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"The Physics of Evolving Matter: Connectivity, Communication, and Growth" The Geilo School 2023, March 13-23, Geilo, Norway

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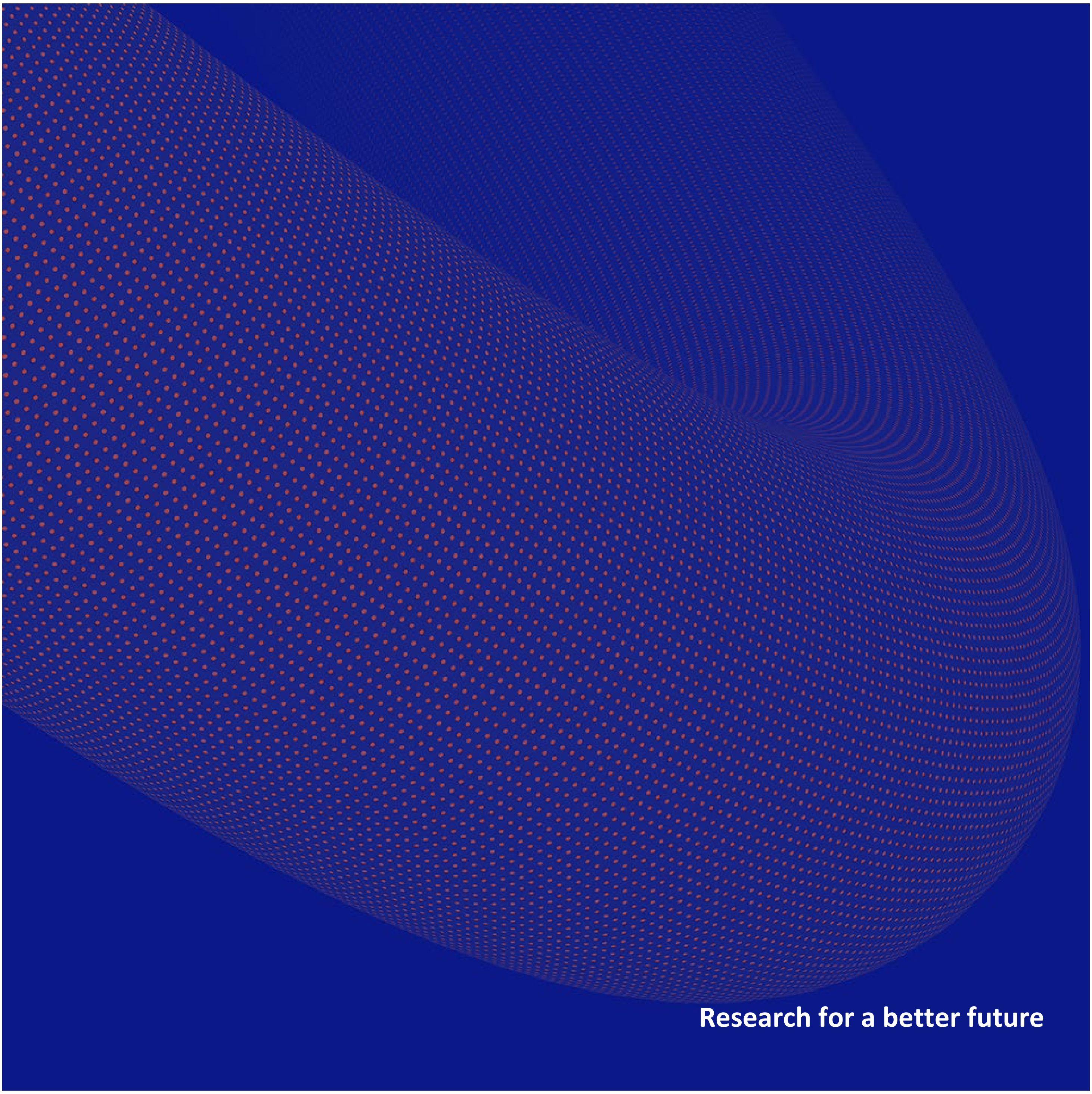

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“Physics of Evolving Matter: Connectivity, Communication and Growth”
The Geilo School 2023, March 13-23, Geilo, Norway

Summary:
This report contains the complete program, poster abstracts, lists of lecturers and participants at the “Geilo School” held at Bardøla hotel, Geilo (Norway) March 13-23, 2023.

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1 Introduction

This report contains the complete program, poster abstracts, lists of lecturers and participants at the "Geilo School" (GS) held at Bardøla hotel, Geilo (Norway) March 13-23, 2023. This is the twenty-seventh GS in a series held every two years since 1971. The theme of the school was "*Physics of Evolving Matter: Connectivity, Communication and Growth*", which is in the forefront of current research in soft matter science, complex matter physics, and biological physics. Condensed Matter Physics involves the study and characterization of how individual components like atoms, molecules, particles, and other entities self-organize in some collective state and where the behavior of the collective is more important than the behavior of the individuals. The physics of evolving matter has applications in biology and other fields.
The sub-themes of the School are outlined below.

