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"Physics Inspired by Living Matter: Dynamics, Topology and Functionality" The Geilo School 2017, 20-30 March, Geilo, Norway

Institute for Energy Technology

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Report title

"Physics Inspired by Living Matter: Dynamics, Topology and Functionality"
The Geilo School 2017, 20-30 March, 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 20-30, 2017.

	Name	Signature
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Contents

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 20-30, 2017. This is the twenty-fourth GS in a series held every two years since 1971 [1]. The theme of the School was "Physics Inspired by Living Matter", which is in the forefront of current research in the area of mimicking natural phenomena and biological systems using the tools in physics.

The sub-themes of the School are outlined below.

A - Collective dynamics occurs for example in birds flocking, swimming bacteria colonies, and cells forming dynamic aggregates. In these systems, known as *active matter,* the energy is injected at the level of the "particles". In *driven matter* the energy is injected at a macroscopic global scale, such as systems subject to vibrations, thermal gradients, electric or magnetic fields. Active matter and driven matter generally exhibit self-assembled or self-organized dynamic structures.

B - Topological features affect the physical properties of matter from nano- to macroscales. Important examples of topological effects are disclinations in liquid crystals, knots and entanglement, twisting and chirality of filaments. Living matter provide numerous examples of such phenomena, ranging from nano-fibrular cellulose to proteins.

C - Functionality relates to the properties of engineered materials inspired by living matter, such as materials formed by colloidal and polymeric building blocks that can be tuned precisely to achieve macroscopic features such as non-wettability, thermal insulation, or structural coloration.

Financial support to this Geilo School was principally from the Research Council of Norway, grant no. 271109. Support was also received from the University of Amsterdam (the Netherlands), DTU, Copenhagen (Denmark), NTNU, Trondheim (Norway) and the Institute for Energy Technology, Kjeller (Norway).

A list of previous Geilo schools may be found here:
http://www.ife.no/departments/physics/projects/geilo

April 2017

Arne T. Skjeltorp

Director of the Geilo School 2017

2 Program

1st Day Monday March 20		
14:00-19:00	*Arrival*	*Communal transportation from Oslo to Geilo*
19:00-19:30	*Registration*	
19:30-20:00	*Reception*	
20:00-21.30	*Dinner*	
21:30-22:00	*Opening*	
2nd Day Tuesday March 21		
08:30-11:30	Francesco Ginelli	The Physics of the Vicsek model and beyond
11:30-15:30	*Outdoor activities and lunch*	
15:30-17:30	Pawel Pieranski	Topological defects in liquid crystals
17:30-18:30		Tutorial group meetings and discussions with lecturers
3rd Day Wednesday March 22		
08:30-09:30	Pawel Pieranski	Topological defects in liquid crystals (ctd.)
09:30-11:30	Giovanni Dietler	Some Aspects about Polymer Physics and Topology using DNA as a model system
11:30-15:30	*Outdoor activities and lunch*	
15:30-16:30	Giovanni Dietler	Some Aspects about Polymer Physics and Topology using DNA as a model system (ctd.)
16:30-17:30	Andreas Carlson (Seminar)	Bio-inspired adhesion; how to get stuck and stay that way
17:30-18:30		Tutorial group meetings and discussions with lecturers
4th Day Thursday March 23		
08:30-11:30	Silvia Vignolini	Photonic Structures in nature
11:30-15:30	*Outdoor activities and lunch*	
15:30-17:30	Julia Yeomans	New topics in Active Matter
17:30-18:30		Tutorial group meetings and discussions with lecturers
5th Day Friday March 24		
08:30-09:30	Julia Yeomans	New topics in Active Matter (ctd.)
09:30-11:30	Igor Musevic	Liquid Crystal Colloids
11:30-15:30	*Outdoor activities and lunch*	
15:30-16:30	Igor Musevic	Liquid Crystal Colloids (ctd.)
16:30-17:30	Geir Helgesen (Seminar)	Magnetic propulsion of microspheres in fluids
17:30-18:30		Tutorial group meetings and discussions with lecturers
6th Day Saturday March 25		
08:30-11:30	Maria Helena Godinho	Cellulose micro/nano filaments
11:30-15:30	*Outdoor activities and lunch*	
15:30-17:30	Heloisa Bordallo	Neutrons: the key to understanding hydrogen bonds and improving our quality of life
17:30-18:30		Tutorial group meetings and discussions with lecturers
7th Day Sunday March 26		
Free	***Choice of excursions to nea scenic places or various ski events in the mountains***	

