81st International Scientific Conference of the University of Latvia 2023

Section

Magnetic, Soft and Active Matter

Abstract Book

UNIVERSITY OF LATVIA

Magnētisku Mīkstu Materiālu Laboratorija

LAB OF MAGNETIC SOFT MATERIALS

https://mmml.lu.lv/

Programme

Chair: Dr. Andris Pāvils Stikuts		
10.00–10.05	Opening	
10.05–10.15	Dr. Andris Pāvils Stikuts	How to determine the physical parameters of an elastic ferromagnetic filament
10.15–10.25	MSc student Paula Biseniece	Experimental determination of essential parameters of flexible ferromagnetic filaments in rotating field
10.25–10.35	PhD student Māra Šmite	Characterization of ferromagnetic microswimmers using micro particle image velocimetry
10.35–10.45	PhD student Lāsma Puķina-Slava	Comparison of magnetic micro-convection in magnetic field perpendicular or parallel to the microfluidics chip
10.45–11.00	Break, discussions	
11.00–11.10	Dr. Guntars Kitenbergs	Using droplets to probe parameter temperature dependence in phase-separated magnetic fluid
11.10–11.20	Dr. Viesturs Šints	A look at hematite cube chains in rotating magnetic field
11.20–11.30	Dr. Mārtiņš Brics	Short hematite chains
11.30–11.40	Dr. Rūdolfs Livanovičs	Preliminary work on ferrofluid modelling with lattice Boltzmann methods
11.40–12.00	Break, discussions	
12.00–12.10	Prof. Andrejs Cēbers	Levitated magnet on superconductor
12.10–12.20	MSc student Ojārs Mārtiņš Eberliņš	Influence of dissipation on the dynamics of a levitated ferromagnetic particle in an external magnetic field
12.20–12.30	PhD student Bhagyashri Shinde	Dynamical study of an aggregate of rotlets
12.30–12.40	Dr. Jānis Cīmurs	Active diffusion of HexBug in 2D
12.40–13.00	Break, discussions	

How to determine the physical parameters of an elastic ferromagnetic filament

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Microscopic Ferromagnetic filaments combine magnetic and elastic properties which enables them to be used as micro-swimmers or micro-mixers in a homogeneous time varying magnetic field [1]. To compare the experiment with the model, three parameters need to be determined: the magnetoelastic number Cm, the elastic deformation time τ, and the ratio of transverse to longitudinal drag coefficient $\zeta_{\perp}/\zeta_{\parallel}$. Due to their microscopic size, it is hard to probe these parameters experimentally directly. The situation becomes even more complicated when we note that the drag coefficients and thus τ is a function of the height above the microscope sample slide [2].

For this reason, a height independent method is devised to determine Cm. When a ferromagnetic filament is placed in a rotating field, it makes an angle with the magnetic field H (figure 1.). This angle is proportional to the field rotation angular frequency ω and inversely proportional to H. In the limit where this angle is small, up to a scaling factor, the shape is just a function of the magnetoelastic number Cm, which significantly simplifies the comparison with experiment.

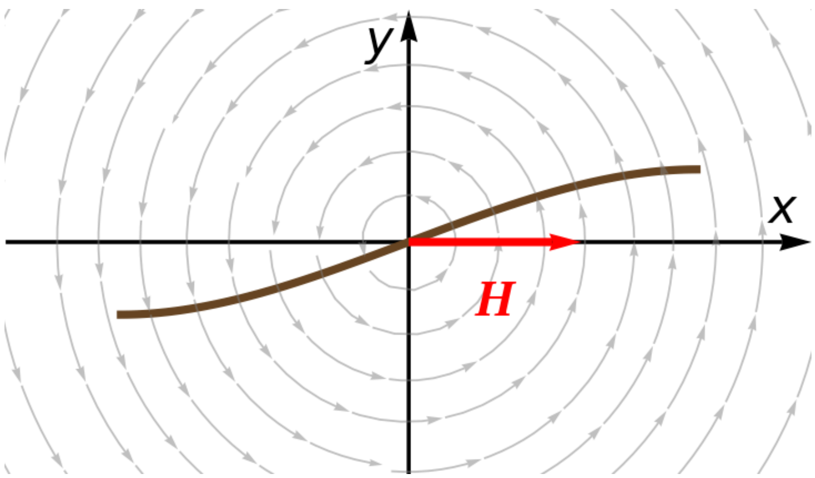

Figure 1. The shape of a ferromagnetic filament in a rotating field. The plot is shown in the reference frame of the magnetic field. A rotating flow thus arises in this frame.

