

Dynamical Wetting of flexible, adaptive & switchable substrates (SPP2171)

Monday 28 June 2021 - Thursday 01 July 2021

Online

Book of Abstracts

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Adaptive Substrates Session / 3

Adaptation of PS/PAA copolymer to water

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When a droplet is sliding on surfaces, adaptation of the surface leads to changes of the dynamic contact angles [1]. Hereby two adaptation processes play a role: (i) the adaptation of the surface upon bringing in contact to the droplet (wetting) and (ii) the adaptation of the surface after the droplet passed (dewetting). In order to study both processes, we investigated samples made from polystyrene (PS) polyacrylic acid (PAA) random copolymers by using a tilted-plate method and by sum-frequency generation spectroscopy (SFG). For the wetting process, the advancing and receding contact angles of water droplets decrease when PS/PAA surface adapts to water. We measured a relaxation time of ~1 ms for 40 - 100 nm thick PS/PAA films adapting to water by a tilted-plate method [2]. Here, both water diffusion and polymer reorientation play a role in the adaptation process. For the dewetting process, the sliding droplet velocity decreased for subsequent droplets with different droplet intervals. From the drop interval and the drop velocity, we calculated the time that is required for the surface to (re-)adapt to air. While for the wetting process water diffusion and copolymer reorientation played a role, it is not clear to which extend both effects are present during dewetting. Therefore, we performed SFG experiments on PS/PAA surfaces to determine the contribution of both effects.

[1] H. J. Butt et al, *Langmuir* 34 (2018), 11292–11304.

[2] X Li et al, *Langmuir* 37(2021), 1571–1577.

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Electrowetting – how to make drops move

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Electrowetting is a flexible manner to modify the wettability of droplets of conductive liquids such as water by applying a voltage between the drop and an electrode that is submerged in the substrate under a thin hydrophobic dielectric layer. Electrowetting allows to vary the contact angle locally by more than 90° on a time scale much faster than any hydrodynamic response time of the drop. In this first lecture, I explain the physical principles of electrowetting and illustrate a number of applications including (i) drop actuation for lab-on-a-chip, (ii) controlled trapping and release of drops on inclined planes, (iii) electrowetting-controlled reduction of contact angle hysteresis and (iv) electrowetting-enhanced water condensation.

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Reverse Electrowetting and other manners to harvest energy from moving drops

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While conventional electrowetting uses electric actuation to generate mechanical deformation and motion of drops, reverse electrowetting makes use of the inverse process: it makes use of mechanical motion of conductive drops to generate electrical currents by means of electrostatic induction. These currents are fed into electrical circuits and can be used to operate and/or charge low power electric devices. I will discuss the physical principles of a few common approaches and discuss in detail the physical processes involved in harvesting energy from (rain) droplets falling onto electrically charged surfaces in so-called electrical nano-generators.

Switchable Substrates Session / 6

Time scales in multiscale dynamics of droplets on switchable substrates

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The dynamics of droplets on switchable substrates is an interplay of multiple time scales calling for a multiscale theoretical modelling. We combine a microscopic Molecular Dynamics model (MD) and a mesoscopic thin film model (TF) to investigate detailed changes in the contact region in the MD model, while simultaneously analyzing long term stabilities of pattern analytically in the context of the lubrication approximation described by the TF model. Using the dimensionless version of both models, the time scales can then be determined using experimentally measure quantities like the viscosity or the surface tension. However, for quantitative comparisons such a time scale mapping would not be accurate enough due to the uncertainties of the relevant quantities. Instead we matched the profiles from both MD and TF models and obtained the relation between the time scales. In this talk we introduce this general procedure and discuss the alternative possibility to use measure characteristic times within both models.

Poster Session / 7

Wettability study of smart surfaces with tunable geometry

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Various living organisms have structured surfaces with specific wettability that allows their efficient adaptation to the environment and improves their survival rate. For example, the rice leaves have micro- and nanoscale structures on their surface that form a superhydrophobic surface for self-cleaning and water repellence[1]. Bioinspiration of these natural surfaces in science can be beneficial for applications in biotechnology, microfluidics, textiles, fabrication of sensors, etc[2]. Addressing these challenging goals requires the development of both materials with tailored properties and methods for the fabrication of structured surfaces. In comparison to previously reported surface patterning techniques, melt-electrowriting (MEW) is a novel and solvent-free technique that is based on 3D printing and electrospinning which allows programmed deposition of polymeric microfibers [3]. Shape memory polymers offer a very interesting combination of properties such as switching of mechanical properties and the capability of stimuli-induced restoration of shape after deformation

[4, 5].

