

DY 39: Wetting, Microfluidics and Confined Liquids I (joint session CPP/DY)

Time: Wednesday 9:30–13:00

Location: C 264

Invited Talk

DY 39.1 Wed 9:30 C 264

Slippage over superhydrophobic surfaces: fundamentals and local phenomena — ●CLARISSA SCHÖNECKER^{1,2}, DAVID SCHÄFFEL², KALOIAN KOYNOV², DORIS VOLLMER², and HANS-JÜRGEN BUTT² — ¹Lehrstuhl für Mikrofluidmechanik, TU Kaiserslautern — ²Max-Planck-Institut für Polymerforschung, Mainz

Superhydrophobic surfaces can provide a significant slip to a fluid flowing over the surface, making them attractive for the development of functional coatings. Although the global behaviour of flow past such surfaces has been widely investigated, understanding the local fundamentals that lead to slippage is still lacking. We studied in detail the local slip length and local flow field for water in the Cassie state on a structured superhydrophobic surface. Using fluorescence correlation spectroscopy, we revealed that the local slip length of a superhydrophobic surface is finite, non-constant and anisotropic. Furthermore, it can be strongly influenced by the presence of surface active substances. All these properties are in accordance with and can be explained by a theoretical model of the local hydrodynamics close to the surface. The study shows the effect of surface properties, like the surface geometry or interfacial forces.

DY 39.2 Wed 10:00 C 264

How drops start sliding over solid surfaces — DORIS VOLLMER¹, NAN GAO^{1,2}, FLORIAN GEYER¹, DOMINIK PILAT¹, SANGHYUK WOOH¹, HANS-JÜRGEN BUTT¹, and ●RÜDIGER BERGER¹ — ¹Max Planck Institute for Polymer Research, Ackermannweg 10, 55128 Mainz, Germany — ²Fudan University, 220 Handan Road, Shanghai 200433, People's Republic of China

We report that the lateral adhesion force between a liquid drop and a solid can be divided into a static and a kinetic regime. This striking analogy with solid-solid friction is a generic phenomenon that holds for liquids [1]. We have investigated the lateral adhesion forces of liquids of different polarities and surface tensions on smooth, rough and structured surfaces. The lateral adhesion forces were measured with a home build instrument [2] and calculated by the occurring changes of the rear and the front of the drop, its changes in drop widths and the liquid-air surface tension. Our studies indicate that the lateral adhesion force is dominated by contact line friction and interfacial friction only plays a minor role. Finally, the lateral adhesion force measurements can provide quantitative information on the homogeneity or cleanliness of surfaces.

References:

- [1] N. Gao, F. Geyer, D.W. Pilat, S. Wooh, D. Vollmer, H.-J. Butt, R. Berger, *Nature Physics* (2017), doi: 10.1038/NPHYS4305
 [2] D. W. Pilat, P. Papadopoulos, D. Schäffel, D. Vollmer, R. Berger, H.-J. Butt, *Langmuir* 28, 16812-16820(2012), doi 10.1021/la3041067

DY 39.3 Wed 10:15 C 264

Beyond the Navier-de Gennes Paradigm: Slip Inhibition on Ideal Substrates — MARK ILTON^{1,2}, THOMAS SALEZ^{3,4}, PAUL FOWLER^{1,5}, MARCO RIVETTI⁵, MOHAMMED ALY⁶, MICHAEL BENZAQUEN^{4,7}, JOSHUA MCGRAW^{1,6}, ELIE RAPHAEL⁴, KARI DALNOKI-VERESS¹, and ●OLIVER BÄUMCHEN⁵ — ¹McMaster University, Hamilton, Canada — ²University of Massachusetts, Amherst, MA, USA — ³Univ. Bordeaux, Talence, France — ⁴ESPCI Paris, Paris, France — ⁵Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — ⁶Ecole Normale Supérieure, Paris, France — ⁷Ecole Polytechnique, Palaiseau Cedex, France

Hydrodynamic slip of a liquid at a solid surface governs liquid transport at small scales. For polymeric liquids, de Gennes predicted that the Navier boundary condition together with the theory of polymer dynamics imply extraordinarily large slip for entangled polymer melts on ideal surfaces; this Navier-de Gennes paradigm was confirmed using dewetting experiments on ultra-smooth, low-energy substrates. Here, we use capillary leveling of polymeric films on these same substrates to measure the slip length from a robust one-parameter fit to a lubrication model. We show that at the low shear rates involved in leveling experiments, the employed substrates can no longer be considered ideal. The data is instead consistent with physical adsorption of polymer chains at the solid/liquid interface. We extend the Navier-de Gennes description using one additional parameter, namely the density of physically adsorbed chains per unit surface. The resulting model is found to be

in excellent agreement with the experimental observations.

