RIGA WORKSHOP

Soft Matter Physics in Living Systems

Collection of abstracts

University of Latvia
House of Science
24 May 2024

UNIVERSITY OF LATVIA

Magnētisku Mīkstu Materiālu Laboratorija
LAB OF MAGNETIC SOFT MATERIALS

Riga Workshop “Soft Matter Physics in Living Systems”.
Collection of abstracts. Riga: University of Latvia. 2024. 16 p.

UNIVERSITY OF LATVIA

Magnētisku Mīkstu Materiālu Laboratorija
LAB OF MAGNETIC SOFT MATERIALS

Scientific Committee:
Paul Albert Janmey, Andrejs Cēbers

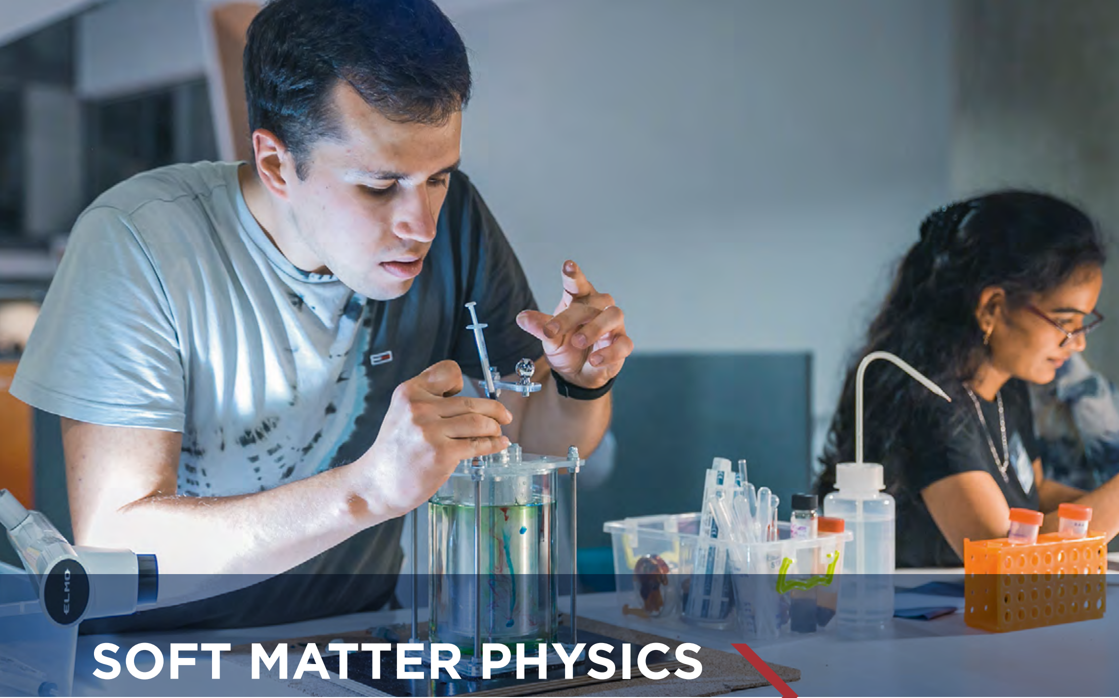
Editor:
Andrejs Cēbers

Language editor: Andra Damberga
Computer graphics and design: Baiba Lazdiņa

© Authors of abstracts, 2024
© University of Latvia, 2024

ISBN 978-9934-36-221-7
ISBN 978-9934-36-222-4 (PDF)

CONTENT



SOFT MATTER PHYSICS IN LIVING SYSTEMS

10:00 **Fred MacKintosh**
Nonlinear Mechanics of Extracellular Matrices as Phase Transition

10:30 **David Sept**
New Insights into Microtubule Structure and Dynamics

11:00 **Christoph Schmidt**
Mechanics of the Bacterial Cell Wall

11:30 **Alison Patteson**
Can Bacterial Colonies Sense Substrate Stiffness?

