CPP 54: Wetting, Micro and Nanofluidics (joint session CPP, DY)

Time: Wednesday 15:00–18:15 Location: C 243

CPP 54.1 Wed 15:00 C 243

Lateral adhesion force of superhydrophobic surfaces — •Doris Vollmer, Dominik Pilat, Nan Gao, Periklis Papadopoulos, Frank Schellenberger, Rüdiger Berger, and Hans-Jürgen Butt — MPI for Polymer Research, Mainz, Germany

We designed an instrument to measure the lateral adhesion force of drops on surfaces (1). The forces required to slide a sessile drop over a surface was measured by means of the deflection of a capillary that stuck in the drop. This allows the investigation of the dynamic lateral adhesion force of water drops on superhydrophobic surfaces. The movement of the drop relative to the surfaces enabled us to resolve the pinning of the three-phase contact line. This was related to the shape of the drop profile, which was recorded by video microscopy. The lateral adhesion of a drop on a superhydrophobic pillar array was quantified in dependence of pillar spacing and drop velocity.

(1) D.W. Pilat, P. Papadopoulos, D. Schaeffel, D. Vollmer, R. Berger, and H.-J. Butt, Langmuir 2012, 28, 16812.

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Drying and Wetting transitions on irregular rough substrates. — •Segun Gideon Ayodele, Ciro Semprebon, Renaud Dufour, Stephan Herminghaus, and Martin Brinkmann — Max-Planck Institut für Dynamik und selbstorganisation, 37077 Göttingen.

Drying and wetting transitions on non-flat solids of homogeneous wettability are studied employing a sharp interface model. Interfacial configurations in the Grand canonical ensemble and corresponding numerical energy minimizations for a non-zero microscopic contact angle are compared to predictions based on the statistical model proposed in Refs. [1,2]. This mean field model considers exclusively local descriptors of the substrate topography such as the distribution of heights, as well as averages of the slope and its square at a given height. In contrast to the continuous desorption isotherm of a zero microscopic contact angle, we observe an increasingly discontinuous decay of the average film thickness in our numerical simulations during a desorption as the microscopic contact angle is increased. The pressure of the final drying transition as observed in the simulated annealing and numerical energy minimization is in agreement with predictions of the 'Wenzel prewetting' transition in the mean field model [1,2].

1. S. Herminghaus, Eur. Phys. J. E 35, 43 (2012).
2. S. Herminghaus, Phys. Rev. Lett., 109,236102 (2012).

CPP 54.3 Wed 15:30 C 243

Dynamic Trapping of Sliding Drops on Wetting Defects — •Andrea Cavalli[1], Michiel Musterd[2], Rudy Lagraauw[1], Dieter 't Mannetje[1], Dirk van den Ende[1], and Frieder Mugele[1] — [1]University of Twente, MESA+ Institute for Nanotechnology; Physics of Complex Fluids, Enschede, The Netherlands — [2]Delft University of Technology, Delft, The Netherlands

We present a numerical analysis of the dynamic interaction of sliding drops on an inclined plate with wetting defects. Our three-dimensional model, developed with OpenFOAM allows us to describe intertial and viscous effects, as well as the internal degrees of freedom of the droplet. We observe that the ability of a drop to deform and stretch enhances the strenght and range fo the wetting defect, as compared to a simplified analytic description of a non-deformable drop. Yet, the key physical parameters, namely the ration between trapping strength and driving force as well as the ratio between interial and viscous time scale prevail as governing control parameters. We further investigate the role of the strength, size and steepness of the wetting defect in retaining the drop. Finally, we compare our simulations with trapping experiments on electrowetting obstactles. The quantitative agreement shows that the trapping of sliding drops follows a universal behavior, which is largely independent of the specific nature of the defect.