8th Day Monday March 27		
08:30-11:30	Vinny Manoharan	1. Principles of self-assembly (some of which we've learned from experiments on colloids) 2. Self-assembly in simple systems 3. How does a simple virus self-assemble?
11:30-15:30	*Outdoor activities and lunch*	
15:30-17:30	**Poster session**	**Posters left on display until Wedn. March 29**
17:30-18:30		Tutorial group meetings and discussions with lecturers
9th Day Tuesday March 28		
08:30-11:30	Piotr Szymczak	Proteins: pushing, pulling, knotting and aggregating
11:30-15:30	*Outdoor activities and lunch*	
15:30-17:30	Jon Otto Fossum	Clay Physics Inspired by Living Matter, and vice versa
17:30-18:30		Tutorial group meetings and discussions with lecturers
10th Day Wednesday March 29		
08:30-09:30	Paul Dommersnes	Electric field induced self-assembly of structured matter
09:30-11:30	Jaakko Timonen	1. Externally Driven Non-Equilibrium Ferrofluid Patterns and Structures 2. Magnetically Induced Phase Transitions of Non-Magnetic Colloids
11:30-15:30	*Outdoor activities and lunch*	
15:30-16:30	Jaakko Timonen	3. Controlling Active Matter with Magnetic Fields and Forces
16:30-17:30		Tutorial group meetings and discussions with lecturers
19:30	***Geilo School Closing Dinner***	***Geilo Awards, Poster Prizes etc.***
11th Day Thursday March 30		
08:00-12:00	*Departure*	*Communal transportation of participants to Oslo airport and Oslo*

3 Poster Abstracts

HIGH CHARGE DENSITY SMECTITE CLAYS FOR CO2 CAPTURE

Leide P. Cavalcanti (1), Georgios Kalantzopoulos (2), Pawel Sobas (2), Heloisa N. Bordallo (3, 4), Geir Helgesen (1,2), Kenneth D. Knudsen (1,4), Jon Otto Fossum (5).

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Abstract

This work presents a structural study on the intercalation of carbon dioxide (CO2) into fluorohectorite clays with different interlayer cations. We have recently demonstrated [i] that under certain conditions of pressure and temperature, fluorohectorite clays are able to capture a large amount of CO2, depending on the type of interlayer cation. Intercalation of water in smectite clays occurs naturally and has been extensively studied with a wide range of techniques, among them neutron [ii] [iii] and X-ray scattering [iv] [v]. Recent experiments and simulations have shown that also CO2 can intercalate in smectite clays, both in supercritical [vi], and in gaseous/liquid form [vii]. We have previously demonstrated that CO2 intercalates into synthetic Na-Fluorohectorite (NaFh) clay at conditions close to ambient [viii], at minus 20 °C and 15 bar. These are not the conditions found in the geological storage sites, but can be conditions relevant when clays are considered as an alternative to for example zeolites as a material for capture of CO2. In a recent paper [i] we investigated this further, looking at fluorohectorite clays with three different cations (Na, Ni and Li), showing that Li-fluorohectorite clay is able to retain CO2 up to a temperature of 35°C, at ambient pressure, and that the captured CO2 can be released by heating above this temperature. These conditions are highly relevant for mapping out, and understanding, the mechanisms involved in CO2 capture and retention by smectite clays, either in geological formations, or in CO2 capturing elements. Fluorohectorite is a synthetic 2:1 clay that has been demonstrated by us to be a representative and clean model system of natural smectite clays. Synthetic clays have more homogenous charge distribution than their natural counterparts, which leads to well-defined intercalation states. Synthetic clays also contain significantly fewer impurities (e.g. carbonates, (hydr)oxides, silica, and organic matter) than natural clays. Here we present our last results on the study of CO2 intercalation into a series of synthetic fluorohectorite clays using a Pressure Composition Temperature apparatus, X ray diffraction and Small Angle Neutron Scattering from Jeep II reactor at IFE.

