CPP 3: Wetting - organized by Stefan Karpitschka (Max Planck Institute for Dynamics and Self-Organization, Göttingen) (joint session CPP/DY)

Time: Monday 9:00–16:30   Location: CPPb

CPP 3.1 Mon 9:00 CPPb

Breakup Dynamics of Capillary Bridges on Hydrophobic Stripes — Maximilian Hartmann[1], •Mathis Fricke[2], Lukas Weimar[1], Dirk Gründing[2], Tomislav Maric[2], Dieter Bothe[2], and Steffen Hardt[1] — [1]Nano- and Microfluidics Group, TU Darmstadt, Alarich-Weiss-Straße 10, 64287 Darmstadt, Germany — [2]Mathematical Modeling and Analysis Group, TU Darmstadt, Alarich-Weiss-Straße 10, 64287 Darmstadt, Germany

The breakup dynamics of a capillary bridge on a hydrophobic stripe between two hydrophilic stripes is studied both experimentally and numerically. The capillary bridge is formed from an evaporating water droplet wetting three neighboring stripes of a chemically patterned surface. The simulations are based on the Volume-of-Fluid (VOF) method implemented in Free Surface 3D (FS3D). By considering the breakup process in phase space, the breakup dynamics can be evaluated without the uncertainty in determining the precise breakup time. It is found that within an intermediate inviscid regime, the breakup dynamics follows a $t^{2/3}$-scaling, indicating that the breakup process is dominated by the balance of inertial and capillary forces. For smaller bridge widths, the breakup velocity reaches a plateau, which is due to viscous forces becoming more important. In the final stage of breakup, the capillary bridge forms a liquid thread that breaks up consistent with the Rayleigh-Plateau instability. The existence of satellite droplets in a regular pattern indicates that the primary breakup process is followed by self-similar secondary breakups.

CPP 3.2 Mon 9:20 CPPb

Simulating the hydrodynamics of droplets on photo-switchable substrates — •Josua Grawitter and Holger Stark — Technische Universität Berlin, Institute of Theoretical Physics, Hardenbergstr. 36, 10623 Berlin, Germany

Interfaces between fluids and photo-switchable substrates provide a unique mechanism to precisely manipulate liquid droplets by creating and adapting a heterogeneous wettability landscape. Because droplets respond to changes in wettability, such interfaces provide a means to keep the droplets in non-equilibrium and thereby induce new states of dynamic wetting.

We present a boundary element method to determine the Stokes flow inside a droplet with its curved free surface and its flat interface at the substrate, where we apply the Navier boundary condition to permit motion of the contact line. In our approach we use the Cox-Voinov law [1] and introduce the velocity of the contact-line as a side condition. We also implement an iterative domain-splitting integration scheme capable of treating singular integrands, which are typical for the boundary element method. Using the implemented method, we study how droplets respond to specific spatiotemporal wettability patterns that either move or deform the droplet. Here, we present first studies of the spatio-temporal deformation dynamics induced by oscillating wettability along the contact line and of directed motion initiated by traveling wettability patterns. We specifically investigate how to design the patterns in order to maximize droplet speed.
[1] O. V. Voinov, Fluid Dyn. **11**, 714 (1976).

CPP 3.3 Mon 9:40 CPPb

Dynamics of liquid droplets on switchable prestructured substrates — •Moritz Stieneker[1] and Svetlana Gurevich[1,2] — [1]Institute for Theoretical Physics, University of Münster, Wilhelm-Klemm-Str. 9, D-48149 Münster, Germany — [2]Center for Nonlinear Science (CeNoS), University of Münster, Corrensstrasse 2, D-48149 Münster, Germany

A mesoscopic continuum model is employed to model a thin, liquid film on a substrate with a spatio-temporal wettability. In particular, the effect of a switchable wettability pattern on the structure formation is analyzed for a one-dimensional case with the help of path-continuation techniques and direct numerical time simulations. It is found that if the periodic switching is introduced, the system reaction depends on the ratio between the wetting time scale given by switching and the reaction time of the liquid. The behaviour of the contact angle during the slow and fast switching is investigated in details. Furthermore it is demonstrated that in the case of the slow switching the droplet solutions corresponding to the local minima of the free energy can be stabilized.