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Sub-nanometric substrate structural changes enhance the solid/liquid slip boundary condition — •Joshua McGraw, Antoine Bridet, Samuel Grandthyll, Hendrik Hähl, Frank Müller, and Karin Jacobs — Experimental Physics, Saarland University, 66041 Saarbrücken, Germany

Alkylsilane self-assembled monolayers (SAMs) have long been used as model substrates for their ease of preparation and hydrophobic properties. We have long observed that these monolayers also provide a slip boundary condition for dewetting polymer films, and that the slip condition is switchable if the alkyl chain length is changed (from 12 to 18 backbone carbons, for example). Typically, this change is affected in a quantized way, using one or the other chain length, thus obtaining one or the other slip condition. It has been suggested that the specific structure of the resulting SAM controls the slip condition. Here, we present results in which this structure is changed in two continuous ways. First, we prepare SAMs containing bidisperse mixtures of alkyl silanes, with the composition as a control parameter. Second, we thermally anneal the SAMs, resulting in an irreversible loss of carbon from the monolayer. In both cases, we find an enhanced slip condition which is tuneable over a certain range.

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Universal Regimes in the Relaxation of Stepped Liquid Interfaces near Contact Lines — •Marco Rivetti[1], Thomas Salez[2], Michael Benzaquen[2], Elie Raphael[2], and Oliver Baeumchen[1] — [1]Max Planck Institute for Dynamics and Self-Organization (MPIDS), 37077 Goettingen, Germany — [2]Laboratoire de Physico-Chimie Theorique, UMR 7083 CNRS & ESPCI ParisTech, Paris, France

A liquid droplet on a perfectly smooth surface wets or dewets the substrate according to the difference between initial and equilibrium contact angles [1]. Such a scenario, however, becomes less intuitive whenever the initial shape of the interface is non-spherical. Indeed, the capillary-driven relaxation of the liquid surface may be in competition with the relaxation of the contact angle at the three-phase contact line. Here, we study the dynamics of stepped interfaces of thin polystyrene films on hydrophilic substrates. Annealing the polymeric film above its glass transition temperature induces flow which is precisely monitored using ex- and in-situ atomic force microscopy. Both pinned and receding contact line regimes are observed. Rescaling with regard to the viscosity, surface tension and film thickness collapses the data on a master curve, providing a universal time for the transition between both regimes. In addition, we prove that the pinned interface exhibits self-similar height profiles which are captured by a thin film model in lubrication approximation [2].

[1] S.L.Cormier et al, PRL 109, 154501 (2012); [2] J.D.McGraw et al, PRL 109, 128303 (2012)

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Dynamic Contact Angle of a Soft Linear Viscoelastic Solid — •Stefan Karpitschka[1], Siddhartha Das[2], Mathijs van Gorcum[1], Hugo Perrin[3], Bruno Andreotti[3], and Jacco H. Snoeijer[1,4] — [1]Physics of Fluids Group, Faculty of Science and Technology, Mesa+ Institute, University of Twente, 7500 AE Enschede, The Netherlands — [2]Department of Mechanical Engineering, University of Maryland, College Park, MD 20742, USA — [3]Physique et Mécanique des Milieux Hétérogènes, UMR 7636 ESPCI -CNRS, Univ. Paris-Diderot, 10 rue Vauquelin, 75005, Paris, France — [4]Department of Applied Physics, Eindhoven University of Technology, P.O. Box 513, 5600MB Eindhoven, The Netherlands

The wetting motion of a liquid over a rigid solid gives rise to a dynamic liquid contact angle. Here we show that on a soft, viscoelastic substrate, a moving contact line leads to a dynamic contact angle of the solid. The initially flat solid surface is deformed elastically into a sharp ridge. The ridge shape and the orientational angle of its tip depend on the contact line velocity. We present a theory based on linear response that reveals how the dynamics of the wetting ridge emerges from the substrate rheology. The theory is validated experimentally with measurements of the dynamic contact angle on a silicone gel.