This research is funded by the Latvian Council of Science, project A4Mswim, project No. lzp-2021/1-0470.

Bibliography

[1] A. Cebers, K. Erglis, Flexible Magnetic Filaments and their Applications. *Adv. Funct. Mater*., **26**, 3783-3795, (2016).
[2] L. Koens, T. D. Montenegro-Johnson. Local Drag of a Slender Rod Parallel to a Plane Wall in a Viscous Fluid. *Physical Review Fluids,* **6**, 064101, (2021).

Experimental determination of essential parameters of flexible ferromagnetic filaments in rotating field

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Flexible ferromagnetic filaments are interesting from both a fundamental perspective and a potential practical use for medical purposes. Put under different external magnetic fields, the filaments exhibit various shapes and motion, including a deformed S-like shape [1], the U-shape swimmer [2] and others.

In this study, we put filaments under a uniformly rotating external magnetic field, where they exhibit a continuous rotation around the center of the mass. By altering magnetic field frequency and amplitude, we determine how they affect the shape of the filament and, in particular, measure the distance from the glass cell boundary to the plane of rotation. We find that an increase in frequency causes the filament to rotate further away from the surface. Finally, we compare experimental findings with the theoretical results.

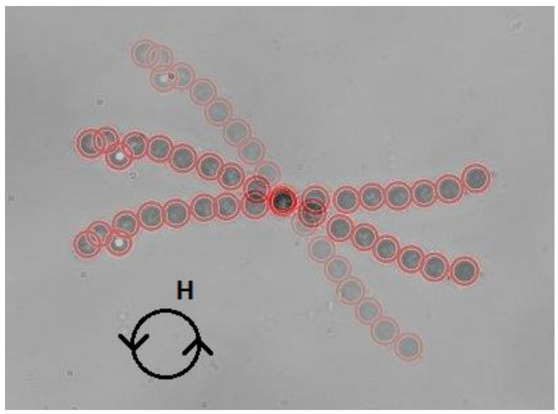

Figure 1. Rotation of the magnetic filament in external field.

This research is funded by the Latvian Council of Science, project A4Mswim, project No. lzp-2021/1-0470.

Bibliography

[1] A. Zaben, G. Kitenbergs, A. Cēbers, Deformation of flexible ferromagnetic filaments under a rotating magnetic field. *Journal of Magnetism and Magnetic Materials*, **499**, 166233, (2020).
[2] A. Zaben, G. Kitenbergs, A. Cēbers, Instability caused swimming of ferromagnetic filaments in pulsed field. *Scientific Reports*, **11**, 23399, (2021).

Characterization of ferromagnetic microswimmers using micro particle image velocimetry

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Magnetic microswimmer can be created by applying alternating magnetic field to ferromagnetic chain. Due to buckling instability, the filament will move in direction perpendicular to the direction of the magnetic field [1].

The movement dynamics of a ferromagnetic microswimmer can be characterized by micro particle image velocimetry (μPIV), a technique in which small tracer particles are added around the microswimmer and then double frames with very short times between images are taken. The flow field can be drawn around the swimmer from displacement data, obtained using cross-correlation algorithms.

Tracer particle quantity is directly correlated with the vector quality obtained with the μPIV measurement. Limited quantity of tracer particles that can be added to the microswimmer buffer solution, before they begin to influence the flow around it, makes the data processing challenging. Here we show how using several data processing techniques we compensate for the scarce data and obtain a flow field around a microswimmer in 4 positions of its movement period. As a result, we obtain flow fields for microswimmers in bending, relaxing and stationary positions and compare them with numerical simulation results (see Figure 1). These results will be used for validation of the theoretical model of microswimmer behavior, as well as a step towards measuring flow fields around other microscopic swimmers.

