spatial evolution of its "fingers".

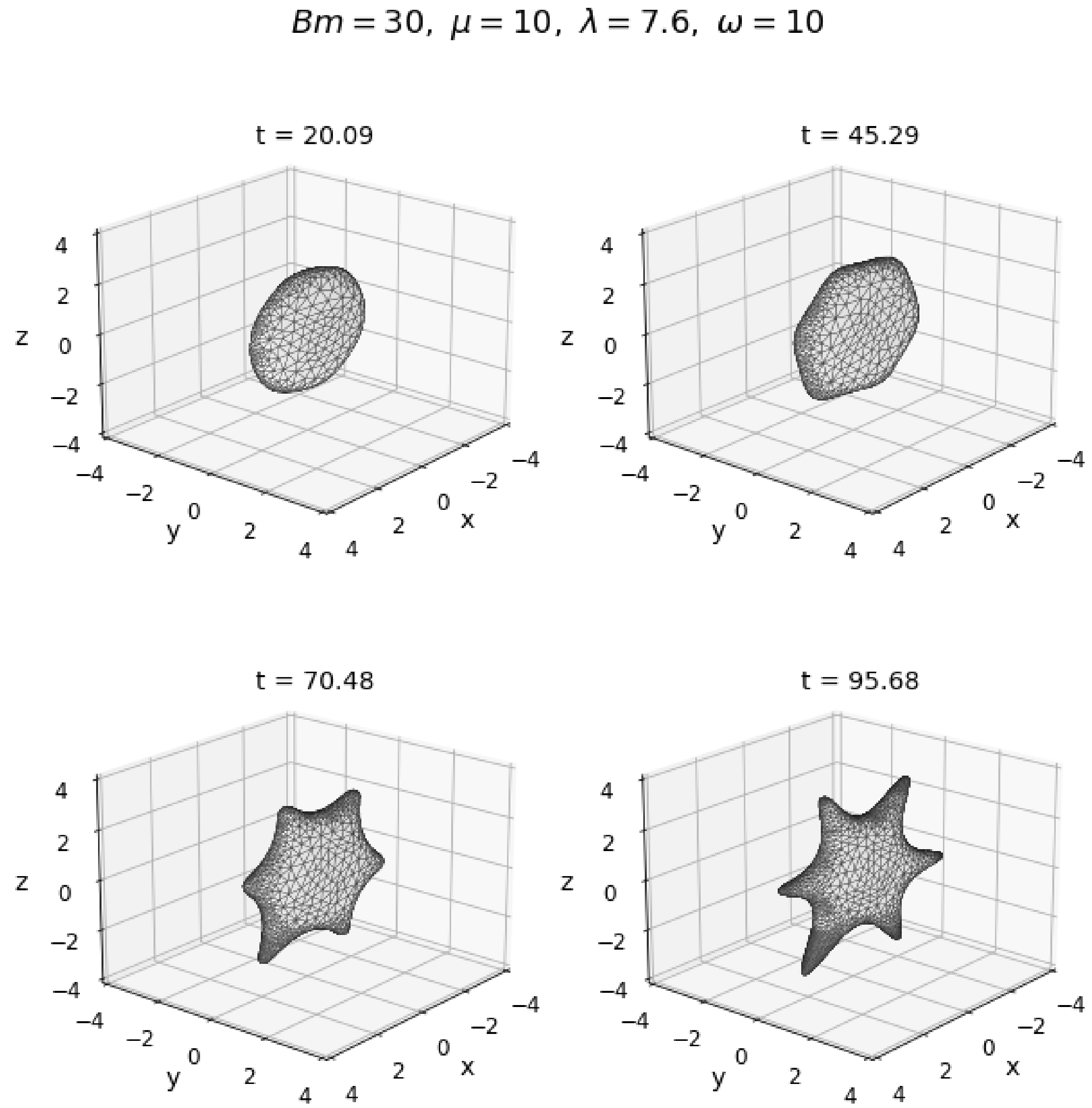

Figure 1 The Rosensweig instability in a rotating magnetic field

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About

This seminar is organized 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.

Seminar chair is Professor Andrejs Cēbers.

Seminar organizing committee includes Dārta Antāne, Ivars Driķis and Guntars Kitenbergs.

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