In this work, we report the fabrication of surfaces with tunable geometry and mechanical properties with high aspect ratio surface features (50:1) and the investigation of their wetting properties. For the fabrication of the topographical surface, we melt-electrowrite lamellas structure with a thermoplastic polyurethane with shape memory behavior (Polybutylene adipate based TPU). Our smart surfaces were programmed by the use of extra small forces driven by the surface tension of water. The actuation and switching of surface topography occurs in few minutes (below 5 min). This investigation can open the door for further research in the application of micro/millifluidic devices, creating smart locks to allow the passage of fluids by changing the temperature of the set.

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Switchable Substrates Session / 8

The Interplay of Spreading, Imbibition and Evaporation of Water Droplets on Nanoporous Surfaces

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The study of fluid dynamics in nanoporous materials is nowadays a topic of great interest due to the often significantly modified thermal equilibrium and non-equilibrium properties of extremely spatially confined liquids compared to their bulk counterparts. However, fluid transport in nanoscale geometries plays also an increasing role in functional materials consisting of fluid-infused solids, such as supercapacitors and porous materials with integrated actuation, sensation [1] and adaptive lubrication [2].

Here we present a study on the spreading of water droplets on nanoporous silicon as a function of time. The evolution of the droplet volume is analyzed theoretically and experimentally considering the evaporation and the radial imbibition of the liquid into the porous substrate. The scaling behavior of these quantities are qualitatively in agreement with phenomenological descriptions [3,4], however also substantial deviations compared to Molecular Dynamics simulations on this phenomenology are revealed [5]. Our experiments shall serve as a base for future studies employing electrowetting to control the competition of spreading and imbibition [6].

Soft Substrates Session / 9

Dynamic wetting ridge of soft surface

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When a liquid droplet is sitting on a soft surface, the capillary forces of liquid deform the soft solid into a sharp wetting ridge. The amplitude of this wetting ridge is determined by the elasto-capillary length. If such droplet moves, a strong viscoelastic dissipation occurs in the soft solid. In this research, we visualise the moving wetting ridge created on a soft surface by water and fluorinated oil and measure the solid and liquid contact angles. We have noticed that the rotation of the wetting ridge follows the dynamic contact angle at slow contact line speed. On the other hand, the rotation angle starts to decrease at high contact line speed. In this talk, we will explain how does this phenomenon can be explained by dynamic solid surface tension.

Poster Session / 10

Spiropyran thin film preparation and photoswitching

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Wetting is a ubiquitous phenomenon that can be found in everyday situations such as a rain-soaked glass pane or a piece of rotten wood. However, it plays a key role in more sophisticated tasks that our society relies on, such as oil extraction, inject printing or protein adsorption.

In order to improve the wetting process and enhance its applications, it is necessary to understand the physicochemical properties of wetting. Surfaces that under external stimuli are able to switch from more hydrophobic to less hydrophobic states constitute a powerful tool to understand at the molecular scale the wetting process. The spiropyran/merocyanine (SP/MC) (Figure 1) pair of molecules are two isomers that can be switched to each other by light. The feature that makes them so interesting is the difference in their dipole moment which happens to take values from 4-6 D for spiropyran to 14-18 D for merocyanine.

In this work, we focus on the preparation of SP/MC thin films and study the change in the water contact angle of these films.

Poster Session / 11

A High-Order Sharp Interface Method with Contact Line Singularities

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When distinct phases interact, contact lines occur. Characteristically, singularities are observed at the contact lines, e.g. a jump in pressure or varying surface tensions. This offers a significant obstacle for high order methods, where generally smooth functions are required to obtain a high order of convergence. By introducing a flexible discontinuous polynomial ansatz space, we overcome this restriction. We construct an extended discontinuous Galerkin (XDG) method that resolves contact line discontinuities while maintaining a high order of convergence.

We will briefly summarize the XDG method, concentrating on one of its pillars: the level set function. The zero isocontour of the level set function implicitly defines the surfaces of the contact lines. We will focus on two central components: first, contact line regularization and evolution and second, quadrature methods for surfaces and volumes with singularities.

