

**The 4rd Polish-Slovenian  
International Seminar on Soft Matter  
2026 \_ ONLINE EDITION**

**BOOK  
of  
ABSTRACTS**

**EDITED by: Aleksandra Drozd-Rzoska and Samo Kralj**

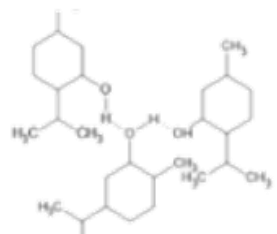
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26<sup>th</sup> - 27<sup>th</sup> January 2026  
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# 4<sup>th</sup> PSIS on Soft Matter

## “Faces of Soft Matter”

### 2026

It is with great pleasure that we had the honor of welcoming esteemed guests, researchers, faculty members, and students to our conference, the 4th PSIS on Soft Matter.

This 4th edition, entitled “Faces of Soft Matter,” marks an important milestone in the development of our Soft Matter community, which is an integral part of the broader research landscape.

The conference aims to integrate diverse theoretical and experimental approaches to address both endogenous and exogenous influences on soft matter systems and to identify emerging universal principles governing their behavior.

We are delighted to bring together leading experts and young researchers, creating a platform for inspiring discussions and fruitful collaborations. The PSIS on Soft Matter conference reflects our strong commitment to fostering a dynamic research environment that supports scientific exchange, scholarly growth, and intellectual exploration. It promotes an interdisciplinary perspective and stimulates new avenues of inquiry in the field.

Our invited and distinguished speakers include leading experts and internationally recognized specialists in the field of Soft Matter. The lectures cover a remarkably broad range of topics, illustrating that Soft Matter research spans physics, chemistry, biology, medicine, and even demography.

This Book of Abstracts provides an overview of the contributions presented at the Seminar and highlights the collaborative and interdisciplinary nature of the Soft Matter field.

Sincerely,

Directors of the 4th PSIS on Soft Matter

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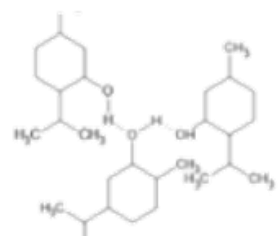
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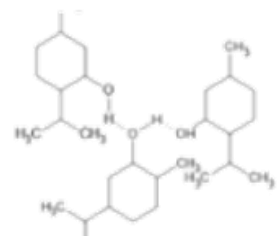
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Soft Matter

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# 4<sup>th</sup> PSIS on Soft Matter

## “Faces of Soft Matter”

### PROGRAMME

 SCIENTIFIC SESSIONS:



 YOUNG4SOFTMATTER DAY:



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# 1st DAY

## 26<sup>th</sup> January 2026

### SCHEDULE

#### OPENING LECTURE

#### SESSION I

- Liquid Crystalline Anisotropic Soft Matter?

#### SESSION II

- Soft Materials & Phase Transitions

#### SESSION III

- Bridging Soft Matter & Materials Physics

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# OPENING LECTURE

✪ Ewa GÓRECKA \_ POLAND

## SESSION I

✪ Uroš TKALEC \_ SLOVENIA

✪ Alenka MERTELJ \_ SLOVENIA

✪ Przemysław KULA \_ POLAND

✪ Samo KRALJ \_ SLOVENIA

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## OPENING LECTURE

### Helical or/and Polar Structures

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**Abstract:** One of the most intriguing phenomena in liquid crystals is the spontaneous breaking mirror symmetry, leading to local chirality of structure and spontaneous ordering of electric dipoles that is referred to as ferroelectricity. Ferroelectric properties in liquid crystalline phases were first discovered in the 1970s and, for two decades, were believed to be intrinsically linked to molecular chirality. The emergence of long-range dipole order in smectic layers was attributed to the absence of inversion symmetry elements in systems composed of chiral molecules. The discovery of ferroelectricity for achiral, bent-core molecules introduced a new perspective on the relationship between polarity and chirality. In these systems, polarization arises due to steric constraints that restrict molecular rotation. Interestingly, in such systems the polarization vector, in combination with the tilt direction and the layer normal, defines either a left- or right- handed coordinate system—leading to spontaneous emergence of structural chirality, even though the constituent molecules themselves are achiral. This finding demonstrated that although the molecular chirality is not a prerequisite for ferroelectricity in liquid crystals, a connection between ferroelectricity and chirality persists.

A major breakthrough came with the discovery of proper ferroelectricity in the least-ordered liquid crystalline phase—the nematic NF phase - and subsequently in certain smectic phases as well. For strongly polar molecules, with dipoles moment  $>10D$ , dipole-dipole interactions alone could give rise to ferroelectric order. For a time, it appeared that in proper ferroelectric liquid crystals chirality and ferroelectricity were independent phenomena. However, in 2024, a pivotal discovery revealed that helicity can also emerge spontaneously as a mechanism to minimize macroscopic polarization - once again linking chirality and ferroelectricity. This finding reestablishes connection between the polar order and chirality, helical structures can be induced purely through electrostatic interactions in achiral, strongly polar systems.

In this context, the properties of helical nematic and smectic phases formed by achiral but strongly polar mesogenic molecules will be discussed, as well as the complexities introduced by molecular chirality. Both basic and advanced experimental techniques used to probe the structure and polar properties of these phases will be presented, including non-resonant and resonant X-ray diffraction, optical and atomic force microscopy (AFM), dielectric spectroscopy, and more.

Acknowledgments: This work was funded by NCN UMO-2024/53/B/ST5/03275

**Keywords:** liquid crystals; helical structure; spontaneous ordering

#### References:

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- [2] Mandle, R. J., Cowling, S. J., & Goodby, J. W. (2017). A nematic to twist-bend nematic phase transition in cyano-biphenyl dimers. *Physical Chemistry Chemical Physics*, 19, 11429–11435. <https://doi.org/10.1039/C7CP01570H>
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## Microhydrodynamics of Nematic Liquid Crystals

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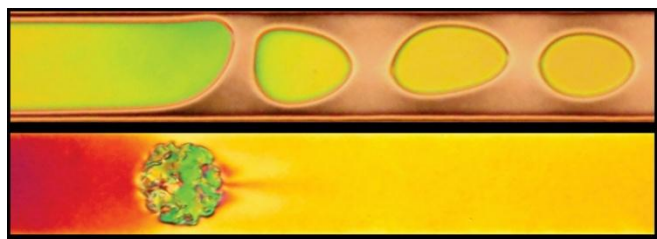
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**Abstract:** The rheology of simple fluids has been studied in detail since the 19th century and continues to play a central role in physics and engineering. In contrast, complex fluids, which exhibit properties such as viscoelasticity, spatial inhomogeneity, anisotropy and chirality, pose additional challenges and their flow behavior is still not fully understood. In this framework, we experimentally investigate the pressure-driven flow of achiral and chiral nematic liquid crystals in rectangular microchannels with homeotropic surface anchoring, supported by theoretical analyses and numerical simulations. We show that the structural organization of nonequilibrium nematic fluids within microfluidic geometries is strongly influenced by the coupling between orientational order and hydrodynamic flow. The flow profile can be fine tuned by external pressure modulation, channel geometry, and, in combination with laser tweezers, allows precise control over the formation and stabilization of homogeneous and chiral domains. We also demonstrate the formation of intermediate structures with chiral features that can arise prior to the transition from homeotropic alignment to flow-induced ordering. Furthermore, we investigate how chiral states can be manipulated by variations in channel geometry, flow rate, and the introduction of a chiral dopant. The presence of chirality favors helical organization, that competes with the aligning effects of shear flow. This competition leads to a wide range of orientational states and a complex interplay between domains and domain walls. We quantify the resulting phase behavior as a function of flow velocity and characterize the orientational structures that can be induced and stabilized by flow in chiral nematic systems.



**Keywords:** liquid crystals; microfluidics; topological defects; fluid dynamics

### References:

- [1] Emeršič, T., Zhang, R., Kos, Ž., Čopar, S., Osterman, N., de Pablo, J. J., & Tkalec, U. (2019). Sculpting stable structures in pure liquids. *Science Advances*, 5(2), eaav4283. doi:10.1126/sciadv.aav4283
- [2] Čopar, S., Kos, Ž., Emeršič, T., & Tkalec, U. (2020). Microfluidic control over topological states in channel-confined nematic flows. *Nature Communications*, 11(1), 59. doi:10.1038/s41467-019-13789-9
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## The Interplay Between Flexoelectricity and Electrostatic Effects in Antiferroelectric Nematic Liquids

Alenka Mertelj<sup>1\*</sup>, P. M. Rupnik<sup>1,2</sup>, E. Hanžel<sup>1,2</sup>, N. Sebastián<sup>1</sup>, A. Sterle<sup>1,2</sup>, M. Lovšin<sup>1,2</sup>, N. Osterman<sup>1,2</sup>, R. Mandle<sup>3,4</sup>, C. J. Gibb<sup>3,4</sup>, J. Hobbs<sup>3,4</sup>

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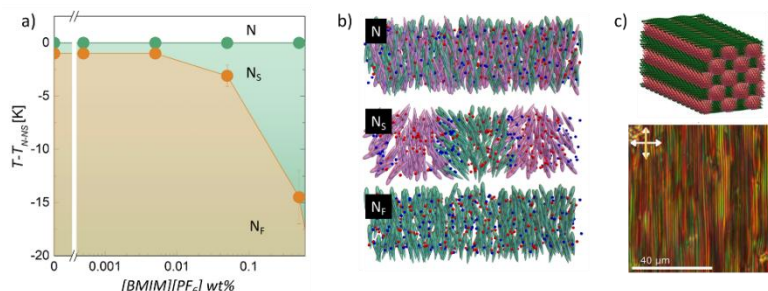
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**Abstract:** The interplay between flexoelectricity and electrostatic effects strongly influences the phase behavior and morphology of ferroelectric nematic liquids. This interplay can be systematically studied by introducing free ions into the system, which screen local electric fields. We used this approach to elucidate the structure and formation mechanisms of the antiferroelectric phase, for which flexoelectric and electrostatic effects were proposed as competing mechanisms. We demonstrated that flexoelectric coupling between electric polarization and the director splay deformation plays a primary role in the emergence of antiferroelectric order. The addition of ions significantly expands the temperature range over which the antiferroelectric phase is observed, with the range increasing as the ion concentration increases. Optical experiments revealed a two-dimensional modulation of the splayed antiferroelectric structure. The model previously used to describe pretransitional behavior was extended by incorporating the electrostatic contribution of ions. This revised model shows qualitative agreement with experimental results, reproducing both the phase diagram and the temperature-dependent evolution of the modulation period of the observed structure.