A) *Connectivity* in evolving matter is essential in the ability of all living matter to efficiently self-organize.

B) *Communication* enables cells and entities in all living matter to connect and self-organize in some collective state.

C) The phenomenon of *Growth* is the origin of all changes of form in living matter.

Financial support to this Geilo School was principally from the EU H2020-MSCA-ITN-ETN project "PICKFOOD" (Pickering emulsions for food applications) - grant agreement number 956248, Norwegian University of Science and Technology (NTNU), Trondheim (Norway), and the Institute for Energy Technology, Kjeller (Norway).

A list of previous Geilo schools may be found here:
https://ife.no/en/project/the-geilo-schools/

May 2023

Arne T. Skjeltorp

Director of the Geilo School 2023

2 Program of the Geilo School 2023

The Physics of Evolving Matter: Connectivity, Communication and Growth

1st Day Monday March. 13		
18:00	*Arrival*	*Bus transportation of participants from Oslo airport (14:45) and Oslo central station (14:00) to Geilo*
18.00-19.00	*Registration*	
19.00-20.00	*Reception*	*Welcome Drink in the Bar*
20.00 -22.00	*Dinner*	
22.00-22.15	Arne Skjeltorp	*Opening*
2nd Day Tuesday March 14		
08:30-11:30	Petter Holme	Models of human interaction
11:30-15:30	*Discussions, outdoor activities and lunch*	
15:30-17:30	Orlin Velev	Active soft matter controlled and powered by electric and magnetic fields 1. General principles and directed assembly and manipulation
17:30-18:30		Tutorial group meetings and informal discussions with lecturers
3rd Day Wednesday March 15		
08:30-09:30	Orlin Velev	2. Propulsion of active particles and active matter reconfiguration
09:30- 11:30	Ivan Davidovitch	Inference of network connectivity from neural activity in Neuroscience
11:30-15:30	*Discussions, outdoor activities and lunch*	
15:30-16:30	Ivan Davidovitch	Inference of network connectivity from neural activity in Neuroscience (Ctd.)
16:30-17:30	Olli Ikkala	From bio-mimetic materials to life-inspired dynamic materials
17:30-18:30		Tutorial group meetings and informal discussions with lecturers
4th Day Thursday March 16		
08:30-10:30	Olli Ikkala	From bio-mimetic materials to life-inspired dynamic materials (Ctd.)
10:30-11:30	Vinny Manoharan	Viruses: a perspective from soft-matter physics
11:30-15:30	*Discussions, outdoor activities and lunch*	
15:30- 17:30	Vinny Manoharan	Viruses: a perspective from soft-matter physic(Ctd.)
17:30-18:30		Tutorial group meetings and informal discussions with lecturers
5th Day Friday March 17		
08:30-11:30	Stéphane Douady	Morphogenesis of Interconnecting networks 1) examples: cities, rivers, leaves, gorgons, jellyfishes 2) analysis of spatial networks / growth rules 3) morphogenesis and evolution
11:30-15:30	*Discussions, outdoor activities and lunch*	
15:30-18:30	**Poster session**	**Bardølasalen - Posters left on display until Wednesday, March 22**

6th Day Saturday March 18		
08:30- 09:30	Maciej Lisicki	Twist and turn. Elastohydrodynamics of soft and living matter
09:30- 10:30	Jarle Breivik	The evolutionary meaning of cancer
10:30- 11:30	Florence Elias	The physics of liquid foams
11:30-15:30	*Discussions, outdoor activities and lunch*	
15:30-17:30	Florence Elias	The physics of liquid foams (Ctd.)
17:30-18:30		Tutorial group meetings and informal discussions with lecturers
7th Day Sunday March 19		
Free	***Choice of excursions to nearby scenic places or various skiing or hiking events in the mountains***	
8th Day Monday March 20		
08:30- 11:30	L. Mahadevan	1. Embodied Intelligence - from bugs to bots 2. Motifs in Morphogenesis - from bodies to brains
11:30-15:30	*Discussions, outdoor activities and lunch*	
15:30- 17:30	Min-Hui Li	Soft actuators and artificial muscles by liquid crystal elastomers
17:30-18:30		Tutorial group meetings and informal discussions with lecturers
9th Day Tuesday March 21		
08:30- 09:30	Min-Hui Li	Soft actuators and artificial muscles by liquid crystal elastomers (Ctd.)
09:30- 11:30	Albert-László Barabási	Network Science
11:30-15:30	*Discussions, outdoor activities and lunch*	
15:30- 16:30	Albert-László Barabási	Network Science (Ctd.)
16:30-17:30	Yves Méheust	Flow-induced constraint drives phenotypic heterogeneity in bacterial growth and adhesion on surfaces
17:30-18:30		Tutorial group meetings and informal discussions with lecturers
10th Day Wednesday March 22		
08:30- 10:30	Françoise Brochard-Wyart	A tour of my soft matter garden
10:30- 11:30	Christophe Eloy	Planktonic navigation
11:30-15:30	*Discussions, outdoor activities and lunch*	
15:30-17:30	Christophe Eloy	Planktonic navigation (Ctd.)
17:30-18:30		Tutorial group meetings and informal discussions with lecturers
19:30	***Geilo School Closing Dinner***	***Geilo Awards, Poster Prizes etc.***
11th Day Thursday Nov. March 23		
08:30-12:30	*Departure*	*Bus transportation of participants from Geilo to Oslo airport (12:30) and Oslo central station (13:30)*