CPP 3.4 Mon 10:00 CPPb

Gradient dynamics model for drops spreading on polymer brushes — •Simon Hartmann and Uwe Thiele — Institut für Theoretische Physik, Westfälische Wilhelms-Universität Münster, Deutschland

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. We present a generic mesoscale hydrodynamic model for such processes that is written as a gradient dynamics on an underlying energy functional. We specify the model details for the example of a drop spreading on a dry polymer brush. There, liquid absorption into the brush results in swelling of the brush causing changes in the brush topography and wettability. The liquid may also advance within the brush via diffusion (or wicking) resulting in coupled drop and brush dynamics. The specific model accounts for coupled spreading, absorption and wicking dynamics when the underlying energy functional incorporates capillarity, wettability and brush energy. We employ a simple version of such a model to numerically simulate a droplet spreading on a swelling brush and provide an in-depth analysis of the simulation results and some interesting quantities.

40 min. meet the speakers - break

Invited Talk   CPP 3.5 Mon 11:00 CPPb

Liquid-liquid Dewetting: From Spinodal Breakup to Dewetting Morphologies and Rates — •Ralf Seemann[1], Roghayeh Shiri[1], Stefan Bommer[1], Dirk Peschka[2], Sebastian Jachalski[2], Lenoie Schmeller[2], and Barbara Wagner[2] — [1]Saarland University, Experimental Physics, D-66123 Saarbücken — [2]Weierstrass Institute, Mohrenstr. 39, D-10117 Berlin

The dewetting of liquid polystyrene (PS) from liquid polymethylmethacrylate (PMMA) is studied. At dewetting temperatures, both polymers can be considered as Newtonian fluids with the same viscosity. Provided that the liquid PS layer is below 10 nm, breakup occurs by spinodal dewetting. Due to the low interfacial tension of the buried interface compared to the PS-air interface and the large mobility, a very short spinodal wavelength develops with a larger amplitude of the buried interface than that of the free PS-air interface. The spinodal patterns of PMMA-PS and PS-air interface are anti-correlated and the observed wavelength is within the range predicted from thin film models. For a later dewetting stage, when dewetting rims in the range of the PMMA film thickness have formed, characteristic profiles of both PMMA-PS and PS-air interface develop, which depend on the PMMA/PS thickness ratio. The dewetting rates are approximately linear but do not obey any well-defined scaling behavior. Based on the agreement of experimental results with theoretical predictions, we use the numerical simulations to predict local flow fields and energy dissipation that would otherwise be inaccessible to experiments.

CPP 3.6 Mon 11:40 CPPb

Wetting transitions on soft substrates — Marek Napiorkowski[1], •Lothar Schimmele[2], and Siegfried Dietrich[2,3] — [1]Institute of Theoretical Physics, Faculty of Physics, University of Warsaw, Poland — [2]Max-Planck-Institut für Intelligente Systeme, Stuttgart, Germany — [3]IV. Institut für Theoretische Physik, Universität Stuttgart, Stuttgart, Germany

Within mean-field theory we study wetting of elastic substrates. Our analysis is based on a grand canonical free energy functional of the fluid number density and of the substrate displacement field. The substrate is described in terms of the linear theory of elasticity, parametrized by two Lamé coefficients. The fluid contribution is of the van der Waals type. Two potentials characterize the interparticle interactions in the system, the long-ranged attraction between the fluid particles and a potential characterizing the substrate-fluid interaction. By integrating out the elastic degrees of freedom we obtain an effective theory for the fluid number density alone. Its structure is similar to the one for wetting of an inert substrate. However, the long-ranged attraction between the fluid particles is replaced by an effective potential which also contains a term bilinear in the substrate-fluid interaction.