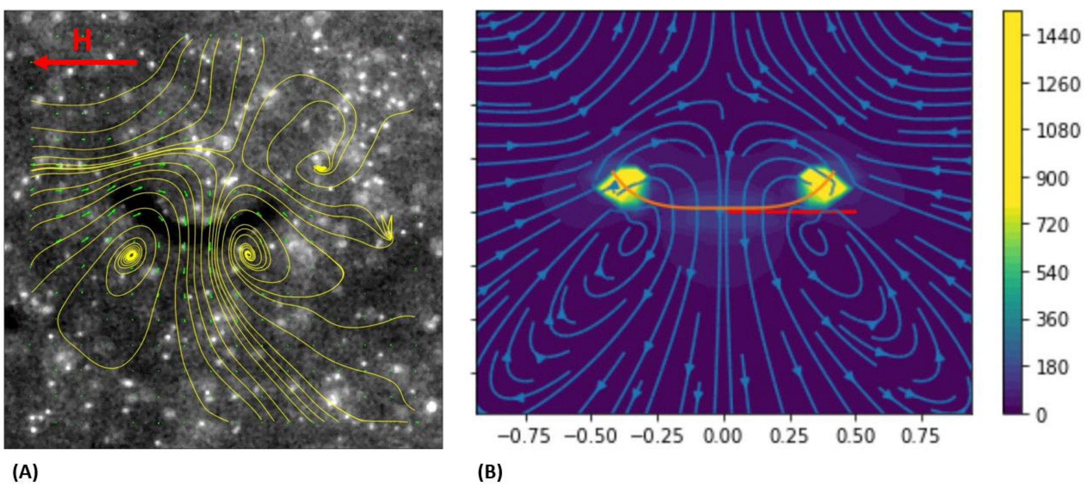

Figure 1. (A) Experimentally obtained flow fields around a ferromagnetic microswimmer in bending position, (B) Numerical simulation of flow fields of a microswimmer in bending position.

This research is funded by the Latvian Council of Science, project A4Mswim, project No. lzp-2021/1-0470.

Bibliography

[1] A. Zaben, G. Kitenbergs, A. Cēbers, Instability caused swimming of ferromagnetic filaments in pulsed field. *Scientific Reports*, **11**, 23399, (2021).

Comparison of magnetic micro-convection in magnetic field perpendicular or parallel to the microfluidics chip

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In this study active mixing with magnetic micro-convection of two miscible fluids in a vertical microfluidics chip is investigated experimentally. The magnetic micro-convection that enhances the otherwise slow diffusion drive mixing is an instability with a finger-like interface between both fluids.

We have showed previously that the mixing dynamics with the magnetic micro-convection is affected by gravity [1]. Here we investigate how the mixing is affected by direction of the applied magnetic field. The magnetic micro-convection is induced by two different experimental setups with different directions of the external magnetic field (see fig.1.). The mixing dynamics and effectiveness is compared between these two cases varying a set of different other experimental parameters.

Distilled water and several water based magnetic fluids with various properties are used as the mixing fluids. We measure the characteristic critical fields for the instability development, the wavelength of the finger-like instabilities and the mixing enhancement due to the magnetic micro-convection for both directions of magnetic field.

The results show that the magnetic micro-convective mixing is restricted by the amount of initial smearing between the fluids and gravity, but can be improved by increasing external magnetic field. The properties of magnetic fluids significantly affect the mixing dynamic- if susceptibility and nano-particle concentration of the magnetic fluid increases, the mixing due to micro-convection also increases. Experimental results show that mixing in magnetic field perpendicular to the chip is more effective than mixing in a parallel field.

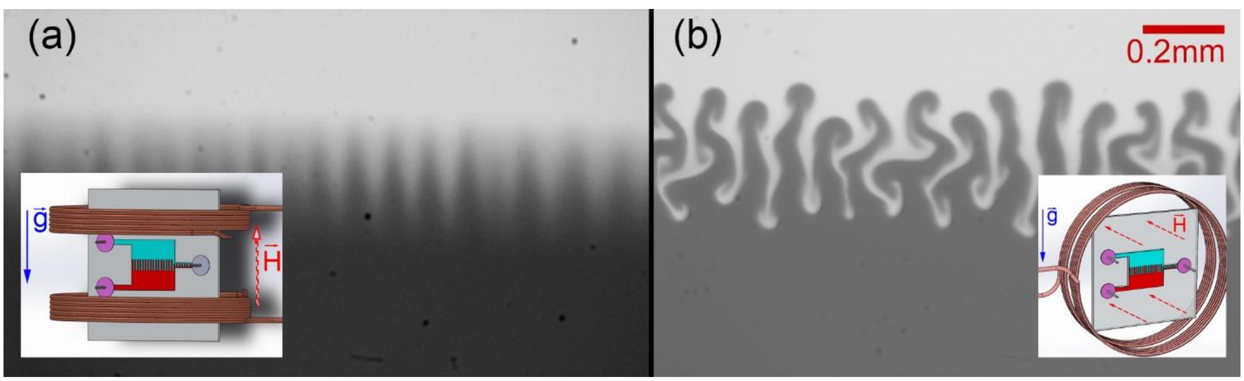

Figure 1. Magnetic micro-convection in the experiment with magnetic field (a) parallel to the microchip, (b) perpendicular to the microchip. Gravity points downwards, parallel to the microchip.