Switchable Substrates Session / 12

Molecular Changes and Wetting Dynamics of Arylazopyrazole Monolayers on α -Al₂O₃(0001)

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There is great interest in smart surfaces that can change their wetting behavior on demand and which have application potential e.g. for self-cleaning surfaces. Using light as a stimulus to change the wetting behavior allows to confine the stimulus both in space and time which renders light as stimulus highly interesting to address dynamic wetting of surfaces. Here we have synthesized a new class of photoswitchable molecules - arylazopyrazole phosphonic acids (*butyl*-AAP-C₁₈-PA) that can undergo *E/Z* photoisomerization reactions and are highly useful to decorate aluminum oxide surfaces with photo-responsive monolayers. On an Al₂O₃ substrate, the AAP moieties are irreversibly adsorbed because of strong covalent interactions of the PA head group with the Al₂O₃ substrate surface. Modification of α -Al₂O₃(0001) surfaces is done by a Langmuir-Blodgett transfer of *butyl*-AAP-C₁₈-PA monolayers. The prepared layers with a surface coverage of 4 molecules/nm² were shown to exhibit the largest differences in terms of static contact angle change. In particular, we show that with the use of *butyl*-AAP-C₁₈-PA monolayers the contact angle can be changed reversibly between 84° (*E* state) and 76° (*Z* state). While contact angle measurements can quantify the changes in the macroscopic wetting, the application of inherently interface specific sum-frequency generation (SFG) spectroscopy can provide more detailed information on the interfacial molecules as well as on the kinetic changes of AAP monolayers as a function of light irradiation and thus *E/Z* configuration of *butyl*-AAP-C₁₈-PA moieties. For instance, we have used time-resolved SFG spectroscopy to study C-H stretching vibrations of the *butyl*-AAP-C₁₈-PA monolayers under different light irradiations, which is useful to address the switching kinetics on a molecular scale and can be further compared to the macroscopic changes of the contact angle. Using time-resolved SFG spectroscopy, we show that a steep initial decrease in contact angle for *E* to *Z* switching (green to UV irradiation) is accompanied by a substantial reduction of aromatic C-H modes and the electronic non-resonant contribution to the SFG spectra. A possible explanation for this might be an order / disorder transition or a change in the net molecular orientation of the molecular groups contributing to the SFG spectra. The time scale of the molecular changes is ~10 s (*E* to *Z*) and ~200 s (*Z* to *E*) from one equilibrium state to other. For *E* to *Z* switching this is comparable to the initial fast change of the contact angle, however, the contact angle shows also subsequent slower changes.

Wetting Dynamics Session / 13

Droplet Scanning Microscopy

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Sliding drops on solid surfaces experience lateral adhesion owing to capillary forces. Local capillary forces of drops are of interest for fundamental wetting science and industrial applications such as self-cleaning surfaces or paint spraying. In particular, functional coatings can be stained on purpose or unintentionally as a defect during a coating deposition process. Therefore, techniques are required to map capillary forces over large areas. Attempts have been made by measuring locally the vertical adhesion forces [1] or the roll-off angles. However, both techniques are time-consuming and cannot examine a relatively large area at once.

In order to overcome these limitations, we have built a setup that allows us to measure the sliding force of drops over area of 5x2 cm², with different hydrophobicities, within 1-5 minutes. The drop

of 15 μL volume is immobilized by a metal ring, which is attached to a glass capillary. While the drop is sliding over the surface, the lateral deflection of the glass capillary, which is proportional to the sliding force [2], has been recorded in form of a video. The obtained deflection of the glass capillary is multiplied with its spring constant which results in the lateral sliding force. Subsequently, we plot the force values for the respective positions in form of 2D-Heat map. With this technique, we mapped heterogeneous hydrophobic surfaces made from PFOTS and OTS (Figure 1(a)). This scanning technique allows studying the lateral distribution of different hydrophobicities. As our contribution, we will discuss the setup and the origin of forces while water drops are drawn over different hydrophobically stained areas. Our initial experiments reveal that we can detect stained areas smaller than 1/4th fraction of the drop diameter.

Poster Session / 14

Capillary Statics in Nanowedges

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Understanding of capillary transport in porous media is beneficial for a manifold of industries and technologies, which can be exemplified by ink-jet printing, oil and gas production, food production, and water resources research. The geometry of porous media is in most cases tremendously complicated and cannot be always represented by interconnected cylindrical capillaries. Instead, the corner-containing geometries can serve as a more realistic representation of the porous media topology.

