Fluids and Complexity 3

6-8 Dec 2023, Nice, France

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Wednesday, December 6

Active interfaces

Cécile Cottin-Bizonne

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Active matter systems, comprised of self-propelled particles, exhibit rather intriguing dynamic properties, which have attracted considerable attention in recent years. In this study, we focus on active interfaces by considering a sediment of self-propelled Janus colloids. At low densities, they behave like a perfect hot gas, but at intermediate densities, we observe new collective phenomena, such as the formation of clusters. This leads us to question whether wetting-type effects occur in these active fluids. In this context, we investigate an analogy to the classical capillary rise effect in the realm of active matter. Specifically, we examine how a non-phase separated sediment of self-propelled Janus colloids behaves when in contact with a vertical wall.

Emerging patterns of phoretic wet active matter: from crystalline solids to active turbulence

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Phoretic microswimmers, such as Janus colloids and isotropic active droplets, are promising constituents for self-organized active materials. However, the underlying mechanisms governing their self-organization remain unclear, despite numerous experimental observations in various regimes. Here, we perform large-scale simulations to investigate a paradigmatic suspension of isotropic phoretic disks representing active droplets, explicitly resolving their many-body, long-range hydrochemical interactions. We observe that they exhibit diverse collective phenomena, including the formation of crystalline solids resembling Wigner crystals, melting, gas-like chain formation, active transition and turbulence. Our work reproduces and reconciles seemingly conflicting experimental observations on chemically active systems, emphasizing the importance of incorporating full physicochemical hydrodynamics. Remarkably, altering activity alone induces solid-fluid phase transition and, subsequently, the laminar-turbulent transition of the fluid. These two progressively emerging transitions, hitherto unreported, bring us closer to understanding the parallels between active matter and traditional matter. Our findings will help enhance the understanding of long-range, many-body interactions among phoretic agents, offer new insights into non-equilibrium collective behaviors, and provide potential guidelines for designing reconfigurable materials.

*Speaker

Transition to universality, intermittency and maximal chaosin living fluid turbulence

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Living fluids, like dense bacterial suspensions, are a complex organization of matter driven at the scale of itsconstituent agents. While flows in these systems may assume confounding dynamical states like "active *turbulence*", analogies with high Reynolds number, inertial (Kolmogorovean) turbulence have not survived beyond the qualitative. Active turbulence, consequently, was largely deemed non-universal, non-intermittent and merely diffusive. Using a continuum hydrodynamic model for bacterial turbulence, we now show a robustly emerging universal turbulent state beyond a critical drive. Following this transition, the flow becomes further marked by non-Gaussian fluctuations and maximal chaos with multiscale perturbation growth dynamics, similarly to inertial turbulence. Interestingly, this asymptotic flow state manifests superdiffusion via Lévy walks, and consequently a host of Lagrangian anomalies, which we trace back to emergent patterns in the Eulerian flow fields – a feature that sets living flows distinctly apart from inertial turbulence limited to classical diffusion. All of this makes the phenomenology of living matter rich and riddled with surprising nuances, which at times bridge the analogy with inanimate inertial turbulence, and at others break them. Broad-brushed parallels,therefore, obfuscate what may be biologically relevant strategies for survival and growth.

*Speaker

Chemo-hydrodynamic self-organization around reaction fronts

Anne De Wit

Univ. Libre Bruxelles, Belgium

Phyllotactic patterns, i.e. regular arrangements of leaves or flowers around a plant stem, are beautiful and fascinating examples of complex structures encountered in Nature. In botany, their peculiar symmetries develop when a new primordium periodically grows in the largest gap left between the previous primordium and the apex. Experiments using ferrofluids droplets have also shown that phyllotactic patterns spontaneously form when identical elements repulsing each other are periodically released at a given distance from an injection center and are advected radially at a constant speed. More recently, we did observe analogous spiralling patterns in the context of precipitation experiments obtained by radial injection in a confined geometry. Inspired by those experiments, we show here that classical models of phase separation and Turing patterns do also produce spiralling patterns when coupled to a radial injection dynamic. Our results suggest that these models are part of a larger family of self-organised phyllotactic structures, which originate when a spatial symmetry-breaking system giving spotted structures with an intrinsic wavelength is coupled to radial growth.

Phyllotactic structures in reactive spatial symmetry-breaking systems

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[1] Nonlinear Physical Chemistry Unit, Université Libre de Bruxelles – Belgium

Phyllotactic patterns, i.e. regular arrangements of leaves or flowers around a plant stem, are beautiful and fascinating examples of complex structures encountered in Nature. In botany, their peculiar symmetries develop when a new primordium periodically grows in the largest gap left between the previous primordium and the apex. Experiments using ferrofluids droplets have also shown that phyllotactic patterns spontaneously form when identical elements repulsing each other are periodically released at a given distance from an injection center and are advected radially at a constant speed. More recently, we did observe analogous spiralling patterns in the context of precipitation experiments obtained by radial injection in a confined geometry. Inspired by those experiments, we show here that classical models of phase separation and Turing patterns do also produce spiralling patterns when coupled to a radial injection dynamic. Our results suggest that these models are part of a larger family of self-organised phyllotactic structures, which originate when a spatial symmetry-breaking system giving spotted structures with an intrinsic wavelength is coupled to radial growth.

*Speaker

Transport properties in inert 2D Droplet Interface Bilayer Networks

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In a tissue, cells that are in direct physical contact with each other can exchange molecules via protein clusters called gap junctions, that form channels across the membranes of adjacent cells. Artificial systems that mimic cellular tissues can be used as a way to overcome the complexity of cell-cell communication in biological tissues. For this, a simplified biomimetic approach is used. Tissues are mimicked with 2D arrays of aqueous droplets connected by lipid membranes called Droplet Interface Bilayers (DIBs) decorated with inert transmembrane nanopores. The diffusion of calcein across the DIB network is thoroughly studied.
The results are directly confronted with theoretical and numerical models of the transport of molecules in these artificial tissues using continuous time random walks.

*Speaker

Free volume theory explains the unusual behavior of viscosity in a non-confluent tissue during morphogenesis

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A recent experiment on zebrafish blastoderm morphogenesis showed that the viscosity (η) of a non-confluent embryonic tissue grows sharply until a critical cell density (Ï•S). The increase in η up to Ï•S is similar to the behavior observed in several glass forming materials, which suggests that the cell dynamics is sluggish or glass-like. Surprisingly, η is a constant above Ï•S. To determine the mechanism of this unusual dependence of η on Ï•, we performed extensive simulations using an agent-based model of a dense non-confluent two-dimensional tissue. We show that polydispersity in the cell size, and the propensity of the cells to deform, results in the saturation of the available free area per cell beyond a critical density. Saturation in the free space not only explains the viscosity plateau above Ï•S but also provides a relationship between equilibrium geometrical packing to the dramatic increase in the relaxation dynamics.

*Speaker

Dynamics of microparticles interacting with charged lipid vesicles

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The study of interactions between biomimetic membranes and microparticles serves as a fundamental cornerstone for understanding various biological processes. However, the limited availability of experimental studies constrains a comprehensive grasp of the underlying physical principles. In this context, we aim at controlling the engulfment of microparticles in the absence of any externally applied force. We identify critical parameters governing non-specific adhesion mechanisms between spherical microparticles of distinct sizes (1-4 μm) and chemical compositions (silica, polystyrene, melamine formaldehyde), and artificial cells, namely giant unilamellar vesicles (GUVs) with modulated membrane tension and lipid composition. Our specific focus centers on GUVs composed of DOPC and DOTAP, a cationic lipid. Bright-field and fluorescence microscopy are used to investigate the dynamics of our system and optical tweezers allow microparticle manipulation and measure of forces. Under these conditions, our findings notably unveiled that a force on the order of several piconewtons was exerted between a vesicle and an oppositely charged microparticle in immediate proximity. This force induces a partial or complete engulfment of the microparticle through the membrane. Our investigation also reveals that the penetration depth does not significantly affect the friction of the microparticle.

*Speaker

Friction when changing neighbours: adhesion-regulated junction slippage controls cell intercalation dynamics in living tissue

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During development tissues undergo dramatic shape changes to build and reshape organs. In many instances, these tissue-level deformations are driven by the active reorganisation of the constituent cells. This intercalation process involves multiple cell neighbour exchanges, where an interface shared between two cells is removed and a new interface is grown. The key molecular players involved in neighbour exchanges, such as contractile motors proteins and adhesion complexes, are now well-known. However, how their physical properties facilitate the process remains poorly understood. For example, how do cells maintain sufficient adhesive contact while actively uncoupling from one another? Then, how does a new interface grow in a contractile environment? Many existing biophysical models cannot answer such questions, due to representing shared cell interfaces as discrete elements that cannot uncouple.

Here, we develop a model where the junctional actomyosin cortex of every cell is modelled as a continuous viscoelastic rope-loop, explicitly representing cortices facing each other at bicellular junctions and the adhesion molecules that couple them. The model parameters relate directly to the properties of the key subcellular players that drive dynamics, providing a multiscale understanding of cell behaviours. The code is distributed as an open-source free software.

We show that active cell neighbour exchanges can be driven by purely junctional mechanisms. Active contractility and cortical turnover in a single bicellular junction are sufficient to shrink and remove a junction. Next, a new, orthogonal junction extends passively. Our Apposed-Cortex Adhesion Model (ACAM) reveals how the turnover of adhesion molecules regulates tension transmission and junction deformation rates by controlling slippage between apposed cell cortices. The model additionally predicts that rosettes, which form when a vertex becomes common to many cells, are more likely to occur in actively intercalating tissues with strong friction from adhesion molecules.

*Speaker

Spatio-temporal Instabilities of Blood Flows in Microvascular Networks

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Microcirculation of blood flows in networks can show strong heterogeneities in Red Blood Cells distribution due to the coupling of phase separation at bifurcations, complex rheology as well as cell-cell and wall-cell interactions (*1-3*). Theoretical investigations have shown that multiple flow configurations for a given network geometry and blood characteristics can co-exist, leading to oscillations between those states (4*, 5*). These oscillations have also been observed in-vivo (6, 7), and raise important issues in tissue oxygenation, blood regulation. They may be involved in the development of diseases such as Alzheimer (8-10).
We experimentally evidenced those instabilities by injecting RBC suspensions in a two-rung symmetric network (Fig. 1), on large ranges of hematocrits and for different channel widths.
Local RBC velocities and concentrations were measured performing image analysis in the branches of the network (cf. Fig. 1, a), and the results highlight that a channel width below $w = 20\mu m$ and hematocrit above 0.5 trigger a symmetry breaking (Fig. 1, b and Fig. 2) revealed by non-zero flow in the bridges. In addition, the thinner the channel, the higher the amplitude of RBC velocity fluctuations in the bridges.