This research was supported by the European Social Fund Project No. 8.2.2.0/20/I/006.

Bibliography

[1] G. Kitenbergs, et al., Gravity effects on mixing with magnetic micro-convection in microfluidics. *Eur. Phys. J. E*, **41**, 138, (2018).

Using droplets to probe parameter temperature dependence in phase-separated magnetic fluid

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Materials with a strong magnetic response are of high interest for various applications. One such example is phase-separated magnetic fluids. In such systems one of the phases is more magnetic, typically creating droplets or holes that can be strongly and variously deformed even by small magnetic fields [1].

Here we study the typical parameters of the phase separated magnetic fluid (magnetic permeability, surface tension, viscosity) and their dependence on temperature. For that we deform small droplets with a stepwise external field and register their shape (see Figure 1), what allows to find the parameters [1]. This is a non-destructive measurement and can be repeated at different temperatures over long periods of time.

We analyze these measurements and show that the change in temperature only changes the magnetic permeability and viscosity, while the surface tension remains constant. These results can help in finetuning phase separated magnetic fluid systems for specific applications.

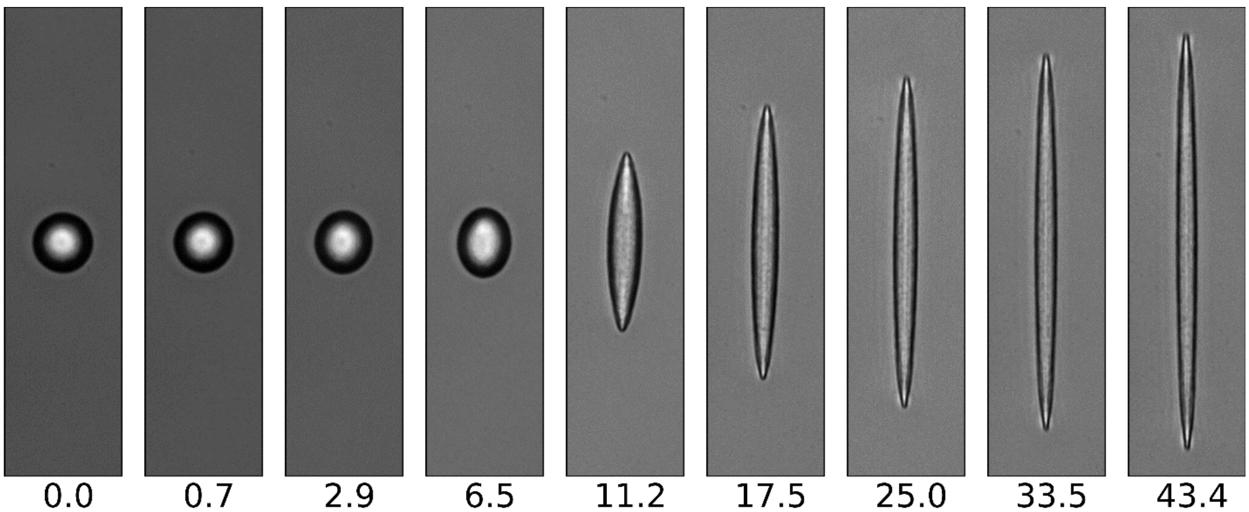

Figure 1. Field induced stepwise stretching of a drop in a phase-separated magnetic fluid. Values are given in H2R units [mOe2·cm].

This research is funded by the Latvian Council of Science, project BIMs, project No. lzp-2020/1-0149.

Bibliography

[1] J. Erdmanis, et al. Magnetic micro-droplet in rotating field: numerical simulation and comparison with experiment. *Journal of Fluid Mechanics*, **821**, 266-295, (2017).