The simplest element of the angle-containing structures is an open wedge (corner). It is well known that when the Concus-Finn condition $\theta + \alpha > \pi/2$ relating the contact angle of the wetting liquid θ and the wedge opening angle 2α is fulfilled, the steady state of liquid in the wedge is possible. Otherwise, the rivulet driven by the curvature-induced pressure is expected to propagate infinitely along the corner. However, at the nanoscale, the wetting behavior is drastically affected by surface forces.

To date, the understanding of the nanowetting of the corner geometries is still poor. In the present work, we investigate wetting of the wedge-shaped nanochannels accounting for the surface forces and show that introduction of the latter leads to the appearance of steady state of meniscus in the wedge in the cases for which the Concus-Finn condition is violated. We present and discuss the influence of the surface force parameters as well as the corner geometry on the equilibrium rivulet profile.

Soft Substrates Session / 15

Wetting Ridge Dynamics on Soft Surface Wetting

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In veins, objects like vesicles adhering to the endothelium (i.e. inner channel walls) can become harmful as they cause high blood pressure or, more severely blood clots. Understanding how such adhering objects interact with soft surfaces is essential to decrease the risk. Liquid droplets are good approximations of vesicles in terms of their wetting behavior. To understand the interaction, we investigate liquid droplets sliding on soft substrates. The substrate can be swollen by another liquid solvent. During sliding, the solvent, the substrate, the droplet, and the ambient do interact via mass and momentum transfer which can be coupled. The contact domain where droplet, surface, and

ambient meet (so-called wetting ridge) governs the most important coupling between the involved components. We combine optical methods such as confocal- and interferometric microscopy, which allows us to a) discriminate between components, and b) resolve length scales, much below the wavelength of visible light. Both methods are appropriate to dynamically map the wetting ridge while the droplet while it slides over the surface. A novel force sensor setup facilitates the direct force measurement between droplet and surface during the sliding motion.

Wetting Dynamics Session / 16

Lattice Boltzmann simulations of liquid lens coalescence

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The lattice Boltzmann method is an efficient approach to simulate complex fluids and wetting processes. We present results based on the colour gradient method which is particularly designed for multicomponent fluids and is able to obtain thermodynamically consistent results over wide ranges of viscosities and surface tensions. After demonstrating benchmarks to analytically accessible solutions such as the Laplace pressure, Neumann angles, Hagen-Poiseuille velocity profiles or surface tension deduced from drop oscillations, the method is applied to investigate the dynamics of liquid lens coalescence. Thereby the respective asymptotic power-laws obtained from similarity solutions of the thin-film equations are verified in the viscous and inertial limit.

Switchable Substrates Session / 17

Photoswitchable surface properties of soft and flexible spiropyran-containing photorheological fluids

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Movement of the droplets induced by changes in surface properties such as wettability has been of great interest for many applications such as microfluidic devices [1], functional coatings [2], transport of chemical species with a droplet [3], etc. Special stimuli-responsive materials with switchable surface properties are capable to offer the possibility of droplet movement in the material or across the surface [2,3].

Spatially controllable and reversible photoswitching of colorless hydrophobic Spiropyran (SP) to magenta hydrophilic Merocyanine (MC) makes this class of molecular switches especially promising for responsive materials. Spiropyran has been already integrated into reverse micellar lecithin/bile salt organogels with highly viscoelastic behavior [4]. It was possible to prove with dynamic rheological measurements that they present photoswitchable rheological properties and go under significant changes of viscosity under UV irradiation after SP addition [4-6]. Such special stimuli-responsive soft materials can be utilized to move a droplet between spots with different softness upon a high-resolution photoswitch on the surface. Herein, we have obtained a few micrometer-resolution for photoswitching of the transparent thin layer of the lecithin-based samples using a maskless stereolithography machine [7]. Also, commonly used volatile solvents for the lecithin-based organogels have been successfully replaced with a non-volatile organic solvent, isopropyl palmitate [8] to stabilize the properties during the application. Next, localized photoswitching of the sample created a

softness gradient resulted in the droplet movement into the fluid and later, the concept will be used to induce droplet movement across the surface.