DY 39.4 Wed 10:30 C 264

Consistency condition for macro- and mesoscopic descriptions of contact line with surfactant — ●UWE THIELE¹, SARAH TRINSCHER¹, JACCO H. SNOEIJER², and KARIN JOHN³ — ¹Institut für Theoretische Physik, Universität Münster, Wilhelm-Klemm-Str. 9, Münster — ²Physics of Fluids Group, Faculty of Science and Technology, University of Twente, Enschede — ³Laboratoire Interdisciplinaire de Physique, Université Grenoble-Alpes, CNRS

Consider a three-phase contact line where a liquid-gas interface meets a solid. For a simple liquid at equilibrium it is described on the macroscale by the Young-Dupré law relating the three interfacial energies to the equilibrium contact angle θ_e . On the mesoscale, it is modelled by a film-height-dependent wetting energy $f(h)$. Macro- and mesoscale description are consistent if $\gamma \cos \theta_e = \gamma + f(h_a)$ where γ and h_a are the liquid-gas interface energy and the thickness of the equilibrium adsorption layer, respectively.

Our contribution discusses the incorporation of insoluble surfactant. We derive the macro- and mesoscopic equilibrium models for spatially inhomogeneous states (consistent with the dynamic approach of [1,2]). Discussing the case of a static contact line with surfactant, we show that again there exists a consistency condition between macro- and mesoscopic descriptions. It imposes a particular dependence of the wetting energy on surfactant concentration. This is illustrated at a simple example. [1] U. Thiele, A. J. Archer and M. Plapp, *Phys. Fluids* 24, 102107 (2012). [2] U. Thiele, A. J. Archer and L. M. Pismen, *Phys. Rev. Fluids* 1, 083903 (2016).

15 min. break

DY 39.5 Wed 11:00 C 264

What determines the lateral adhesion force? — ●DORIS VOLLMER, NAN GAO, SANGHYUK WOOH, RÜDIGER BERGER, and HANS-JÜRGEN BUTT — MPI für Polymerforschung, Mainz

The mobility of drops on surfaces depends on the interactions between the drop, the surface and its surrounding medium. The strength of the interactions is reflected in the lateral adhesion force, FLA. We have investigated the lateral adhesion forces of droplets of water on a superhydrophobic periodic structure made of TiO₂ pillars or varying distance, using a laser deflection system. The force per pillar across the effective contact width did not change with the spacing ratio. Notably, the lateral adhesion force can be calculated, knowing either (i) the apparent contact width and the apparent contact angles or the (ii) real contact width and the contact angle on the corresponding flat surface.

DY 39.6 Wed 11:15 C 264

Efficient Condensation and Droplet Removal on Electrowetting-Functionalized Surfaces — DAVOOD BARATIAN, RANABIR DEY, HARMEN HOEK, DIRK VAN DEN ENDE, and ●FRIEDER MUGELE — University of Twente; Physics of Complex Fluids, Enschede, The Netherlands

Efficient condensation of vapor and collection of fog from the atmosphere are important to life in arid environments. Nature has come up with various strategies to optimize the processes by a combination of both topographic and chemical functionalization of solid surfaces that are imprinted passively into the structure of the surface. One crucial aspect in this process is the removal of liquid from the solid surface once it has condensed. In here, we present a novel active approach to improve the efficiency of vapor condensation onto hydrophobic surfaces that are functionalized by electrowetting. We fabricated electrowetting-functionalized surfaces with submerged interdigitated electrodes. Upon exposure to supersaturated vapor droplets condense onto these surfaces in an initially random pattern. As the droplets grow, electrowetting mobilizes the growing drops and induces early coalescence, giving rise to alignment of drops and to early shedding. Mobilization and early shedding are controlled by the effective reduction of contact angle hysteresis in AC electrowetting. Drops are found to grow algebraically, initially with a self-similar growth law as in conventional drop condensation. At a later stage, self-similarity is broken and the statistical drop size distribution is altered. We discuss poten-

tial applications in terms of heat transfer.