A look at hematite cube chains in rotating magnetic field

Viesturs Šints, Mārtiņš Brics
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Microsized hematite cubes form chains of various lengths. When subjected to a rotating magnetic field, the chains enter a regime of rotation determined by the magnitude and frequency of rotation of the field, as well as orientation of the chain relative to the field (this is discussed in detail in [1]). Regimes of rotation available to the chains vary from solid body rotation with frequency identical to that of the field, to periodic breakup of the chains.

Experimental setup of a microscope in combination with a coil system for the creation of a rotating magnetic field has been used to explore the characteristics and parameters of hematite cube chain rotation under the various regimes (figure 1). A sweep of field magnitudes and rotation frequencies has allowed us to classify areas of parameter space corresponding to each rotation regime and both orientations of chains relative to the field.

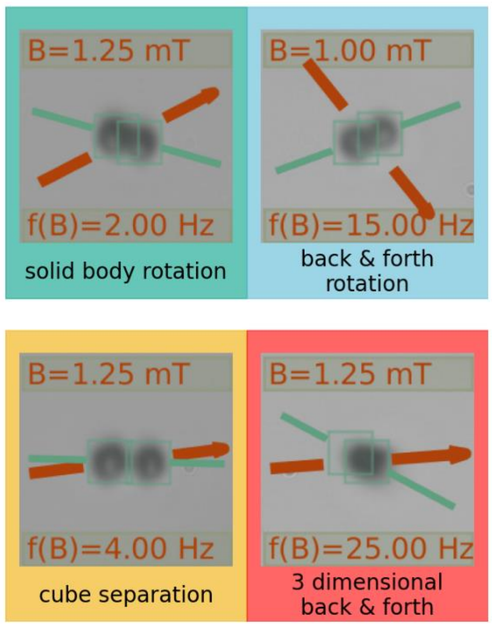

Figure 1. Observed hematite cube chain configurations in various rotation regimes.

This research is partially funded by the Latvian Council of Science, PostDocLatvia project No.1.1.1.2/VIAA/3/19/562

Bibliography

[1] M. Brics, V. Šints, G. Kitenbergs, A. Cēbers, Energetically favorable configurations of hematite cube chains, *Physical Review E*, **105**, 024605-024619, (2022).

Short hematite chains

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At room temperature hematite is a weak ferromagnetic material with an unorthodox magnetization orientation, thus hematite colloids represent a unique system to study interactions between two particles [1]. In scientific literature several experiments can be found with such colloids and particularly interesting are experiments by Soni et al. [2] where they show that a two-dimensional chiral fluid can be created using hematite colloids with cubic-shaped hematite particles in rotating magnetic field.

Swarming experiments [3] of micron-sized hematite cubes in a rotating magnetic field show that swarms and therefore chiral fluid consist of short interacting hematite chains. Therefore, to better understand these phenomena here we look at building blocks, i.e., short hematite chain behavior in rotating and static magnetic field. We find equilibrium structures of chains in static magnetic field and oversevere chain dynamics in rotating magnetic field. We find and experimentally verify that three motion regimes are possible: solid body rotation, back-forth motion, chain breaking and assembly.

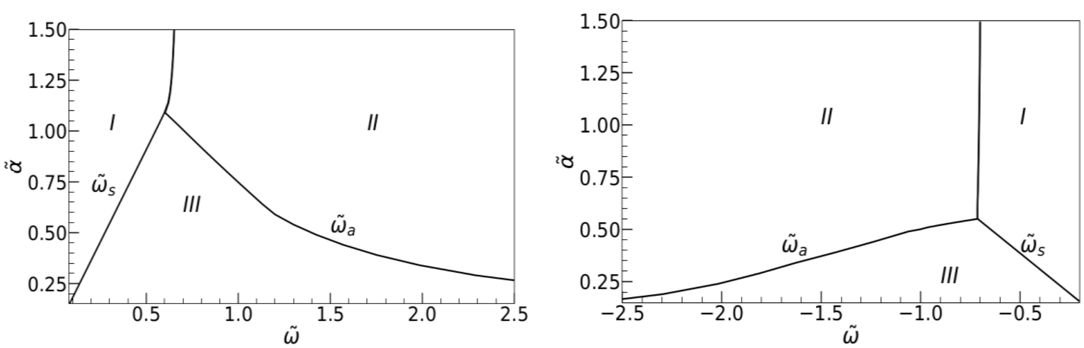

Figure 1. Borders of long-time dynamics regimes. In region I chain rotates as a solid object with the frequency of the rotating field, in II the back-forth motion is observed, in III the chains break and after some time can reassemble.