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Soft Substrates Session / 18

Comparative Study of the Dewetting Dynamics from Elastic to Visco-Elastic Substrates

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When a thin layer of polystyrene of about 100 nanometres is dewetting from a PDMS layer we observe the appearance of nucleated holes at the surface. The polystyrene that is removed from the dry centre of the hole accumulates at a dewetting rime surrounding the latter. These dewetting rims have characteristic shapes and grow with time accumulating more and more of the dewetted polystyrene. For the dewetting dynamics we can distinguish three regimes according to the elasticities of the PDMS substrates by spanning a range of three orders of magnitude (few MPa to few kPa). The first regime concerns elastic moduli of few MPa to few hundreds kPa where we could observe dewetting velocity decreases for decreasing elastic module. The second regime (from few hundreds kPa to few ten kPa) is a regime where the dewetting velocity is very low (tends to zero); and the last regime concerns elasticities in the range of only a few kPa where we could observe an increasing dewetting velocities for decreasing elastic moduli. A comparison of the rim shapes, heights, and contact angles for these three regimes gives valuable hints about the influencing parameters involved on the dewetting dynamics and therefore would lead for a better theoretical description.

In the latter stage of the dewetting process, the dewetting rims coalesce and form a pattern of straight ribbons that decay by Rayleigh-Plateau instability into isolated droplets which are the equilibrium state of dewetting and enable to characterize E-module and size dependent contact angles that can be correlated to the dewetting dynamics in the three different regimes.

Our experiments consist of polystyrene 18kg/mol layers with a typical thickness of 120 nm dewetting from PDMS rubber substrates with typical thicknesses of 6-10 microns and variable E-module. The polystyrene layers are prepared in a glassy state and dewetting is started when heating the samples above the glass transition temperature of the polystyrene. When a desired dewetting situation is reached the sample can be quenched down to room temperature and the rim or droplet shape can be obtained by atomic force microscopy. Lifting the glassy polystyrene layer off from the rubber PDMS layer using a UV-curable glue enables additionally to image the formerly buried polystyrene/PDMS interface and thus to obtain the full three dimensional shape of the dewetting morphologies.

Adaptive Substrates Session / 19

Memory effects of PNiPAAm brushes in different atmospheres

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Some polymer brushes show a co-nonsolvency effect: They collapse in a mixture of two good solvents at some specific mixing ratio. Previous studies focused on the response of brushes which are entirely covered by a liquid. Here, we concentrate on partial wetting of co-nonsolvent polymer brushes, i.e., on the dynamics of a three-phase contact line moving over such brushes.

We use Poly(N-isopropylacrylamide) (PNiPAAm) brushes and water and ethanol as good solvents. In water/ethanol mixtures, the brush thickness is a non-monotonous function of the ethanol concentration. The memory seen by consecutively depositing drops at the same position. Previously deposited drops adapt the brush and changes the wetting behavior (advancing contact angle) of subsequent drops [1].

One approach to test for the competition between water and ethanol in the brush, is to measure with a water drop in an ethanol-saturated atmosphere. At the three-phase contact line, the air and probably also the brush will transition from an ethanol-rich state to a water-enriched state. Thus the brush might pass through the regime of the co-nonsolvency effect. On large time scales the ethanol enriched gas phase and the water drop will become mixtures of ethanol and water. We present strategies to counter this mixing effect. The memory effect shown above cannot be experienced in an ethanol-enriched atmosphere.

1. Schubotz, S., et al., Memory effects in polymer brushes showing co-nonsolvency effects. *Advances in Colloid and Interface Science*, 2021. 294: p. 102442.

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Scientific Writing Workshop: How to see ghosts and communicate science

Every stage of a researcher's career is built on foundations of writing and other forms of communication, yet this topic is rarely taken seriously in European schools and universities. Students who don't master the basic skills will struggle with every paper, crucial applications for jobs and funding, and routine requirements of their jobs. The ability to clearly and effectively communicate science is somehow connected to the quality of a scientist's thinking and research – but why should that be true? And what are the implications?

A few years ago, I began a very systematic study of the problems scientists have when communicating in different contexts: with experts from their own field, across disciplinary boundaries, and with the lay public. This work revealed some fascinating patterns. Communication problems have an underlying logic that can be captured in a general model to explain what goes wrong and how they can be fixed. The model has very clear implications for how we teach communication and how we ought to be teaching science. It suggests a way of thinking about writing and giving talks that not only make these tasks a lot easier, but can ultimately improve your research.