DY 39.7 Wed 11:30 C 264

Forced dynamic dewetting of structured surfaces: Influence of surfactants — ●GÜNTER K. AUERNHAMMER^{1,4}, FRANZISKA HENRICH¹, DOROTA LINKE¹, HANS MARTIN SAUER², EDGAR DÖRSAM², STEFFEN HARDT³, and HANS-JÜRGEN BUTT¹ — ¹MPI Polymer Research, Mainz, Germany — ²TU Darmstadt, IDD, Germany — ³TU Darmstadt, Nano- und Mikrofluidik, Germany — ⁴IPF, Dresden

We investigate dynamic dewetting on structured surfaces. The focus lies on the interplay between surface structure and surfactants concentration in forced dewetting. The structured surfaces are printing plates for gravure printing with different sizes of the gravure cells. These plates were mounted on a rotating horizontal cylinder that is half-immersed in an aqueous solution of the anionic surfactant sodium 1-decanesulfonate. On the printing plates, structured and unstructured areas were side by side to enable a direct comparison. When rotating the cylinder a liquid meniscus is partially drawn out of the liquid. The moving contact line was pinned on the borders of the gravure cells, leading to a strongly varying receding contact angle. For this reason we compare the height differences of the meniscus on the structured and unstructured area. With increasing size of the gravure cells this height difference increases. By adding surfactant, the height difference for the same surface decreases. We conclude that the surfactant reduces the influence of a structured surface on dynamic dewetting. Characterizing the emptying mechanism of the gravure cells revealed that some liquid is left in the gravure cell.

DY 39.8 Wed 11:45 C 264

Spatially Resolved NMR with Micrometer Resolution in Static Field Gradients — ●BENJAMIN KRESSE, MARK HÖFLER, ALEXEI F. PRIVALOV, and MICHAEL VOGEL — TU Darmstadt, Hochschulstr. 6, 64289 Darmstadt, Germany

A new probe head is presented which is specially designed for magnetic resonance imaging (MRI) with ultrahigh resolution in one dimension using a static field gradient magnet. In contrast to clinical MRI scanners with a spatial resolution of typically 0.1 to 1 mm a resolution of about 2 μm is reached due to the high field gradient of 73 T/m. Systems with a rotational symmetry can be investigated by scanning the sample slice-wise. The key feature of the probe is a precise computer controlled adjustment of the sample position and orientation e.g. to adjust the sample axis parallel to the gradient of the magnetic field.

Wetting processes can be investigated. For example, droplets on surfaces can be studied in terms of density by inspecting the signal amplitude and in terms of molecular dynamics by measuring the relaxation time of the nuclear spins. Furthermore, concentration gradients of mixtures can be examined by measurements on different isotopes. It is also possible to investigate biological objects with flat geometries like skin. In principle non-stationary processes like in microfluidics can be explored with an increased time resolution by a boosted signal-to-noise ratio using stripline designs.

DY 39.9 Wed 12:00 C 264

Feedback-Control of Photoresponsive Fluid Interfaces — ●JOSUA GRAWITTER and HOLGER STARK — Institut für Theoretische Physik, Technische Universität Berlin, 10623 Berlin, Deutschland

New microfluidic devices promise powerful applications in diagnosing and combatting illness around the world. Conventional, pressure-driven devices rely on static channel geometries designed for specific flow patterns. Light-driven devices instead use photosensitive surfactants to produce surface tension gradients that drive Marangoni currents. By changing their light patterns in response to fluid flow, light-driven devices add feedback control methods to the microfluidic toolbox.