**Figure:** a) Phase diagram of the RM734 and ionic liquid [BMIM][PF6] mixture. b) Schematics of nematic (N), antiferroelectric splay nematic ( $N_S$ ), and ferroelectric nematic ( $N_F$ ) phases of the mixtures. Red and blue dots depict ions redistributing in the  $N_S$  phase to screen local fields. c) Schematic and POM image of the 2D  $N_S$  phase.

**Acknowledgments:** This work was supported by ARIS (grant no. P1-0192 and J1-50004) and UKRI via a Future Leaders Fellowship, grant no. MR/W006391/1. The ferroelectric nematic liquid crystal FNLC-1571 also used in this work was supplied by Merck Electronics KGaA.

**Keywords:** nematic phase; liquid crystals

### References

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## From Dual Frequency Nematics to Ferroelectric Twist-Bend Nematics - the Short Story

Przemysław Kula<sup>1\*</sup>, J. Karcz<sup>1</sup>, N. Rychłowicz<sup>1</sup>, D. Węglowska<sup>1</sup>, J. Herman<sup>1</sup>

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**Abstract:** The concept of the nematic phase dates back almost to the beginning of the history of liquid crystals, in 1916 Max Born, based on his attempts to apply mathematical methods to describe liquid crystal theories, speculated that a polar liquid could exist if the dipoles of the components are large enough so that the dipole-dipole interactions between them could overcome the thermal fluctuations. For over a century, Born's theory remained in the sphere of historical curiosities, until 2017, when two research groups demonstrated the existence of a new phase of  $N_F$ , for the compounds DIO and RM734. This phase shows a symmetry breaking resulting in director  $\mathbf{n}$  being different from  $-\mathbf{n}$ . Another important discovery among new nematic phases is the chiral heliconical  $N_{TB}$  phase, which is most often exhibited by bimesogenic compounds, and whose model compound is CB7CB and odd  $CBnCB$  homologues. This lecture will present the development from early compounds exhibiting a nematic monotropic ferroelectric phase from the dual frequency originated families, through compounds with the enantiotropic  $N_F$  phase, to the latest discovery of compounds exhibiting a twist bend ferroelectric phase  $N_{TBF}$ , which is a chiral polar phase, from the point of view of molecular structure evolution and the formation of complex heliconical and polar phases.

**Keywords:** nematic phase; liquid crystals; twist-bend ferroelectric phase

### References:

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## Chargeless Nematic Line Defects

**Samo Kralj**<sup>1,2,3</sup>

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**Abstract:** Topological defects (TDs) appear in all systems reached via a symmetry breaking phase transition and are consequently observed at all physical scales, including particle physics, condensed matter and even cosmology. Liquid crystals (LCs) are particularly adequate media to study TDs because they exhibit a rich variety of qualitatively different TDs and in them defects could be relatively easily experimentally observed, e.g., using polarizing microscopy. Of particular recent interest are the so-called twist disclinations in nematic LCs which do not carry the 3D topological charge, however, have nonzero 2D charge. Therefore, in 3D they are not topologically stable. Thus, in ordinary conditions they vanish soon after their creation. However, one can stabilize them energetically by imposing appropriate local orientational frustrations.

In the lecture I will present basic properties of twist disclinations and general conditions via which they can be stabilized. Furthermore, I will demonstrate their importance from the perspective of basic physics (they might be analogues of the intriguing neutrinos in particle physics) and applications (they could be exploited as reconfigurable paths for controlled transport of appropriate nanoparticles).

**Keywords:** liquid crystals; phase transitions; topological defects; disclinations

### References:

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## SESSION II

✂ Wojciech ZAJĄC \_ POLAND

✂ Venkata S. R. JAMPANI \_ SLOVENIA

✂ Eva KLEMENCIC \_ SLOVENIA

✂ Brigita ROŽIČ \_ SLOVENIA

## SESSION III

✂ Alexander R. UMANTSEV \_ USA

✂ Ramón CASTAÑEDA-PRIEGO \_ MEXICO

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## Soft Matter Characterisation via Routine and Advanced Neutron Scattering

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**Abstract:** The term *soft matter*, coined in the 1970's, and made popular by Pierre-Gilles de Gennes in his 1991 Nobel Prize lecture, once referred to complex systems like polymers, gels, liquid crystals, etc. exhibiting a common feature of large values taken on by the relevant response functions. Nowadays, *soft matter* encapsulates an almost unlimited wealth of materials, including surfactants, microemulsions, colloids, micelles, many nanoparticles, and even some quasicrystalline matter, biological systems, to name just a few, all sharing some collective attributes, such as weak stress/large strain (small elastic modulus), easily relaxable stress, viscoelasticity, etc., all being commonly referred to as *softness*. Rarely are they 100% amorphous, often exhibiting short-range order, and self-assembly phenomena leading to the onset of hierarchical structures or superstructures are not uncommon.

In-depth characterisation of such materials requires a variety of complementary research methods, among which neutron scattering (NS) offers an extremely powerful and versatile suite of experimental techniques. Perhaps the most straightforward would be neutron radiography and tomography, often coupled with complementary X-ray attenuation methods (even within the same experimental set-up, as on NEXT at ILL), routinely used nowadays e.g. to study *in situ* real-time processes in materials for energy storage. Neutrons of wavelengths of the order of interatomic distances have energies comparable to those of internal vibrations. Being non-destructive and highly penetrating, they can deliver structure- and dynamics-related information from the whole sample, not just its surface. The study of residual strain/stress, or characterisation of deeply buried surfaces or interfaces in neutron reflectometry are good examples. Neutron scattering cross sections (coherent and incoherent) vary from isotope to isotope, making NS sensitive to light atoms (hydrogen in particular). Moreover, isotopic substitution (e.g. H/D) opens the field of contrast variation, for example in small-angle scattering (SANS) and reflectometry. Neutron is a fermion, whose spin itself is a very powerful research probe. Not only do I mean the study of magnetic structures, including diffraction, reflection or SANS, but also the application of polarisation analysis in diffuse scattering experiments of polarised beams (separation of coherent and incoherent scattering possible) now accessible on D007 at ILL, LET at ISIS, and soon on SHERPA spectrometer, also at ISIS; as well as slow dynamics investigated by Larmor precession techniques (Spin Echo).

**Keywords:** soft matter; neutron scattering

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## Self-Shaping Liquid Crystals

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**Abstract:** Liquids attain their equilibrium shape due to surface tension. In recent years, the minimized spherical surface dictated by the interfacial tension of simple oils suspended in surfactants has evolved into vivid non-spherical structures. In particular, partially ordered liquids—liquid crystals (LCs)—possess bulk elasticity, and the shape transformation of LC droplets into fibers using binary mixtures was first reported two decades ago. The effort to control LC droplet shape effectively continues to use specially synthesized surfactants fluorinated LCs, and polydispersed oligomers to date. Although it is not clear specifically how the nanoscale interfacial dynamics contribute to the shape transformation, each reported system stands out for its unique ability to transform LC droplets. So far, no reliable method works for arbitrary LC compounds and phases.

In this talk, I present our work on transforming LC droplets into spectacular, uniform-diameter curved fibers by balancing LC bulk elasticity and interfacial energy. Our approach to this problem applies to any LC material and phase. In detail, we used a surfactant, a co-surfactant dispersed in the aqueous medium, and an LC material, respectively, to achieve self-shaping under external thermal stimuli. Further, the tuning of the LC elastic constants with the temperature drives the LC droplet into controllable fiber diameters with branches and back reversibly (Fig.1). In addition, the nematic to SmA LC phase transition drives the fiber structures into monodispersed micro-droplets with a tunable diameter dictated by the cooling rate. The extension of the self-shaping phenomenon in the SmC phase opens the route to generate helical fibers with an equal probability of right and left-handed helices. Moreover, the SmC\* phase exhibits life-like self-shaping LC shell structures analogous to biomembranes in living systems.



Fig.1 Self-shaping CCN37 LC droplet is taken at 28°C.

**Keywords:** self-shaping LC; liquid crystals

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## Phase Transitions and Giant Caloric Effects in Anisotropic Soft Materials

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**Abstract:** Caloric effects, reversible temperature changes induced by external fields under adiabatic conditions, provide a promising route toward solid-state and soft-matter-based thermal management. While traditionally explored in ferroic materials, recent studies reveal that anisotropic soft matter can exhibit large caloric responses due to its entropy-dominated free energy landscape and strong coupling between external fields and internal degrees of freedom. In contrast to crystalline solids, soft materials offer enhanced susceptibility, tunability, and mechanical compliance, making them attractive for miniaturized and energy-efficient thermal devices.

Our focus is on electrocaloric and elastocaloric effects in thermotropic liquid crystals and liquid-crystalline elastomers. These systems undergo symmetry-breaking phase transitions between isotropic, nematic, and smectic phases, enabling efficient entropy transfer between orientational, translational, and lattice contributions. Using a Landau–de Gennes-type theoretical description, external electric fields and mechanical stresses act as effective ordering fields, reshaping phase behavior, shifting transition temperatures, and modifying the character of phase transitions.

We show that large caloric temperature changes are governed primarily by latent heat and discontinuous ordering, rather than by critical fluctuations alone. In particular, direct isotropic–smectic transitions in liquid crystals and stress-driven nematic ordering in elastomers generate giant caloric responses due to the large associated entropy change. These findings are supported by theoretical analyses and high-resolution calorimetric experiments, highlighting the unique potential of anisotropic soft matter for controllable thermal functionality.

**Keywords:** electrocaloric; elastocaloric; liquid crystals; phase transitions

### References:

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## Caloric Materials for New Heat-Management Technologies

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**Abstract:** Caloric effects manifest in the heating or cooling of a caloric material due to the application or removal of the external field under nearly adiabatic conditions. With increased environmental awareness, the search for an environmentally friendlier heat-management device has been the topic of many scientific studies. Materials with large caloric effects, such as the electrocaloric (EC) and elastocaloric (eC) effects, have the promise of realizing new solid-state refrigeration techniques. A review of recent direct measurements of the large eC effect in liquid crystal elastomers (LCEs) will be given in this contribution, including the application aspect. In particular, the eC in main-chain (MC) LCEs exceeds 2K, with the eC responsivity about three orders of magnitude larger than the average eC responsivity found in the best shape memory alloys. However, this soft material can play a significant role as active cooling elements and parts of thermal diodes or regeneration material in developing new cooling devices.