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DYNAMICS OF VISCOUS DROPS IN STRONG ELECTRIC FIELDS

Debasish Das[1] and David Saintillan[2]

Affiliation[1]: Department of Theoretical and Applied Mathematics, University of Cambridge
Affiliation[2]: Department of Mechanical and Aerospace Engineering, University of California San Diego

Abstract

Weakly conducting dielectric liquid drops suspended in another dielectric liquid and subject to an applied uniform electric field exhibit a wide range of dynamical behaviors contingent on field strength and material properties. These phenomena are best described by the Melcher–Taylor leaky dielectric model, which hypothesizes charge accumulation on the drop-fluid interface and prescribes a balance between charge relaxation, the jump in Ohmic currents from the bulk and charge convection by the interfacial fluid flow. Most previous numerical simulations based on this model have either neglected interfacial charge convection or restricted themselves to axisymmetric drops. In this work, we develop a three-dimensional boundary element method for the complete leaky dielectric model to systematically study the deformation and dynamics of liquid drops in electric fields. The inclusion of charge convection in our simulations permits us to investigate drops in the Quincke regime, in which experiments have demonstrated a symmetry- breaking bifurcation leading to steady electrorotation. Our simulation results show excellent agreement with existing experimental data and small-deformation theories.

MORPHOLOGY OF PROMOTER COMPLEXES AS A REGULATION FACTOR OF CONVERGENT TRANSCRIPTION

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Abstract

Last years a lot of evidence has been accumulated that transcription interference (TI), interaction of two RNA polymerase (RNAP) molecules initiating transcription from two promoters in opposed directions, serves as a mechanism of regulation of gene expression. In case two RNAP molecules move towards each other during transcription (convergent transcription) the effect of transcription suppression is much more pronounced [1]. However, the molecular mechanisms underlying TI remain not well studied.

To elucidate the contribution of different structural factors in TI, we have constructed the set of DNA plasmids with closely spaced convergent promoters differing by interpromoter distance. The distance between transcription initiation points was either close to integer number of turns of DNA double helix (N) or to (N+1/2) turns. The morphology of open promoter complexes was studied using atomic force microscopy (AFM).

All studied plasmids form double open promoter complexes (OPC), however, with different frequency of formation. The frequency of formation of double OPC with plasmids pRLM1, pRLM2 and pRLM4 (interpromoter distance is close to N helical turns) was very low (~1%), whereas for pRLM3 (interpromoter distance differs from that of pRLM2 by a half-turn) it was significantly higher (~20 %). Moreover, the shape of double OPCs was different for these two cases: two RNAP molecules were located either along (pRLM3) or across (pRLM1, pRLM2 and pRLM4) the DNA scaffold.

Basing on the obtained results, we have proposed the model of TI taking into account the interaction of two closely spaced RNAP molecules on the DNA scaffold. Such interaction is mediated by a DNA bend produced by RNAP binding with the promoter. According to this model, either a "pocket" (U-shaped configuration) or S-shaped configuration may be formed depending on the mutual orientation of initiation transcription points. U-shaped configuration sterically hinders the formation of double OPC, whereas S-shaped configuration – does not. The proposed model is in agreement with the results of *in vitro* transcription assays.

This work is supported by Russian Foundation for Basic Research (grant 15-32-20629).

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SEDIMENTATION OF KNOTTED AND UNKNOTTED ELASTIC LOOPS

Magdalena Gruziel, Piotr Szymczak, Maria-Ekiel Jeżewska.

Abstract

Heavy objects, like stones or house keys, fall straight down in water, as everybody knows. However, when the object is elastic and the medium - highly viscous, the process of sedimentation may become intriguing and fascinating, yielding sometimes interesting stationary or periodic motions. To give an example, a rigid chiral particle rotates when sedimenting. If the paticle is elastic and knotted in a configuration of a torus knot, the rotation is accompanied by interwinding of the loops formed by the knot. Interestingly, such a motion is also possible for similar, but unknotted structures. In this work we study numerically, via Stokesian dynamics simulations, the sedimentation process of knotted elastic fibers as well as unknotted loops and present diversity of possible sedimentation modes.