The authors appreciate the financial support from PostDocLatvia grant No.1.1.1.2/VIAA/3/19/562.

Bibliography

[1] M. Brics, V. Šints, G. Kitenbergs, A. Cēbers, Energetically favorable configurations of hematite cube chains, *Phys. Rev. E,* **105**, 024605, (2021).
[2] V. Soni, et al., The odd free surface flows of a colloidal chiral fluid, *Nature Physics,* **15**, 1188, (2019).
[3] O. Petrichenko, et al., Swarming of micron-sized hematite cubes in a rotating magnetic field – experiments, *JMMM,* **500**, 166404, (2020).

Preliminary work on ferrofluid modelling with lattice Boltzmann methods

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Ferrofluids exhibit many interesting phenomena subject to intense theoretical and experimental study. Topical applications include magnetic drug targeting, contrast agents in MRI, cell sorting, vibration damping and others. Numerical modelling of ferrofluids is traditionally conducted using either boundary integral type methods or finite element models coupled with moving mesh techniques for interface tracking. Both types of methods are complex to implement and difficult to make computationally efficient on modern computer hardware.

In computational fluid dynamics, lattice Boltzmann methods have garnered considerable attention due to their apparent ease of implementation and parallel scalability. However, LB methods also suffer from the need to formulate boundary conditions in terms of abstract velocity distribution functions, which leads to considerable complexity and issues with numerical stability for coupled multiphysics models. Recently, a simplified lattice Boltzmann method (SLBM) has been proposed [1], which does not require directly evolving the velocity distribution functions and therefore permits direct enforcement of physical boundary conditions. This talk will describe a preliminary implementation of a coupled SLBM model, suitable for the numerical simulation of multiphase ferrofluid flows.

This research is funded by the Latvian Council of Science, project BIMs, project No. lzp-2020/1-0149.

Bibliography

[1] Z. Chen, et al. A simplified lattice Boltzmann method without evolution of distribution function. *Advances in Applied Mathematics and Mechanics,* **9.1,**1-22, (2017).

Levitated magnet on superconductor

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In the frame of Quantera project “Levitated magnets for quantum metrology” small magnets are considered as the sensors of magnetic field. One protocol considers levitated above superconductor of I kind permanent magnets. Different oscillation modes of magnets are experimentally observed, and the Quality factors of oscillators determined [1]. The question is what are the relaxation processes which determine the Quality factor. Here the characteristics of oscillator are calculated considering dynamics of permanent magnet in the magnetic field created by the screening currents of the superconductor. The equations for permanent magnet takes into account the Einstein-de Haas and Barnett effects. The dissipation is due to the motion of magnetic moment with a respect to a solid body. By the perturbation theory approach the equations are reduced to the equation for oscillator and its eigenfrequency ω and damping λ are determined. These read

$$\omega^2 = \frac{1}{I}\frac{\mu^2/r^3 \mu H_a}{(\frac{\mu^2}{r^3}+\mu H_a)} \qquad (1)$$

$$\lambda = \frac{1}{2}\omega_0 \frac{\beta}{1+\beta^2}\frac{\left(\mu^2/r^3\right)^2}{(\frac{\mu^2}{r^3}+\mu H_a)^2} \qquad (2)$$

Here μ magnetic moment of permanent magnet, r is the distance between magnet and its image, I its moment of inertia, H_a effective field of magnetic anisotropy, the Einstein frequency $\omega\_0 = \frac{\mu}{|\gamma| I}$ (γ is gyromagnetic ratio), parameter β (usually $10^{-1} \div 10^{-2}$) determines the ratio of the precession period of magnetic moment and its relaxation time.

Numerical estimate of the Quality factor according to the relation (2) is $Q = 2.6 \cdot 10^{11}$, what is significantly larger than the experimental value [1]. Obtained relations (1,2) are in good agreement with numerical calculations.

This research is funded by the Latvian Council of Science, QuantERA project LEMAQUME, project No. ES RTD/2022/12.

Bibliography

[1] A.Vinante, P.Falferi, G.Gasbarri, A.Setter, C.Timberlake, and H.Ulbricht, Ultralow mechanical damping with Meissner-levitated ferromagnetic microparticles, *Phys.Rev.Appl.*, **13**, 064027, (2020).