**Keywords:** caloric effect; soft matter; refrigeration techniques

### References:

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## Thermodynamic Theory of Dislocation-Mediated Plasticity

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**Abstract:** Motion of dislocations is a common mechanism of plasticity in many materials. Dislocation mediated deformation is essentially an inhomogeneous process, which is manifest in formation of persistent slip bands and complicated subgrain structures. Adiabatic shear bands, that is, high local temperature increases, characterize thermal properties of dislocation plasticity. Acoustic emissions and stress bursts turned out to be integral parts of this mechanism also. Adequate description of these processes is an important goal of Materials Theory, which aims to describe mechanical properties of materials and their reliability in service.

In this presentation, I will introduce a novel approach to dislocation plasticity capable of describing these processes, derive an equation of dislocation dynamics, and discuss computational experiments intended to model these modes of deformation in samples of various makeup and sizes. It turns out that the dislocation slip-line and cell-wall structures appear in the theory as ordinary solutions of the equilibrium equations without any arbitrary assumptions; adiabatic shear banding is related to plastic work and latent energy of the specimen; and the acoustic emission events and stress bursts self-organize into the dislocation avalanches, which propagate at a speed determined by the conditions of loading. In the compressive creep experiments the avalanches arrange into slow moving slip bands while in the shock compression experiments the avalanches move faster than sound.

**Keywords:** plasticity; dislocations; mechanical properties

**References:**

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## Depletion Forces Beyond the Diluted Limit

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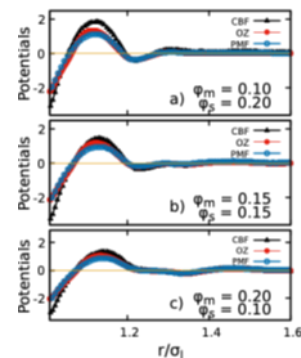
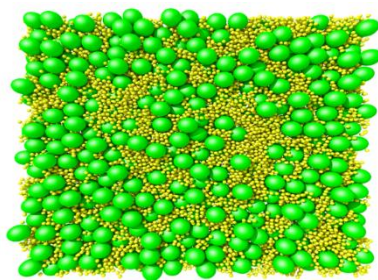
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**Abstract:** We show a detailed study of the effective depletion potentials in colloidal mixtures at finite concentration. We explicitly demonstrate that a new physical formalism, which allows determining the effective forces by contracting the description of colloidal systems at the level of bare forces, here referred to as the contraction of the bare forces (CBF), provides an accurate route to get the depletion forces between large colloids. The physical consistency of the results obtained through the CBF scheme is verified in bidimensional systems of binary and ternary mixtures of disks. As further proof of the feasibility of the CBF algorithm, we show that in the diluted limit of large particles, the effective potential reproduces the AO-Vrij limit. Subsequently, we show a study of the effective potentials in tridimensional systems of mixtures of spherical colloidal particles, in this case, the results obtained with the CBF algorithm are compared with the potential of mean force and with effective potentials obtained through the theory of integral equations; the results show that the CBF approach is more efficient and accurately determines the depletion interactions. We also show a new colloidal stability mechanism based on the use of two different species of depletant agents at low and equal concentrations. A very important result is the way in which the effective potential between large particles depends on their concentration and that this dependence can be eliminated when we keep the chemical potential of small particles fixed as large particles are added. Finally, we show once again the versatility of the CBF approach by studying the effects generated by polydispersity on the effective potential and when a temperature protocol is introduced to estimate the evolution of the depletion forces towards thermodynamic equilibrium.



**Keywords:** depletion forces; entropic potential; binary mixtures; molecular dynamics

### References:

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## 2nd DAY

### 27<sup>th</sup> January 2026

## SCHEDULE

### OPENING LECTURE

#### SESSION IV

- Specific Complexity in Soft Materials

#### SESSION V

- Biological & Living Soft Matter

#### SESSION VI

- Population Growth & Soft Matter Dynamics

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Soft Matter

# OPENING LECTURE

✦ Aleš IGLIČ \_ SLOVENIA

## SESSION IV

✦ Atsushi YOSHIZAWA \_ JAPAN

✦ Blaž ŠVAJGER \_ SLOVENIA

✦ Andreja JELEN \_ SLOVENIA

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## OPENING LECTURE

### Orientational Ordering of Water Molecules and Ions in Electric Double Layer

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**Abstract:** Electric double layer is described within a mean-field lattice statistics approach by taking into account the asymmetry in the size of ions and the orientational ordering of water molecules. Analytical expressions for the space dependence of ions and water molecules and relative permittivity are derived. It is shown that due to orientational ordering of the water dipoles near the charged surface the relative permittivity is locally strongly decreased. Asymmetric camel-like shape of the voltage dependence of the differential capacitance is also predicted within the model. Bikerman-Wicke-Eigen model of electric double layer is derived as a limit case of the presented more general model of electric double layer.

**Keywords:** Bikerman-Wicke-Eigen model; orientational ordering

#### References:

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## The Formation of Supramolecular Chiral Materials from Achiral Molecules Using a Liquid-Crystalline System

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**Abstract:** Recently, the formation of chiral materials by self-organization of achiral small molecules has attracted much attention. Interesting approaches, for example, mechanical rotation, circularly polarized light, and asymmetric solvent, have been performed. They require external asymmetric stimuli. On the other hand, mirror symmetry breaking has been observed in achiral liquid crystals. But it cannot produce homochirality. I show the following approach to produce chiral materials without a chiral source. The spontaneous mirror symmetry breaking induces supramolecular chirality in the soft crystalline dark chiral conglomerate (DC) phase. Two kinds of domains with opposite twist senses exist in non-equal population. The dominant chiral domains are amplified to produce a homochiral state. The chirality is transferred to a polymer film in the course of polymerization of achiral monomers by using the homochiral state as a template. Finally, we discuss how this chiral transfer system relates to the origin of homochirality in life.

**Keywords:** liquid crystals; supramolecular chirality; mirror symmetry breaking; chirality transfer

### References:

- [1] Niu, X.; Zhao, R.; Yan, S.; Pang, Z.; Li, H.; Yang, X.; Wang, K. Chiral materials: Progress, applications, and prospects. *Small* 2023, 19, 2303059.
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## Geometry and Field Dependent Percolation of Anisotropic Particles

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**Abstract:** We study the phase transition in a liquid crystal (LC) where we add conductive nanoparticles (NP). By adding a sufficient volume of conductive NP, the system becomes conductive. To reduce the relative volume share of the NP we use an external electric field to induce order. This allows a smaller relative volume of NP to induce a conductive phase of the LC. To simulate, we use a simulation that adds particles in a box until the sides perpendicular to the z-axis are connected by NP and therefore conductive. The particles we use are rounded cuboids. Simulating the ordering effect of the external electric field are the limitations in the orientation of the NP. The stronger the ordering effect the smaller the angle of deviation of NP vectors from the base vectors.

We apply this to transistors where we study the adiabatic process. As the entropy is affected by temperature and the order of NP. Using an external field to induce a phase change. By changing the phase, we change the entropy of the system. In an adiabatic process the total change in entropy must be zero thus a change in entropy because of orientational ordering of NP leads to an opposite change in entropy dependent on temperature as the temperature of the system changes to compensate. By doing this process we can quickly change the temperature by influencing the NP with an external ordering field. However, the problem that can arise is that by changing the temperature we can induce a second thermotropic phase transition that transforms the system in a nonconductive state.

**Keywords:** liquid crystal; phase transition; percolation; transistors

### References:

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## Patterns and Complexity in High-Entropy Alloys

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**Abstract:** Being a microscopist and spending a lot of time observing different specimens, sometimes we observe the shapes of our investigated material that can easily be associated with the known objects in our everyday life. In this contribution, I will present three different complex metallic materials – two of them are high-entropy alloys and one is intermetallic compound. They are designed for different purposes, having various physical properties, but all of them exhibiting the shape of the heart.

High-entropy alloys (HEAs) represent novel metals-based materials with complicated microstructures, where at least five different chemical elements, all in majority concentrations, are mixed on a simple crystal lattice. Likewise, the materials are usually comprised of more than one phase on different microscopic levels, ranging from a few nm to 1 mm. Intermetallic compounds were proven to be attractive alternatives to pure and alloyed metals as catalyst materials in heterogeneous catalysis because of their increased selectivity to specific reactions and better long-term stability.

Our Slovenian High-Entropy Alloys (HEAs) research group at the Solid State Physics Department has been investigating HEAs over the last 12 years. In that time, many findings have been solved regarding structure – magnetic properties relationships. It has been revealed that magnetism of the constituent elements plays a role in organizing the atomic, nano- and micro-structure into the specific patterns. Those patterns in return dictate the magnetic properties of the bulk material. Furthermore, those patterns caused attention by current developments in theoretical physics of structural complexity – discovering the basic natural lawfulness of our planet. SEM images of a) Ga<sub>3</sub>Ni<sub>2</sub> intermetallic compound, b) TiZrHfSnFe superconducting HEA and c) ScTiHfTa refractory HEA.



**Keywords:** complexity; scanning electron microscopy; magnetic properties; high-entropy alloys

### References:

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## SESSION V

✂ Kazimierz ORZECOWSKI \_ POLAND

✂ Veronika KRALJ-IGLIČ \_ SLOVENIA

✂ Victor TEBOUL, Quoc T. Truong \_ FRANCE

## SESSION VI

✂ Alessio ZACCONE \_ ITALY

✂ Aleksandra DROZD-RZOSKA \_ POLAND

## CLOSING LECTURE

🕒 Sylwester Janusz RZOSKA \_ POLAND

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## Dielectric Probe in Intraoperative Breast Cancer Detection

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✦ I am applying for **Bruker Customer Excellence Award** (see Bruker Awards Guideline at [eucmos2025.uwr.edu.pl](http://eucmos2025.uwr.edu.pl))

**Abstract:** I will present a method designed to verify the presence or absence of cancerous tissue at surgical margins during breast cancer surgery — commonly referred to as the "clean margins" issue. The technique involves measuring the dielectric properties of breast tissue removed from the operative site. Significant differences between cancerous and normal breast tissue have been recognized since the 1930s. However, only recently have we resolved the challenges associated with conducting dielectric measurements in the long-wavelength (LW) range in the presence of highly conductive biological fluids such as blood and lymph.