ELECTRIC FIELD-DRIVEN ASSEMBLY OF SULFONATED POLYSTYRENE MICROSPHERES

Khobaib Khobaib[1], Alexander Mikkelsen[1], Jarosław Wojciechowski[2], Michal Rajňák[3,4], Juraj Kurimský[4], Ahmet Kertmen[5], and Zbigniew Rozynek[1]

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[2] *Department of Chemistry, University of Warsaw, Ludwika Pasteura 1, 02-093 Warsaw, Poland;*
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Abstract

Designed assembly of particles at liquid interfaces offers many advantages for materials development, and can be performed by various means. Electric fields provide a flexible method for structuring particles on droplets, utilizing electrohydrodynamic circulation flows, dielectrophoretic and electrophoretic interactions. In addition to the properties of the applied electric field, the manipulation of particles often depends on the intrinsic properties of the particles to be assembled. Here, we present an easy approach to produce polystyrene microparticles with different electrical properties. These particles are used for investigations on electric field-guided particle assembly in bulk and on surfaces of oil droplets. By sulfonating polystyrene particles, we make a set of particles with a range of dielectric constants and electrical conductivities related to the sulfonation reaction time. The paper presents diverse particle behavior driven by electric fields, including particle assembly at different droplet locations, particle chaining, and formation of ribbon-like structures with anisotropic properties.

SI NANOPARTICLES AS FRACTALS NUCLEATING IN FREE SPACE

Samson Y. Lai[1], Thomas J. Preston[2], Hallgeir Klette[2], Kenneth D. Knudsen[1], Trygve T. Mongstad[2]

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[2]*Solar Energy Department, Institutt for Energiteknikk (IFE), Kjeller, Norway*

Abstract

Fractals are mathematical concepts with naturally-occurring phenomena, including in living organisms such as crustaceans and flowering plants. As such, the formation of fractals, the study of their properties, and the implementation of fractals as engineered features of materials has both significant interest and potential benefits as a form of “biomimicry”.

Recently, fractal-like patterns have been observed in the synthesis of silicon nanoparticles and nanoparticle aggregates from a free space reactor designed for silane pyrolysis at the Institutt for Energiteknikk (IFE). Among its many practical applications, silicon holds promise as a next-generation negative electrode for lithium-ion batteries and has already seen some utilization commercially in conjunction or as a substitute for graphite. Free space reactors offer the option of scalability and fine control of process parameters such as reactor temperature, quench rate, and dwell time. Thus, nanoparticles and nanoparticle agglomerates of various sizes and size distributions can be created, as verified by electron microscopy in combination with an in situ particle extraction method. As has been used in the similar field of soot aggregates, fractal dimension can be used to characterize particle and aggregate formation. Fractal geometry measurements provide more complex and rich information about the structure of particle aggregates in ways that simpler methods are flawed, particularly for partially sintered particles.

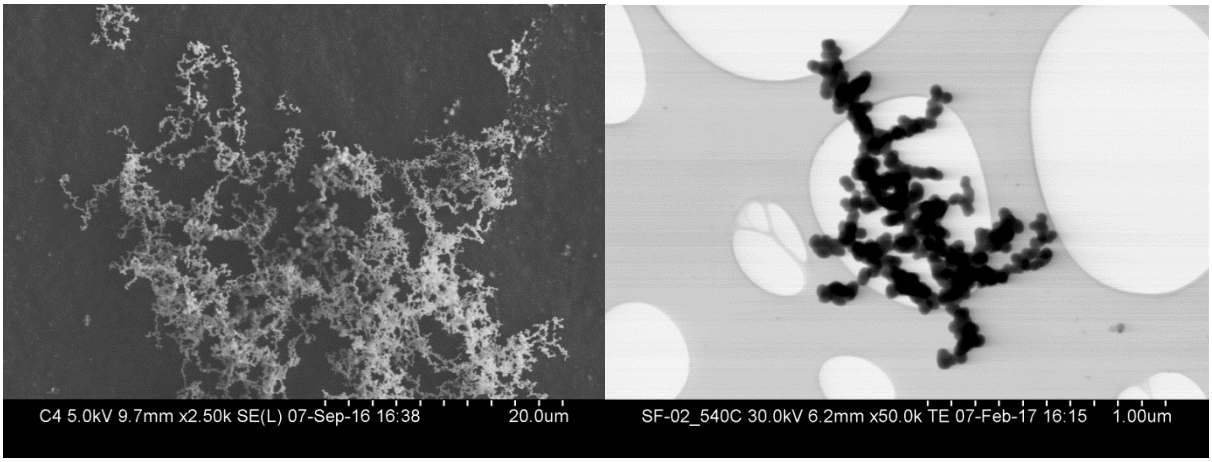

Figure 1. Silicon nanoparticle aggregates collected from two different process parameters of a free space reactor.