We discuss the corresponding wetting transitions in terms of an ef-

fective interface potential depending on the thickness of the wetting layer. We show that in the case of algebraically decaying interactions the elasticity of the substrate may suppress critical wetting transitions, and may even turn them first order.

CPP 3.7 Mon 12:00 CPPb

A Thermodynamic Consistent, Instantaneous Dividing Surface to Study Wetting Phenomena — •AMAL KANTA GIRI and MARCELLO SEGA — Helmholtz Institute Erlangen-Nürnberg for Renewable Energy, Forschungszentrum Jülich, Fürther Straße 248, 90429 Nürnberg, Germany

A detailed knowledge of the microscopic structure and dynamics in the interfacial region of soft materials is a necessary step on the way to develop novel materials and is also key to a deeper understanding of the statistical mechanics of fluid interfaces out of equilibrium. The presence of thermal capillary waves, however, hinders efforts to investigate the local structure of interfaces by smearing out observable quantities computed in the global reference frame. To recover a detailed picture of the interface neighborhood, one needs to compute observables in the local, instantaneous reference frame located at the interface, although the determination of this frame is, in general, not unique.

Here, we report on the possibility of using computational geometry approaches to determine the set of instantaneous surface atoms in a way which is thermodynamically consistent with the Gibbs (equimolar) dividing surface. We apply these methods to the determination of the instantaneous, fluctuating contact line of droplets on solid substrates, with an outlook on the problem of dynamic wetting of soft, deformable substrates.

CPP 3.8 Mon 12:20 CPPb

Core-shell latex colloids as interfaces for tailoring wetting properties — CALVIN J. BRETT[1,2,3], JOAKIM ENGSTRÖM[3,4], VOLKER KÖRSTGENS[5], PETER MÜLLER-BUSCHBAUM[5,6], EVA MALMSTRÖM[4], and •STEPHAN V. ROTH[1,4] — [1]DESY, 22603 Hamburg, Germany — [2]KTH, Dept. Mechanics, SE-10044 Stockholm, Sweden — [3]WWSC, SE-10044 Stockholm, Sweden — [4]KTH, Dept. Fibre and Polymer Technology, SE-10044 Stockholm, Sweden — [5]TUM, Physik Department, 85748 Garching, Germany — [6]MLZ, TUM, 85748 Garching, Germany

Facile surface functionalisation of latex colloids makes them most promising materials for broad thin film applications. However, the effect of these colloids on chemical film and wetting properties is not easily evaluated. Core-shell particles can deform and coalesce on the nanoscale during thermal annealing yielding tailored physical properties. We investigated two different core-shell systems (soft and rigid) with identical shell but with chemically different core polymer and core size. These core-shell colloids are probed during thermal annealing on surfaces in order to investigate their behavior as a function of nanostructure size and rigidity. X-ray scattering allows us to follow the re-arrangement of the colloids and the structural evolution in situ during annealing. Evaluation by real-space imaging techniques reveals a disappearance of the structural integrity and a loss of colloids' boundaries. We present the possibility to tailor and fine-tune the wettability by tuning the core-shell colloid morphology in thin films, thus providing a facile template methodology for repellent surfaces.

CPP 3.9 Mon 12:40 CPPb

Drop Impact on Hot Plates: Contact, Lift-Off and the Formation of Holes — •KIRSTEN HARTH[1,2], SANG.HYEON LEE[3], MAAIKE RUMP[2], MINWOO KIM[3], DETLEF LOHSE[2], KAMEL FEZZAA[4], and JUNG HO JE[3] — [1]Institute of Physics, Otto von Guericke University Magdeburg — [2]Physics of Fluid and Max Planck Center, University of Twente, The Netherlands — [3]X-Ray Imaging Center, Pohang University of Science and Technology, Korea — [4]X-Ray Science Division, Argonne Ntnl. Laboratory, USA