I will present both the physical principles and clinical results supporting this method. An intraoperative breast cancer detection probe has been developed and patented, and a startup company, *Onco Scanner Ltd*, has been established to bring this innovation to clinical practice.

**Keywords:** breast cancer; biological fluids; dielectric measurements

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## Mechanisms of Formation of Extracellular Particles: Vesiculation, Fragmentation and Extracellular Assembly

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**Abstract:** Acknowledged mechanisms of extracellular vesicles formation are microvesiculation of the plasma membrane, formation of exosomes in the internal compartments, which are then expelled from the cell and fragmentation during the apoptosis. In order to assess the extracellular vesicles in the samples, isolation procedure is usually applied. These procedures induce thermal and mechanical stress on the cells which may cause further fragmentation. Extracellular particles may be observed in isolates, but also directly in cultures. Besides the above listed mechanisms, nanoparticles can form also subject to self assembly of molecules in the outer solution of the cell. In particular, microalgae may due to some external stimuli expel phosphates which form spherical extracellular particles in the outer solution.

Different mechanisms of extracellular particle formation will be described in the lecture. Experimental evidences imaged with electronic microscopes will be presented. As regards membrane-enclosed extracellular vesicles, shape transformations leading to membrane budding and vesiculation will be presented.

**Keywords:** extracellular particles; vesiculation; extracellular assembly; cell membrane dynamics

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## Dynamic Phase Transition in Soft Active Matter

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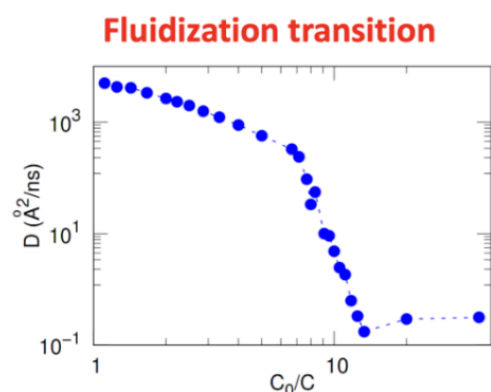
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**Abstract:** Mediums that contain particles able to move by themselves like synthetic molecular motors, or motor proteins in living organisms are called actives. Active matter has attracted large interest due to its connection to biology and out of equilibrium statistical physics. It was mainly introduced as a physical model to study living matter. Active molecules were found to be able to induce the fluidization of a soft material, a behavior also found in living organisms like bacteria, while in other conditions active molecules have the opposite effect.

Using molecular dynamics simulations, we study this fluidization transition using a model system and extend our investigation to sluggish water at low temperature, a medium that has similarities with water confined inside cells. We find that a few active molecules are able to trigger a dynamic fluidization transition in both mediums. We interpret the transition as due to an aggregation of the excitations induced by facilitation mechanisms, leading to the fluidization of the whole medium. Water's complexity due to hydrogen bonding and poly-amorphism, leads then to a transition between the low temperature phases of water. We observe that the fluidization transition

promotes the high-density liquid phase even at very low temperature, leading to an induced liquid-liquid structural phase transition between low and high-density water. As low-density liquid water is a precursor of ice, we expect this transition to hinder crystallization in supercooled water, leading to a new route for cryopreservation of biomaterials.



**Keywords:** extracellular particles; vesiculation; extracellular assembly; cell membrane dynamics

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## Random Sphere Packings: Finding Solutions, from Structure to Mechanical Deformations

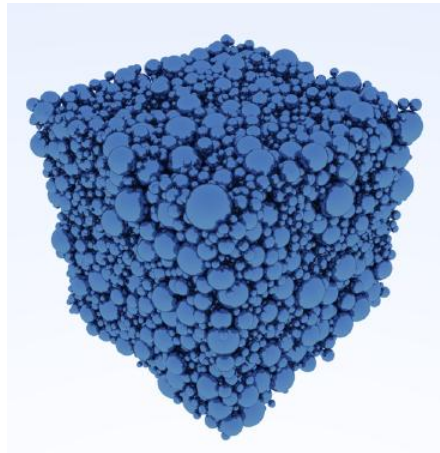
**Alessio Zaccone**

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**Abstract:** I will discuss recent theoretical approaches to determine the densest disordered packings of spheres in 3D and 2D, including experimentally important effects such as particle size polydispersity. The main concept is that disordered hard sphere systems can be densified in an amorphous fashion up to the point at which the system becomes rigid. Like the random close packing fraction, also the shear modulus can be described theoretically in a fully analytical way in quantitative agreement with numerical simulations, provided that one duly takes subtle non-affine particle rearrangements into account. Finally, I will show that the same concept of non-affine displacements leads to the identification and discovery of topological-like defects in glasses, which are similar (but by no means the same!) to dislocations in crystals.



**Keywords:** hard spheres; jamming; elasticity; soft materials; topological defects; theory

**References:**

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## Complex Systems Perspective on Population Growth: New Scaling Framework

**Aleksandra Drozd-Rzoska**

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**Abstract:** The lecture presents a new concept for portraying Global Population changes over a 12,000-year period, since the Holocene onset, based on scaling relations from the analysis of complex Soft Matter systems. In particular, new relations that extend the standard exponential Malthusian model are considered. They have been termed the Super-Malthusian scaling. It includes the empowered exponential relation, in the 'stretched exponential' and 'compressed exponential' versions. Such modelling evokes characterizations recalling the Glass Transition topic. Alternatively, the prevalence of simple critical-like behaviour is also demonstrated.

A unique new feature of this modelling, compared to previously dominant concepts, is the limitation to only three fitted parameters and the avoidance of nonlinear fitting, which always qualitatively increases the uncertainty of the results, despite 'apparently fair' reproduction of empirical characteristics. It was also achieved through a unique 'inverse analysis' that first focuses on the experimental data themselves to determine the extent to which a given model can be applied. The next step involves a straightforward linear-regression-based fit that yields optimal values for all relevant parameters, along with their errors. Previous research exploring this model-concept is available in the reports below.

Acknowledgements: This research was supported by the National Science Centre (NCN) through grant OPUS-23 no. 2022/45/B/ST5/04005.

**Keywords:** global population, glass transition, critical-like behaviour, population dynamics, carrying capacity

**References:**

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## CLOSING LECTURE

### Soft Matter Under Compression – the New Philosopher's Stone

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**Abstract:** For centuries, the alchemists' dream was to transform low-value metals or even stones into precious ores, such as e.g., gold. Today, such a role seems to be played by the application of high pressures. The *Holy Grail* of such searches is obtaining metallic hydrogen, which could revolutionize our civilization. However, despite reports announcing success, this remains an unachieved goal – and requires pressures and temperatures higher than those in Earth's core. Such conditions also imply working in micro- or milligram amounts, and, after decompression, the return to the 'ambient basic state' occurs. Therefore, the experimental evidence for the existence of an 'exotic' state of matter is only the beginning of decades of research aimed at recovering it in large quantities under controlled conditions.

Studies in IHPP PAS follow a different path, focusing on Soft Matter where pressures below 1 GPa are sufficient for the 'exotic transformation'. It makes it possible to compress in HPP PAS high-pressure processors with chamber volumes up to 50. In this way, IHPP obtained, for example, high-pressure-processed (HPP) human milk that retains its native quality even after 2 weeks of storage in an ordinary refrigerator. Also, even 200% amplification of the bioactivity of immunoglobulins or leptins is possible. These are HPP foods, with the qualities of fresh products, lasting for months. It is also food pickling shortened to minutes in time. On the other hand, it means innovative glass for displays with a super-hard surface or "glass" amorphous cathodes for innovative batteries with high electric conductivity "formed" by compressing. In any case, these remarkable and important application properties are retained after decompression, and the existing plants at IHPP PAS enable pilot-scale processing.

**Acknowledgements:** This research was supported by the National Science Centre (NCN) through grant OPUS-23 no. 2022/45/B/ST5/04005.

**Keywords:** soft matter; high-pressure processors; decompression

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## 3rd DAY

# Young4SoftMatter DAY

## SCHEDULE



## OPENING LECTURE



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## OPENING LECTURE

### Nature, Foods, Cosmetics & Soft Matter. Supercritical Properties of Linseed Oil as Revealed from High Pressure & Temperature Studies

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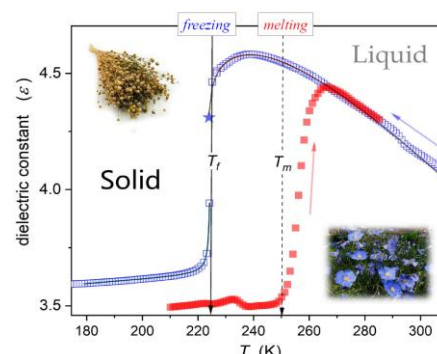


**Abstract:** Linseed oil offers many health benefits and is also used in cosmetics as a softener, with these properties linked to its unique composition. Here, a new factor– supercriticality, previously omitted, that can yield and/or support extraordinary properties, is evidenced. It has been discovered via dielectric constant scans that revealed great pretransitional changes, following the pattern characteristic for supercritical phenomena. It is shown in the Figure on cooling. Notably, the freezing temperature is reached regardless of the cooling rate, which further supports the hypothesis of the dominance of collective critical-type fluctuations. Worth stressing is the extension of the critical-like pattern to the solid phase, as the unique critical post-freezing effect.

The impact of critical-type features also extends to dynamic properties, such as diffusion or the coupled primary relaxation time. It is validated by the optimal model-portrayal via the 'Activated & Critical' relation, introduced earlier by the author of this presentation for modeling previtreous dynamics of glass formers. The uniqueness of supercriticality in linseed oil can also be attributed to significant changes in the dissipation factor, indicating a possible degree of energy conversion processes.

The presented studies employed high-resolution broadband dielectric measurements at temperatures between 120 K and 330 K, supplemented by high-pressure tests up to  $P \sim 0.9$  GPa.