THE EFFECT OF ADSORPTION ON THE MICRORHEOLOGY OF NANOPARTICLES/HYDROGEL COMPOSITES

Maayan Levin and Yael Roichman

School of Chemistry, Tel Aviv University

Abstract

It has recently been shown that nanoparticle solutions can be used as hydrogel adhesives due to an adsorption process of the polymer, poly(dimethylacrylamide) (PDMA) onto the silica particles. In this work, we measure the viscoelastic properties of hydrogel-silica composites using microrheology. We compare two composite materials; one which adsorbs to silica (dimethylacrylamide), and one that doesn't (acrylamide). We find that adsorption of the polymer to the nanoparticle fillers causes a composite material made by polymerizing dimethylacrylamide in the presence of silica nanoparticles to alter its internal structure.

SELF-ORGANIZED DYNAMIC STRUCTURE OF NANOPARTICLES IN HETEROGENEOUS PLASMA, THEIR TOPOLOGICAL FEATURES AND THE EFFECT ON THE PLASMA BREMSSTRAHLUNG IN THE RADIO FREQUENCY RANGE

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Abstract

Radio-frequency component of electro-magnetic radiation (EMR) of heterogeneous plasma (HP), in rarefied atmosphere or cosmic space, appears as a result of complex interaction between structural PDF elements and self- self consistent electro-magnetic field of the system Generation of long-wave radiation by plasma medium is created, first, by the slowing-down radiation of charges which acquire acceleration in a self-consistent electrostatic field of the system. Due to that it, radio-component EMR carries in itself integrated information concerning the motion and interaction of HP-charges. For non-relativistic speeds of charged HP particles of the magnetic component of the charge interaction it is possible to disregard, so the problem of describing EMR characteristics of the plasma system can be limited to, describing the motion of plasma free charges in the electrostatic field, which they create jointly, coordinating their motion in the phase space due to correlations. Because of the far-reaching action of coulomb forces, solving the problem of micro fields and charges interaction in plasma medium meets classical complication of the theory of many bodies with long-range Coulomb interactions far-acting power, i.e. the impossibility of bringing potential energy of structural elements (the charges of the system) down to pair interaction. Using continual statistic approach, based on the definition of density functional of the potential energy of PDF gives the possibility to bring the problem down to an effective electrostatic problem, but also demands the elaboration of new methods of statistic equation for parameters of the system with far reaching Coulomb far action [1-3].

In the paper, we use a method of statistical equation (averaging) of the charge density according to the ensemble of the " electroneutral cells in plasma" and the definition of effective distribution of local electrostatic potential in heterogeneous plasma medium. The evolution of location and motion of separate charges is viewed as a temporary sequence of their anharmonic oscillations in the excited cell of electrical neutrally HP, in which distribution of the local electrostatic field "is checking" "to keep track of" activated displacement of a separate charge from equilibrium position. Results of computer simulation to define spectral components of plasma radiation of the products of powdered aluminum combustion in the atmosphere air were compared to the data of natural experiments. Very good qualitative and quantitative coordination of the data of both the computer and the natural experiments were observed.

The main ideas of the statistics cell-based approach to the description of the properties of HP applied to the analysis of peculiarities of formation of dynamic structures in "living systems" (e.g. - school of fish) in the presence of factors external stochastic influence on the movement of a single "live particles".