Sponsors:

3 Poster Abstracts

A Microfluidics approach to study the coalescence dynamics of Pickering emulsions

Xuefeng Shen, Siddharth Deshpande, Jasper van der Gucht, Physical Chemistry and Soft Matter, Wageningen University & Research, the Netherlands

When two surfactant-stabilized liquid droplets contact, a microscopic connecting liquid bridge forms and rapidly grows as the two droplets merge into one. Whereas coalescence has been thoroughly studied when surfactant-stabilized droplets coalesce in an outer liquid, the knowledge of coalescence dynamics of particle-stabilized droplets remains poorly understood. Particle-stabilized emulsions, also known as Pickering emulsions, have garnered exponentially increasing interest in recent years. Due to their remarkable stability, it is a hurdle to observe the spontaneous coalescence of Pickering emulsion droplets. Conventional methods for producing Pickering emulsions generate droplets with a broad distribution of sizes and have limited control on the particle-loading process, which complicates the quantitative analysis of coalescence dynamics. Microfluidics offers a highly controlled environment to study the Pickering emulsion droplets dynamics on chip. In this work, we will use a microfluidic approach to generate monodispersed droplets that undergo same shear history. Based on microfluidic geometric and flow parameters considerations, we can control the coverage of adsorbed particle at the droplet interfaces and the coalescence behaviors of droplets.

Bio-hybrid micro robots remotely controlled by light

Ojus S. Bagal, Nicola Pellicciotta, Viridiana Carmona Sosa, Giacomo Frangipane, Roberto Di Leonardo*
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Active particles can apply forces on passive structures and generate mechanical work [1]. Using light-driven bacteria [2] as propellers we can steer 3-D printed microbots by unbalancing light intensity over different microbot parts. We show that by a dynamic feedback loop that couples position and orientation to the projected light pattern we can independently guide multiple microbots through a series of checkpoints distributed in space. These bio-hybrid micro-machines are very efficient in converting light power, so that in principle hundreds of such systems could be controlled simultaneously with optical powers in the milliwatts range. The microstructures are produced by two-photon polymerization and are designed to capture individual bacteria within their compartmentalised structure in order to optimally harness their propulsion mechanism. This remote control micro shuttles can provide a powerful microrobotic tool for lab-on-chip applications.

Breakthrough-Induced Loop Formation in Evolving Transport Networks

Stanisław Żukowski (1,2), Annemiek Cornelissen (2), Stéphane Douady (2), Piotr Szymczak (1)
(1) Institute of Theoretical Physics, University of Warsaw, Poland
(2) Laboratoire Matière et Systèmes Complexes, Université Paris Cité, France

Transport networks, such as vasculature or river networks, provide key functions in organisms and the environment. Their performance and robustness to damage strongly depend on the topology, which can either be branched or contain loops. They often emerge as a result of unstable growth processes, in which growing branches compete for the available flux. This leads to effective repulsion between the branches and screening of the shorter ones. Although this classical picture easily produces branched structures, it does not capture attraction between the branches leading to the emergence of reticulated networks. We show that a striking transition from repulsive to attractive interactions between the branches takes place as the leading branch reaches the boundary of the system. The shorter branches revive then and grow toward the leading one forming loops, which changes the topology of the growing network. This results in a characteristic hierarchical pattern which can be observed in a large variety of systems: dissolving fractures, viscous fingering, discharge patterns, and even gastrovascular canals on jellyfish.

CO_2 intercalation in cation exchanged natural and synthetic clay minerals

Konstanse K. Seljelid (NTNU), Paulo H. M. Brito (NTNU), Sunniva Omdal (NTNU), Torstein Nordvik (NTNU), Kenneth D. Knudsen (IFE), Josef Breu (University of Bayreuth), Jon Otto Fossum (NTNU).

CO_2 emissions into the atmosphere is a global challenge, and innovative solutions are necessary to help mitigate this. Clay minerals have shown great potential for capturing CO_2, which could, for instance, be utilized to filter out CO_2 from combustion gases. Previous studies of CO_2 intercalation into a synthetic Nickle-fluorohectorite clay have shown that CO_2 only enters in interlayers containing a hydroxide structure (1,2). To investigate this further several hydroxide forming cations, such as Zn, Mg, Mn, Cu and Fe(III) have been used for cation exchange. Preliminary results from X-ray diffraction show basal spacings of 10.2 – 10.8 Å for the hydroxide exchanged clays, compared to 9.6 Å for other cations. This indicates at least some partial formation of hydroxides in the interlayers. Additionally the Fe(III)-fluorohectorite display some intercalation of CO_2 at 50 bar, which is retained when pressure is reduced to ambient pressure. Similar results have also been obtained for Nickle exchanged natural clays, which is encouraging for potential upscaling for industrial purposes.