Everyone who poured water into a hot pan has experienced the manifold boiling behaviours of drops impacting on a hot plate, a problem which is of high relevance in many technical applications. When the drop is gently deposited, and the surface temperature is sufficiently high, it hovers on a vapour layer (Leidenfrost effect). For impacting drops, this critical temperature for a contact-less rebound is substantially increased, and much harder to determine. In fact, determining contact times between drops and smooth substrates from side view imaging is impossible for most temperatures above the boiling point. We combine High-Speed Total Internal Reflection and synchrotron X-Ray measurements to reliably determine contact times and the Leidenfrost temperature for drops impacting on smooth hot surfaces. Fur-

thermore, we study the lift-off characteristics. A local minimum in lift-off times correlates with spontaneous lamella rupture and the morphology of the contact.

60 min. meet the speakers - break

Invited Talk   CPP 3.10 Mon 14:00 CPPb

Sinking droplet durotaxis and engulfment — •ANNE JUEL — Department of Physics & Astronomy, University of Manchester, Oxford Road, Manchester M13 9PL, UK

Durotaxis refers to the spontaneous motion of objects along stiffness gradients of the supporting substrate. In droplet durotaxis migration occurs down rigidity gradients towards the softer regions of the substrate due to elasto-capillary interaction. We perform experiments in the limit of very soft PDMS substrates, where the cross-linked matrix of the gel can yield under the capillary stresses exerted by the sessile droplet. We find that the droplet moves towards the softest i.e. deepest parts of the gel layer while also sinking into the gel and that droplet durotaxis is much faster when engulfment is associated with the motion. For comparison, we focus on engulfment of aqueous droplets deposited onto a substrate layer of silicone oil. On substrates with a depth gradient, we observe qualitatively similar behaviour to the sinking durotaxis case. On deep layers, the droplet is ultimately engulfed in the oil layer. This involves rapid submersion of the droplet driven by capillary forces in the oil surface, followed by the much slower peeling of the droplet from the interface to which it is adhered. The later peeling stage is driven by a combination of geometric constraints at the apparent contact line and gravity pulling on the droplet. Gravitational effects are therefore essential to complete engulfment, even for micrometric droplets. Furthermore, the opposing effects of geometry and gravity result in the longest engulfment times for droplets of intermediate size.

CPP 3.11 Mon 14:40 CPPb

Droplets fighting contamination — •ABHINAV NAGA, WILLIAM WONG, ANKE KALTBEITZEL, MARIA D'ACUNZI, HANS-JÜRGEN BUTT, and DORIS VOLLMER — Max Planck Institute for Polymer Research, Mainz, Germany

Lubricated surfaces are prone to accumulating contaminants due to their sticky yet slippery nature. The presence of contaminants, such as dust and dirt particles, alters their performance. An understanding of the effect of contaminated particles on the friction of surfaces is important not only from a fundamental perspective whereby further insight can be gained of the underlying mechanisms, but also from an applied perspective to predict the effectiveness of lubricated surfaces in the presence of contaminants.

In this study, we systematically contaminate lubricated silicone surfaces (Sylgard 184) and non-lubricated surfaces with spherical glass microparticles. We place a droplet on each surface and measure the force needed to push the droplet at different speeds towards an individual microparticle. We visualise this process with laser scanning confocal microscopy, focusing on the deformation inflicted by the microparticle on the droplet and its lubricant ridge. We combine these visualisations with our force measurements to suggest a mechanism for the removal of contaminated particles from surfaces using droplets, and we outline the differences between the outcomes on the lubricated and the non-lubricated surfaces. This work will help to understand droplet dynamics on imperfect or dirty lubricated surfaces.