Recalling unique properties of the supercritical domain which is often indicated as a new & exceptional state, a question arises if exceptional linseed oil features are not also driven by this phenomenon. This finding can also be important for applications of linseed oil as an ecological cooling agent in certain technological facilities, opening a new avenue for a substantial increase in process effectiveness.



**Keywords:** linseed oil; glass formers; supercritical phenomena

#### References:

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## Global Population, Carrying Capacity, and High Quality Foods

**Agata Angelika Sojecka**

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**Abstract:** In 1927, Pearl introduced the concept of Carrying Capacity (CC) to describe the resources necessary to a population evolving in a given system. This concept arose from an attempt to implement Verhulst's scaling relation to describe changes in biological populations, the US population, and the global population. In the latter case, the problem was the very limited reference data available at the time. In recent decades, CC has become one of the fundamental metrics for the concept of Sustainable Civilization, now seen as a necessity in the face of global environmental threats.

This lecture addresses the considerable ambiguity in attempts to define global CC, due to its broad and variable scope across cultures and time. It is suggested that CC research should instead follow the path indicated by Cohen (1995), who proposed focusing on changes in CC, particularly those reflected in global population dynamics. Following this concept, the lecture demonstrates a direct relationship between the evolution of CC and the per-capita Relative Growth Rate (RGR) in global population change, as determined from available empirical data. The study further demonstrates the relationship between these characterizations and the Weibull hazard function, which indicates the probability of success or failure of actions based on the obtained parameter values.

Since the beginning of the Anthropocene, food has been a resource of crucial importance to humans, and then to the global Carrying Capacity. The Industrial Revolution epoch solved the problem of the quantity of food necessary for a rapidly growing population, with a significant surplus. In the 21st century, equally important are also the appropriate food qualities. This trend is referred to as High Quality Foods, meaning food with the qualities of a fresh product, optimally health-promoting, and with limited undesirable environmental impact – both in production and logistics to the consumer. Essential support for this path yields innovative food preservation methods, such as High Preservation Processing and the next-generation Supercritical Fluids Processing. Significant, related reports are recalled below.

**Acknowledgements:** This research was supported by the National Science Centre (NCN) through grant OPUS-23 no. 2022/45/B/ST5/04005.

**Keywords:** global population; carrying capacity; high quality foods; sustainable civilization

**References:**

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## Phase Equilibria in Mixtures with Limited Miscibility – New Perspective

Jakub Kalabiński<sup>1,\*</sup>, A. Drozd-Rzoska<sup>1</sup>, S. J. Rzoska<sup>1</sup>

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**Abstract:** Physics of Phase Transition represents one of the greatest intellectual achievements in the field of physical sciences in the last 100 years. In this great cognitive achievement noticeable research gaps still exist regarding the area of binary critical solutions with limited miscibility. These systems exhibit isomorphism with the most “classical” phase transition - the liquid-gas transition.

The first emerging experimental problem is the lack of an effective method for determining the critical density of a mixture with limited miscibility. The second is the absence of reliable evidence for the so-called diameter of the coexistence curve, an issue highlighted in 1986 by J.S. Rowlinson. This shows that the aforementioned research gaps in the area of critical phenomena and processes related to critical fluctuations fundamentally stem from the lack of a concept enabling the development of a suitable technique for determining phase coexistence curves, critical parameters, and the diameter of the coexistence curve. Specifically: (i) precise phase coexistence curves are still lacking, even for basic systems such as solutions with an upper critical point; (ii) phase coexistence curves for systems with a lower critical point are very limited; (iii) experimental evidence for the influence of pressure on critical concentrations, critical temperatures, and the shape of the phase coexistence curve remains very limited; (iv) a significant problem is the invalidation of the Cailletet-Mathias Law (Rectilinear Diameter Law).

Presentation explains the concept, design and construction of an innovative measurement system for investigating phase equilibria in solutions with limited miscibility and demonstrates study results of selected research systems.

Acknowledgements: This research was supported by the National Science Centre (NCN) through grant OPUS-23 no. 2022/45/B/ST5/04005.

**Keywords:** critical mixtures; mixtures with limited miscibility; coexistence curve

### References:

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## High Pressure Treatment of Sodium Olivine-Like Glass: Increased Conductivity in Possible Future Cathode Material

Aleksander Szpakiewicz-Szatan<sup>1\*</sup>, T. K. Pietrzak<sup>2</sup>, S. J. Rzoska<sup>1</sup>,  
J. E. Garbarczyk<sup>2</sup>

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**Abstract:** One of less examined fields in physics of energy storage materials is high pressure treatment. Currently, most of the batteries used are based on various lithium compounds. Lithium phosphoolivine (LiFePO<sub>4</sub>) is one of more perspective lithium combinations due to it's safety and use of common (besides lithium) elements. However, (besides lithium scarcity) most significant drawback of this compound is it's moderate conductivity, which typically is improved with carbon doping. In order to address those shortcomings our team studied impact of HPHT (high pressure high temperature) treatment on this compound and it's sodium based analog (NaFePO<sub>4</sub>).

Heat treatment at pressure ranging from 1 to 3 GPa allowed us to transform amorphous phosphoolivine analogs into nanocrystalline composites embedded within glassy matrix. Next, high pressure heat treatment was correlated with in situ high pressure thermal analysis. Following, ex situ (at atmospheric pressure) X-Ray Diffraction and Broadband Dielectric Spectroscopy measurements were utilized to detect permanent changes of structural and electrical properties of those materials (in potential application range).

Compared with their precursor obtained through HPHT treatment nanocomposites, exhibit improvement of electrical properties. Observed apparent DC electric conductivity was increased by orders of magnitude, and apparent activation energy was reduced. It was confirmed that final conductivity of the sodium analogue was higher than measured in the lithium compound studied previously<sup>(1)</sup>. Moreover, different performance of electronic and ionic conductivities depending on temperature, and sample's state (glassy or nanocomposite), was observed for sodium analogue, which was further supported by AC conductivity studies.

Acknowledgements: This research was supported by the National Science Centre (NCN) through grant OPUS-23 no. 2022/45/B/ST5/04005.

**Keywords:** high pressure; sodium phosphoolivine; glass; nanocomposite

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## Structural Properties of V<sub>2</sub>O<sub>5</sub> Glasses Compressed under High Pressure. Combined Experimental and Computational Study

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**Abstract:** Vanadium pentoxide is a candidate cathode material for rechargeable batteries, which possess a layered structure that can reversibly intercalate lithium or sodium cations. Furthermore, the presence of multiple oxidation states of vanadium ions creates remarkable conditions for electronic conductivity due to polaron hopping. Thermal nanocrystallization of vanadate glass is a known method for further improvement of its conductivity.

An application of high pressure of the order of GPa during high-pressure treatment of the material can induce further structural changes, such as densification and increased coordination, which may be another way to influence the electric properties of the material. Previously such effects have been studied both experimentally and numerically in other types of glass, particularly silicates.

In this work, we focus on the influence of high-pressure (HP) treatment on structural and electrical properties of V<sub>2</sub>O<sub>5</sub>-based glasses. Experimental XRD and electrical investigation of 95V<sub>2</sub>O<sub>5</sub>-5P<sub>2</sub>O<sub>5</sub> glasses subjected to pressures up to 8 GPa are compared with molecular dynamics studies of the structure of HP-treated V<sub>2</sub>O<sub>5</sub> glasses using ReaxFF potential. In particular, we verify the structure obtained from ReaxFF with literature and show that it reproduces the complex nature of V-O bonds. Furthermore, experimentally observed phenomenon of temperature-induced reduction of vanadium is also reproduced by ReaxFF MD simulations.

Acknowledgements: This research was supported by the National Science Centre (NCN) through grant OPUS-23 no. 2022/45/B/ST5/04005.

T.K.P. and A.W.P. were additionally supported by the European Union under the Horizon Europe grant OMINO - Overcoming Multilevel Information Overload (grant number 101086321, <http://ominoproject.eu>).

**Keywords:** vanadate glasses; cathode materials; high pressure

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## Si-doped $\text{Na}_2\text{VFe}_2(\text{PO}_4)_3$ Nanocrystalline Alluaudites as Prospective Cathodes for Sodium-Ion Batteries

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**Abstract:** The rapid evolution of battery technology in recent decades has led to their ubiquitous application, ranging from consumer electronics and electric vehicles to grid stabilization systems. In this context, sodium-ion batteries (NIBs) are emerging as a cost-effective and sustainable alternative to lithium-based systems. Alluaudites, first described by Fisher, represent a promising class of cathode materials for NIBs, offering a theoretical gravimetric capacity of approximately 170 mAh/g. However, poor electrical conductivity is one of the main obstacles to their implementation.

Our prior investigations into amorphous analogues of cathode materials demonstrated that thermal nanocrystallization can significantly enhance conductivity by creating favorable conditions for polaron hopping. Specifically, we examined alluaudite-like materials with nominal compositions of  $\text{Na}_2\text{Fe}_3(\text{PO}_4)_3$ ,  $\text{Na}_2\text{Fe}_2\text{V}(\text{PO}_4)_3$ , and  $\text{Na}_2\text{FeMnV}(\text{PO}_4)_3$ . We observed a significant (5 orders of magnitude) and irreversible increase in the conductivity, resulting in nanomaterials with  $\sigma(25^\circ\text{C}) \approx 1 \text{ mS/cm}$ . We also elaborated optimal synthesis conditions to obtain alluaudite-like nanomaterials with maximum possible phase purity [6]. We performed electrochemical characterisation of the most prospective samples in prototype sodium cells. Their average performance, however, did not reflect the superior electrical conductivity of the active material.

Addressing this discrepancy, the present study focuses on the synthesis of  $\text{Na}_2\text{Fe}_2\text{V}(\text{PO}_4)_3$  alluaudite-like glass modified with silicon dioxide. We hypothesize that the introduction of  $\text{SiO}_4$  tetrahedra will modify the ion transport landscape within the nanocrystalline structure, thereby improving electrochemical behavior. Here, we present the thermal (DSC), structural (XRD) and electrical (impedance spectroscopy) properties of our novel nanomaterials.

Acknowledgements: M.J., K.G., and T.K.P. are grateful to the National Science Centre (NCN), Poland, for support in the framework of a grant OPUS-23 no. 2022/45/B/ST5/04005.