Influence of dissipation on the dynamics of a levitated ferromagnetic particle in an external magnetic field

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Levitated ferromagnetic particles with an angular momentum that is determined by electron spin polarization act as a ferromagnetic gyroscope under the influence of an external torque. Such torques can be induced using a constant magnetic field and as a result different types of dynamics can be observed at different field magnitudes. This includes atom-like Larmor precession if the field values are sufficiently small, when the mechanical orbital angular momentum is much smaller than the intrinsic spin angular momentum.

There have been studies on the behavior of such freely floating ferromagnetic particles, but there are very limited interpretations on how the dissipation of such a system influences rotational dynamics in comparison to the non-dissipative case. This is why, the influence of dissipation is analyzed at different field magnitudes, where different dynamics can be observed.

This research is funded by the Latvian Council of Science, QuantERA project LEMAQUME, project No. ES RTD/2022/12.

Dynamical study of an aggregate of rotlets

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The magnetic droplets aggregate results in an ordered structure when exposed to an external magnetic field, which has been studied in a few works [1,2]. The present work is inspired by experimental results where the aggregate of magnetic droplets under the external magnetic field forms a rotating crystal-like structure [2]. We have considered a 2D aggregate of rotlets interacting due to induced flows. The dimensionless equation of motion for the system reads

$$\vec{v_i} = \sum_{i \neq j} \frac{\vec{e_z} \times (\vec{r_i} - \vec{r_j})}{|\vec{r_i} - \vec{r_j}|^3}.$$

Numerical simulation of N particles reveals the following: (i) if the interaction between particles is solely hydrodynamic, the disordered aggregate of particles remains unchanged (Fig. 1. (a)), (ii) if we introduce the repulsion into the aggregate, then particles form a rotating crystal-like structure with hexagonal order (Fig. 1. (b)), and (iii) if there are two aggregates of particles at some distance from each other, then initially, they rotate around their centre of mass similarly to point like particles. At later times the aggregate starts to exchange particles and finally merge. The resulting disordered aggregate further becomes ordered (Fig. 2.). To characterize these systems, we are studying different physical parameters like hexagonal order parameter, hexagonal lattice parameter, phase diagram, and others.

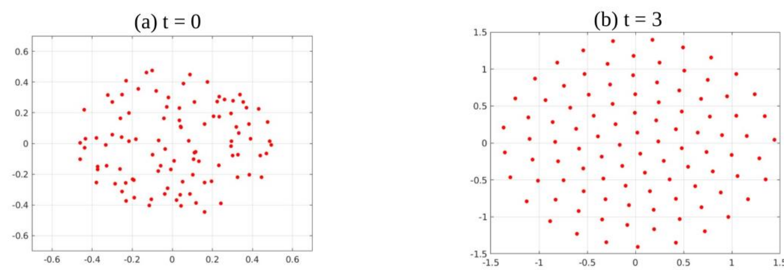

Figure 1. Aggregate of particles N=100, λ=20, rs=0.05

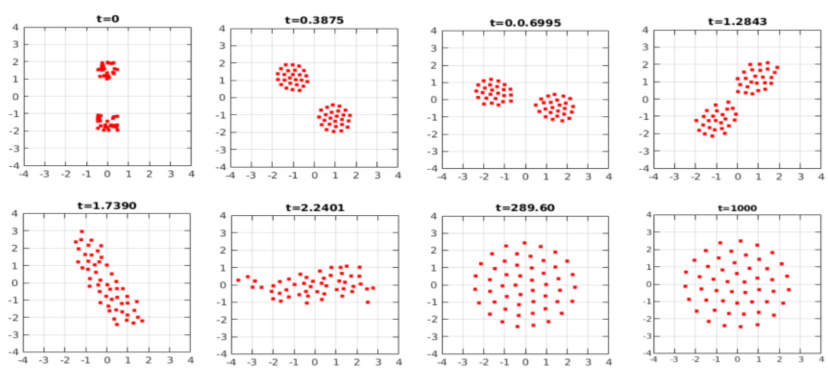

Figure 2. Merging aggregates of particles N=50, λ=100, rs=0.05

This research is funded by the Latvian Council of Science, project BIMs, project No. lzp-2020/1-0149.