12:00 **Coffee break**

12:30 **Robert Bucki**
Antibiotic Susceptibility Under Mechanical Load

13:00 **Peter Galie**
Engineering Soft Materials to Match Tissue Stiffness

13:30 **Paul Janmey**
Electrically Conductive Soft Substrates for Cell Culture

14:00 **Andrejs Cēbers, Guntars Kitenbergs, Māra Šmite**
Magnetotactic Bacteria as Magnetic Active Matter: Experience of MMML

14:45 **Māra Šmite, Oksana Petričenko, Andrejs Cēbers**
Soft Magnetic Materials in MMML

Fred MacKintosh,
Departments of Chemical & Biomolecular Engineering, Chemistry, and Physics & Astronomy, Center for Theoretical Biological Physics. Rice University, Houston, TX, USA

Nonlinear Mechanics of Extracellular Matrices as Phase Transition

The mechanics of cells and tissues are largely governed by scaffolds of filamentous proteins. Particularly common examples of these are the collagen fiber networks of extracellular matrices. There is now increasing evidence that the mechanics of such fibrous structures are governed by underlying mechanical phase transitions reminiscent of the rigidity transition identified by Maxwell for macroscopic engineering structures: networks of struts or springs exhibit a continuous, second-order phase transition at the isostatic point, where the number of constraints imposed by connectivity just equals the number of mechanical degrees of freedom. By contrast, fibrous networks in 3D exhibit a line of critical transitions as a function of strain rather than connectivity. These transitions have shown remarkable richness, including non-mean-field critical behavior. We will present recent theoretical predictions and experimental evidence for such strain-controlled mechanical phase transitions in biopolymer networks, including two-component hydrogels and extracellular matrices with colloidal inclusions.

David Sept,
Department of Biomedical Engineering & Biophysics,
Associate Dean for Academic Programs and Initiatives,
Rackham Graduate School University of Michigan. Ann Arbor, MI, USA

New Insights into Microtubule Structure and Dynamics

Microtubules are formed by the polymerization of tubulin, resulting in a unique structure that is referred to as the microtubule lattice. This lattice structure is key to many functions, since both molecular motors and many microtubule-associated proteins (MAPs) communicate through structural changes in this lattice. In this talk, I will discuss recent MD simulations we have performed, using all-atom microtubules in different states. These simulations provide a new insight into how features such as tubulin isotype, bound nucleotide, and bound drugs or MAPs affect the dynamics, structure, and allosteric communication in the tubulin lattice.

Christoph Schmidt,

Departments of Physics, Biology, Biomedical Engineering, Mechanical Engineering and Materials Science, Duke University, Durham, NC, USA

Mechanics of the Bacterial Cell Wall

The bacterial cell wall supports a multitude of transport and sensory functions, but also serves as a tough container, containing turgor pressures around 1 atm in gram-negative bacteria and up to 20 atm in gram-positive bacteria. Mechanical stretch stiffness and shape maintenance are provided by the covalently linked peptidoglycan layer that is, nevertheless, an active material, undergoing constant growth. We have developed an AFM-based method to track turgor pressure in living cells, as well as cell wall response to deformation and pressure. We model the PG layer as an anisotropic elastic network composed of two types of nonlinear springs (glycans and oligopeptides). We vary structural properties, such as glycan length distribution, angular distribution, and cross-link density (pore size distribution) to accurately reproduce the observed mechanical properties, such as stress-strain relationships (elastic moduli), strain and stress ratios between axial and hoop directions.

Alison Patteson,
**Physics Department and BioInspired Institute,
Syracuse University, Syracuse, NY, USA**

Can Bacterial Colonies Sense Substrate Stiffness?