This is confirmed when following the evolution in time of the same quantities at high hematocrit ($H \approx 0.6$) and three different channel widths (Fig. 3). It reveals that the system spontaneously jumps from state to state, with velocity reversals in the bridges when $w \leq 17\mu m$ and an amplitude of asymmetric states that increases when channel width is decreased.
This work confirms the existence of multiple or oscillatory dynamic states in microvascular networks, and we believe that it presents a strong interest for investigations in diseases caused by this instability of RBCs in blood vessel networks, since the experimental conditions investigated are close from physiological ones in the human body ($d\_\{vessel\} \approx 10\mu m$, $H = 0.4 - 0.6$). Furthermore, we will show that the experimental results are in good agreement with theoretical models, allowing us to better understand the physical phenomena driving those instabilities, and *in fine* the RBCs heterogeneities observed in vivo.

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*Speaker

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Flow of sticky particles

Olivier Pouliquen

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Characterization and prediction of the 'flowability' of powders are of paramount importance in many industries. However, our understanding of the flow of powders is sparse compared to the flow of coarse granular media. The main difficulty arises from the presence of adhesive forces between the grains, which prevent smooth and continuous flows. In this talk, we will present the results of both discrete simulations and experiments on model cohesive granular materials made of sticking grains, revealing new behaviors compared to simple dry granular materials.

Chladni patterns induced by differential diffusion

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When sand is sprinkled on a vibrating membrane, the grains move until they settle in the vibration nodes. During this phenomenon, the grains behave like passive particles, forming what are known as Chladni patterns, which make it easy to visualise the modes of the membrane. These patterns contributed greatly to the development of the science of vibrations and are still useful when designing or tuning a musical instrument. However, what pushes the grains towards the nodes, and more generally the underlying mechanisms that govern the movement of the grains, remain incompletely modelled. We propose here to consider the grains as random walkers, whose diffusivity increases with the amplitude of the membrane. This simple approach allows us to recover the dynamics of the system when the grains are sufficiently light and do not interact with the movement of the membrane.

*Speaker

About Rayleigh-Taylor instabilities in dry granular flows

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Rayleigh-Taylor instabilities occur in dry granular flows (D'Ortona & Thomas, PRL 2020). When an assembly of dense particles is put atop of light particles, a RT instability develops when the system is put into motion. More surprisingly, dry granular material flowing on rough inclines can experience a self-induced Rayleigh-Taylor (RT) instability followed by the spontaneous emergence of
convection cells. For this to happen, particles are different in size and density, the larger particles are the denser but still segregate towards the surface.

For a system initially made of two layers, dense particles above, a stability analysis is performed following the evolution of a sinusoidal perturbation of the interface. Like in fluids, the perturbation amplitude growths exponentially, the growth rate varies linearly with the Atwood number, and like in systems confined between two horizontal walls, the wavelength (l) is proportional to the flow thickness (H) l=1.9 H. In the case of very thin flows (around H=10 particles), a transition occurs where
the particle diffusion prevents the RT instability.

When the system is initially made of one homogeneous layer mixture, the granular segregation leads to the formation of an unstable layer of large-dense particles at the surface which subsequently destabilizes in a RT plume pattern. The unstable density gradient is only induced by the motion of the granular matter. This self-induced Rayleigh-Taylor instability and the two-layer RT
instability are studied using two different methods, experiments and simulations. At last, contrarily to the usual fluid behavior where the RT instability relaxes to two superimposed stable layers of fluid, the granular flow evolves to a pattern of alternated bands with recirculation cells analogous to Rayleigh-Benard convection cells where segregation sustains the convective motion. An unstable state that is self-induced by the flow is unusual in fluid mechanics. It is interesting to note that this very simple system, flowing particles having different sizes and densities, brings the sufficient mechanisms to induce self-organisation, pattern formation and
instability, features that are usually met in more complex systems like biological systems or complex chemical reactions.

*Speaker

Scaling description of frictionless dense suspensions under inhomogeneous flow

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Predicting the rheology of dense suspensions under inhomogeneous flow is crucial in many industrial and geophysical applications, yet the conventional μ(J) framework is limited to homogeneous conditions in which the shear rate and solids fraction are spatially invariant. To address this shortcoming, we use particle-based simulations of frictionless dense suspensions to derive new constitutive laws that unify the rheological response under both homogeneous and inhomogeneous conditions. By defining a new dimensionless number associated with particle velocity fluctuations and combining it with the viscous number, the macroscopic friction and the solids fraction, we obtain scaling relations that collapse data from homogeneous and inhomogeneous simulations. The relations allow prediction of the steady state velocity, stress and volume fraction fields using only knowledge of the applied driving force.

*Speaker

Quantification of the morphology of oxide powder particles in relation to their manufacturing history and flow properties

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To deepen the understandings of the physics involved in the production of nuclear fuels from ceramics, the knowledge of flow properties is essential. Indeed, the elaboration of fuels is based on successive steps of powder metallurgy processes (grinding, sieving, stirring, pressing and sintering), which require a good flowability. This good flowability also allows to obtain quality pellets and to minimize retention phenomena in the transport pipes between operations. In the literature, the flow of granular media has been subject to studies aiming at establishing the link between the physical properties of powders and their flow. The impact of parameters such as particle size, density, morphology and surface texture of particles constituting the powder has been studied in various fields such as food processing (1) or pharmaceutical (2). The application to actinide powders has also been studied (3) but only the influence of the particle size on the flow properties has been demonstrated in a quantitative way. In this work, we propose to establish a quantitative link between the morphology of oxide powder particles and their flow properties. We have developed a method to characterize the morphology of the particles, based on the Shape Filter module (4) of ImageJ, by analyzing the optical images obtained by the 2D projection of each aggregate. The morphological parameters used to characterize the powder are elongation, circularity and solidity. These images are obtained either during a dry dispersion of the powder (digital optical microscope), or during a liquid dispersion (granulomorphometer). The dry dispersion method allows keeping the integrity of the agglomerates of the powder while the liquid dispersion one leads to a deagglomeration of the powder. For a given powder, we visualize a large number of aggregates in order to perform a statistical analysis of the data. Concerning the rheological properties, they are obtained with a FT4 powder rheometer. The powder undergoes different tests (permeability, compressibility, shear...) which allow quantifying its flowability and its behavior during the transfer. Finally, we establish a link between these different properties.

*Speaker

Thermal properties of 'athermal' granular materials

Kasra Farain * [1], Daniel Bonn [2]

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Two and a half centuries after Coulomb's explanation of the angle of repose of a granular pile in relation to frictional slip between different layers, our understanding of yielding processes in granular materials remains incomplete. The main reason for this is that granular piles are comprised of a vast ensemble of discrete solid particles that interact through intricate molecular contact forces. We explore the dynamics of a dry granular system at both the granular and molecular levels, revealing two qualitatively distinct yielding behaviors. We show that, while the friction peak associated with the granular rearrangement is independent of time, the molecular friction displays aging that is thermal in nature. We observe that a granular system subjected to a sub-critical stress can show thermally activated processes through slow creep deformations. As a result, the system under stress, without granular-level friction, is susceptible to a spontaneous failure, which may occur after a delay as long as several hundred seconds. These findings have important practical implications for understanding the yielding of granular materials under various loading conditions at different temperatures, with potential applications spanning from the processing of powdered materials in the polymer, pharmaceutical, and food industries to geotechnical engineering and geophysics.

*Speaker

Effect of salinity on flows of dense colloidal suspensions

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We experimentally study the effects of salt concentration on the flowing dynamics of dense suspensions of micrometer-sized silica particles in microfluidic drums. In pure water, the particles are fully sedimented under their own weight, but do not touch each others due to their negative surface charges, resulting in a "frictionless" dense colloidal suspension: when the pile is in inclined above a critical angle
*theta*_c _˜ 5○ a fast avalanche occurs, similar to what is expected for classical athermal granular media ; when inclined below this angle,the pile slowly creeps until it becomes flat. The addition of ions in solution screens the repulsive forces between particles, and the flowing properties of the suspension are modified. We observe significant changes in the fast avalanche regime: a time delay appears before the onset of the avalanche and increases with the salt concentration, the whole dynamics becomes slower, and the critical angle
*theta*_c increases from _˜ 5○ to _˜ 20○. In contrast, the slow creep regime does not seem to be heavily modified. These behaviors can be explained by considering an increase in both the initial packing fraction of the suspension, and the effective friction between the particles. These observations are confirmed by confocal microscopy measurements to estimate the initial packing fraction of the suspensions, and AFM measurements to quantify the particles surface roughness and the repulsion forces, as a function of the ionic strength of the solution.

*Speaker

Thursday, December 7

Freezing of emulsions

Detlef Lohse

Physics of Fluids Group, Univ. Twente, Netherlands

An immersed soft particle or oil droplet is severely deformed when engulfed into an advancing ice front. This deformation strongly depends on the engulfment velocity, even forming pointy-tip shapes for low velocities. We found that such singular deformations are mediated by interfacial flows in nanometric thin liquid films separating the nonsolidifying dispersed soft particles or droplets and the solidifying bulk. The competing forces in the thin film originate from the disjoining pressure and the surface tension gradient (Marangoni forces). We analytically modelled the fluid flow in these intervening thin films, using a lubrication approximation in the boundary layers. In an exact analytical calculation and with a formal analogy to a nonlinear pendulum, we then related the fluid flow to the deformation sustained by the dispersed droplet. We find it astounding that the nanoscopic interaction (van der Waals forces, disjoining pressure) determines the shape of the macroscopic immersed soft particle or droplet. We then extended this line of research to the interaction of several immersed soft particles or droplets over which a solidification front is passing. This time it is the relative thermal conductivity of the soft particles and the liquid which determines whether the two soft particles repel or attract. We call the effect the frozen Cheerios effect. Finally, we identified a freezing-induced topological transition of a double-emulsion, i.e., an oil droplet with an immersed water droplet inside, and as a whole immersed in water, passing through a freezing front. Whether the water droplet inside the oil droplet survives or whether it literally bursts due to pressure forces emerging at solidification depends on the control parameters, in particular the freezing front velocity. This is joint work with Jochem Meijer, Pallav Kant, Vincent Bertin, and Duco van Buuren, all Physic of Fluids group, University of Twente.