1. Loch P, Hunvik KWB, Puchtler F, Weiß S, Seljelid KK, Røren PM, mfl. Spontaneous formation of an ordered interstratification upon Ni-exchange of Na-fluorohectorite. Appl Clay Sci. november 2020;198:105831.

2. Hunvik KWB, Loch P, Cavalcanti LP, Seljelid KK, Røren PM, Rudić S, mfl. CO 2 Capture by Nickel Hydroxide Interstratified in the Nanolayered Space of a Synthetic Clay Mineral. J Phys Chem C. 3. desember 2020;124(48):26222–31.

Environmental changes in Ukraine

L B Anisimova1, P H Pihulevskyi2, O K Tiapkin3
1 Institute of Geotechnical Mechanics of the NAS of Ukraine
2 Institute of Geophysics of the NAS of Ukraine
3 Dnipro University of Technology

The mining complex (enterprises for the extraction and enrichment of ore and coal) generates waste. For several reasons, 90% of the extracted raw materials turn into waste containing Mn and Fe (total) and pollute the environment. A general analysis of the mobility of the main polluting elements as a result of agricultural activities makes it possible to establish a significant effect of the migration of the corresponding chemical elements on the ecogeochemical state of soils, natural surface and ground-water.

The quality, quantity and ratio of polluting components, the impact on environmental components is changing due to changes in the structure of industry. New sustainable natural and manmade geoecosystems have been formed as a result of the combined action of factors of industrial and agricultural production for a long time.

The consequences of past intensive activities and waste accumulated over a long period of time pose a long-term threat of pollution of various areas of the biosphere and geosphere.

Now it is relevant to develop a methodology for differentiation the contribution of various areas of industrial and agricultural production, as well as the consequences of past intensive activities and modern production.

Geometrical measures of wormholes in dissolving rocks

Rishabh P. Sharma, Max P. Cooper, Piotr Szymczak

Institute of Theoretical Physics, Faculty of Physics, University of Warsaw, Poland

Dissolution of carbonate rocks is a highly non-linear process in which the interaction of flow, transport, and reaction lead to the spontaneous formation of highly permeable conduits, known as wormholes. The wormholes grow and compete for the available flow and reactant concentration, forming an intricate, branched network inside the rock matrix. In this work, we aim at geometrical and topological characterization of this network, based on the sequence of tomographic scans of dissolving limestone cores. This data allows us not only to characterize the final network of dissolution channels emerging in the sample but also to track the evolution of this network over time. The scans are subtracted from the initial scan and the resulting images are further processed using segmentation and connected components method to identify the wormhole network. The wormholes are then characterized in terms of tortuosity, branching ratio, and growth rates of different branches. We observe that after the initial period when these quantities change in a very rapid manner, they reach a steady state. The steady-state geometrical characteristics of the wormholes are then correlated to the flow rate under which the experiment was performed and the pore-space properties of the dissolving rocks.

Hydrodynamic properties of supercoiling-induced shapes of DNA minicircles

Radost Waszkiewicz (U. Warsaw), Maduni Ranasinghe (U. Lethbridge), Jonathan M. Fogg (Baylor College of Medicine), Daniel J. Catanese, Jr. (Rice U.), Maria L. Ekiel-Jezewska (Polish Academy of Sciences), Maciej Lisicki (U. Warsaw), Borries Demeler (U. Montana & U. Lethbridge), Lynn Zechiedrich (Baylor College of Medicine), and Piotr Szymczak (U. Warsaw)

DNA in cells is organized in negatively supercoiled loops with a surprisingly wide variety of 3-D shapes. The interplay between supercoiling, looping, and shape influences how DNA is stored, replicated, transcribed, and repaired. To understand the consequences of negative supercoiling and curvature on the hydrodynamic properties of DNA, we submitted 336 bp and 672 bp DNA minicircles to analytical ultracentrifugation (AUC). We found that the diffusion coefficient, sedimentation coefficient, and the DNA hydrodynamic radius strongly depended on circularity, loop length, and degree of negative supercoiling. We applied linear elasticity theory to predict DNA shapes, and combined these with hydrodynamic calculations to interpret the AUC data, with reasonable agreement between theory and experiment. These complementary approaches, together with earlier Cryo-EM data, provide a framework for understanding and predicting the effects of supercoiling on the shape and hydrodynamic properties of DNA.