CPP 3.12 Mon 15:00 CPPb

Lucas-Washburn equation applies for four phase contact point — •PEYMAN ROSTAMI[1,2] and GÜNTER AUERNHAMMER[1,2] — [1]Max Planck Institute for Polymer Research, 55128, Mainz, Germany — [2]Leibniz Institute of Polymer Research, 01069, Dresden, Germany

A four-phase contact point, e.g., in merging of immiscible drops, is the point where the liquid-liquid interface advances along the contact line of one drop. The dynamics of drop merging involve various driving and dissipating forces in the dynamics of the four-phase contact point. The viscous friction, i.e. the flow field, within liquids is influenced by the different boundary conditions on the different interfaces (liquid-gas, liquid-liquid, liquid-solid). Additionally, Marangoni stresses between the two liquids and the spreading coefficients along the contact lines play a role. Effectively, these effects lead to a capillary force acting on the four-phase contact point. In total, the situation resembles the capillary flow in open V-shaped groove. The important difference is that, in the classical problem, the grooves are made out of two solid

walls, but in the present case one of the *walls* is liquid, i.e., flowable and deformable. We investigate a range of liquids with different combination of physical properties (viscosity ratio, surface and interfacial tensions). The results show a good qualitative agreement for different liquids of the experimental results with the classical Washburn equation (h~square root of time), where h is the filled length of the *groove*.

CPP 3.13   Mon 15:20   CPPb

Imbibition-Induced Deformation Dynamics in Nanoporous Media — •Juan Sanchz[1], Zhuoqing Li[2], Michael Froeba[3], and Patrick Huber[4] — [1]Institute of Materials Physics, Hamburg University of Technology — [2]Institute of Materials Physics, Hamburg University of Technology — [3]Institute of Anorganic and Applied Chemistry, Hamburg University — [4]Institute of Materials Physics, Hamburg University of Technology

We present time-dependent macroscopic dilatometry experiments on the deformation of nanoporous monoliths (carbon and silica) upon spontaneous, capillarity-driven invasion of water. We find two distinct dynamical regimes. One of them can be quantitatively traced to deformations originating in changes in the surface stress at the inner pore walls (dynamic Bangham's regime) upon water invasion, whereas the second one results from Laplace pressure effects. Our study demonstrates that it is possible to dynamically monitor imbibition dynamics by simple dilatometry measurements.

CPP 3.14   Mon 15:40   CPPb

Macroscopic Capillary Number for Characterization of Two-phase Flow in Porous Media — •Hu Guo and Rudolf Hilfer — Institute for Computational Physics, Universität Stuttgart, Stuttgart, Germany

The Capillary number (Ca) defined as the ratio of viscous force to capillary force is widely used to qualitatively characterize multiphase flow in porous media as in carbon dioxide geologic sequestration and chemical enhanced oil recovery (EOR). The main difficulty is to characterize forces porperly. There exists 22 definitions for Ca (Guo et al, IOR 2020). The most concise definition is $Ca = \frac{v\mu}{\sigma}$ with velocity v, viscosity μ and interfacial tension σ (Saffman and Taylor, 1958). It is supported by core flooding tests and most widely used. However, this definition is less sound than the one that involves the wettability parameter (Moore and Slobod, 1955). Meanwhile, the values of these Ca are regarded as too small to reflect the actual force balance (Dullien, 1979). It was shown theoretically, that this Ca is microscopic in nature and incorrectly used (Hilfer and Øren, 1996, Trans. Porous Media).

We study the new macroscopic capillary number $Ca = \frac{\mu\phi vL}{KP_b}$ with viscosity μ, porosity ϕ, velocity v, permeability K, length L and capillary breakthrough pressure P_b (Hilfer et al, 2015, Physical Review E). The new Ca explains some of the latest observations (Doorwar and Mohanty, 2017, SPE J; Qi et al, 2017, SPE J; Rabbani et al, 2018, PNAS; Zhao et al, 2019, PNAS) that contradict predictions obtained from the microscopic Ca. EOR field practice also verified that the macroscopic Ca is more profound.

30 min. meet the speakers - break