DY 16: Droplets, Wetting, and Microfluidics (joint session DY/CPP)

Time: Monday 15:00–18:30 Location: ZEU/0118

DY 16.1 Mon 15:00 ZEU/0118

Rayleigh instability in the presence of elastocapillarity — •Niphredil Klint and Andreas Isacsson — Chalmers University of Technology, Gothenburg, Sweden

A liquid jet, such as a stream of water, will disintegrate and form droplets if the length-to-radius ratio exceeds a critical value. This occurs due to propagating surface instabilities, a phenomenon known classically as the Rayleigh instability. At the nanoscale, thermal fluctuations affect the breakup dynamics, which may enter a stochastic regime [1]. Placing an elongated nanoscale liquid drop with a high aspect ratio on top of a highly compliant surface, the breakup process is affected by additional noise from thermally excited flexural phonons [2] as well as effects whereby the wetting causes the underlying surface to deform. We use large scale molecular dynamics (MD) simulations to examine the dynamics of the Rayleigh instability in the presence of elastocapillary effects at ambient temperatures. Specifically, we study the interactions between water and suspended graphene, where wetting induced deformations may occur for nanoscale droplets [3]. We focus on characterising the breakup and instability wavelength and isolate the effects of introducing graphene through a comparison of these results to simulations of only water. We also identify the correlation between out-of-plane fluctuations of the graphene and the concentration of water.

[1] J. Eggers, Phys. Rev. Lett. 89, 084502 (2002).
[2] M. Ma et al., Nature Mater. 15, 66 (2016).
[3] M. Kateb et al, Langmuir 39, 12610 (2023).

DY 16.2 Mon 15:15 ZEU/0118

Air layers and wetting under drops impacting on pre-wetted surfaces — •Kirsten Harth and Shiva Moradimehr — Fachbereich Technik, Technische Hochschule Brandenburg, Germany

Drop impact at low Weber numbers causes the formation of a (temporary) air cushion between the drop liquid and the substrate. On hard, dry substrates, its qualitative thickness profile and the location of the thinnest point are strongly governed by the Weber number. For impact on bulk, soft surfaces, like PDMS gels, it was found that impacts on softer substrates entrap more air [1]. Are there similar effects of thin liquid films?

We address the air layer shapes, entrapped air volume and wetting underneath droplets impacting on a hard substrate pre-wetted by microscopic oil layers. We control the Weber number, the oil layer thickness (in the range of micrometers), the oil viscosity, and in that way the *softness* of the substrate. Despite the thinness of the film, we observe clear effects of the oil layer on the volume and drainage of the air entrapment, its profile shapes, and the wetting behavior.

[1] K.R. Langley et al., Soft Matter 16, 5702 (2020)

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DY 16.3 Mon 15:30 ZEU/0118

Memory Effects in Contact Line Friction — •Niklas Wolf and Nico van der Vegt — TU Darmstadt, Darmstadt, Germany

When a drop of liquid comes into contact with a solid surface, it relaxes towards an equilibrium configuration, either wetting the surface or remaining in a droplet-like shape with a finite contact angle. The speed of this relaxation strongly depends on a friction force opposing the movement of the three-phase contact line. In analogy to the treatment of hydrodynamic friction we present an exact method, based on the Mori-Zwanzig formalism, to extract this friction from equilibrium data. Within the linear response regime, we obtain the frequency-dependent dissipative and elastic response of the contact line to an external perturbation, including a frequency-dependent friction coefficient. We find that the contact line exhibits long-lasting memory with a power-law decay due to coupling to the systems hydrodynamic modes. As a result the microscopic contact line dynamics are neither Markovian nor determined by the movement of a few molecules in the vicinity of the contact line.