The impact of polymer concentration on hydrogel freezing

Lila Seguy * [1], Suzie Protiere [1], Axel Huerre [2]

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Hydrogel is a polymer matrix able of retaining a significant amount of water. During directional freezing (the hydrogel is frozen from one side), we observe a variety of phenomena due to the presence of the polymer.
For instance, the freezing front is not flat but composed of oriented crystals whose size depends on the polymer concentration. This mechanism is notably employed in tissue engineering for bone and muscle reconstruction (1). Our experimental setups allow us to understand the influence of various parameters (velocity, temperature, polymer concentration) on the structure of this front. To observe the appearance of these crystals, we freeze a thin layer of hydrogel by placing it in contact with a copper substrate below 0○C. At high speeds, the ice is divided into circular cells separated by a mixture of polymer and water. At lower speeds, oriented crystals are formed (Supp Mat, Fig.1). The transition between these two structures is highly dependent on the hydrogel's polymer concentration.

The polymer concentration also plays a significant role in the expulsion of water by the hydrogel during freezing. Indeed, the volume increase associated with the phase change from water to ice exerts pressure on the unfrozen part of the hydrogel, causing the liquid phase release. This phenomenon can be quantitatively described in a Hele-Shaw cell, and nicely illustrated in a circular geometry. We place the 2D hydrogel drop on a cold copper substrate in a humidity-controlled atmosphere and observe its deformation as it freezes (Supp Mat, Fig 2). Depending on the polymer concentration, the hydrogel surface will not deform homogeneously, unlike a drop of pure water (2): water is expelled in particular zones.

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*Speaker

Inverse Leidenfrost impacting drops

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We investigate the spreading of ambient-temperature Newtonian drops after their normal impact on a quartz plate covered with a thin liquid nitrogen layer. As the drops expand, liquid nitrogen evaporates, generating a vapour film that maintains the drops in levitation. Consequently, the latter spread freely in *inverse Leidenfrost conditions*, undergoing biaxial extension until reaching a maximum diameter. Three spreading regimes are observed: (I) inertio-capillary (balancing inertial and capillary stresses); (II) inertio-viscous (balancing inertial and viscous stresses); and (III) inertio-viscous-capillary (for which inertia, capillarity and viscosity are all relevant). Their physical mechanisms are underlined through a mixed approach combining experiments with multiphase three-dimensional numerical simulations in light of spreading dynamics analyses, energy transfer and scaling laws. Lastly, our results are summarised in a two-dimensional diagram linking the drops' maximum expansion and spreading time with the observed spreading regimes through a single dimensionless parameter given by the square root of the capillary number (the ratio of the viscous stress to the capillary one).

*Speaker

Bouncing of Leidenfrost jets

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The Leidenfrost effect consists of a liquid droplet surfing over its evaporating vapor layer. It is now widely studied essentially because of its analogy with a drop being on a perfectly super-hydrophobic substrate. This effect has also been evidenced for systems different than the original Leidenfrost droplets: for example, drops over granular materials, sublimating solids over a heated solid substrate, or a droplet over a heated liquid. Surprisingly, the case of liquid jets has been studied solely for macroscopic jets impinging on heated plates at normal incidence to characterize the heat transfer and subsequent cooling of the plate at the contact boiling transition. In this study, we show for the first time that the Leidenfrost effect exists for millimetric impinging jets. The influence of several parameters, such as jet radius and velocity, incident angle and substrate temperature are experimentally investigated. We mainly focus on the minimal thickness of the vapor cushion and on its typical area over which the jet bounces on its own vapor layer. We also show that a directed percolation-like transition appears just before the jet enters contact boiling on the heated substrate.

*Speaker

Thermal antibubbles: when thermalization of encapsulated Leidenfrost drops matters

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Antibubbles are ephemeral objects composed of a liquid drop encapsulated by a thin gas shell immersed in a liquid medium. When the drop is made of a volatile liquid and the medium is superheated, the gas shell inflates at a rate governed by the evaporation flux from the drop. This thermal process represents an alternate strategy for delaying the antibubble collapse. We model the dynamics of such 'thermal' antibubbles by incorporating to the film drainage equation the heat-transfer-limited evaporation of the drop, which nourishes the gas shell with vapor, as for Leidenfrost drops. We demonstrate that the inflation of the gas shell is drastically inhibited by the thermalization of the initially colder drop. Because of this thermalization effect, smaller drops evaporate much faster than larger ones.

*Speaker

Flows in soap films

Isabelle Cantat

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The thinning of the liquid films separating bubbles in a foam or in a bubbly liquid controls the coalescence process and the foam stability, and is highly relevant in many industrial processes. The spatiotemporal evolution of the film thickness is governed by nonlinear equations, the solutions of which are still mostly unknown. In this talk we will discuss a few examples of flows in the plane of a horizontal foam film, driven by tiny capillary forces. These original flows will allow us to revisit the old problem of the 'marginal regeneration', a peculiar instability occuring between a flat film and a meniscus, which controls the drainage of the film.

Bursting of non-aqueous suspended liquid films induced by the spreading of emulsified droplets

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Liquid mixtures can foam (1) owing the enhanced stability of the thin liquid films trapped between bubbles. As compared to pure liquids, this stability was recently ascribed to the difference in the molecules partition between the bulk and the film interfaces with air. This results in a thickness-dependent surface tension for liquid mixtures. Consequently, in foams, thickness gradients between the films and their edge translate into surface tension gradients that contribute to feed the films and impair their drainage. Hence, the lifetimes of thin suspended films and foams of liquid mixtures are larger than that of pure liquids. As a practical consequence, industrial processes involving mixtures of non-aqueous liquids often face unwanted foaming issues. This problem is generally solved by adding anti-foaming agents, which are low-surface tension oils that are dispersed in the liquid as microdroplets. In the case of aqueous foams, the mechanisms responsible for the destabilization of the foam by these droplets have been extensively studied (2). However, the effect of antifoaming agents on oil foams is still poorly understood (3). We have shown previously (4) that Polydimethylsiloxane-rich (PDMS-rich) microdroplets dispersed in an oil mixture coalesce and spread at the air/liquid interface causing a decrease of surface tension. In this talk, I will present how these microdroplets induce the bursting of thin liquid oil films. Using a microfluidic set-up, we create suspended thin liquid films. Observing the films by interferometry allows for the measurement of the film thickness and reveals the presence of depressions, whose thickness is about 50 nm, in a fraction of the films. Occurrence of these depressions correlates well with shorter lifetimes, demonstrating that the film bursting occurs earlier in the life of the film when a microdroplet is trapped in the film. Our results show that microdroplets spread at the film interface through a Marangoni effect which causes the film to thin down faster. The effect of PDMS viscosity on the destabilization of thin films is also studied.

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*Speaker

Gravitational study on mobile soap film drainage in solid frames

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Foam stability is proven to be related to the properties of the soap films that connect its bubbles. These films are subject to evaporation and drainage, that we study experimentally. Soap films drain and thin under the effect of gravity, which is observed with single soap films supported by a solid frame where we observe Newton's rings corresponding to the local film thickness. For soap films with mobile interfaces, Mysels et al. showed the existence of an instability along the edges of the frame. Thinner soap film elements are extracted close to the meniscus and rise due to effective buoyancy, a phenomenon governing the drainage and lacking complete understanding. Here, we propose two studies to investigate the gravity role on this phenomenon.

Firstly, we tune the effective gravity in a rectangular frame, by controlling its inclination. The film thins from top to bottom. We propose an original characterisation of the drainage velocity by following the position of each Newton's rings/fringe over time. We demonstrate that the fringe speed reaches a maximum drainage value Vmax that grows linearly with the film thickness highlighting a self-similar process.

Secondly, we spin a circular soap film, in this configuration centrifugal force mimics gravity. Tuning the rotation speed enables us to vary gravity from 0.1 g to 200 times earth gravity. The film now thins from the center to the edges. We observe two zones in the film. Close to the center, concentric Newton's fringes form and close to the edges, thinner elements are extracted from meniscus. The thinner elements rise due to effective buoyancy towards the center, invading the film increasingly. Thus, the boundary between the "fringe zone" and the "thinner element zone" evolves with time. The thinner elements join their equilibrium position when they meet equivalent soap film thickness giving the boundary position over time. Align with the findings of Nierstrasz et al. for earth gravity, we find that whatever the rotation speed, the thickness of these thinner elements is always proportional to the film thickness at the border where they are produced.

These findings provide a first characterisation of the thinner elements with gravity variation, a key ingredient to understand the marginal regeneration phenomenon that governs drainage for mobile interfaces.

*Speaker

Droplet deformation under extensional flow in the presence of surfactants

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Taylor's historic experiment (1) to deform a drop under extensional flow has recently been revisited to measure the surface tension of a drop in a highly surfactant-concentrated solution (2).
In our work, we show that at lower concentrations, around the critical micellar concentration, surface tension is not sufficient to explain the observed deformation. In the vast majority of the cases we studied, the deformation undergone by the droplet is reduced compared to the case of a homogeneous interface with the same surface tension. We propose a qualitative model showing that such an observation can be explained by a strong asymmetry between the slow adsorption of surfactants at the equator and their rapid desorption at the poles.

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*Speaker

Enhanced lifetimes of foams of binary mixtures: modelling pinching dynamics

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The enhanced lifetimes observed in foams of binary mixtures remained unexplained until recently. The effect originates from slight differences in molecular concentrations between the bulk and the surfaces, leading to a thickness-dependent surface tension of thin films. In a recent study, a mechanism for equilibration of film tension was explored and an analytical solution formulated which describes the film profile before significant drainage occurs due to local pressure gradient. In this work, we further model the equilibration of the pressure gradient causing drainage and subsequent marginal pinching. The governing equations are derived in the lubrication limit of Navier-Stokes equations, coupled with an evolution equation for surface tension, derived from thermodynamic principles. We describe a parabolic velocity profile without imposing immobile interfaces to describe the pinching dynamics of binary mixtures. Our model suggests a scaling law for film lifetime which successfully validates experimental findings of films in binary mixtures, that cannot be explained by earlier theoretical models based on immobile interfaces. Our work provides new insight on the rupture of thin films stabilised by a surfactant-like effect.

*Speaker

Flows in bursting soap films

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A soap film is a thin layer of liquid with surfactant at its interface. Surfactants lower its surface tension and stabilize it.
When a liquid film without surfactant molecules is punctured, a hole appears and grows at a well-defined speed called Taylor-Culick velocity, resulting from the balance between surface tension forces and inertia (1). With surfactant the film retraction is more complex. Indeed, during the film bursting, ahead of the hole edge's called rim, flow can sometimes be observed. This area containing the flow is then named the aureole (2).
This flow arises from the reduction in surface tension within the aureole, leading to a local thickening of the film due to the Marangoni effect. It does not come without an impact on the film's opening speed, as it decreases at the same time. The variation in surface tension is caused by the rapid bursting of the film (the film area decreases and vanishes in few ms), which compresses the surfactants at the interface, making it a completely out-of-equilibrium phenomenon (3). The relation between surface tension and the degree of film compression is referred to as elasticity.
To probe this elasticity, a dedicated setup has been built to track the aureole dynamics. We first create a vertical fluorescent soap film of 20 centimeters from the top to the lower meniscus and then puncture it. The entire thickness field is measured by the brightness of fluorescence emission with a high-speed camera during the opening. Combining the mass and momentum conservation equations and the thickness measurement, we can estimate the local flow and surface tension during the bursting.