To explore their potential, we develop a diffusion-advection-reaction equation for photosensitive surfactants and calculate Marangoni currents at fluid-fluid interfaces. We then study how the interface responds when illuminated by spots of light. Switching on a single light spot, the density of the switched surfactant spreads in time and assumes an exponentially decaying profile in steady state. Simultaneously, the induced radial Marangoni flow reverses its flow direction from inward to outward. We use this feature to set up specific feedback rules, which couple advection velocities sensed at the light spots

to their intensities. As a result two neighboring spots switch on and off alternately. When we arrange more light spots on regular polygons, regular and irregular oscillations in light intensity emerge for certain numbers of spots. This demonstrates how light-driven feedback control may be used to create responsive and versatile microfluidic devices.

DY 39.10 Wed 12:15 C 264

Collective Orientational Order and Phase Behavior of a Discotic Liquid Crystal under Confinement — ●ARDA YILDIRIM¹, KATHRIN SENTKER², PATRICK HUBER², and ANDREAS SCHÖNHALS¹ — ¹Bundesanstalt für Materialforschung und -prüfung (BAM), Unter den Eichen 87, 12205 Berlin, Germany — ²Institut für Materialphysik und -technologie, Technische Universität Hamburg, Eißendorfer Str. 42, 21073 Hamburg, Germany

Discotic liquid crystals (DLCs) are a promising class of soft matter for electronic applications. This is due to their ability to self-organize into columns in a hexagonal columnar mesophase, driven by the overlapping of the π orbitals of their aromatic cores. This leads to a high charge-carrier mobility along the column axis. Previous studies on DLCs showed that their properties, such as phase transition temperatures and enthalpies, are susceptible to nanoconfinement [1,2]. In this study, 2,3,6,7,10,11 hexakis[hexyloxy] triphenylene (HAT6) was confined into parallel aligned cylindrical nanopores of anodic aluminum oxide (AAO) membranes by melt infiltration. Furthermore, the pore surfaces of a series of membranes were chemically modified, resulting in a more hydrophobic pore surface than the unmodified ones. Collective orientational order and phase behavior of HAT6 confined into modified and unmodified nanopores of AAO were investigated by broadband dielectric spectroscopy and differential scanning calorimetry respectively. [1] C. Krause and A. Schönhals, J. Phys. Chem. C, 2013, 117, 19712. [2] C. Krause et al., Colloid Polym. Sci., 2014, 292, 1949

DY 39.11 Wed 12:30 C 264

Reversible smectic layer buckling of a ferroelectric liquid crystal confined in anodic aluminum oxide nanochannels — ●MARK BUSCH¹, ANDRIY V. KITKYK^{2,1}, TOMMY HOFMANN³, DIRK WALLACHER³, and PATRICK HUBER¹ — ¹TU Hamburg-Harburg, Hamburg, Germany — ²Czestochowa University of Technology, Czestochowa, Poland — ³Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Germany

The temperature-dependent structural and electro-optical properties of the ferroelectric liquid crystal 2MBOCBC inside the confining cylindrical nanochannels of anodic aluminum oxide are investigated.[1] The channel walls of the 42 nm diameter pores are coated with a polymer to enforce a planar anchoring of this chiral mesogens. By means of neutron diffraction a fully reversible temperature-dependent smectic C* layer buckling towards a symmetric chevron-like structure is found. The formation of this structure coincides with a dramatic decrease in the linear electro-optical response, being explained by the aforementioned structural rearrangement.

[1] Busch et al., Nanoscale (2017), DOI: 10.1039/C7NR07273B

DY 39.12 Wed 12:45 C 264

Transport processes in water vapour sorption experiments on grained hygroscopic materials — ●ALEXANDER MURR — Institute for Structural Engineering and Material Science, University of Innsbruck

Water vapour sorption (WVS) experiments are frequently used to characterise the behaviour of hygroscopic materials for a variation in humidity. Sample material is exposed to a step change in relative humidity (RH) and the mass change is measured gravimetrically.

In order to identify the involved transport processes, WVS experiments on grained wood and cellulose have been performed. A comparison on the sorption kinetics of four different grain layer filling levels indicates the necessity of including the water vapour transport between the sample surface and the forced air stream. Analysing the initial kinetics shows this transport being relevant for the whole range of RH. Additionally, the limitation of a non-instantaneous step change in RH will be discussed. An analysis based on a simple diffusion equation with an instantaneous sink provides further insights on the measured sorption kinetics. Consequently, the relaxation and reorganisation processes could be more easily separated and characterised in future experiments.