Reference: bioRxiv 2023.01.04.522747; doi: https://doi.org/10.1101/2023.01.04.522747

Inference of 3D force atlases from fluorescence microscopy

Sacha Ichbiah, Fabrice Delbary, Hervé Turlier (College de France)

The morphogenesis of tissues and embryos results from a tight interplay between gene expression, biochemical signaling and mechanics. While sequencing methods allow the generation of cell-resolved spatiotemporal maps of gene expression in developing tissues, creating similar maps of cell mechanics in 3D has remained a real challenge. Exploiting the foam-like geometry of cells in embryos, we propose a robust end-to-end computational method to infer spatio-temporal atlases of cellular forces from fluorescent microscopy of cell membranes. Our method generates precise 3D meshes of cells geometry and successively predicts relative cell surface tensions and pressures in the tissue. We validate it with 3D active foam simulations, study its sensitivity to noise and prove its biological relevance on mouse, ascidian and C.Elegans embryos. 3D inference allows us to recover mechanical features identified previously, but also predicts new ones, unveiling potential new insights on the spatiotemporal regulation of cell mechanics in early embryos. Our code is freely available and may fill an important gap to unravel unknown mechanochemical feedbacks controlling embryo and tissue morphogenesis.

Lyotropic Aqueous Ionic Liquid Crystals and Their Shear-Induced Foams

Andreia F.M. Santos1, J.L. Figueirinhas3, Madalena Dionísio1, Luis C. Branco1, Maria H. Godinho2*

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Lyotropic systems are ubiquitous in nature, being found mainly in aqueous media. Ionic liquid crystals (ILCs) are low melting organic salts exhibiting liquid crystalline properties, whose mesomorphic behaviour can be induced by adding long alkyl chains to either cation or anion, making them amphiphilic [1]. Herein, thermotropic ILCs based on picolinium cations [2] were converted into lyotropic aqueous systems, which showed liquid crystalline behaviour at room temperature. Two-dimensional liquid foams were also observed under shear and their appearance/disappearance was monitored by POM between crossed polars. Moreover, the meet vertices and the number of the birefringent side walls, surrounding dark domains, were followed in time. In addition, several solutions with different concentrations were prepared from ILCs and characterised by Electrical Conductivity, POM, XRD and 1H Spin-Lattice Relaxation Time measurements. Results indicate the formation of birefringent micellar systems, whose micelle and lyotropic critical concentrations were determined.

References:

[1] Chem.Rev., 2016,116,4643–4807.

[2] Liq.Cryst., 2022,49,1809–1821.

Programmable patchy particle model for understanding complex self-assemblies and designing functional materials

Qian-Ze Zhu (Harvard University), Chrisy X. Du (Harvard University), Ella M. King (Harvard University), Michael P. Brenner (Harvard University)

Predicting functions from material microscopic structures is fundamental to both understanding the complex behaviors of biological self-assemblies and designing functional materials with desired properties. However, the design space of current models is too vast to efficiently search for the desired functional features. Here we present an end-to-end differentiable physical model with novel features that can reproduce the functional behaviors of some biological self-assemblies, such as the dynamical growth of microtubules. Furthermore, our proposed model can directly optimize desired properties in high-dimensional parameter space (building block geometry, interaction strength, etc) using automatic differentiation. These results advance a substantial step towards understanding the complex biological behavior and inverse design of functional materials.

Renewing Active Matter: from cell competition to evolving materials

Yoav G. Pollack (University of Göttingen, MPI-NAT, MPI-DS), Philip Bittihn (MPI-DS), Ramin Golestanian (MPI-DS, University of Oxford)

Proliferating active matter deals with non-equilibrium systems, prominently multicellular ones, driven microscopically by growth, division, and death. Dense systems of this sort, whose biological equivalents are tissues and biofilms, can be viewed as soft materials, but can also exhibit novel features that are not available in inert and thermal matter or even in motility-driven active matter. For example, cell competition can lead to an evolution of the material composition and its properties. Here, we discuss stochastic competition for free space in confined systems with cell renewal and consider the special importance of dead matter elimination in this scenario, revealing a novel fitness advantage[1]. We then examine the consequences of such competition, ignoring the more traditional biological aspects and focusing on its implications for renewing cellular materials that can change their mechanical properties.

[1] Y. G. Pollack, P. Bittihn, and R. Golestanian, “A competitive advantage through fast dead matter elimination in confined cellular aggregates”, New Journal of Physics 24, 073003 (2022).

Robust statistical properties of T1 transitions in confluent tissues

Harish Pruthviraj Jain

Njord, Department of Physics, University of Oslo, Norway

Large-scale tissue deformation which is fundamental to tissue development hinges on local cellular rearrangements, such as T1 transitions. In the realm of the multi-phase field model, we analyse the statistical and dynamical properties of T1 transitions in a confluent tissue. We identify an energy profile that is robust to changes in several model parameters. It is characterized by an asymmetric profile with a fast increase in energy before the T1 transition and a sudden drop after the T1 transition, followed by a slow relaxation. The latter being a signature of the fluidity of the cell tissue. We show that T1 transitions are sources of localised large deformation of the cells undergoing the neighbour exchange and induce other T1 transitions in the nearby cells through a chaining of events that propagate local cell deformation to large scale tissue flows.

SAXS studies of Pickering emulsions with pea protein

Eleonora Olsmats (Uppsala University), Adrian R. Rennie (Uppsala University)

The conventional method to stabilize food emulsions is by using surface active compounds. By using solid state particles at the emulsion drop surface, Pickering emulsions can provide a better stability against coalescence, be more environmentally friendly and have less volatile organic compounds. In this project, we investigate pea protein or pea protein aggregates as potential Pickering stabilizers in oil-in-water (O/W) emulsions with rapeseed oil and water.