15 min. break

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Capillary force acting on a particle correlated with the shape of the meniscus — •Frank Schellenberger, Periklis Papadopoulos, Stefan Weber, Michael Kappl, Doris Vollmer, and Hans-Jürgen Butt — Max Planck Institute for Polymer Research, Mainz, Germany

Capillary bridges play a important role for the stability of colloidal systems. The forces of these bridges strongly correlates with their shape. It is possible to measure capillary forces with an Atomic Force Microscope (AFM), but it is impossible with such a device to image the shape of the capillary bridge at the same time.

Analytical and numerical calculations exist that correlates the force of the capillary bridges with the shape of the liquid . However experimentally capillary bridges could not directly be imaged with the corresponding force in the micrometer range so far. A Laser Scanning Confocal Microscope (LSCM) can visualize the shape of a liquid bridge on solid surface in a three-dimensional form. We built a combined LSCM and AFM device and measured the forces with colloidal probes on liquid surfaces. The combination of force spectroscopy and confocal microscopy allows us to image capillary bridges and simultaneously measure the corresponding force.

With our setup we can now verify the theoretical forces, calculated from the shape of the meniscus, and the corresponding force curves. We present our results of the simultaneous AFM and LSCM measurements of capillary bridges.

CPP 54.8 Wed 17:00 C 243

Wettability-independent bouncing on flat surfaces

— Jolet de Ruiter, Rudy Lagraauw, Dirk van den Ende, and •Frieder Mugele — University of Twente; MESA+ Institute for Nanotechnology, Physics of Complex Fluids, Enschede, The Netherlands

The impingement of drops onto solid surfaces plays a crucial role in a variety of processes, including inkjet printing, fog harvesting, anti-icing, dropwise condensation and spray coating. Recent efforts in understanding and controlling drop impact behaviour focused on superhydrophobic surfaces with specific surface structures enabling drop bouncing with reduced contact time. Here, we report a different universal bouncing mechanism that occurs on both wetting and non-wetting flat surfaces for both high and low surface tension liquids. Using high-speed multiple-wavelength interferometry, we show that this bouncing mechanism is based on the continuous presence of an air film for moderate drop impact velocities. This submicrometre air cushion slows down the incoming drop and reverses its momentum. Viscous forces in the air film play a key role in this process: they provide transient stability of the air cushion against squeeze-out, mediate momentum transfer, and contribute a substantial part of the energy dissipation during bouncing.

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Surfactants in droplet-based microfluidics – Adsorption, Exchange and Biocompatibility

— •Birte Riechers[1,2], Philipp Gruner[2], Florine Maes[1,2], and Jean-Christophe Baret[1,2] — [1]Center de Recherche Paul Pascal, Bordeaux, France — [2]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

Emulsions are omnipresent in industry, research and daily life. They are widely used in painting materials, cosmetics as well as for medical and biotechnology applications [Bremond et al. Soft Matter 2012]. Emulsions are multiphase liquids stabilised using surfactants. These amphiphilic molecules adsorb to interfaces changing their properties (e. g. surface tension, interfacial rheology) [Baret Lab Chip 2012]. They also chemically or physically interact with the dispersed aqueous phase effecting solubility of solutes in all phases [Skhiri et al. Soft Matter2012].

Here, we analyse the properties of surfactants which result in undesirable reactions and interactions with the interior of the droplets. We present a microfluidic method to determine the adsorption kinetics of surfactants. The principle is based on miniaturised pH measurements at the micron-scale. We show that the surfactant exchange between the droplet interface and the continuous phase occurs within seconds and significantly effects the loss of chemicals from droplets. Our method provides new means to analyse surfactant interfaces and their interactions with the aqueous phase of emulsion droplets. We anticipate that our approach can be used to optimise surfactants and formulations for applications in emulsion-based biochemical analysis.