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*Speaker

Generation of tsunami waves by landslides

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Tsunami waves can be generated by earthquakes but also by landslides such as by the recent partial flank collapse of Anak Krakatau (Indonesia) in 2018. To improve the prediction of these dangerous waves, we have considered the gravity driven collapse of a granular column into water in a quasi-two-dimensional setup and systematically investigated the influence of the initial geometry of the column and the water depth on the impulse wave generated. Our experiments reveal three nonlinear wave regimes: transient bores and solitary waves for shallow water, and "Cauchy-Poisson" waves for deep water. By coupling the dynamics of the column collapse to the wave generation in shallow water, we develop a model that allows us to estimate the amplitude of the generated wave either to the initial conditions or to the final immersed volume of grains. As a result, the tsunami wave generated by a landslide can be estimated from the knowledge of the pre-landslide geometry and bathymetry in a preventive approach, or from the final immersed deposit of a past geophysical event. The present modeling contributes to a better understanding of such events with complex granular and fluid flows.

Impact of shear-thickening capsules

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Dense suspensions exhibit shear-thickening, denoting a reversible increase in viscosity under external shear. While the steady-state rheology of dense suspensions has been extensively studied, the dynamics of the shear-thickening transition remain to be described. By filling thin elastic shells with shear-thickening suspensions, we study the deformation of capsules during their impact on a solid substrate. Liquid-filled elastic capsules are known as an analogue of liquid drops during impact. We will first describe the influence of the liquid viscosity on the spreading of capsules filled with Newtonian liquids. We will then show how the dynamics of the deformation of a capsule is dramatically altered in the case of a shear-thickening content. Finally, we will demonstrate how those observations provide access to rheological measurements and rare insights into the dynamics of solidification during the shear-thickening transition.

*Speaker

Yielding of soft glasses under oscillatory shear: new insights from intra-cycle response and microscopic dynamics

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Concentrated colloidal suspensions and emulsions are amorphous soft solids, widespread in technological and industrial applications and studied as model systems in physics and materials sciences. They are easily fluidized by applying mechanical stress, undergoing a yielding transition that still lacks a unified description. By inspecting the intra-cycle stress response of different soft glasses to an imposed oscillatory deformation and decomposing it into an elastic and a viscous contribution, we will first show that yielding very generally consists in a continuous transition from a transient shear thickening to a shear thinning behavior, the latter appearing when the two stress components are both nearly constant within the same finite window of strain and strain rate. We revise the standard definition of yielding, namely the crossover between the first harmonic storage and loss modulus, in the light of this new finding.
At the same time rheo-scattering experiments have allowed recently to investigate the yielding transition on the microscopic scale, showing that yielding consists in a transition from "quiescent" ballistic to shear-driven diffusive dynamics.

To rationalize such fundings we have introduce a new on-lattice model (1,2) in which the dynamics of mesoscopic portions of a glass result from both spontaneous and shear-induced relaxation processes, and from the dynamical coupling between neighboring sites. A mean field solution of the model yields a law of correspondent states equivalent to trajectories on a "cusp catastrophe" (3) manifold, a well-known class of problems, including first order phase transitions in real gases, producing an abrupt jump of the system properties upon a continuous change of a control parameter, the strain amplitude here. We show that disorder in the coupling between neighboring sites is a key ingredient to obtain states in which fluid and glass portions of the system can coexist, hence determining the sharpness of the yielding transition.

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*Speaker

Nanorheology and Dynamic SFA

Nathan Bigan * [1,2], Antoine Niguès [1], Marc Pascual [2], Lyderic Bocquet [1], Alessandro Siria [1]

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Tapping mode Atomic Force Microscopy used as dynamic Surface Force Apparatus is a powerful method to access fluids rheological properties. It allows to decouple real and imaginary mechanical impedances corresponding respectively to the elastic and viscous responses of the studied fluid. Such a device has been successfully used to study ionic liquid response under confinement (1), shear thinning of suspensions (2), ice friction (3) to name a few.
Generally, an increase of the frequency shift is observed during the approach, as the studied fluid is confined between the probe and the substrate. However, in certain configurations, a decrease of the frequency shift has been reproducibly observed (see fig 1b of the article about capillary freezing of ionic liquids (4)). Such a decrease cannot be explained by van der Waals attraction.

Using fluids of different viscosities, different substrates, various probes and resonators (millimetric and centimetric), we isolate the relevant parameters at stake and build a model explaining these observations. Besides, the advantage of using a macro resonator instead of a standard quartz tuning fork relies on its ability to proceed in environmental conditions with high reproducibility and easier handling (5). Another asset of this setup is the ability to work with millimetric probes.

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*Speaker

Non-Hermitian hydrodynamics of viscoelastic channel flow: Short review

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I shortly review mostly experimental results and development for the last several years in polymer solution channel flow including non-normal elastic instability, elastic turbulence, drag reduction, elastic waves, mechanism of vorticity amplification by elastic waves, universality in properties of non-Hermitian hydrodynamics independent of external perturbation intensity, and recently stochastic resonance.

*Speaker

Influence of adhesion in the shear-thinning of non-Brownian suspensions

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The mechanisms at play in the shear-thinning of non-Brownian suspensions still raises open questions. In the present work, we propose to study experimentally the influence of adhesive forces on the shear-thinning behavior of suspensions. To this aim, we compare the rheological behaviors of different suspensions of polystyrene particles whose surface properties have been modified by click chemistry. The recorded shear-thinning behaviors are correlated with direct measurements of adhesive forces performed by AFM. The results are then confronted to semi-empirical models.

*Speaker

Numerical Investigation of Dynamic Behavior of two Fluids in a Rotating Cylinder

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The behavior of vortices in multiphase flows is a challenging aspect of fluid mechanics. These vortices can be encountered in various industrial applications, such as in the wake of a propeller, where they are characterized by an air vortex
core surrounded by water.
In the research field, multiple approaches have been explored to comprehend their dynamics. One of these approaches involves studying the dynamic behavior of two non-mixable fluids confined within a rotating cylindrical container,
with the axis of rotation oriented perpendicular to the gravitational field.
For our analysis, we take a numerical approach using the CFD Basilisk flow solver (Popinet 2009) in a 2D configuration.
The main aspect of this setup revolves around the difference in density between the two fluids. The density ratio causes the denser fluid to move toward the cylinder wall due to centrifugal forces.
At high rotational speeds, a quasi-periodic motion of the inner fluid around a slightly off-center mean position is observed, with this mean shift scaling inversely with the Froude number (Fr). This behavior is in good agreement with
the experiment (1). At low rotational speed (Fr $<$ 3), the inner fluid migrates into a region of higher velocity, leading to a chaotic motion and vortex shedding from the interface. The critical Froude number (Fr_c) matches with the analytical analysis of Phillips (2). A stability analysis conducted by Kozlov et al. (3), omitting surface tension and viscosity, reveals the appearance of two distinct
waves at the interface with different frequencies.
Furthermore, we perform an additional analytical study to investigate the impact of surface tension and viscosity on the system's stability.
Keywords : Multi-phase flow, Vortex, CFD, Surface Tension, Stability Analysis.

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*Speaker

Taylor's Swimming Sheet near a Soft Wall

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In 1951, G.I.Taylor1 modelled swimming organisms by hypothesizing a 2D infinite sheet swimming due to a wave passing through it. This simple model not only captured the ability to swim as a result of wavy motion of the flagella but further development into the model captured the optimal nature of metachronal waves observed in ciliates. While the effect of confinement near rigid walls was studied by Katz2 and Reynolds3, we focus on the correction to swimming velocity generated due to the softness of the wall. By following the analysis akin to the studies on lift forces observed near soft gels and elastomers, we explore whether this softness of the boundary can enhance the swimming velocity of the micro-organism or not, for a small compliance of the wall.

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*Speaker

Optimum control strategies for maximum thrust production in underwater undulatory swimming

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Fish, cetaceans and many other aquatic vertebrates undulate their bodies to propel themselves through water. Numerous studies on natural, artificial or analogous swimmers are dedicated to revealing the links between the kinematics of body oscillation and the production of thrust for swimming. One of the most open and difficult questions concerns the best kinematics to maximize this later quantity for given constraints and how a system strategizes and adjusts its internal parameters to reach this maximum. To address this challenge, we exploit a biomimetic robotic swimmer to determine the control signal that produces the highest thrust. Using machine learning techniques and intuitive models, we find that this optimal control consists of a square wave function, whose frequency is fixed by the interplay between the internal dynamics of the swimmer and the fluid-structure interaction with the surrounding fluid. We then propose a simple implementation for autonomous robotic swimmers that requires no prior knowledge of systems or equations.

*Speaker

Stick-slip to stick transition of liquid oscillation in U-shaped tubes: a projection method

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The role of wetting properties in the damping of liquid oscillations is a long-standing problem in hydrodynamics. A series of lab-scale experiments(1,5) have revealed that the damping of liquid natural oscillations varies nonlinearly with the oscillations amplitude, indicating a dependence on the contact line behaviour and hence on the solid substrate material. This effect has been attributed to a source of dissipation localized near the sliding triple line, which may exhibit a complex hysteretic behaviour due to solid-like wall friction. Consistently with previous observations(5), Dollet et al. (2020)1 have confirmed that contact angle hysteresis can explain and qualify this wall friction, responsible for the contact line finite-time arrest. In this work, assuming an experimentally inspired phenomenological contact line behaviour(3,5), we apply to U-shaped tubes the projection method formalized in Bongarzone et al. (2021)(2) for idealized two-dimensional viscous capillary-gravity waves. This approach is based on successive linear eigenmode projections for solving numerically the nonlinear dynamics in the limit of small oscillation amplitudes. Each projection, corresponding to each stick-slip transition, eventually induces a rapid loss of total energy in the liquid motion and contributes to its nonlinear damping(5). In order to retain the viscous dissipation occurring at the sidewall boundary layers, the original formulation(2) is amended with a wall-slip condition with a spatially variable slip length(4). Quantitative comparisons with experiments(1) show that the projection method correctly captures the final stick-slip to stick transition, as well as the secondary fluid bulk motion following the associated arrest of the contact line, overlooked by previous asymptotic analyses(1,3).