The basic principle of Pickering particles to stabilize emulsions is not complex, but the functionality and structure of the emulsion is often complicated in real physical systems. By using X-ray scattering techniques (SAXS, WAXS) as well as the Bonse-Hart USAXS setup, a broad range of length scales (~3pm-200µm) can be analyzed and give structural information (size, shape and surface area) about the emulsion droplets and the proteins. To understand the stability of the emulsions, experiments with different oil to water ratios and pea protein concentrations has been performed, and a ternary diagram was also created.

SAXS/WAXS characterizations of continuous carbon fiber composites subjected to low-velocity-impact

Alexander Sexton (NTNU), Matti Knaapila (NTNU)

Composite materials are used in a variety of high-performance demanding application, such as in airplane wings for their high strength and low weight, and in electric vehicles to compensate for the weight of heavy batteries. Damage to the composites may appear after, for instance, sudden and accidental impact, and as a result the mechanical properties degrade. In this ongoing work, we examine the characteristics of such damages to carbon fiber composites in a polymer matrix by means of small- and wide angle x-ray scattering, and thus monitor changes to the polymer crystallinity and micro-cavities in both polymer and fibers. The idea is to use these characterizations and others for predicting the remaining useful lifetime of the composites.

Self-assembled microtubules: a possible quantum “grey matter” for artificial intelligence

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It is believed that living organisms process information quantum-mechanically using microtubules [1,2]. In [2], this process is linked to superconductivity. Here experiments are reported, which directly visualize self-assembly of the microtubules in an extract from a mammalian brain and a fungi. The evidence of superconductivity is presented. The influence of Fe_3O_4 nanoparticles on the self-assembly and the possibilities to use the network of the self-assembled microtubules as a “grey matter” for artificial intelligence will be discussed.

1. S. Hameroff Quantum computation in brain microtubules? The Penrose Hameroff ‘Orch OR’ model of consciousness, Phil. Trans. R. Soc. A. 356 1869–1896 (1998). https://doi.org/10.1098/rsta.1998.0254.

2. P. Mikheenko, Nano Superconductivity and Quantum Processing of Information in Living Organisms, IEEE Xplore Digital Library 9309703 (2021). https://doi.org/10.1109/NAP51477.2020.9309703.

Study I-V Characteristics of Resonant "and Tunneling Diodes using Non-equilibrium Green's function (NEGF)

Nar Bahadur Gurung

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In this work, we perform a comprehensive analysis of modeling of resonant tunneling diode (RTD) based on quantum model. RTDs operate on the principle of quantum mechanical tunneling of electrons through a potential barrier into quantized well states resulting in resonances in the transmission characteristics. The electron density and the charge self-consistent electrostatic potential profile in the device is analyzed by employing Thomas-Fermi model and Hartree model. The Non-equilibrium Green's function (NEGF) formalism using effective mass approach is developed to study GaAs/AlGaAs RTD to obtain the I–V characteristics. The Performance characteristics of the device like negative differential resistance (NDR) and Peak-to-Valley Current Ratio (PVCR) has been discussed. The Variation in I–V characteristics with variation of well-width and barrier-width has been plotted and their causes have been analyzed.

Weak localization as quantification of defects in 2D metallic nanolayers

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2Indianapolis university – Purdue university (IUPUI), Indianapolis, Indiana, USA

Weak localization1 (WL) is a quantum phenomena, where at cryotemperatures, electrons in metal move around the closed loop and returns to their initial point of origin rather than proceed forward in the lattice, which increases resistivity of metal. Typically, metals with defects exhibit transition from normal metallic conductivity to WL regime at low temperatures. We have observed in 2D metallic MXene 2, measuring the temperature and field dependence of resistivity, that depending on the amount defects, temperature of the transition increases with increasing amount of defects. Properties of the 2D nanosheets were studied by complementary experiments such as XRD, AFM and SEM. It turned out that measurement of resistivity, which is a fast experiment, is completely sufficient and superior in order to unambiguously quantify amount of defects in 2D metal nanosheets in general.

1. Falko, V. I. et al. Weak localization in graphene. Solid State Commun 143, 33–38 (2007).

2. Gogotsi, Y. & Anasori, B. The Rise of MXenes. ACS Nano 13, 8491–8494 (2019)

Locomotion of bacteria through Soft Matter

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The natural environments of bacteria are colloidal in nature and show complex flow behaviors (1). The colloidal particles present in this liquid environment endow the fluids with viscoelastic properties resulting from diverse interactions. Such liquid systems are found in biological systems as the lungs and stomach lining and in the ecosystem (ocean, rivers). Understanding the swimming behavior of bacteria in these complex liquid systems is critical to unlocking important biological processes as disease infection and ecosystem health.