**Keywords:** alluaudites; glass; nanocrystallization; cathode

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## Socio- & Econo-Physics view on Population Changes in Industrial Revolution Era

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**Abstract:** The report confronts the dramatic rise in global population over the last two centuries, along with the sociological and economic changes of this unique epoch.

It has been shown that the long-term evolution of the World Gross Product, particularly after World War II, can be well described by a simple exponential function with a crossover around 1970, coinciding with a crossover in global population scaling to a slowing growth pattern.

For such basic parameters as the S&P 500 (Standard & Poor's 500) index of the World's largest companies, the single-exponential behaviour extends back to at least the mid-nineteenth century. It is notable that the detailed short-term insight, focused on the last quarter of the century, revealed a crossover to an even faster power-law dependence, despite notable irregularities. Major crises, such as the two major world wars, seem to have had an almost imperceptible impact on these trends. However, derivative-based, subtle distortions-focused analysis reveals such impacts. It is also worth emphasizing the 'critical' and continuous increase in the number of patents from ~1830, when such data became available, until the present day.

The possible relationship to the evolution of microorganism growth and death is also discussed. The latter is confronted with the development of a model human population on the isolated Island of Rapa Nui.

Acknowledgements: The research associated with this presentation was supported the National Science Center (NCN, Poland), OPUS grant, ref. 2022/45/B/ST5/04005.

**Keywords:** World Gross Product; global population' human population

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## Phase Behaviour of Twist-Bend Nematic Phase

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**Abstract:** We study theoretically the twist-bend nematic (Ntb) phase using Landau-de Gennes mesoscopic approach. The Ntb phase is commonly exhibited by curved mesogenic liquid crystalline (LC) dimers. Its basic structure is typically determined by the nematic director  $\vec{n}$  which points along a local mesoscopic uniaxial molecular order, where the states  $\pm\vec{n}$  are physically equivalent. In the Ntb phase  $\vec{n}$  forms an oblique helical pattern consisting of periodic twist-bend deformation. The configuration possesses a double degenerate handedness, has a typical pitch in the order of 10 nm and  $\vec{n}$  essentially forms spatially constant conical angle with respect to the direction of helix axis. The Ntb phase is typically formed by lowering the temperature from the conventional uniaxial nematic (N) phase.

To describe the N- Ntb phase behavior, we use the Landau-de Gennes approach in terms of the nematic tensor order parameter and the electric polarisation vector order parameter field  $\vec{p}$ . We expand the free energy of the system in terms of order parameters up to the fourth order, considering symmetry restrictions. Our model predicts either a second-order or first-order N-Ntb phase transition. Moreover, we consider the Halperin- Lubensky-Ma effect considering pseudo layers mimicking the helicoidal Ntb pattern. We show that in the latter case the N-Ntb transition is always discontinuous. Furthermore, we study also the impact of different nanoparticles (NPs) on the phase behaviour. We assume that the NPs exhibit either cylindrical or spherical symmetry and are homogeneously dispersed within the LC-NP mixture. We illustrate conditions for which NPs could introduce qualitatively different behaviour with respect to the bulk LC reference.

**Keywords:** twist-bend nematic; phase behaviour; liquid crystal dimers

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## Optimization of Liquid Crystal Materials for Photo- and Thermomechanically Responsive Elastomers

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**Abstract:** Photo- and thermo-controlled liquid crystal polymer networks (LCNs), being tunable photonic switches, can be used in several fields of application such as optical communications, sensors, and imaging systems. The photomechanical response of such functional materials can be used to convert either thermal or light energy into different forms of mechanical energy.

In this work, we demonstrate the process of the preparation and the investigation of photo- and thermomechanical responsive liquid crystalline elastomers (Figure). The photoalignment method to prepare liquid crystal polymer films with different director profiles was used. Moreover, the influence of various parameters such as cross-linking time and temperature on the thermomechanical properties and the laser-directed bending of liquid crystal monomer films was investigated. The morphology of liquid crystal elastomers was studied in detail by polarizing optical microscopy.

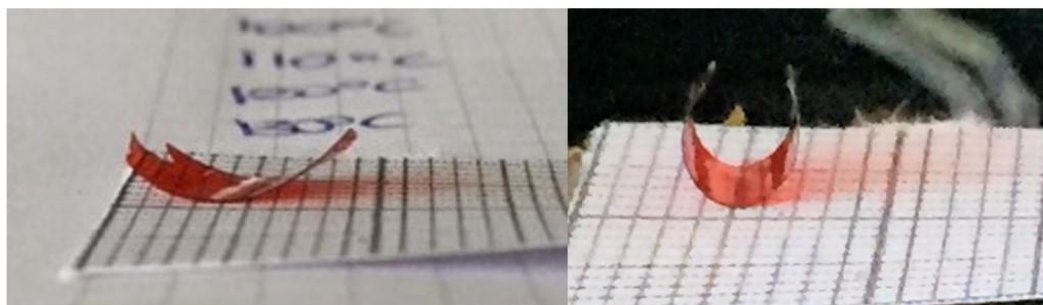


Figure: Thermomechanical response of the liquid crystal elastomers: at room temperature (on the left) and at 90°C (on the right). That process is reversible.

**Acknowledgments:** This work was supported by the Military University of Technology (UGB 2026 project number 22-531).

**Keywords:** liquid crystals; ionic dopants; intelligent liquid crystals; elastomers

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## Visualizing Order Parameter Spaces and Topological Defects in Ordered Media

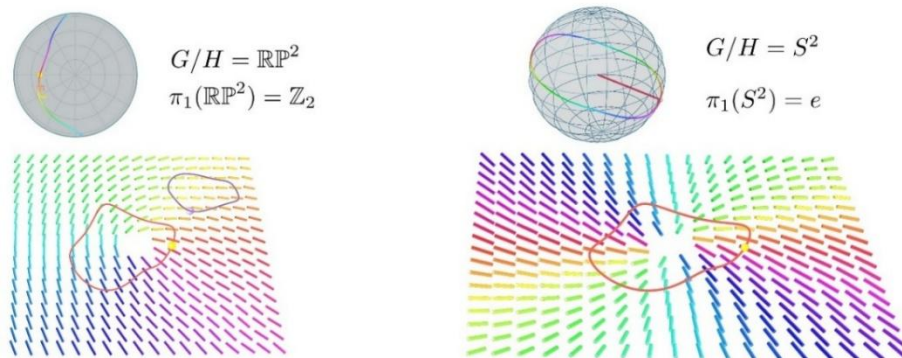
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**Abstract:** Topology, along with group theory, is an increasingly important mathematical language describing physical properties in various areas of modern physics (Mermin, 1979) (Kleman M. a., 2003). A state, which can be described by a topological invariant, exhibits stability that is resistant to energetic perturbations and is independent from the microscopic details of the system. Using a python library (Manim, 2026), we investigate visual representations of the otherwise abstract mathematical formalism of symmetry groups, quotient spaces and the first fundamental group of the order parameter spaces found in condensed matter systems (Kleman M. , 2003), namely the classical Heisenberg ferromagnet, the uniaxial and the biaxial nematic liquid crystals (Alexander, 2012). These systems host directly observable topological defects, which provide us with a visually accessible way of discussing the topological properties of their order parameter space and how the symmetry and dimension of each system affect those properties. We show the mapping between loops in physical space and loops in order parameter space gives us a more intuitive way of recognizing which defects are topologically protected. It additionally allows us to determine the topological equivalence of defects with different geometric description.



**Keywords:** order parameter space; topological defects; fundamental groups; topology visualization

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## Non-Linear Dielectric Response for Menthol Solutions

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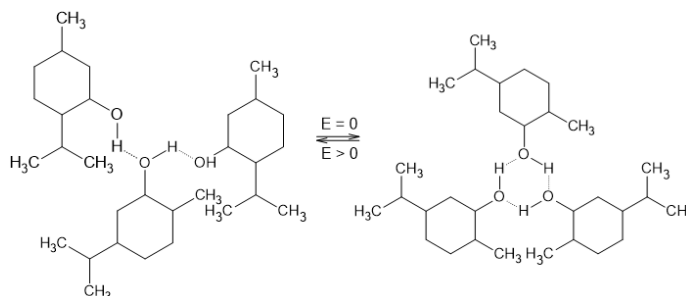
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**Abstract:** The non-linear dielectric effect (NDE) is a technique employed in dielectric studies, in which the NDE increment ( $\Delta\epsilon$ ) is determined as the difference between the electric permittivity measured at high electric field ( $\epsilon'_E$ ) and at low electric field strength ( $\epsilon'_{E \rightarrow 0}$ ).  $\Delta\epsilon = \epsilon'_E - \epsilon'_{E \rightarrow 0}$ .

According to the Debye–Langevin theory, simple dipolar liquids are expected to exhibit a negative nonlinear dielectric effect increment, which is proportional to the square of the applied electric field. Nevertheless, a positive NDE increment has been reported in certain liquids, including nitrobenzene, 1,2-dichloroethane, and higher alcohols. This anomalous behaviour is explained by conformational changes in 1,2-dichloroethane and by strong electric field-induced structural rearrangements of intermolecular complexes in nitrobenzene and alcohols.

In this paper, the case of menthol is examined. A positive NDE increment is observed in a both liquid phase (at temperatures above the melting point) and in solutions with p-xylene. It is unlikely that conformational changes are responsible for the observed positive NDE effect. Instead, we propose that this effect arises from a shift in the association equilibrium from cyclic to linear structures induced by a strong electric field. Alcohols form molecular associates through hydrogen bonds, which may exist as polar linear (open) and non-polar cyclic (closed). The application of an electric field promotes alignment of dipolar associates, favouring the formation of linear structures.