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The structure and dynamics of topological defects in motile bacterial biofilms

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Abstract

Bacteria possess diverse systems for propelling themselves through their environment. Of these, the best studied is flagellar motility, in which cells rotate corkscrew shaped appendages to swim through liquids. However, the majority of bacteria live in dense, surface attached structures called biofilms where flagellar motility is ineffective. Biofilms are highly resistant to both disinfectants and antibiotics, and consequently are an important factor in the progression of many clinical infections. Within biofilms, many bacterial species use hair-like appendages known as Type IV Pili (TFP) to pull themselves across the surface they are attached to as though using microscopic grappling hooks. Here, we develop a controlled experimental system to study how the pathogenic bacterium *Pseudomonas aeruginosa* uses pilus-based motility to spread across surfaces. We find that these rod shaped cells rapidly form an active 2D monolayer that exhibits highly ordered nematic alignment, indicating that biofilms can form 'active fluid matter'.

We leverage automated, high resolution microscopy and novel image analysis techniques to resolve both the individual behavior of single cells and emergent large scale phenomena they collectively generate. We observe formation of topological defects within the 2D nematic of the monolayer and isolate the movement of individual cells around these defects, revealing complex flow patterns. Our experimental observations are found to closely match predictions from both an individual-based model and a continuum model based on the equations of nematohydrodynamics. These results suggest that biofilm bacteria have adapted to negotiate complex nematic environments and may offer us new tools to control biofilms by disrupting their ability to spread.

MASTERING THE WRINKLING OF SELF-SUPPORTED GRAPHENE

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Abstract

We present an approach that allows for the preparation of well-defined large arrays of graphene wrinkles with predictable geometry (Figure 1). In general, any topological defects in graphene, such as wrinkles, can effectively modify the intrinsic properties of graphene by varying the electrostatic potential of the layer. We created wrinkled graphene networks on hexagonal arrays of the SiO_2 nanopillars with different dimensions, varying pillar heights and inter-pillar distances. Chemical vapor deposition (CVD)-grown graphene transferred onto the pillar arrays forms a complex network of two main different types of wrinkle arrangements. The first type is composed of arrays of aligned equidistantly separated parallel wrinkles propagating over large distances, and originates from line interfaces in the graphene, such as thin, long wrinkles and graphene grain boundaries. The second type of wrinkle arrangement is formed by non-aligned short wrinkles, which are formed in areas without line interfaces. Apart from the presented hybrid graphene topography with distinct wrinkle geometries induced by the pre-patterned substrate, the graphene layers are suspended and self-supporting, exhibiting a large surface area and negligible doping effects from the substrate. All these properties make this wrinkled graphene candidate a material with enhanced chemical reactivity that is useful in nanoelectronic applications.

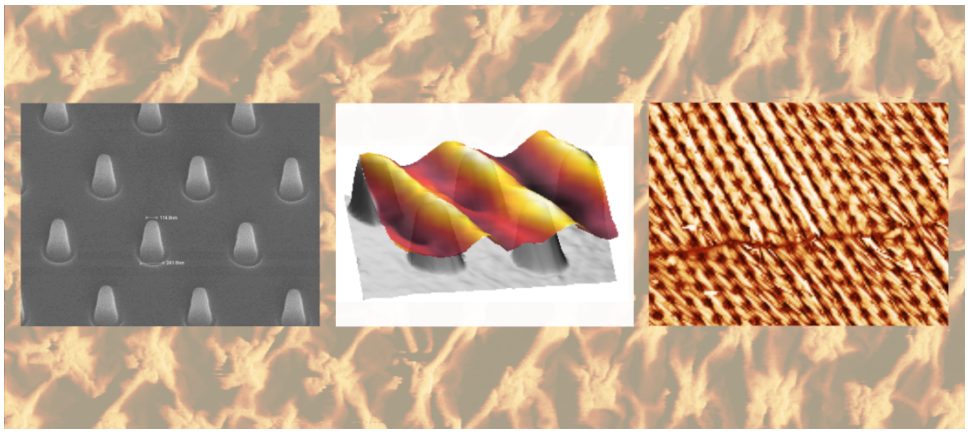

Figure 1: Visualization of the ordered wrinkle networks created on hexagonal nanopillar arrays. Left: SEM image of the typical hexagonally ordered nanopillars. Middle: 3D AFM image of the wrinkled graphene on the nanopillars. Right: AFM phase image of the typical aligned wrinkle network, with the wrinkles formed on the line defect.