In this work we aim to combine experimental data and theoretical analysis to explain the mechanism of bacterial motility in soft matter using clay suspensions as the model system. Aqueous clay suspensions are viscoelastic fluids whose material response depends on the clay mineral, particle concentration and ionic strength of the aqueous media. In aqueous solution, clay particles form ordered network structures, and rheological measurements provide information on the flow properties and interactions present in these suspensions (2). Bacteria swimming through this structured environment will be determined by the clay particle size and interactions in the suspensions, and this can be related to the rheology of the clay suspensions. The swimming dynamics of bacteria in the clay suspension is studied through observation of the 3D tracks of the bacteria in the fluid using the 3D Lagrangian tracking technique (3).

Here we present preliminary results of the swimming dynamics of E. Coli in 0.02wt% Laponite RD suspension. The 3D tracks show significant changes in the position of the bacteria as a function of time. Also, the bacteria displayed two swimming regimes with modal swimming velocities of $7.4 \pm 2.1 \mu m/s$ and $1.9 \pm 0.9 \mu m/s$ respectively. Future experiments will focus on the swimming dynamics of E. Coli and alkalophilic bacteria in clay suspensions of varying particle concentrations and ionic strength.

Reference:

(1) Kamdar S.; Shin S.; Leishangthem P.; Francis L.F.; Xu X.; Cheng X. The Colloidal Nature of Complex Fluids Enhances Bacterial Motility. *Nature*. 2022, 603, 819-823.

(2) Joshi Y.M.; Reddy G.R.K.; Kulkani A.L.; Kumar N.; Chhabra R.P.; Rheological Behavior of Aqueous Suspensions of Laponite: New Insights into the Ageing Phenomena. *Proc. R. Soc. A*. 2008, 464, 469-489.

(3) Darnige T.; Figueroa-Morales N.; Bohec P.; Lindner A.; Clement E. *Review of Scientific Instruments*. 2017, 88, 0155106.

Pickering Droplets: Formation, Deformation and Rheology

Negar Azizi[1], Jon Otto Fossum[1], and Paul Gunnar Dommersnes[1]

[1]Department of physics, Norwegian University of Science and Technology-NTNU, Trondheim, Norway

Abstract:

Pickering emulsions are emulsions stabilized by particles instead of surfactants. Due to capillary interactions small particles like to sit at the interface of two liquids. This can result in droplets being covered by a layer of particles, which protect neighbouring from coalescing. Pickering emulsions can be very stable when left alone but they can be unstable when subject to mechanical forces (stirring). This can for example be caused by scratching of the droplets or other deformations open or rupture the Pickering layer. It is therefore important to understand the mechanics and rheology of the Pickering layer.

Magnetic response of nematic suspensions of clay nanosheets

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Orientation and manipulation of 2D clay nanosheets is important in various areas, such as encapsulation and release of droplets/particles, capture and transportation of molecules. In this study, we perform experimental investigations of the magnetic alignment of nematic phases formed by delaminated fluorohectorite synthetic clay mineral ($Na_{0.5}[Mg_{2.5}Li_{0.5}]\langle Si_4\rangle O_{10}F_2$) nanosheets. We use visual observation of birefringence and SAXS to quantify the magnetic response including its dynamics. Magnetic Janus clay nanosheets, composed of clay nanosheets decorated with magnetic nanoparticles on one side of the clay nanosheet, orient with their longest axis parallel with magnetic field displaying an orientation time one order of magnitude faster than that of bare non-decorated clay nanosheets.

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Electric-Induced Oil-in-Oil Pickering Emulsion Formation

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Emulsion is usually a two-phase system composed of oil-in-water (O/W), water-in-oil (W/O), oil-in-oil (O/O) or even water-in-water (W/W) mixture. When it comes to applications, O/W and W/O systems are the most used, conversely O/O emulsions are scarcely explored and are usually patented. The reason is found to be the limitation of proper solvent pairs for such a system, which requires a good knowledge of oils' physico-chemical properties. To have a long shelf life, the emulsions need a proper stabilization process. Surfactants are commonly used, but there is a matter of concern regarding human health and eco-friendliness in their use. As an alternative, solid particles can be a great solution.

When the emulsions are stabilized by solid particles, protein, or polymers, they are referred to as Pickering emulsions. To assure the stabilization, it is necessary that these particles are placed on the interface of both phases. For this purpose, electrohydrodynamic (EHD) flow can be used, but a set of parameters need to fit depending on the type of EHD process chosen, which intensifies for O/O emulsion. Such parameters include electric field strength, conductivity, density, and viscosity of both phases. Among the techniques available, electrospraying, electrospinning, bulk and microfluidics stabilization with electric fields can be explored. Since O/O emulsion has no (or very low) water content, it becomes a very interesting system for extended storage time, avoiding microorganisms' proliferation, and it can be applied for hydrophilic payloads' encapsulation, a set of food products, and systems in which water is not desirable.

Here we focus on the application of bulk EHD flow for both droplets formation and stabilization. The phenomena are tested with polymers and solid particles, showing the flexibility of multiple stabilization schemes using the same EHD setup. To ensure stabilization, fluorescent particles are used for better visualization. The results of Pickering emulsions' stabilization are promising for future food product enrichment, in which proper stabilization and food-grade systems are needed.