DY 16.4 Mon 15:45 ZEU/0118

Reaction-Mediated Arrest and Gradient-Driven Droplet Transport — •Stefan Köstler[1,2], Yicheng Qiang[1], Malcolm Steen[1,2], Guido Kusters[1], and David Zwicker[1] — [1]Max Planck Institute for Dynamics and Self-Organization, Am Faßberg 17, 37077 Göttingen, Germany — [2]University of Göttingen, Institute for the Dynamics of Complex Systems, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

Controlling droplet size and position is central to many biological and engineering processes. Chemical reactions can arrest coarsening and sustain spatial concentration gradients, while hydrodynamic flows generally accelerate coarsening and drive droplets along chemical gradients. Using continuum theory, we show that the competition between reactions, diffusion, and hydrodynamic advection yields rich behavior even in binary systems: Advection dominates the coalescence of small droplets, diffusion leads to Ostwald ripening for intermediate sizes, and reactions finally suppress coarsening. Interestingly, a range of droplet sizes is stable, depending on initial conditions and the strength of advection. Crucially, chemical gradients can actively steer droplets and couple to size-control. Our results demonstrate practical routes to control both the size distribution and spatial organization of droplets by tuning chemical activity and gradient-driven flows.

DY 16.5 Mon 16:00 ZEU/0118

From bipedal to chaotic motion of chemically fueled partially wetting liquid drops — •Florian Voss[1] and Uwe Thiele[1,2] — [1]Institute of Theoretical Physics, University of Münster — [2]Center for Data Science and Complexity (CDSC), University of Münster

Chemomechanical coupling is essential to various phenomena in soft matter systems that are kept permanently out of thermodynamic equilibrium, e.g., in reactive complex liquids. Based on a thermodynamically consistent continuum model, we demonstrate that partially wetting liquid drops covered by chemically reacting surfactants display a variety of biomimetic motility modes like shuttling, bipedal, rotational and quasi-random motion when supplied with chemical fuel from an ambient bath. The dynamics originates from chemomechanical feedback between the reaction network on the drop and the Marangoni effect [1] and becomes increasingly complex as a result of competing length scales. Due to the generic underlying thermodynamic structure, we expect that our results are also relevant for other chemically active mixtures and soft matter systems.

[1] F. Voss and U. Thiele, Phys. Rev. Fluids 10, 94005 (2025).

DY 16.6 Mon 16:15 ZEU/0118

Odd Droplets — •Thomas Appleford — University of Amsterdam, Amsterdam, Netherlands

In chiral systems such as active spinning colloidal matter, time-reversal symmetry-breaking interactions often give rise to a macroscopic continuum description in which the stress tensor contains off-diagonal terms. In fluids, these off-diagonal components lead to so-called "odd-viscous" deformations, in which energy is not dissipated. Odd viscous fluids have been shown to exhibit a rich variety of phenomena, including symmetry-broken flow around translating droplets and asymmetric droplet spreading on superhydrophobic surfaces. Our work investigates the behaviour of droplets in suspension. In particular, we present an analytical solution to the droplet-in-shear problem within the framework of two-dimensional odd Stokes flow, followed by the derivation of a formula for the apparent viscosity of a dilute emulsion. We then explore how chirality can be parametrically varied to tune the bulk rheological properties and control the system's overall energy dissipation.

DY 16.7 Mon 16:30 ZEU/0118

Stretching and Sliding Capillary Bridges — •Lennard Holschuh and Lars Pastewka — University of Freiburg, Department of Microsystems Engineering

Capillary forces play a critical role in the adhesion between two contacting bodies. However, existing theories of macroscopic adhesion on rough surfaces often assume dry conditions, attributing adhesive interactions solely to dispersion forces and overlooking the effects of capillary bridge formation. This study employs molecular dynamics simulations to directly examine the interactions of nanoscale probes with nominally flat surfaces in the presence of liquid bridges, which form due to condensation in humid environments. The objective is to link the thermodynamic understanding of capillary bridges with molecular simulations and atomic-force microscopy experiments. These calculations focus on investigating energy dissipation during adhesion (normal separation of the probe from the surface) and friction (lateral motion of the probe). By quantifying the interplay between relative humidity, adhesion, and friction, this work aims to improve the understanding of macroscopic adhesion in humid conditions and guide the development of materials with tailored properties for high-precision applications, such as microelectronic manufacturing.