The workshops I offer are based on the scientific work of the participants; the content comes from texts from your field and your own work. The first (morning) session is a theoretical introduction that use examples to expose problems and give participants a new way to think about communication tasks. Faculty and other guests are welcome to sit in. The afternoon will get practical, providing tools and strategies to apply what we've done to your writing.

About the instructor:

In over two decades as a science writer, Russ Hodge has witnessed “the good, the bad, and the completely ridiculous” sides of science and its practitioners. Besides being a diplomat trying to negotiate new boundaries between science, humor, and art, Russ is one of Europe's most respected science communicators and teachers. In 1997 he was plucked from a peaceful existence as a writer and musician to launch the Office of Information and Public Affairs at EMBL. He helped shape it

into one of the most respected centers of public outreach for molecular biology in the world. He currently works as science writer and communications trainer at the Max Delbrück Center for Molecular Medicine in Berlin. He has written thousands of articles, dozens of book-length journalistic reports for institutes across Europe and the US, and published 8 books on science. He is a co-author on 10 original scientific papers, has written highly successful international grants, and most recently written and illustrated a children's book on evolution. Alongside humorous pieces on his blog, he is carrying out important work on the theory, practice and didactics of science communication. Some of his work can be found at: www.goodsciencewriting.com. His artwork can be seen at russhodge.wordpress.com.

His author page at Amazon is: www.amazon.com/Russ-Hodge/e/B0024J8XO0/

Adaptive Substrates Session / 22

Modeling forced (de-)wetting of adaptive substrates

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When a liquid drop spreads on an adaptive substrate the latter changes its properties what may result in an intricate coupled dynamics of drop and substrate. In [1] we presented a mesoscale hydrodynamic model for a droplet spreading on a polymer brush as a gradient dynamics on an underlying energy functional. The model accounts for coupled spreading, absorption and wicking dynamics, while the underlying energy functional incorporates capillarity, wettability and brush energy.

In this talk, we give a brief recap of the model and provide further insights into the (de)wetting behavior and the dynamics of a moving contact line on polymer brushes that we obtain from numerical simulations.

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Soft Wetting Dynamics

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Droplet spreading and sliding on soft substrates is typically much slower than on rigid surfaces. This effect is called "viscoelastic braking": it is caused by the motion of the wetting ridge that is transported along with the moving contact line. The moving ridge induces a time-dependent deformation, which causes viscoelastic dissipation inside the substrate. In this talk we quantify the substrate deformation, the dissipation, and show how one can predict the dynamic contact angle on viscoelastic substrates. We also discuss other dynamical soft wetting phenomena such as stick-slip motion and the cheerios effect

Poster Session / 24

Impact of salt on sorption isotherms in nanoporous media

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Salt water is ubiquitous in nature (e.g. geomaterials, soil, clouds formation) and in technology (e.g. desalination, concrete weathering, heritage conservation). In most of these situations, salt water is confined within a porous medium, often with pores down to the nanometer scale: for example, crystallization and dissolution cycles induced by humidity changes are known to induce structural damage to building materials, artwork, etc. And yet, these processes are not well characterized, especially when pores are in the nanometer range. Here, we investigate the response of the salt water confined in several porous silicon samples (average pore diameter from 3 nm to 20 nm) to humidity cycles. We performed sorption isotherms where we monitored optically water content in the porous medium. We systematically characterized how the salt concentration impacts the shape of the isotherms and compared these results to a minimal model coupling solution thermodynamics to capillarity, nucleation and confinement effects.

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Tutorial Lecture on "Relating the macroscale and mesoscale descriptions of wettability"

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After spilling some liquid on my desk I will remind you the macroscale description of wettability and capillarity followed by experimental examples illustrating that a more appropriate description on smaller is needed scales. Such a description is provided by a mesoscale theory based on wetting potential/disjoining pressure. At this point I switch to pen and pad to discuss some details of the two formulations and their relation. This includes a derivation of the macroscopic Laplace and Young-Dupre laws and of their mesoscale equivalent. These are then used to (i) relate contact angle and wetting potential, (ii) establish consistency relations for the two levels of description, and (iii) discuss the stability of thin films of partially wetting liquids. Finally, it is briefly explained how the mesoscale description feeds into the gradient dynamics approach as explained in detail in the February 2020 SPP Winter School. If time remains, we discuss how wetting potentials can be obtained from microscale models and dwell on an extension of the approach towards complex liquids (surfactant covered films, or films of mixtures).