Bibliography

[1] Q. Wang, L. Yang, B. Wang, E. Yu, J. Yu, and L. Zhang, *ACS Appl. Mater. Interfaces*, (2019)
[2] A. P. Stikuts, R. Perzynski, A. Cēbers, Spontaneous order in ensembles of rotating magnetic droplets, *JMMM*, **500,** 166304, (2020).

Active diffusion of HexBug in 2D

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In Soft Matter Physics course I created a lab work where students tried to measure active diffusion of electric “mouse” (I will call it HexBug, because originally such toys were created by company HexBug and are called HexBug nano) (shown in picture). They were given large paper with concentric circles and small python code which captures time moments of the button press. They had to press the button whenever the HexBug crosses any circle.

The HexBug should obey Run-and-Tumble motion which in short time scales has ballistic regime and in long time scale has diffusion regime. From the data you can obtain the velocity of the HexBug, diffusion constant of the HexBug and characteristic time or distance when the ballistic regime turns into diffusion regime.

The students were quite innovative: some of them used Lucas-Kanade optical flow algorithm to track the particle in the video; some students have removed the legs of the HexBug to reduce the speed.

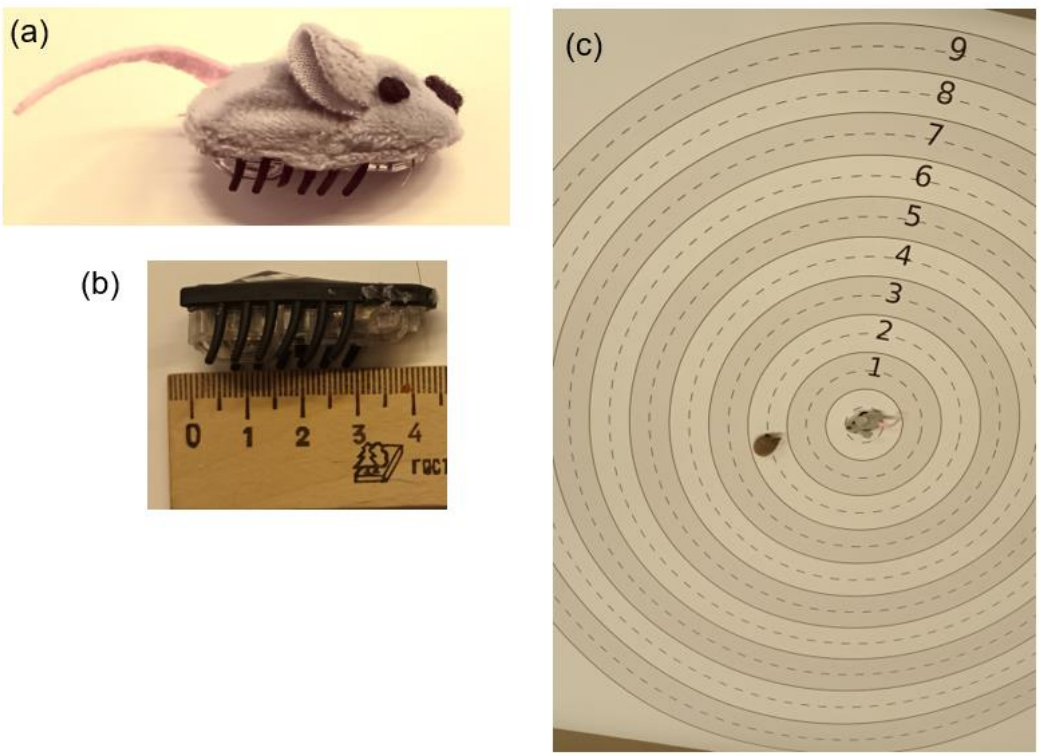

Figure 1. Experimental setup: (a) HexBug with “mouse” cover; (b) HexBug without “mouse” cover; (c) concentric circles on the paper for easy tracking of HexBug (mouse shown in the center), distance between the solid lines is 5cm.

Magnētisku Mīkstu Materiālu Laboratorija

LAB OF MAGNETIC SOFT MATERIALS

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.

Section chair is Dr. Andris Pāvils Stikuts.

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

A notable part of results presented in this section is connected with research performed in the framework of two Latvian Council of Science Fundamental and Applied Research Projects (#FLPPLV) “Biologically inspired models of active matter driven by electromagnetic field” (BIMs, lzp-2020/1-0149) and “Advancement of methods for measuring the motility of microswimmers” (A4Mswim, lzp-2021/1-0470). We acknowledge the funding from these sources.

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