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*Speaker

Wake structure of a robotic fish

Christophe Brouzet * [1], Christophe Raufaste [1], Médéric Argentina [1]

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Aquatic locomotion is at the origin of a complex interplay between the undulating body of the swimmer and the induced flow. At intermediate and high Reynolds numbers, vortex formation and organization in the wake are central for the generation of a propulsive force. Understanding the different wakes that a swimming animal can produce is fundamental as the wake represents the hydrodynamic signature of the motion of the animal and can influence drastically how several animals swim together. In this work, Particle Image Velocimetry (PIV) experiments have been performed to study the wakes of a robotic fish swimming in a water tunnel. The observed wakes exhibit a classical V-shape. The angle and the structure of the wakes will be discussed in detail in the framework of fluid/structure interactions and vortex dynamics within each wake, as a function of the swimming control parameter.

*Speaker

Instabilities of two bubbles or drops in contact

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The mathematical solution for axisymmetric surfaces with constant mean curvature (Delauney surfaces (1)) is used to understand mechanical interactions between drops, bubbles or capillary bridges (2,3). We show the limitations of this model for different constraints with two bubbles in contact sitting on a fixed frame with radius R and distance $2h$ (see figure). We use experimental, theoretical and computational approaches (Surface Evolver (4)). The figure shows our obtained shape diagram, which indicates under which constraints the bubbles remain axisymmetric and in contact. Due to four different instabilities, the bubbles lose contact or lose their axisymmetry. Two of these four instabilities (2 and 3) have been discovered by us. The influence of different contact angles θ between the bubbles is also investigated. The shape diagrams of the two limiting cases with θ=0° and θ=180° have been obtained. Using these diagrams and theory, the stability and mechanical properties of capillary bridges or bubbles in contact under tension or compression can be predicted (5). The provided analysis holds equally for bubbles or drops.

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*Speaker

Friday, December 8

Roaming condensation and explosive freezing of droplets

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Drop coalescence in early stages

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Despite the large body of work dedicated to the problem of coalescence, currently experiment, theory, and computation are not in agreement with respect to the earliest times following the initial contact of the two drops. We show experimentally by using a system with an ultralow interfacial tension that the very first instants are governed by thermal fluctuations at the interfaces, revealing a crossover between deterministic hydrodynamic motion and stochastic thermally driven motion. Subsequently, the contact grows hydrodynamically, but is observed to do so in a way that is strongly influenced by the geometry: two drops show inertio-capillary coalescence whereas a drop and its bulk liquid exhibits inertially limited viscous dynamics, in which capillarity, viscosity and inertial forces compete.

*Speaker

Receding contact line dynamics on textured surfaces and the capillary bridge technique.

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Superhydrophobic surfaces are known for their exceptional water repellency. These surfaces have been extensively studied in the literature, but their dynamic behaviour has received less attention, and to the best of our knowledge, there is no literature on water contact angles as a function of contact line velocity on superhydrophobic surfaces. Previous studies have often used more viscous liquids to extend the range of experimentally accessible capillary numbers (1).
We have investigated the dynamic wetting properties (receding contact angles) of textured surfaces using the capillary bridge technique (2-3) that allows the exploration of large contact areas (centimetric scale) involved in practical applications.

We present water dynamic contact angle measurements on superhydrophobic surfaces made of a micropillars array, with contact line speeds spanning five decades. We have investigated the effect of pillar fraction on the dynamic contact angles from the smooth surface (f =1) to f =0,2. We have compared these measurements with similar systems reported in the literature and with theoretical models.

We show that a higher surface fraction of pillars leads to a stronger dependence of the contact angle on the contact line velocity. These results are interpreted in terms of different sources of dissipation for superhydrophobic surfaces, shedding light on the underlying mechanisms governing their unique dynamic behaviour.
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*Speaker

Hydrogen bubble growth on model wire electrodes

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In order to optimize the production of hydrogen by water electrolysis, the current trend in industrial systems is to increase overall electrode area by shifting from flat surface electrodes to complex mesh or printed porous electrodes. This increases the amount of nucleation sites and, hence, bubble production in the system. As bubbles have an insulating effect, their presence is detrimental to hydrogen production. Therefore, understanding how bubbles grow on porous electrodes and how they detach and escape from them is important. In this work, we experimentally examine bubble growth and detachment on model electrodes formed of one or multiple wires. We find that bubble size follows a diffusive-like growth. Once bubbles reach a critical size they interact via coalescence or via scavenging effects during detachment. This determines the overall growth dynamics and the volume of the bubbles that remain attached to the wires. The critical volume at which bubbles detach depends strongly on the geometry of the electrode, given that crossings between wires act as capillary traps hindering detachment.

*Speaker

Stabilité de gouttes liquides confinées couvertes de particules : rôle du transport à l'interface.

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Lorsqu'une goutte d'huile suspendue dans l'eau passe dans un pore dont le diamètre est plus petit que la taille de la goutte, celle-ci se déforme et peut passer le pore si la pression appliquée en aval du pore est suffisamment élevée. La goutte confinée et déformée voit sa surface augmenter, et se déplace dans le canal avec un film de lubrification constitué par la phase continue, qui sépare la goutte de la paroi du pore, et dont l'épaisseur est d'autant plus grande que la goutte va vite.
Dans de nombreux procédés de traitement des eaux, la question de la stabilité de gouttes d'huile dans l'eau se pose, en particulier lorsque des grains solides viennent stabiliser la surface des gouttes, ce qui empêche par exemple la coalescence et le crémage de telles émulsions. La filtration de ces émulsions est alors envisagée : pour cela, on cherche à prévoir la stabilité des interfaces de gouttes d'huile recouvertes de particules solides lors de leur passage dans des pores.
A l'équilibre, une interface liquide/liquide couverte de particules a un comportement qui a été bien décrit dans la littérature. Lorsque le taux de couverture en particules est faible, l'interface est caractérisée par la même tension interfaciale qu'en l'absence de particules. On peut aussi parler de pression de surface et, dans le cas dilué, elle est donc nulle. En augmentant le taux de couverture de l'interface par des particules solides au-delà d'une fraction de surface seuil, l'émergence d'intéractions répulsives entre particules conduit à une augmentation de la pression de surface de l'interface. Un autre seuil peut être franchi lorsque les particules se touchent : l'interface se comporte alors comme une plaque élastique 2D à laquelle on peut attribuer un module de compression et de courbure, de sorte qu'on peut voir l'interface flamber et se rider.
Ainsi, lorsqu'une goutte d'huile couverte de particules traverse un pore, le mouvement de la goutte et celui du radeau de particules sont susceptibles de se coupler via l'émergence de cette pression de surface et de ses gradients. En réalisant des expériences sur un système modèle où une goutte de rayon donné traverse un pore cylindrique à la géométrie bien définie, poussée par une différence de pression contrôlée, nous avons pu décrire les régimes d'écoulements de la goutte et du radeau, en rendre compte par des modèles. Nous avons ainsi établi que lorsqu'une goutte d'huile couverte de particules solides, dans l'eau, traverse un pore, son mouvement est contrôlé par l'écoulement du radeau de particules à l'interface. Ce dernier est limité par la dissipation dans le film de lubrification entre la goutte et le pore, qui peut être soit visqueuse soit frictionnelle, et promu par le gradient de pression de surface créé entre l'avant et l'arrière de la goutte. Si la pression de surface ne relaxe pas, le radeau de particules flambe et si le flambement est géométriquement impossible, les particules sont expulsées de la surface. Ces régimes sont prédictibles et dépendent des dimensions et de la vitesse de la goutte (du nombre capillaire).

*Speaker

Experimental study of confined large bubbles rising in Newtonian and shear-thinning liquids

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Bubbly flows confined in planar thin-gap cells are present in various industrial devices such as photo-bio or photo-chemical reactors, often involving non-Newtonian liquid phases. However, the scaling laws for the motion of confined bubbles are not clearly established. We present a comprehensive experimental study of isolated confined air bubbles of area-equivalent diameter d rising in a liquid initially at rest. Different liquids were tested in a vertical planar cell of large in-plane dimensions and gap width $w <$ d. We explore the inertial-viscous transition using different mixtures of water and glycerol, in contrast to the inertial regime developing in pure water. The results provide comprehensive reference data as a benchmark for experiments in non-Newtonian liquids. Finally we investigate the effect of a shear-thinning rheology by means of low-concentration aqueous solutions of xanthane.

The data compares successfully to existing literature in a confined medium for Newtonian (1) and shear-thinning liquids (2). Our major observations include the evolution of the bubble shape as a function of its size, velocity discontinuities in viscous and shear-thinning liquids, and the formation of a negative wake in shear-thinning liquids (3), which we characterize. Time-resolved PIV was conducted in an attempt to improve our understanding of the different regimes and behaviors, especially in the inertial-viscous transition where most of our cases stand (1).

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*Speaker

Drops bouncing on a vibrating smooth mica sheet

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Drops exhibit fascinating rebound behavior when interacting with superhydrophilic solid surfaces, such as atomically smooth mica sheets (1). Experimental observations show that drop bouncing occurs without the drop ever touching the solid and there is a nanometer-scale film of air that separates the liquid and solid. At touchdown, the drop experiences both primary and secondary reaction forces, strongly influencing its deformation and subsequent jump-off mechanism (2).
In the case of a vibrating stage, the drop can either remain in a 'bound' state, that will eventually lead to contact, or enter a sustained 'bouncing' state triggering harmonic oscillations. We investigate the bouncing and period-doubling thresholds up until chaos for varying accelerations γ/g, with γ the peak stage acceleration, and vibration numbers $2\pi f/\sqrt{}\{\sigma/\rho R3\}$ corresponding to the ratio between the forcing frequency and the characteristic drop oscillation frequency.
We use the free software basilisk (3) to solve the two-phase Navier-Stokes equations in an axisymmetric formulation by the Volume-Of-Fluid method on quadtree adaptive meshes. The numerical results demonstrate a remarkable agreement with experimental observations, facilitating a comprehensive exploration of the system's dynamics and allowing us to extend the regime diagram of previous work on a similar setup (4). Extracting the coefficient of restitution C_R and the characteristic time 'close-to-contact' τ_C, we are able to cast a simplified linear spring model that accurately predicts the drop center oscillation for any given set of parameters. Moreover, precise predictions of the airflow within the thin air layer and the associated viscous dissipation allows us to expand previous numerical investigations (5) on the energetics of the drop rebound.