The ability of bacteria to colonize and grow on different surfaces is an essential process for biofilm development. Here, we report the use of synthetic hydrogels with tuneable stiffness and porosity to assess physical effects of the substrate on biofilm development. Using time-lapse microscopy to track the growth of expanding *Serratia marcescens* colonies, we find that biofilm colony growth can increase with increasing substrate stiffness, unlike what is found on traditional agar substrates. Using traction force microscopy-based techniques, we find that biofilms exert transient stresses correlated over length scales much larger than a single bacterium, and that the magnitude of these forces also increases with increasing substrate stiffness. Our results are consistent with a model of biofilm development, in which the interplay between osmotic pressure arising from the biofilm and the poroelastic response of the underlying substrate controls biofilm growth and morphology.

Robert Bucki,
Department of Medical Microbiology and Nanobiomedical Engineering, Medical University of Białystok, Białystok, Poland

Antibiotic Susceptibility Under Mechanical Load

The growing global problem of infections caused by antibiotic-resistant bacteria, for which there are limited therapeutic options, requires search for new therapeutic strategies that can be developed on the basis of a better understanding of the response of bacterial cells to environmental factors. The ability to recognize and respond to mechanical parameters of the environment is still less known in bacteria compared to mammalian cells. Among the manifestations of the ability of bacterial cells to recognize the mechanical properties of the surrounding environment and respond to external mechanical stimuli are the changes that occur as a result of bacteria attaching to a solid surface after leaving a liquid suspension. It can be assumed that this behavior of bacteria is important in the process of host tissues/cells invasion, the development of infection/inflammation, as well as in the response of bacterial cells to the presence of antibiotics (antibiotic susceptibility). While examining the mechanical properties of bacterial cells using AFM, we observed a temporary increase in their stiffness after the addition of ceragenins, which are analogues of natural antimicrobial peptides, intensively studied in the context of the development of a new group of antibiotics for systemic use. Additionally, we detected a reduced sensitivity to the action of ceragenins of bacteria growing on substrates with increasing stiffness. These observations indicate that mechanical conditions should be taken into account when testing the sensitivity of bacteria to antibiotics.

Peter Galie,
Department of Biomedical Engineering, Rowan University, Glassboro, NJ, USA

Engineering Soft Materials to Match Tissue Stiffness

Matching the mechanical properties of tissue is crucial for the fabrication of biological substitutes intended for implantation to regenerate damaged tissue and for use as *in vitro* testing platforms. Our laboratory is developing photo-crosslinkable polymer networks that allow us to spatially pattern stiffness gradients within a single hydrogel. We have found that using these materials to mimic the heterogeneity of mechanical properties in the spinal cord, e.g., white versus gray matter, improves the regenerative properties of scaffolds implanted in a small animal model following an injury. Additionally, we are formulating strategies to pattern cell-binding ligands within these soft materials, with the goal of fabricating biological substitutes that mimic both the mechanical and biochemical gradients present in the tissue microenvironment.

Paul Janmey,

**Departments of Physiology and Physics & Astronomy, Institute for Medicine and Engineering, Center for Engineering Mechanobiology, University of Pennsylvania, Philadelphia, PA, USA.
Visiting Professor, Laboratory of Magnetic Soft Materials, Department of Physics, University of Latvia**

Electrically Conductive Soft Substrates for Cell Culture

Cells *in vivo* grow in mechanically compliant, structurally complex matrices formed by filamentous protein networks, often interspersed with flexible polysaccharide polymers and other macromolecules. As a result, the cells within these materials, or adhering to their surfaces, function in a microenvironment where mechanical properties, electrical conductivity, and chemical conditions can change rapidly, as a result of blood pressure, gravitational forces, and other mechanical stresses, or more gradually, as a result of normal development, aging, or the onset of disease. New developments in making magnetorheological soft substrates that reversibly change elastic modulus over a large range on a very fast time scale, and electrically conductive substrates with elastic moduli close to those of many soft tissues, including the brain, have the potential to increase understanding of how cells function under the physiological and pathophysiological conditions they encounter *in vivo.*

Andrejs Cēbers, Guntars Kitenbergs, Māra Šmite,
Department of Physics, University of Latvia, Latvia