**Figure:** Formation of associations in menthol



**Keywords:** non-linear dielectric effect (NDE), menthol, association

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## Liquid Droplet Simulations for Material Exploration

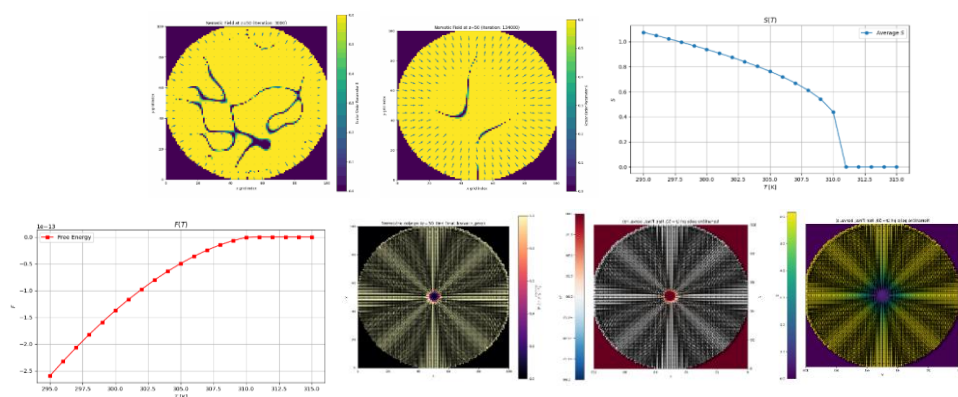
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**Abstract:** In the modern age, where conventional materials are on the brink of their obsolescence due to their inability to cater to ever stricter power regulations and efficiency, or utility, it is fundamental for researchers to delve deeper into the world of meta-materials, and to start looking into what other possibilities exist outside of the natural scope. To address this issue, we discuss in our presentation the viability of our numerical model, which was built on the conventional Landau-deGennes theory of phase transitions with relevant augmentations to achieve a model, which allows us to explore multiple types of possible liquid crystal materials, and those of which are naturally non-occurring. We also explain the current limitations of such a model and a perspective on the future of development of such models. Of the focuses of these simulations, however, is the quenched nematic state, in which we observe a very fast order parameter evolution, but a very slow molecular alignment evolution, meaning that the time scales of the order parameter evolution and molecular alignment are decoupled. In such cases we observe a formation of domains inside a droplet (or confinement space), which can be extrapolated to models encountered in magnetism (Kibble-Zurek mechanism) and vice-versa, where various topological defects are formed during a very fast phase transition, and the effect of critical-slowness plays a pivotal role in the formation of domains within the system, as the system's response to changes is slow around the critical point.



**Keywords:** numeric models; materials; mesoscopic modelling; liquid crystal droplets

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## Dielectric Properties of Reverse Micelles Formed by Nonionic Surfactants

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**Abstract:** Reverse micellar systems formed by nonionic surfactants in nonpolar solvents offer a useful model for studying confined water and aggregation phenomena at the nanoscale. This work investigates such systems composed of polyoxyethylene-based surfactant Tween 20 in cyclohexane, as well as mixed Tween 80/Span 80 surfactants in decane, over a wide range of water contents, with emphasis on their dielectric properties and aggregation behavior.

Measurements of the nonlinear dielectric effect (NDE), consisting of a comparison of the electric permittivity measured at strong and weak electric fields, reveal distinct responses in the studied systems. The Tween 20 system exhibits a predominantly negative NDE, corresponding to a decrease in permittivity under strong fields, while a positive NDE appears only in samples suspected of liquid crystalline ordering. In contrast, the Tween80/Span80 system shows a positive NDE with an unusual response shape at low water contents (below 4 wt%). This behavior persists up to a critical hydration level, where pronounced changes in density, viscosity and dielectric permittivity are observed. Above this threshold, the anomalous NDE response disappears, indicating a structural transition within the reverse micellar system, possibly associated with micellar reorganization and the formation of interconnected water domains that enhance polarization. For comparison, reverse micelles formed by ionic surfactants exhibit an exceptionally large positive NDE, attributed to ion motion in micro-inhomogeneous environments.

Complementary investigations, including phase diagram construction and measurements of viscosity, density and refractive index, support the dielectric findings and enable a broader interpretation of microstructural evolution. These results demonstrate that dielectric spectroscopy, particularly NDE, is a sensitive and noninvasive tool for probing structural organization and hydration-dependent transitions in reverse micellar systems based on nonionic surfactants.

**Keywords:** nonlinear dielectric effect; reverse micelles; nonionic surfactants

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## Synthesis, Properties and Enantioseparation of four-Ring Racemic Smectics

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**Abstract:** Liquid crystals (LCs) represent a unique state of matter combining fluidity with long-range molecular ordering. Among thermotropic liquid crystals, smectic phases are characterised by both orientational and positional order, resulting in layered structures. Smectic A (SmA) phases exhibit the director parallel to the layer normal, whereas more complex arrangements such as smectic C<sub>A</sub> (SmC<sub>A</sub>) involve tilted ordering and anticlinic packing in neighbouring layers.

In this work, two racemic, four-ring aromatic smectics differing in the number of methylene groups in the flexible spacer were synthesised and systematically characterised. Their mesomorphic properties were investigated by polarising optical microscopy and differential scanning calorimetry, confirming the formation of smectic phases SmA and SmC<sub>A</sub> within distinct temperature ranges. Since the synthesised materials occur as racemic mixtures, chiral separation was undertaken to obtain optically pure enantiomers without the need for independent asymmetric synthesis.

Enantioseparation was performed using high-performance liquid chromatography (HPLC) with two polysaccharide-based chiral stationary phases, which remain among the most effective selectors for a wide range of chiral compounds. The influence of chromatographic parameters, including mobile-phase composition and flow rate, was evaluated to establish conditions enabling baseline separation of both racemates. Optimal settings were identified, providing separation suitable for potential scale-up toward preparative purposes.

The results demonstrate that chiral HPLC is an efficient strategy for resolving four-ring smectic racemates, offering access to enantiomerically enriched compounds for further physicochemical studies and application-oriented formulation of liquid crystalline mixtures.

**Keywords:** synthesis; smectics; racemates; chiral chromatography; resolution

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## Phase Transitions and Electrical Properties of High-Pressure High-Temperature Treated Bismuth Oxide Based Material

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**Abstract:** HPHT (high pressure high temperature) annealing slightly below the glass temperature ( $T_g$ ) at pressure of just 1 GPa may lead to unusual properties, that are preserved after decompressing. In IHPP PAS there are HPHT processors operating at pressures up to 2.2 GPa at temperatures up to 1600°C with volumes up to 1 l. In our previous studies HPHT treatment of electron conducting glassy materials lead to simultaneous increase of electrical conductivity of 1-2 orders of magnitude and reduction of activation energy.

Bismuth Sesquioxide is a polymorphous material exhibiting properties of either an oxygen (super)ionic conductor or a semiconductor. It is potential candidate for use in Solid Oxide Fuel Cells due to  $\delta$ -Bi<sub>2</sub>O<sub>3</sub> superionic conductor properties. Previously properties of bismuth oxide (III) have been studied either at near atmospheric pressure or on already crystalline material.

Thermal data allowed for identification of temperatures of glass transition ( $T_g$ ) and crystallization of various phases. Pressure-temperature ( $p$ - $T$ ) plane of phase transitions was proposed after cross-analysis with XRD results<sup>(3)</sup>. Besides expected phases, another, potentially ferroelectric<sup>(4)</sup> phase Bi<sub>2</sub>O<sub>5</sub>Si (bismuth silicate) was identified after application of high enough pressure. Based on those results two additional HPHT treatment procedures were planned: with glass and nanocrystalline  $\delta$  phase.

Electrical properties of both samples were measured, analyzed and compared with use of Impedance Spectroscopy (IS). Total conductivity of HPHT treated ternary system Bi<sub>2</sub>O<sub>3</sub>-Al<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> was lower than HPHT treated  $\delta$ -Bi<sub>2</sub>O<sub>3</sub> nanocomposite. In case of nanocomposite not only total conductivity was measured, but intra-grain conductivity was distinguished. HPHT treatment of glassy ternary system lead to crystallization of nanocomposite consisting of  $\delta$ -Bi<sub>2</sub>O<sub>3</sub> or Bi<sub>2</sub>O<sub>5</sub>Si with  $\gamma$ -Bi<sub>2</sub>O<sub>3</sub> admixture in SiO<sub>2</sub>-Al<sub>2</sub>O<sub>3</sub> glassy matrix. HPHT treatment of HT nanocrystallized  $\delta$ -Bi<sub>2</sub>O<sub>3</sub> results in slightly higher total conductivity of sample and distinguishable (from total) conductivity of  $\delta$ -Bi<sub>2</sub>O<sub>3</sub> grains.

**Acknowledgments:** AlSzSz, SJR, TKP, JEG were supported by the Polish National Science Centre through the grant no. 2022/45/B/ST5/04005.

**Keywords:** high pressure; bismuth sesquioxide; glass; superionic conductor

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## Exceptional Points in Non-Hermitian Metasurfaces

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**Abstract:** Metasurfaces are thin, artificially engineered two-dimensional structures that allow precise control of electromagnetic waves. Since metasurfaces exchange energy with the electromagnetic fields, they are considered open systems and can be described within the framework of non-Hermitian physics, where gain and loss play an important role. We describe such system by using effective non-Hermitian Hamiltonian, whose complex eigenvalues represent gain and loss of the system. When two eigenvalues coalesce, non-Hermitian systems exhibit unique degeneracies, known as exceptional points.

In this work, we consider a simple case of two-mode coupled non-Hermitian metasurface to demonstrate how exceptional points arise. The interaction of light with the metasurface is modeled using a reflection-only 2x2 scattering matrix, focusing specifically on the reflection properties of the system.

We show that in the vicinity of the exceptional point the phase of the reflection eigenvalues changes, reflecting the non-Hermitian nature of the system.