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*Speaker

How “bound” water controls water transport in plant fibers

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How does water penetrate wood and make it swell? Why do we feel more comfortable in cotton, flax, or hemp clothes? Why is it so long to dry wood or paper? Why is it healthier to live in a house made of biobased walls? At the origin of these phenomena is the remarkable ability of these materials to absorb liquid water or vapor from the environment thanks to hydrogen bonds, and thus to form nanoscale water inclusions between cellulose microfibrils. This so-called “bound water” can represent up to 30The transport of bound water and its exchanges with the (standard) liquid and vapor phases lead to complex and original fluid transport properties in cellulosic materials or plant fibers. For example, the spontaneous imbibition of water in wood is not governed by capillary effects but by a bound water diffusion ahead of the liquid front, which slows down the dynamics by several orders of magnitude of time [1]. For its part, the drying of wood is controlled by the bound water diffusion which extracts free water in depth in the sample, again leading to a (slow) two-step diffusion process [2-3]. The observation and quantification of these phenomena require specific techniques or approaches, NMR and MRI being very helpful as they allow to detect molecular water amounts inside solids [4]. We will show how one can determine the transport diffusion coefficient of bound water in a wood piece, in a fiber network (the bound water jumping from one fiber to another in contact with it), and even along a single cellulosic fiber [5]. We will also show how further tests allow to determine specifically the vapor diffusion coefficient through the porosity, which finally makes it possible to build a general diffusion model of the transport of water through such systems under hygroscopic conditions.

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Air invasion in a biomimetic leaf-on-chip

François-Xavier Gauci * [1], Ludovic Keiser , Celine Cohen , Benjamin Dollet , Philippe Marmottant , Xavier Noblin

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Global warming will lead to increasingly severe droughts and threatens most of the forests across the globe (1). Trees facing drought conditions are particularly threatened by the formation of air embolisms, which hinder the flow of sap and could ultimately result in their demise. Within the context of leaves, the occurrence of embolisms has been observed to spread intermittently and possibly result in catastrophic events (2). By using PDMS-based biomimetic leaves to reproduce evapotranspiration (3), it has been shown for a linear geometry that the presence of a narrow constriction in the channel enables to generate intermittent embolism propagation. This intermittent dynamic originates from an elasto-capillary coupling between the air / water interfaces and the compliant structure of the biomimetic leaf venation (4).
In this talk I will show how embolism propagates in a more complex biomimetic network mimicking various leaf venations. By controlling the constrictions size and the coordination of the network, we are able to replicate the main features of embolism growth in real leaves, namely intermittency, trajectories and hierarchy, both experimentally and numerically. We will finally discuss the relevance of our approach in terms of materials and structure.

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*Speaker

The thinning of antibubbles

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An antibubble is a thin film of gas, within a liquid medium, that encapsulates a liquid droplet. Because hydrostatic pressure is higher at the bottom of the thin film than at the top, the gas drains upwards. These drainage dynamics are limited by the ability of the interfaces to carry stress, which induces a shear flow in the gas phase. Several works have studied the effect of surface rheological parameters on this process, in particular: surface viscosity and surface elasticity. The role of gas transfers has also been studied, since those contribute to the overall thinning of the film. The models are verified with the help of lifetime measurements. Here, we propose an original optical methodology to retrieve the absolute thickness profiles of the thin film of air by using coherent monochromatic light. The direct comparison of the measured thinning dynamics and the available models are then discussed in terms of the coupling between surfactant molecules and surface rheological properties of the interfaces.

*Speaker

Poster sessions

Plastocapillary impacting drops

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The impact of fluid drops on solid substrates is a cardinal fluid dynamics phenomenon intrinsically related to many fields. Although these impacting objects are very often non-spherical, and non-Newtonian, previous studies have mainly focused on spherical Newtonian drops. As a result, both shape and capillary-rheological effects on the drop-spreading dynamics remain largely unexplored. Here, we use a mixed approach combining experiments (with bentonite colloidal suspensions) and multiphase three-dimensional numerical simulations to extend works reported in literature. More specifically, we highlight the physical mechanisms driving the spreading of capillary-affected viscoplastic drops after their normal impact onto a solid surface. Such complex fluids are highly common in various industrial domains and ideally behave either like a rigid body or a shear-rate-dependent liquid, according to the stress solicitation. Spherical and prolate drops are considered. The results show that, under negligible viscous effects, the impacting kinetic energy of the drop can be plastically dissipated and/or converted into surface energy during the spreading process, giving rise to three flow regimes: (I) inertio-plastic (balancing inertial stress and yield stress); (II) inertio-capillary (balancing inertial and capillary stresses); and (III) mixed inertio-plasto-capillary (for which inertia, capillarity and plasticity are all relevant). These regimes are deeply affected by the drop initial aspect ratio, which in turn reveals the possibility of using drop shape to control spreading. The physical mechanisms dominating the considered phenomenon are underlined in light of energy transfer, and scaling laws. The results are summarised in a two-dimensional diagram linking the drop maximum spreading, minimum height, final shape, and spreading time with the mentioned spreading regimes through a single dimensionless parameter called here impact number.

*Speaker

Investigation of fibril formation during a tack test on Pressure Sensitive Adhesives

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Pressure sensitive adhesives (PSA) are a type of adhesive that can be applied to a surface with minimal pressure and will adhere strongly to that surface. PSAs are widely used in many applications, such as labels, tapes, and medical devices. The adhesion mechanisms of PSAs are complex and not yet fully understood, but several key factors that contribute to the strong adhesion of these materials have been identified (1) (2).
Probe tack test is a typical method to characterise a pressure sensitive adhesive (PSA). It consists in measuring the force required to detach a probe from an adhesive surface. The test is typically performed using a probe that is, first, pressed against the adhesive surface, then pulled away at a specific velocity. A probe tack test for a PSA typically involves several stages, including the initial contact, the negative loading phase, and the detachment phase. In the initial stages of the debonding, cavitation appears under the effect of the strong negative stresses, which corresponds to an increasing force vs displacement. The maximum measured in the displacement/force curve corresponds to the maximum spreading of these cavities. Beyond this stage, the surface of cavities still increases, while the contact lines movement is stopped. Simultaneously, fibrillation phase occurs, in which fibrils are mostly elongated. The final stage of the test is the detachment phase where the adhesive fibrils break within the adhesive, rather than at the adhesive/substrate interface.

We report on experiments on PSAs with different rheological parameters. We used an ARES G2 rheometer to perform a tack test between two parallel plates and monitor the associated force and fibril geometries (length and density) using optical methods. The tests results are used to determine the relationship between the different dissipative mechanisms induced in the whole process, by varying temperature, probe velocity and confined aspect ratio to initiate different fibrillation patterns.

Keywords: PSA , tack test , viscoelasticity , rheo-optics.

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*Speaker

Linear stability of a generalised Newtonian fluid down an incline: unifying the roll waves

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Free surface flows driven by gravity over an incline are encountered in many domains, such as civil engineering, industrial processes and natural hazards.
When the Reynolds number is above a critical value Rec, the flow becomes unstable because of inertia, and small disturbances amplify into large amplitude roll waves.
In many applications, the fluids involved are non-Newtonian.
We will present a model that predicts the apparition of these instabilities and gives an analytic expression of Rec, for any fluid following a generalised Newtonian rheology, i.e. for which with the shear stress, the shear rate and the apparent viscosity.
We will examine the prediction of the model for several classes of fluids: shear-thinning, shear-thickening and viscoplastic.
We will show that our results agree with the numerous models and experiments found in the literature for specific rheologies; and that it gives a straightforward prediction for fluids with rheologies never studied before in this context.

*Speaker

Experimental investigation of viscoplastic surges over complex topographies

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Viscoplastic fluids are encountered in a wide range of applications, from confined flows in industry to free surface flows in geophysics. For the latter, the flow is often influenced by topographical features that can block, redirect or channel the flux. Finely modelling the complex interactions between rheological effects and topography is of a great importance, e.g. in natural hazard management to predict flow trajectories and runout. If numerous experimental studies of viscoplastic surges down planar slopes or inclined channels can be found in the literature, experiments of viscoplastic surges on complex topographies remain rare. To that end, we report on well-controlled experiments aimed to characterize transient flows of Carbopol on 3D-printed model topographies. The fluid is released from a rectangular reservoir (column collapse). Using Moiré projection and Fourier Transform Profilometry, the evolution of flow thickness over time can be recovered with a typical accuracy of 0.5 mm and a temporal resolution of 250 Hz. Release position, release volume, fluid rheological properties and the topography itself are varied to investigate different flow regimes and interactions with the topographical features. In particular, an abrupt transition is highlighted between an initial inertial regime and a regime mainly controlled by rheological effects. The influence of obstacles (dams, mounds) on this transition is observed. Preliminary comparisons between these experimental results and numerical simulations relying on shallow-flow assumptions will also be shown, with the objective to assess the predictive capabilities of the models.

*Speaker

Wake effects of large particles in a dry granular flow

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We show experimentally and numerically that two large particles in a dry granular flow down an incline interact. The large particles, called tracers, are observed to align in the direction of the flow in all cases. Depending on parameters, the tracers either flow at a defined longitudinal distance, which may be zero (tracers are in contact), or stand as far apart as possible: their interaction can be either attractive or repulsive. A thorough parametric study is performed numerically on the size ratio between the tracers and the small flowing particles and on the thickness of the granular flow, as well as on the incline slope and roughness, and the densities of the tracers with respect to the small-particle density. The DEM simulations demonstrate a difference in height of the tracers within the flow, with a tendency for the front tracer to rise and for the back tracer to sink, and the existence of a master curve that links the equilibrium longitudinal distance between the tracers and their height difference in the flow. We show that the wake effects of each large particle on the other, combined with the vertical shear in the flow, control the relative position of the tracers. For polydisperse flows, this may result in internal flow organizations that break the homogeneity of the flow and can be of major interest in natural granular flows or industrial problems.

*Speaker

Dense Granular Flow: A Fluid of Hard Spheres ?

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Flows of granular matter are commonly observed in industries and geophysical events. Nevertheless, despite decades of research, the theoretical understanding of the rheological properties remains elusive, especially at the grain scale. We tackled the case of dense granular layers flowing down inclined planes. Macroscopic and microscopic properties are obtained from Discrete Element Method simulations for both frictionless and frictional grains. We built a toy-model based on an analogy with the statistical mechanics of a thermal fluid of hard spheres. This theoretical approach properly rationalizes the observations and eventually provides insight into the microscopic foundation of a very popular semi-empirical model, the mu(I)-rheology.