Magnetotactic Bacteria as Magnetic Active Matter Experience of MMML

The research results on a wide variety of magnetotactic bacteria carried out by MMML are reviewed here. Among them are *spirilla* and *cocci* discovered last year in the Ogre River, Latvia. The self-propelling motion of these bacteria depends on the applied magnetic field, illustrated by their trajectories in a rotating field. In some conditions, the switching of the rotary motors is observed, and the effective diffusion coefficient of bacterium trajectory curvature centers are determined. The synchronization of bacteria motion in a rotating field will be discussed. An important feature of ensembles of magnetotactic bacteria is the dependence on active stress due to force dipoles or torque dipoles of self-propelling bacteria on the applied field. That is illustrated by hydrodynamic flow in the magnetic field oblique to the concentration band and by the motion of the swarm of bacteria in oblique to the cell magnetic field obeying the left-hand rule. In conclusion, the results of the last expedition for magnetic bacteria hunt in rivers and lakes of Latvia are presented, and the results of the measurement of their magnetic properties are given.

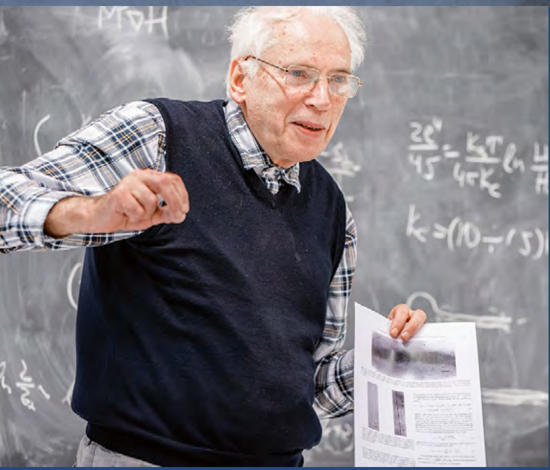
Māra Šmite, Oksana Petričenko, Andrejs Cēbers,
Department of Physics, University of Latvia, Latvia

Soft Magnetic Materials in MMML

Soft magnetic materials are synthesized, characterized, and studied in MMML laboratory. Water-based ferrofluids containing iron oxide nanoparticles, such as maghemite (γ-Fe_2O_3), are produced using the Massart's method, which yields ferrofluids with a positive nanoparticle surface charge, as well as a negative one. By adapting the Sugimoto gel-sol method, various hematite (α-Fe_2O_3) micron-sized particle geometries can be obtained. Hematite particles are antiferromagnetic, and they exhibit swarming behavior in a rotating magnetic field. By filling liposomes with magnetic fluid, we are able to produce magnetoliposomes, which have promising applications in biotechnology.

ORGANIZERS OF RIGA WORKSHOP:

MMML laboratory (Laboratory of Magnetic Soft Materials), founded in 2005, is a research group with a recognized research record on magnetic soft materials. It has the necessary methodology and equipment to tackle the formulated tasks. The laboratory has a strong theoretical background, including competence in various analytical and numerical methods. Our current research interests include bacterial hydrodynamics, pattern formation of magnetic soft matter, and magnetoactive elastomers of interest in cell biology. The laboratory is a part of the Faculty of Physics, Mathematics and Optometry, housed in the recently constructed House of Science of the University of Latvia (opened in January 2019), which has modern offices, collaborative work areas, and advanced experimental facilities. Located on the basement floor, experimental rooms have anti-vibration floor panels, overpressure and decoupled supports for additional equipment and communications. With the support from EU Structural funds and previous projects, the laboratory is supplied with state-of-the-art-equipment, including multiple modern Leica microscopes on optical tables, a variety of stages, cameras and home-built thermally stabilized magnetic coil systems with alternating magnetic fields in any 3D. Additionally, a rheometer, a DLS device, a particle image velocimetry setup and PDMS-based microfluidics protocol and suitable equipment are available here. Various software solutions are used for experiment control, image processing and data analysis. A chemistry room with equipment for magnetic particle synthesis, modification and characterization, as well as a setup for growing microbiological samples is at the disposal of the researchers.



https://mmml.lu.lv/

@MMML_LU