**Keywords:** metasurfaces; non-Hermitian systems; scattering matrix

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## Synthesis and Investigation of Mesophase, Optical, and Spectral Properties of Thieno[3,2-b]thiophene-Based Liquid Crystals

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**Abstract:** One effective strategy to enhance birefringence ( $\Delta n$ ) and dielectric anisotropy ( $\Delta\epsilon$ ) is the incorporation of a polar ring into the molecular structure. Thieno[3,2-b]thiophene has emerged as a key structural unit in the development of high-birefringence liquid crystal (LC) compounds, owing not only to its ability to introduce lateral or longitudinal dipole moments and to alter mesophase behavior, but also due to its strong influence on the overall molecular geometry. The inclusion of sulfur atoms plays a crucial role in modifying the polarity and polarizability of the compound. Sulfur atoms, which contribute n-type electrons capable of interacting with  $\pi$ -conjugated systems, significantly impact the birefringence when introduced into alkyl substituents. In this study, we report the synthesis and characterization of compounds incorporating the thieno[3,2-b]thiophene ring, which exhibit liquid crystalline behavior. The molecular core features an electron-rich heterocycle, complemented by additional structural motifs—such as aromatic rings, ethynyl linkages, and various lateral and terminal substituents—designed to modulate the optical properties of liquid crystalline materials. We evaluated their mesophase behavior, birefringence, dielectric anisotropy, and spectral characteristics

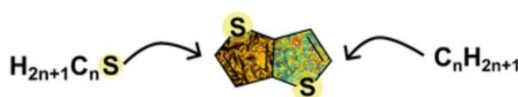


Figure: General structure of designed compounds contain thieno[3,2-b]thiophene ring

**Keywords:** thieno[3,2-b]thiophene; heterocycle ring; microwave

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## Self-assembled benzo[b]thiophene liquid crystals with designed dielectric properties for GHz applications

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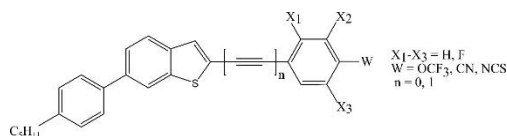
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**Abstract:** Over the past decades, liquid crystal (LC) materials have found increasingly broad applications across a wide range of electromagnetic frequencies. More recently, the emergence of self-assembling systems has renewed interest in employing LCs in the microwave (GHz) region. Among potential molecular cores, benzo[b]thiophene is particularly attractive due to its high thermal stability and extended  $\pi$ -electron conjugation. This enhanced conjugation arises from the fusion of benzene and thiophene rings into a single condensed system, rather than their linkage through a single bond as in phenylthiophene. As a result, both molecular polarizability and dipole moment are increased, making the benzo[b]thiophene core a promising building block for liquid crystals designed for microwave technologies.

Importantly, benzo[b]thiophene-based materials can display either positive or negative dielectric anisotropy ( $\Delta\epsilon$ ), depending on the molecular architecture and the nature of the substituents. Since the direction and magnitude of the molecular dipole moment play a decisive role in determining  $\Delta\epsilon$ , careful selection of terminal and lateral groups is required. Fine control over dielectric anisotropy is essential for optimizing LC performance at GHz frequencies, where key parameters include dielectric tunability ( $\tau$ ) and low dielectric loss ( $\tan\delta$ ). Together, these factors define the Figure of Merit (FoM), which determines the applicability of liquid crystal materials in high-frequency systems.

In this work, we aimed to develop new liquid crystal materials suitable for GHz-range applications. Accordingly, a series of benzo[b]thiophene derivatives designed to exhibit positive dielectric anisotropy was synthesized. Their thermal and mesomorphic behaviour was investigated using differential scanning calorimetry (DSC) and polarized optical microscopy (POM), confirming the formation of liquid crystalline phases and their strong dependence on molecular structure. Structural variations, including the introduction of different lateral and terminal substituents, were employed to modulate dielectric anisotropy - an essential parameter for microwave applications. The detailed results of these investigations are presented in the poster.



**Keywords:** liquid crystals; nematic phase; microwaves; GHz

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## Fabrication of complex-shaped colloids via selective microfluidic trapping

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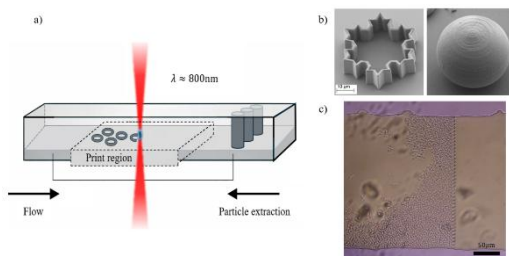
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**Abstract:** Direct laser writing (DLW), based on two-photon polymerization (2PP) enables the fabrication of three-dimensional colloidal particles with precisely controlled geometry on the micro and nanoscale and has become a key tool in soft matter research. In conventional approaches, structures are fabricated while attached to a solid substrate and subsequently functionalized to define anchoring conditions for surrounding liquid crystal molecules. This fabrication route introduces a fundamental limitation: particle regions in contact with the substrate cannot be exposed to surfactants or alignment agents. After mechanical detachment and transfer into a liquid crystal host, this results in heterogeneous surface anchoring. Sacrificial or detachment layers do not resolve this issue, as the required mechanical rinsing steps, such as centrifugation, are incompatible with fragile acrylate based colloids and frequently lead to damage or loss.

Here, we address this problem by extending the microfluidic trapping and permeation concept introduced in, adapting it for DLW fabrication of colloidal particles with controlled surface anchoring, followed by direct exchange of the photoresin with a nematic liquid crystal within the same microfluidic environment. The colloids are printed free-floating in a viscous resin environment, ensuring full access to all particle surfaces and avoiding substrate contact. By printing directly inside the final microfluidic geometry and subsequently exchanging the photoresist with a nematic liquid crystal, high particle yields are achieved without removal, transfer, or mechanical handling. Surface anchoring can be uniformly defined either by surfactant rinsing or by directly writing surface alignment grooves during fabrication, eliminating anchoring asymmetry and enabling reliable studies of director configurations, defect structures, and collective behavior in nematic liquid crystals.

Figure: a) Schematic of the microfluidic DLW setup. b) SEM image of complex-shaped colloidal particles fabricated using DLW. Scale bar: 10  $\mu\text{m}$ . c) Optical micrograph of colloidal particles selectively trapped at the permeable boundary inside the microfluidic channel, forming a dense particle assembly under flow. Scale bar: 50  $\mu\text{m}$ .



**Keywords:** two photon polymerization; direct laser writing; colloidal particles; surface anchoring; microfluidic trapping

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## Liotropic Phases of DNA

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**Abstract:** Research conducted in the 1980s showed that the DNA molecule can form liquid crystalline phases in concentrated solutions. DNA was classified as a lyotropic liquid crystal since the formation of liquid crystalline phases depends on both the temperature and concentration of the solution.

In our research work, we focused on guanine-rich DNA sequences that can form, in addition to the canonical double helix, higher-order structures. One among these are particularly stable supramolecular assemblies, known as DNA quadruplexes. They are formed when four guanine (G) bases are connected through Hoogsteen hydrogen bonding. Multiple G-quartets then stack on top of each other into structures called G-quadruplexes. Further stacking of these quadruplexes can induce the formation of elongated structures in solutions.

Using various experimental approaches, including dynamic light scattering and polarization optical microscopy, we have studied self-organization of DNA-quadruplexes and the formation of lyotropic liquid crystalline phases in concentrated aqueous solutions. Understanding these phenomena contributes to a better understanding of the behavior of higher-order DNA structures in cell-like environments, which is useful for the development of new biomaterials and advanced biotechnological applications.

**Acknowledgements:** This work was supported by the Slovenian Research Agency in the framework of research programs P1-0192 and P1-0403.

**Keywords:** DNA-quadruplex; self-assembly; lyotropic liquid crystals; liquid crystalline phases

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## In situ observation of the nanocrystallisation process in vanadate glasses in the XAS synchrotron experiment

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**Abstract:** Although vanadium oxides were first introduced as cathode materials for lithium-ion batteries in the early 1970s, they remain a subject of intensive research due to their high theoretical gravimetric capacity reaching 440 mAh/g [1]. However, the practical application of these materials is often hindered by their insufficient electronic conductivity and complex discharge characteristics. The thermal nanocrystallization of glassy analogues is a promising strategy to overcome these limitations. The approach allows for precise control over grain size and material properties [2,3].

In the case of vanadate-phosphate V<sub>2</sub>O<sub>5</sub>-P<sub>2</sub>O<sub>5</sub> glasses, our previous studies revealed an increase in electronic conductivity as a result of thermal treatment under optimized conditions [4]. We hypothesize that this enhancement stems from the formation of highly disordered shells surrounding the nanocrystallites, which create favorable conditions for small polaron hopping between aliovalent vanadium ions V<sup>3+</sup>/V<sup>4+</sup>/V<sup>5+</sup>.

Therefore, in this work, we performed in situ X-ray absorption spectroscopy (XANES/EXAFS) at the vanadium K-edge to track the local atomic evolution of the 95V<sub>2</sub>O<sub>5</sub> · 5P<sub>2</sub>O<sub>5</sub> over a temperature range of 20–500°C. Our analysis indicates that the transition from the amorphous to the nanocrystalline phase involves a fundamental rearrangement of the vanadium environment rather than a redox reaction.

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**Keywords:** XANES/EXAFS; in-situ measurements; high temperature; vanadate glasses; crystallization

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## Broadband Dielectric Spectroscopy Investigation of E7 Liquid Crystal with BaTiO<sub>3</sub> and C<sub>60</sub> Nanoparticles

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**Abstract:** Liquid crystal-based nanocomposites represent a promising frontier in materials science, combining the anisotropic properties of liquid crystals with the unique characteristics of nanoparticles. This study investigates the previtreous behavior of glass-forming E7 nematic mixture-based nanocolloids containing two structurally distinct nanoparticles: paraelectric BaTiO<sub>3</sub> (50 nm, globular) and spherical C<sub>60</sub> fullerenes.

The E7 eutectic mixture, composed of four cyanobiphenyl and cyanoterphenol components, exhibits unique glass-forming behavior in the supercooled nematic phase, with glass transition temperature  $T_g = 211.2$  K. Broadband dielectric spectroscopy (BDS) measurements were performed over an extended temperature range, encompassing isotropic liquid, nematic, and supercooled nematic phases for nanoparticle different concentrations below 1 wt.%. Critical findings include: (i) pretransitional effects in the isotropic phase related to the weakly discontinuous isotropic-nematic transition; (ii) significant modifications of the transition discontinuity metric; (iii) nanoparticle-induced permanent arrangement of rod-like LC molecules.

Dynamic properties show dominance of the MYEGA (double exponential) equation over conventional VFT description for BaTiO<sub>3</sub> systems. Building upon previous studies demonstrating dynamics and pretransitional effects in C<sub>60</sub> fullerene-doped liquid crystalline systems, this work extends the investigation to glass-forming E7 nanocolloids. Preliminary comparative studies with spherical C<sub>60</sub> fullerenes are underway to evaluate the role of nanoparticle geometry on previtreous dynamics. These investigations provide crucial insights into how different nanoparticle architectures influence glass transition phenomena in anisotropic molecular systems.

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**Keywords:** glass transition; E7 mixture; BaTiO<sub>3</sub>; C<sub>60</sub> fullerenes; previtreous behavior; nanocomposites; dielectric spectroscopy

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