*Speaker

Enhancement of the magnetorheological effect using discontinuous shear thickening

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The phenomenon of discontinuous shear thickening (DST) is observed in suspensions of solid particles at a very high volume fraction. It is characterized by a sudden increase in viscosity above a critical stress. This jump of viscosity can be reproduced in numerical simulations by introducing a transition from lubricated contacts between particles to frictional ones above a given local force between particles. Using a suspension of conductive magnetic particles at high volume fraction we have, for the first time, demonstrated experimentally the presence of a frictional network of particles by a simultaneous measurement of the electrical resistance of the suspension and of the rheological curve(1). We have shown that this transition can be monitored by the application of a magnetic field and that even a small fraction of ferromagnetic particles (about 5% in volume) within a concentrated suspension of larger non magnetic particles, was sufficient to trigger the DST transition by the application of a magnetic field (2). This is also the case in capillary flows under controlled pressure. We explain these results by the formation, in the presence of the magnetic field, of elongated clusters of the small magnetic particles whose rotation in the cage between the large particles triggers the jamming of the already dense, but still at a subcritical volume fraction, suspension of non magnetic particles (here calcium carbonate).

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*Speaker

Transition to non-newtonian dynamics in drops of polymer solution

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Many natural or industrial flows involve the breakup of liquids into droplets, and many of these liquids contain polymers or suspended grains. At low scales and high strain, the flow reveals the composition of the liquid, since the components may deform, organize, separate, etc, and thereby change the rheology. We first study the pinch-off of drops of polymer solutions; we show that the transition between the well known Newtonian and viscoelastic regimes follows a universal dynamic, linked to the coil-strech transition. Then, we add spherical particles (size range 20-250μm) to the solution. Their presence increase the local strain rate felt by the polymer and so enhance the coil-stretch transition. This experiment enables the measurement of the amplification of strain in the fluid phase of a granular suspension; we perform these measurements for monodisperse and bidisperse suspensions.

*Speaker

Viscoplastic droplet generation in a microfluidic flow-focusing channel

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One of the essential microfluidics applications concerns the fabrication of micrometric drops via stretching and breakup of viscoplastic fluids (materials that ideally behave either like a rigid body or a shear-rate-dependent liquid, according to the stress solicitation) in a flow-focusing microchannel. In these connections, a dispersed viscoplastic phase is stretched by a continuous Newtonian phase leading to the dispersed phase breakup and then giving rise to viscoplastic micro-droplets. Depending on the flow parameters and the capillary-rheological properties of the considered fluids (viscosity, yield stress and surface tension), the obtained droplets can exhibit a variety of final shapes, from spherical to prolate. The stretching/breakup mechanisms driving the generation of each of them are highlighted in the present work through multiphase three-dimensional numerical simulations in light of spreading-breakup dynamics analysis, energy transfer and scaling laws. The results (obtained under negligible inertial effects) are summarised in a two-dimensional diagram linking the different droplet final shapes with the generalised capillary number (ratio of the sum of the viscous and the yield stress to the capillary pressure). Our study has direct applications in several droplet-based situations, which include the encapsulation of bioactive agents (such as drugs, proteins, and cells) for drug delivery, artificial cell generation, tissue engineering, and bioassays.

*Speaker

Lagrangian Tracers in Bacterial Turbulence

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We use the mean-bacterial-velocity model to investigate the irreversibility of two-dimensional (2D) bacterial turbulence and to compare it with its 2D fluid-turbulence counterpart. We carry out extensive direct numerical simulations of Lagrangian tracer particles that are advected by the velocity field in this model. We demonstrate how the statistical properties of these particles help us to uncover a critical, qualitative way in which irreversibility in bacterial turbulence is different from its fluid-turbulence counterpart: For large but negative (or large and positive) values of the activity (or friction) parameter, the probability distribution functions of energy increments, along tracer trajectories, or the power are positively skewed; so irreversibility in bacterial turbulence can lead, on average, to particles gaining energy faster than they lose it, which is the exact opposite of what is observed for tracers in 2D fluid turbulence. Furthermore, we will show how various Lagrangian variables, such as velocity and acceleration, are intermittent (with a multifractal spectrum) for a wider range of parameters as opposed to their Eulerian counterparts, which are intermittent only for extreme activities.

*Speaker

A lattice Boltzmann model to numerically study emulsions, HCS and foams

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A new numerical method based on a pseudopotential lattice Boltzmann (LB) scheme is proposed to model accurately emulsions, highly concentrated suspensions (HCS) and Foams. Lattice Boltzmann methods are widely used to simulate multiphase flows. However, with the original pseudopotential model, droplets in contact tend to merge, which poses a limitation in simulating densely packed droplets without coalescence, as observed in emulsions and foams. To overcome this limitation, we propose a non-coalescence method that is able to simulate a stable system of droplets in close contact. The proposed method is able to simulate 2D and 3D stable highly concentrated suspensions with or without density and viscosity ratios, around 10 and 50 respectively. Volume fractions of the dispersed phase up to 90% has been obtained.

Two applications of this new LB scheme are presented. The first deals with emulsion generation using a 3D micro-fluidic chip where dripping, jetting and threading regimes are put in evidence. A phase diagram that mainly depends on Capillary numbers is obtained, but the effect of chip geometry, Reynolds number and hysteretis on the droplet diameter are discussed. The second shows how the flow of HCS and foams depends on the dispersed phase volume fraction. During the flow, T1 transformation are obtained, and the viscoelastic nature of foams is put in evidence.

*Speaker

Liquid jet development at FERMI free-electron laser

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Free electron lasers (FELs) are powerfull photon sources that generate highly brilliant coherent photon pulses with tunable wavelenght (1) that can be used to study structure and dynamics of matter using various diffraction, scattering and spectroscopy techniques. Study of liquid samples using FEL radiation is challenging due to radiation induced sample destruction and high photon absorbtion by the sample environment. In particular, at low photon energies such as extreme ultraviolet (EUV) and soft x-rays (SXR) low penetration depth of photons requires thin sample in vacuum environment.

A breakthrough in the study of liquid systems using FEL sources is linked to the development of innovative micro-machining techniques which enable the creation of devices capable to deliver and create vacuum stable fast- and free-flowing (sub)micrometric laminar liquid sheets/jets (2). Combination of liquid jet with the FEL radiation allows (time resolved) studies of chemical kinetics, charge transfer, interface phenomena, electronic and atomic structure, nanoparticles, molecular transformations, transport properties in liquids etc. (3, 4, 5, 6).

At FERMI FEL, we develop liquid jet setup for experiments in vacuum. One liquid jet setup has already been developed and successfully tested at FERMI and Elettra synchrotron beamlines (7). The setup is suitable for experiments at beamlines with variable focal point. The main feature of the currently developed setup is its compact and portable design. It has a dedicated miniature chamber with independent vacuum system and ultimately the purpose of its design is to allow the usage of the setup in various experimental chambers. It is thus particularly suitable for the operation at beamlines with fixed focal point. Current design of the setup allows probing of the liquids using FERMI radiation (EUV and SXR) in transmission geometry. Once fully developed the setup will considerably extend the scope of research capabilities for FERMI and Elettra user community interested in liquid systems.

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*Speaker

Landau-Levich transition in capillary bridges during liquid transfer from a bath to a surface

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The pinch-off dynamics of a liquid bridge is relevant to several industrial applications such as transferring a liquid volume to a solid surface. One simple way to transfer a liquid is stretching a liquid bridge formed between two surfaces. When the stretching reaches a certain height the liquid bridge breaks therefore a part of the liquid can be transferred from one surface to the other. This study intents to investigate the mechanisms at the origin of the drag and breakage of the liquid bridge from a liquid bath. We used a capillary bridge technique 1 2 consisting in a spherical surface withdrawn from the bath at a controlled velocity (see figure 1). When the spherical surface is dipped into the bath and is withdrawn from its surface, it drags a liquid bridge. As the surface is pulled-off from the liquid free surface, the contact line recedes and the contact area decreases until it reaches a fixed position on the surface. Due to the curvature of the surface, a given pulling velocity does not imply a constant velocity for the contact line. When this velocity reaches a critical value, the contact line becomes trapped on the surface. Then, the shape of the capillary bridge deviates from its quasi-static form until it breaks. In some conditions, the fluid on the surface can easily slip. In particular, at low velocities, such a dynamic dewetting is well described by static laws as only capillarity and gravity control the shape of the liquid bridge. We tested two different hydrophobic surfaces (NOA and Teflon coating) for the sphere, and three types of liquids, namely, deionised water, water/glycerol mixture with 10% glycerol and water/glycerol mixture with 50% glycerol. We observed that the contact line dynamics depends on the displacement velocity of the solid relative to the liquid, the surface properties and the viscosity of the fluid. Surprisingly, for high pull-off velocities the contact line velocity can reach its critical value at a larger radius as the line is stopped earlier (see figure 1 right). It results in a larger volume transfer to the surface. Finally, we propose an analogy between this transition and the Landau-Levich transition 3 observed when fast dewetting is prevented by viscous dissipation.

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*Speaker

Constrains Over Whirligig Beetle Body Size Due to Water Surface Physics

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Adult whirligig beetles (Coleoptera: *Gyrinidae*) are among the best swimmers of all aquatic insects. They live and feed mostly at the water's surface and their capacity to swim fast is key to their survival. Wave and viscous drag that they face can be modelled thanks to linear wave theory and Blasius boundary layer theory. The total drag they faced is nonmonotonous with speed. The speed regimes that they can access is determined by the total drag and the thrust capacity of their oars locomotory apparatus. A dichotomy between a low and a high-speed regime can then be explained, in line with trajectory recordings. However, the high speed regime appears only accessible to a given size range. The body length of the whirligig beetle species is indeed concentrated around 6.25 mm, whereas larger-size genera appeared only lately in evolution. The size of these beetles appears strongly constrained by the fluid mechanical laws ruling locomotion and adaptation to the water-air interface.

*Speaker

Experimental and Numerical Analysis of Hydrogen-Brine Multiphase Flow in Geological Porous Media: Advancing the Development of a Hydrogen Demonstrator in a Saline Aquifer

Anna-Maria Eckel * [1], Lea Döpp [1], Mrityunjay Singh [1], Juliane Kummerow [1], Wisdom David [1], Marton Pal Farkas [1], Cornelia Schmidt-Hattenberger [1], Ingo Sass [1,2]

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To balance the seasonal fluctuations of supply and demand in renewable energy, hydrogen (H2) can be produced using excess electricity and temporarily stored in geological formations. For long-term underground hydrogen storage (UHS), on the order of months, saline aquifers and depleted hydrocarbon fields offer much larger storage capacities and greater geographical independence than salt caverns. Despite its potential due to its high storage capacity, large-scale UHS in porous media has not been demonstrated yet. It is associated with several geological and operational uncertainties, such as the dissolution of H2 into the formation water, the diffusion and leakage of H2, mixing with other gases, or microbial activity resulting in H2 consumption. Therefore, it is crucial to study, understand, and evaluate these gas displacement processes and H2 losses to successfully develop a UHS operation. As part of the Helmholtz research project GEOZeit, we conduct various multi-phase experimental studies of H2-fluid-rock interactions. This includes the investigation of petrophysical and gas properties, such as relative permeabilities and capillary pressures and their dependencies on fluid and reservoir rock conditions. We perform numerical multi-scale simulations of UHS and its hydrodynamic processes by incorporating reservoir and hydrodynamic properties and assess the capability of underground hydrogen storage operations at the Stuttgart Formation. This geological formation is a potential pore storage reservoir at the Ketzin site in Brandenburg, Germany, and was formerly used for a CO2 storage pilot project. However, H2 and CO2 underground storage differ significantly due to the physical characteristics of the gases, their intended purposes, and the storage mechanisms involved. Therefore, the results and outcomes of the experimental and numerical preparatory studies with H2 can make a substantial contribution to the preparation, development, and assessment of the feasibility of a future hydrogen demonstrator.