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Wetting and freezing on soft surfaces

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Liquids have surface tensions that are widely recognised as playing a crucial role in many aspects of their behaviour. Solids also have a surface tension, but it is typically ignored, as being too small to have an observable affect. However, this is certainly not true for soft solids, where surface tension can completely change wetting behaviour and phenomena like adhesion and composite behaviour.

I will mainly talk about two related aspects of this. Firstly, I will talk about how we can measure solid surface tensions, and why this is not easy to do accurately. In particular, I will focus on recent experiments that measure how surface tensions in gels have an unexpectedly large stretch dependence, and discuss why this is, and what its implications for wetting are. Secondly, I will talk about wetting of non-ideal substrates: ones which have extremely large contact-angle hysteresis, or which can be swollen by the wetting liquid. In particular, I will demonstrate a novel technique, with which we can still measure equilibrium properties in such systems. This is strongly tied to concepts of adaptive wetting, as described by the group of Profs. Vollmer and Butt.

Finally, if time permits, I will also describe our recent experiments looking at freezing on soft surfaces. I will show how stresses are generated at the contact line that are significantly bigger than anything we see in wetting experiments, and talk about how these stresses are the root cause of damage in soft materials caused by freezing.

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Controlling wetting, adhesion and friction using polymer brushes

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Polymer brushes consist of long polymer that are end-anchored to a surface at a high density. Due to this end-anchoring they can be utilized as versatile coatings under many conditions where regular coatings would normally degrade. In this lecture I will provide a general introduction to polymer brushes and explain, via different examples, how to employ them to control surface or interfacial properties, such as wetting, adherence and friction.

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Response of nanoporous media to humidity

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I will present a variety of responses associated with humidity changes in nanoporous media or micro/nano composites, which we investigated using artificial systems. These phenomena include capillary flows (imbibition, drying), osmotic flows, nucleation (cavitation, precipitation) and self-organized evaporation patterns. Through these examples, I will discuss how the interplay of thermodynamics and transport can result in interesting dynamics that can be triggered using external humidity as a control parameter.

Soft Substrates Session / 29

Gradient Dynamics Model for Spreading Drops on soft Substrates

Author: Christopher Henkel¹

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The wetting behaviour of liquids on viscoelastic or elastic substrates is of great interest as it is relevant in many applications. Here, we present a simple model for partially or completely wetting liquids on fully compressible elastic substrates. It is shown that the model faithfully captures not only the double transition of steady drops (with increasing softness), but also features of dynamic processes. We focus on the example of a spreading drop on soft substrates and consider the effect of viscoelastic braking, i.e. the increase of dissipation in the substrate with increasing softness. Furthermore we show that the scaling laws of a Kelvin-Voigt material [1] are correctly recovered for partially wetting liquids and indicates that the behaviour crucially changes in the case of complete wetting.

[1] S. Karpitschka, S. Das, M. van Gorcum, H. Perrin, B. Andreotti, and J. H. Snoeijer. Droplets move over viscoelastic substrates by surfing a ridge. *Nat. Commun.*, 6:7891, 2015. doi:10.1038/ncomms8891

Soft Substrates Session / 30

Phase field model with nonlinear elasticity

Author: Leonie Schmeller¹

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To study the dewetting dynamics of thin liquid films from visco-elastic materials we consider intermediate steps. First, the very soft substrate is described with a phase field model accounting for nonlinear elasticity and for the possibility of phase separation. In this talk, I present the components the two-phase system and derive a weak formulation from which we build our 2d code.

Secondly, a three phase system including an air, liquid and elastic substrate phase is described using two phase field variables. Here, the choice of system parameters, including the interface size $\varepsilon > 0$ and the mobility in the Cahn-Hilliard equation, are crucial for the numerical efficiency of this model. We use an adaptive mesh refinement to facilitate the computations, especially at the three phase contact line.

A future step will be to replace the elastic solid phase in the latter model with the two-phase system described at first.

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Finite Element Methods for Fluids and Dewetting

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This lecture gives a compact introduction to the use of energetic variational methods for modeling and simulation of wetting flows. Therefore, in the first lecture, I will introduce GENERIC structures for the evolution of thermomechanical systems and motivate the use of weak formulations and finite element methods for the description and discretization of these equations. In the second lecture, I will present examples relevant for “Dynamic Wetting of Flexible, Adaptive, and Switchable Substrates” and their explicit discretization will be discussed interactively using the finite element framework FEniCS and presented using Jupyter notebooks.