15 min. break

DY 16.8 Mon 17:00 ZEU/0118

Hyperuniformity in Ternary Fluid Mixtures: The Role of Wetting and Hydrodynamics — •Nadia Bihari Padhan and Axel Voigt — Institute of Scientific Computing, TU Dresden, 01069 Dresden, Germany

Phase separation in multicomponent fluids underlies the organization of complex materials and biological structures, including biomolecular condensates. The Cahn-Hilliard-Navier-Stokes (CHNS) framework provides a natural description of such systems by coupling diffusive and hydrodynamic processes. In this talk, I will present our study of hyperuniformity–suppressed large-scale density fluctuations–in ternary CHNS mixtures. We show that hydrodynamics systematically drives the system toward less hyperuniform states and generates a rich set of morphologies, such as interconnected droplets and double emulsions reminiscent of biological phase separation. In partial-wetting regimes, all three components display comparable hyperuniformity, whereas in complete-wetting regimes the preferred wetting component exhibits a marked loss of hyperuniformity. These results identify wetting asymmetry as a key control parameter for spatial order in multiphase fluids and offer a pathway for tuning large-scale organization in soft-matter and biological systems.

References [1] Boyer, F. and Lapuerta, C., Study of a three component Cahn-Hilliard flow model, ESAIM: Mathematical Modelling and Numerical Analysis, 40, 653-687 (2006). [2] Padhan, Nadia Bihari and Voigt, Axel, Hyperuniformity in ternary fluid mixtures: the role of wetting and hydrodynamics, arXiv:2506.22647, (2025).

DY 16.9 Mon 17:15 ZEU/0118

Effect of Flow Coupling on Defect Binding and Unbinding in Nematic Fluids — •Jayeeta Chattopadhyay, Simon Guldager Andersen, Kristian Thijssen, and Amin Doostmohammadi — Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, Copenhagen, Denmark.

Topological defects play a central role in the ordering and dynamics of nematic fluids. We investigate how coupling to fluid flow modifies defect-mediated phase transitions in two-dimensional nematics using fluctuating nematohydrodynamic simulations. The system is driven by tuning the fluctuation strength, with increasing and decreasing fluctuations defining forward and backward protocols. Without flow coupling, the system undergoes a Berezinskii–Kosterlitz–Thouless (BKT)–like transition via the reversible binding and unbinding of $\pm 1/2$ defect pairs. When hydrodynamics is included, the transition depends on the flow–alignment parameter: non-aligning nematics ($\lambda = 0$) retain BKT-like behavior, whereas strain-rate–aligning nematics ($\lambda \neq 0$) form bend–splay walls, lowering the defect-creation threshold and preventing recombination, leaving defects unbound across all fluctuation strengths. In active nematics, defects remain unbound for all λ, showing that self-generated flows also inhibit bound-pair formation. These results demonstrate that coupling to fluid flow fundamentally alters topological phase behavior, suppressing the equilibrium BKT binding mechanism.

DY 16.10 Mon 17:30 ZEU/0118

Electrophoresis in charged chiral active fluids with odd viscosity — •Reinier van Buel, Bogdan Cichocki, and Jeffrey Everts — Institute of Theoretical Physics, Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warsaw, Poland

Understanding the motion of colloidal particles dissolved in fluids that exhibit odd viscosity – a specific component of the viscous stress tensor found in e.g. chiral active fluids – is of particular interest for realising nontrivial particle transport and characterising out-of-equilibrium thermodynamic properties. Although three-dimensional odd viscosity has not yet been experimentally observed, charge stabilisation is expected to be vital in enabling such measurements. Therefore, we introduce the notion of a charged chiral active fluid and we investigate some of its non-trivial electrokinetic properties. In particular, we focus on electrophoresis of a charged sphere suspended in such an odd viscous fluid. Here, the peculiar nature of odd viscosity breaks the spherical symmetry of the system, and through coupling with the electric double layer and its screening properties, alters the electrophoretic mobility. Using the Lorentz reciprocal theorem, we derive expressions for the electrophoretic mobility of a spherical particle based on the analytical solution for the uncharged flow. Furthermore, we highlight how the Hückel and Smoluchowski limits of the electrophoretic mobility are affected by odd viscosity. Our results demonstrate that odd viscosity leads to directional asymmetries in the electrophoretic mobility tensor, suggesting mechanisms for active control of charged colloidal motion in systems where odd viscosity is prevalent.