CPP 54.10 Wed 17:30 C 243

Coexistence of Various Instabilities on a Single Liquid Filament

— Michael Hein[1], •Jean-Baptiste Fleury[1], and Ralf Seemann[1,2] — [1]Saarland University, Experimental Physics, Saarbruecken, Germany — [2]Max Planck Institute for Dynamics and Self-Organization, Goettingen, Germany

Droplet based microfluidics exploits the decay of a liquid filament or cylinder into droplets of micrometric size. While the physics of droplet breakup on small scales remains a field of vivid interest, droplet based microfluidic systems have become widely used both in fundamental science and application such as (bio-)analytics or micro-chemistry. We present experimental research on the formation of droplets by breakup of a squeezed liquid filament surrounded by an immiscible phase that flows over a topographic step. This non-equilibrium process arises from the interplay between flow properties and interfacial instabilities when the filament is suddenly released from confinement at the step. In contrast to previous studies, a rich variety of different droplet breakup regimes was observed for the used geometry which are characterized by the coexistence of multiple liquid instabilities on a single filament. Surprisingly, these instabilities can be of different type while the filament is exposed to a symmetric flow-field. This spontaneous symmetry breaking is a nontrivial consequence of volume throughput constraints of each individual instability and allows for the specific production of heterogeneous droplet families from one single filament under constant flow rates.

(Michael Hein, Jean-Baptiste Fleury and Ralf Seemann, Submitted)

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Inertial microfluidics: control of lift forces and dynamics of microfluidic crystals

— •Christopher Prohm and Holger Stark — Institut für Theoretische Physik, Technische Universität Berlin, D-10623 Berlin

At intermediate Reynolds numbers, particles in microfluidic channels assemble at fixed distances from the channel axis and bounding walls [1]. This Segré-Silberberg effect can be described in terms of an inertial lift force acting on the particles. At increasing densities the particles form microfluidic crystals due to an interplay of hydrodynamic interactions and inertial lift forces [2]. Microfluidic devices utilizing inertial migration have recently been demonstrated for biomedical tasks such as particle sorting or separation [1].

Here, we investigate the motion of colloidal particles in microfluidic channels using the lattice Boltzmann method [3]. First, we show how the geometry of the channel influences inertial focusing of a single particle. We also demonstrate that manipulating the axial or angular velocity of the particle modifies its lift-force profile, which permits control of the lateral particle position. Second, we investigate suspensions of particles. We describe how they self-assemble into microfluidic particle crystals and discuss the dynamic properties of these crystals.

[1] H. Amini, W. Lee, and D. Di Carlo, *Lab Chip* **14**, 2739 (2014).

[2] W. Lee, H. Amini, H. A. Stone, and D. Di Carlo, *Proc. Natl. Acad. Sci. U.S.A.* **107**, 22413 (2010).

[3] C. Prohm and H. Stark, *Lab Chip* **14**, 2115 (2014).

CPP 54.12 Wed 18:00 C 243

High-throughput and passive trapping of nano-objects using electrostatic forces

— •Michael Adrian Gerspach[1,2,3], Nassir Mojarad[2], Yasin Ekinci[2], and Thomas Pfohl[1,3] — [1]Swiss Nanoscience Institute, Basel, 4056, Switzerland — [2]Paul Scherrer Institute, Villigen, 5323, Switzerland — [3]Department of Chemistry, University of Basel, Basel, 4056, Switzerland

Contact free trapping of nano-objects in solution is of broad interest. Although several methods have been developed, like optical tweezers, stable and high throughput trapping of nanometer-sized particles remains challenging. Our approach of trapping charged nano-objects is geometry induced electrostatic trapping [1], a method based on altering the surface topology of nano-channels that are negatively charged when exposed to water. Here we present the on chip contact free trapping of single 40 to 80 nm gold particles in nanometer-sized pockets without the use of any externally applied forces. The particles in the solution are pushed into the pockets and trapped only because of the difference in electrostatic potential between the nanofluidic channel walls and the finer pocket structures. Increasing the salt concentration of the solution leads to screening of the surface charges by free counter ions and therefore, weakens the trap strength and shortens the average time a particle dwell in a trap. Thus by chancing the concentration of the solution or the height of the nanofluidic channels, the particles can be trapped from microseconds to several minutes. In future we plan to extend this method to trap and investigate the dynamics of biological entities such as DNA or large proteins. [1] Nature 457 (2010), 692-695