*Speaker

Investigating underground hydrogen storage: an experimental and numerical approach for diffusivity measurement and dissolution dynamics

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As the global transition to carbon-neutral energy systems gains momentum, the focus on efficient and secure underground storage of hydrogen as an energy carrier becomes increasingly important. This study aims to investigate the diffusion coefficient of hydrogen in brine in the context of a deep saline aquifer at the Ketzin site in Brandenburg, Germany as a potential underground hydrogen storage site. The Ketzin site was formerly used to store town gas and hydrogen had a major share in the town gas. Gravitational instability and dissolution-driven convection processes are modeled based on the experimentally measured diffusion coefficient. The research presents an integrated framework comprising experimental investigations and numerical simulations to explore the molecular scale diffusivity and reservoir scale dissolution in saline reservoirs overtime during the hydrogen storage processes. Dissolution trapping occurs primarily due to density-driven convection for the gas mixture. In the framework of the Helmholtz GeoZeit project, an experimental setup featuring a dual-chamber system was employed to assess hydrogen diffusion through various rock samples, including Bentheimer sandstone, Werra rock salt, and Opalinus clay. The diffusion coefficients ranged from 10ˆ8 to 10ˆ9 mˆ2/s, and the breakthrough times varied significantly among the materials. Wetted samples showed higher hydrogen retention, which is due to (i) the water saturation of the pores in the porous rocks and (ii) the closure of microcracks due to the recrystallization of the grain boundaries in the rock salt. In complementing the experimental findings, a reservoir simulation spanning 180 days was executed, capturing the complex, multi-regime behavior of hydrogen dissolution. The model accounted for transitions from diffusion-dominated to convective dissolution regimes, ultimately culminating in a shut-down stage where the system reaches hydrogen saturation. Results show that the duration and onset of the diffusive-convective transition regime can vary depending on the selected rock formation. Consequently, the empirical and computational preliminary investigations utilizing hydrogen will significantly inform the conceptualization, maturation, and evaluative scrutiny of the practicability of an impending hydrogen-based demonstration project.

*Speaker

Superhydrophobic Immersion

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Non-wetting solids have been extensively studied over the last twenty years due to their interesting properties relative to water. When immersed in water, these particular surfaces have been reported to entrain a plastron of air along the surface. We reproduce here classical coating experiments with an aerophilic surface plunged under water and investigate the quantity of air that is entrained underwater during its immersion. We present an experimental method to measure the thickness of the air layer in the case of a superhydrophobic immersion and model the entrainment of the air plastron with an approach similar to the one performed by Landau, Levich and Derjaguin (LLD) for wetting liquids. We demonstrate the robustness of the LLD model to describe the air coating of an immersed superaerophilic, with a small change in the prefactor of the law due to the interchange of the two phases (liquid and air).

*Speaker

Significance of Void Fraction in Bubble Clouds formed by Single and Multi-Plunging Jets

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The impact of a plunging jet with a liquid surface induces air entrainment beneath the surface, resulting in the formation of a bubble cloud. This ubiquitous phenomenon is widely encountered in nature, like breaking waves in water bodies, and in industrial techniques like reducing foam formation in chemical processes. The depth (H) of this bubble cloud is an important parameter for modeling in such applications. Using laboratory scale experiments and novel optical probes to carefully measure the local bubble void fraction (Φ), we demonstrate that a simple momentum balance including only liquid inertia and buoyancy force due to the bubble cloud volume provides a very good estimate for the depth H, when Φ is known. Furthermore, we show that bubble clouds can be classified as inertial or buoyancy-dominated based on a Froude number given by a characteristic bubble terminal speed, cloud depth and the cloud's net void fraction. Thereby, our findings help unify a large body of data in the literature corresponding to a wide range of injector diameters (250 μm - 20 cm) and cloud depths from few centimetres to a few metres. Finally, we use a simple set-up of closely packed multi-injectors as model to investigate air entrainment by large scale plunging jets. Our preliminary results confirm that inertia imparted by the plunging liquid jet and the bubble cloud volume are sufficient to determine the cloud depth even in such complex cases, if the bubble void fraction is given.

*Speaker

Wave field of capillary surfers

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Capillary surfers are wave-driven particles at a vibrating fluid interface that have been recently introduced. These active particles are characterized by high tunability and have the potential to fill the gap between overdamped and inertial active systems. In addition, they exhibit multistability since their interaction forces are long-ranged and spatially oscillatory. Capillary surfers are asymmetric solid objects. It has been suggested that their propulsion is due to asymmetric wave generation on the liquid surface, which would result in an asymmetric transfer of momentum from the surfer to the liquid and net radiation stress. We check this propulsion mechanism by measuring the wave field of capillary surfers using a surface reconstruction technique. Wave field measurements are performed by varying forcing frequency and amplitude and with surfers with different shapes. Indeed, in all cases, the wave field asymmetry is compatible with the direction of the surfer propulsion. A comparison of the measured wave field with an existing theoretical model is also attempted.

*Speaker

Quantification of zipping and its origin in pillar array imbibition

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The wetting of a droplet onto a rough surface let two kinds of behaviour. Either the liquid does not spread and the contact angle remains larger than on the corresponding smooth surface, or the liquid will explore the whole textured of the material. In the case of liquids that have a good affinity for the subtract, the droplet will start to spread in a Wenzel state and eventually shift to a wetting called hemiwicking. This wetting behaviour on textured surfaces has been explored for decades and different aspects have been highlighted. Generally, the displacement of a liquid film is proportional to the square root of the time, as described by Washburn in the beginning of the 20th century. Nevertheless, some experimental works have described imbibition that does not necessarily follow this trend. As an example, orthogonal liquid displacement, called zipping, has been observed during hemiwicking, without any quantification of this phenomenon.
In this work, we have quantitatively analysed this zipping phenomenon on pillar arrays with a viscous oil (170 mPa.s) and found that its velocity i) is much more rapid than the spreading of the liquid) ii) depends on the aspect ratio of the pillars iii) is constant all along the spreading. On the more, we were able to highlight that the liquid film within the pillars, close to the wetting line, plays a major role in the spreading of the oil, with a dynamic dissociated to the droplet reservoir one.

*Speaker

Multiphase Flow Simulation of Hydrogen Storage in a Saline Aquifer: A Case Study at Ketzin, Germany

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As part of the preparations for a demonstrator for the underground storage of hydrogen in a saline aquifer in Brandenburg, a multiphase flow simulation is being used for an initial assessment. For first considerations, the location Ketzin is analysed.
This site has already been used as a town gas storage facility and natural gas facility in the past. The site was also successfully used as a CO2 storage pilot site. This experiences and data can now be applied to a potential hydrogen storage system. The main focus is on how fluid and subsurface properties, such as porosity, (relative) permeability, salinity and capillary pressure, will affect the quantity of hydrogen that can be stored, as well as the recovery rate. Due to the heterogeneity of the Stuttgart formation, which is used as a storage formation in this case, the results provide information about the economic efficiency of the storage facility.
Future work will focus on optimizing the simulation, such as integrating hysteresis, improving the geological model and integrating the lithological heterogeneity of the site.

*Speaker

Coalescence of precursor films from droplets in total wetting state.

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The spreading of droplets on solid substrates is a fundamental phenomenon of substantial interest in various scientific and engineering domains, such as in coating process and surface science. When a polymer melt droplet is deposited on high energy surfaces, it's expected a nanometer-thick precursor films spreading out of the macroscopic droplet (1). In this film, Van der Waals interactions give rise to either disjoining or conjoining Derjaguin pressures, which respectively work to either separate the film interfaces or bring them closer together (2). During the last decades, they have been the interest of fundamental and applied studies focused on the spreading of a single droplet (3). However, the growth dynamic of the coalescence of two precursor films has not been studied yet in the literature.
This study aims to investigate what happens when the precursor films of two droplets come into contact while varying the molecular weight, relative humidity, and the distance between the drops. By taking advantage of ellipsometric microscopy, we studied the morphology and dynamics of these films for polydimethylsiloxane (PDMS) droplets under total wetting conditions. We present, for the first time, systematic observations and measurements of the coalescence dynamics of precursor films. These experiments aim to explain the transport mechanisms involved in the time evolution of the film profile.

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*Speaker

Break up and Relaxation of coalescing drops with insoluble surfactants at high Capillary number

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A new phenomenon is reported, discovered while extending previous studies on the relaxation of two viscous drops, previously undergoing a head-on collision in an extensional flow for low Re(1), to the case with insoluble surfactants at the interface. As the Capillary number increases above 0.1, the drops are highly deformed, to the point that each drop forms two lobes separated by a thinning neck. Surfactants are convected outside the neck area and, given enough time, the
drops will break up into four smaller drops. However, for certain neck thicknesses and surfactant concentrations and diffusivities, if the flow is stopped, the drops will relax back towards a spherical shape, but the Marangoni stresses, generated by the initial surfactant distribution, will also create a flow that will push the matrix fluid towards the inside of the drops. Eventually, two facing spherical drops will be formed, each having inside another surfactant-rich tiny drop, resulted from a break up mechanism resembling tip streaming or tip dripping(2)

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*Speaker

Data-driven closure model for viscoelastic drag-reducing channel flows

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In this work, we introduce a new data-driven strategy through which a low-cost-low-fidelity Reynolds-averaged Navier-Stokes simulation (RANS) of a Newtonian turbulent channel flow using the k-epsilon model is empowered by Deep Neural Network techniques to predict high-fidelity results given by a Direct Numerical Simulation (DNS) of a viscoelastic turbulent channel flow. We equally show that such a strategy can be used to predict DNS results of viscoelastic turbulent channel flows from a Machine Learning-assisted DNS of Newtonian turbulent flows.

*Speaker

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