DY 16.11 Mon 17:45 ZEU/0118

Experimentally probing microscale torsional memory in a viscoelastic fluid — •Niloyendu Roy[1], Rupayan Saha[2], Debankur Das[2], Matthias Krüger[2], and Clemens Bechinger[1] — [1]Fachbereich Physik, Universität Konstanz, Konstanz, Germany — [2]Institut für Theoretische Physik, Universität Göttingen, Göttingen, Germany

Motion of a colloid inside viscoelastic fluids follows non-Markovian dynamics, meaning its trajectory is influenced by past motion. Such memory effects are typically attributed to intrinsic material timescales arising from relaxation of the fluid microstructure and are usually probed using translationally driven colloids. Here we show experimentally that rotational driving of a colloid by a controlled torque elicits a far richer form of memory: the relaxation of the resulting torsional stresses spans a broad distribution of timescales, even though the fluid itself possesses a single dominant relaxation time. This behaviour allows time-dependent torsional driving histories to be encoded and subsequently read out through characteristic non-monotonic recoil responses. By mapping the flow field and the spatial distribution of torsional stresses, we demonstrate that the geometry of rotation generates an orthogonality between the propagation of angular momentum and the storage of torsional stresses, producing a spatio-temporal memory field not accessible through translational forcing. These results establish torsional driving as a powerful route to generate, store, and retrieve memory in viscoelastic fluids, opening new possibilities for soft-matter information storage and torque-responsive microdevices.

DY 16.12 Mon 18:00 ZEU/0118

3D Optofluidic Control Using Reconfigurable Thermal Barriers — •Falko Schmidt[1,2], Carlos David Gonzalez[3], Marc Sulliger[1], Emilio Ruiz-Rena[4], Raul A. Rica[3,5], Jaime Ortega-Arroyo[1], and Romain Quidant[1] — [1]Department of Mechanical and Process Engineering, ETH Zurich, Zurich 8092, Switzerland — [2]Peter Debye Insitute for Soft Matter Physics, Leipzig University, 04103 Leipzig, Germany — [3]Universidad de Granada, Department of Applied Physics, Granada 18071, Spain — [4]Department of Applied Physics II, University of Malaga, Malaga 29071, Spain — [5]Universidad de Granada, Research Unit Modeling Nature (MNAT), Granada 18071, Spain

Optothermal manipulation enables precise control of small particles via optical and thermal forces, leveraging thermo-osmotic and convective flows for short- and long-range motion. We present a reconfigurable optofluidic method enabling diverse manipulations such as guiding, sorting, trapping, and separating particles. Using light absorption on plasmonic surfaces of gold nanorods, localized hot spots are generated, creating temperature-driven flows. A near-infrared laser spatially modulates temperature landscapes, monitored by 3D holographic microscopy and optical diffraction tomography. Single and double heat sources produce three-dimensional flow control. This creates an optofluidic barrier that redirects particles within a microfluidic chamber. This approach offers a versatile foundation for advancing microfluidic technologies, enabling applications in sorting, trapping, and adaptive system design.

DY 16.13 Mon 18:15 ZEU/0118

Dynamics and Ordering of Microdroplets in Marangoni Flow Field — •Akshay Kallikkunnath and Frank Cichos — Molecular Nanophotonics, Peter Debye Institute for Soft Matter Physics, Faculty of Physics and Earth System Sciences, Leipzig University, Linnéstraße 5, 04103 Leipzig, Germany

Collective organization and internal dynamics are intimately linked and emerge across biological scales, with ordered structures providing a framework within which individual constituents remain dynamically active. Here, we study a system of water-in-oil microdroplets containing heat-releasing particles that organize under thermally induced flows. A sub-kelvin temperature increase from the heated particle at the air-oil interface generates Marangoni circulation that advects the droplets. Interactions through the flow field lead to robust ordering, while internal particle dynamics reflect coupling between local thermal gradients and microscale hydrodynamics. This provides a controllable platform to probe self-organization and emergent order by generating flows driven by weak, localized thermal fields in a fully fluid-in-fluid environment.