FORMATION OF PRINTABLE GRANULAR AND COLLOIDAL CHAINS THROUGH CAPILLARY EFFECTS AND DIELECTROPHORESIS

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Abstract

One-dimensional conductive particle assembly holds promise for a variety of practical applications, in particular for a new generation of electronic devices. However, synthesis of such chains with programmable shapes outside a liquid environment has proven difficult. Here we report a route to simply "pull" flexible granular and colloidal chains out of a dispersion by combining field-directed assembly and capillary effects. These chains are automatically stabilized by liquid bridges formed between adjacent particles, without the need for continuous energy input or special particle functionalization. They can further be deposited onto any surface and form desired conductive patterns, potentially applicable to the manufacturing of simple electronic circuits. Various aspects of our route, including the role of particle size and the voltages needed, are studied in detail. Looking toward practical applications, we also present the possibility of two-dimensional writing, rapid solidification of chains, and methods to scale up chain production.

SYNERGETIC MODEL OF MIXING OF FIELDS TO DESCRIBE THE CRITICAL FLUID ENERGY AT DIFFERENT SPATIAL AND TEMPORAL SCALES, FUNDAMENTAL AND APPLIED ASPECTS

Ye.G. Rudnikov, A.D. Alekhin, V.I. Kovalchuk

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A new synergetic model [1] has been proposed for construction of the equations of state of substance near the critical point [2]. These equations join together the order parameter, entropy, and internal energy. They describe all limiting critical directions and it can be represented in a self-consistent manner in terms of any thermodynamic variables [3]. The equations have been formulated in the framework of the symmetric algebra of fluctuating variables that mixes the order field and the disorder field. Three-dimensional phase diagrams corresponding to their experimental behavior have been built for the fluctuation region. It should be noted that the anomalous (the most useful) properties of the critical fluid are the most pronounced in the fluctuation region! Unfortunately the current supercritical or subcritical fluid technologies work outside of the fluctuation region. Proposed equations allow us to develop the method of obtaining the critical fluid with predetermined parameters in the fluctuation region by adiabatic or isothermal expansion of the critical fluid to a fixed volume. The symmetric algebra of fluctuating quantities that mixes critical fields, associated with the Hamiltonian and the momentum of the flowing fluid, has been also proposed to describe the observed equilibration kinetics [4] of gravity effect near the critical point. Proposed approach can allow to predict the universal behavior of collective sensitive systems such as glue flowing, mountain avalanches moving, impact of ions or Laponite on critical behaviour, spreading of biological populations.

New models of mixing of critical fields allow to find relations between the energy characteristics of the system at the meso-scale (in universal manner it depends on the collective interactions of the molecules within the fluctuations of the order parameter) and at the macro level (mainly it depends on the individual properties of given substance). During going away from the critical point the correlation contribution to the internal energy of a separate fluctuation increases [2], while the total internal energy of macro-system depends on the limiting critical direction [1] of going away from the critical point on the three-dimensional phase diagrams. Proposed principle [1,3] of full consistency of thermodynamic variables and its kinetic analogue allow to analyze the topological features of the three-dimensional phase diagrams as well as to develop a geometric representation of thermodynamics [5] and mechanics near the critical point.

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STABILITY AND EARNSHAW'S THEOREM IN A VISCOUS FLUID

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Abstract

Earnshaw's Theorem is a classic result showing that arrangements of particles interacting via conservativeforces in a vacuum cannot be stable. However, there exist conditions under which two settling charged particles move through a non-inertial fluid may enter into an equilbrium which is asymptotically stable to pertubations.

This simple example shows that Earnshaw's Theorem does not hold in a fluid. These conditions are examined with an eye towards potential applications.

SELF-MIXING OF FLY LARVAE DURING FEEDING

Olga Shishkov, Christopher Johnson, Alexander Reyes, David L. Hu.

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Abstract

How do we sustainably feed a growing world population? One solution of increasing interest is the use of black solider fly larvae, pea-sized grubs envisioned to transform hundreds of tons of food waste into a sustainable protein source. Although startups across the world are raising these larvae, a physical understanding of how they should be raised and fed remains missing. In this study, we present experiments measuring their feeding rate as a function of number of larvae. We show that larger groups of larvae have greater mixing which entrains hungry larvae around the food, increasing feeding rate. Feeding of larvae thus differs from feeding of cattle or other livestock which exhibit less self-mixing.

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