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Laponite Nanodisks as Platform for Water Purification

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Abstract
Safe and clean drinking water is essential for every human being. However, clean water is sometimes scarce and not readily available due to industrial pollutant activity or runoff from natural geochemical processes. In the present work, it is shown that water quality can be improved by using Laponite as an adsorbent because of a large surface area. Laponite is a synthetic hectorite clay composed of disk-shaped nanoparticles with a diameter of about 20 nm and a thickness of about 1 nm. In a sample of 1 g laponite, there are about 10^{18} particles. The total surface area for adsorption of pollutants will thus be about 1000 m^2.

The underlying idea in the present work was thus to use functionalized laponite decorated with magnetic nanoparticles. This could enable removal of oil and soluble contaminants such as heavy metals, emulsifiers, surfactants, and micro-nano plastic from water flowing in a pipe. To succeed this, one must have magnets with efficient and high yield separation capabilities. For this it is important to have a strong force F acting on the magnetic bodies, given by the following equation:

$F = V \cdot \Delta\chi \cdot B \cdot \mathrm{grad}B / \mu_0$.

Here, V is the volume, $\Delta\chi$ is the difference in the susceptibility of the magnetic particles and the surroundings,

$B \cdot \mathrm{grad}B$ is the product of the magnetic field and field gradient and μ_0 is the vacuum permeability.

Many permanent magnets on the market have large magnetic fields B, but weak field gradients. The GIAMAG magnets have unique and patented designs that produces both very large magnetic fields and high field gradients, resulting in the most forceful magnetic separation available on the market [1,2].

Qualitative and quantitative measurements of water purification will be reported, in particular removing small oil droplets.

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STRUCTURAL STUDIES OF PICKERING EMULSIONS

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Norway Emulsions are generally categorized into three types - oil-in-water (O/W), water-in-oil, (W/O) and oilin-oil (O/O). The emulsions are thermodynamically unstable and the conventional method to stabilize them is by using surfactants. However, surfactants are organic compounds that can affect health (irritation or hemolysis) and cause environmental problems when released into nature. An alternative stabilization technique is by using adsorbed particles on the surface of emulsion droplets, thus forming so-called Pickering emulsions (1). In our current research project, named “Pickfood”, funded by the EU Horizon 2020 MSCA-ITN programme, a range of techniques are used to gain detailed information about the mechanisms underlying the stabilization of certain classes of Pickering emulsions. The advantage of using small-angle scattering is that it is possible to get information about the interfacial layer, particle interactions, and stability in the bulk under realistic conditions. The theoretical scattering model for Pickering emulsions developed by LarsonSmith et al (2) based on spherical particles will be used as a starting point for this work. Finally, different stabilization mechanisms will be addressed, depending on the type of system. Oil in water emulsions will be studied with B-lactoglobulin as the Pickering particles. Protein-based biopolymers are considered ideal Pickering stabilizers due to their stability, particle-like nature, and high nutritional value (3). We will use small-angle scattering techniques to get information on the structure and stability of oil-in-water (O/W) focusing on the effect of the surface layer between the two phases.

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Lectures and seminars

- L. Mahadevan, Harvard University, USA,
 Embodied intelligence in swarms
- Stéphane Douady, Université Paris Cité, France
Morphogenesis of Interconnecting networks
1) examples: cities, rivers, leaves, gorgons, jellyfishes
2) analysis of spatial networks / growth rules
3) morphogenesis and evolution
- Petter Holme, Aalto University, Finland
Models of human interaction
- Albert-László Barabási, Northeastern University, Boston, USA
Network Science
- Florence Elias, Université Paris Cité, France
The physics of liquid foams
- Francoise Brochard-Wyart, Institut Curie, France
A tour of my soft matter garden
- Ivan Davidovitch, Kavli Institute for Systems Neuroscience, NTNU, Trondheim, Norway
Inference of network connectivity from neural activity in Neuroscience
- Vinny Manoharan, Harvard University, USA
Viruses: a perspective from soft-matter physics
- Christophe Eloy, Aix-Marseille University, France
Planktonic navigation
- Orlin Velev, North Carolina State Univ., USA
Active soft matter controlled and powered by electric and magnetic fields
1. General principles and directed assembly and manipulation
2. Propulsion of active particles and active matter reconfiguration
- Olli Ikkala, Aalto Univ., Finland
From bio-mimetic materials to life-inspired dynamic materials
- Min-Hui Li, Ecole Nationale Supérieure de Chimie de Paris, France
Soft actuators and artificial muscles by liquid crystal elastomers

- Yves Meheust, Univ. Rennes, Geosciences, France

Flow-induced constraint drives phenotypic heterogeneity in bacterial growth and adhesion on surfaces

- Jarle Breivik, Univ. Oslo, Norway

The evolutionary meaning of cancer

- Maciej Lisicki, Univ. Warsaw, Poland

Twist and turn. Elastohydrodynamics of soft and living matter

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6 Geilo School 2023 group photo