DY 17: Focus: Droplets (joint session DY/CPP)

The physics of droplets is surprisingly rich - and full of surprises. This holds for droplets in ambient gas and for droplets in other liquids. The geometric and dynamical parameters which enter are size and velocity and the material properties are density, surface tension, velocity, volatility, freezing and melting points, latent heat, viscosity, thermal conductivity,... and all this holds for both the drops and for the surrounding gas or liquid. Moreover, both droplet and surrounding can be multicomponent and phase transitions and chemical reactions. The consequence of this huge parameter space is a plethora of often very surprising phenomena - and many are technologically very important. The systematic optimization of processes involving such phenomena needs a fundamental understanding of the physics. In this session various examples are given in which the community has worked towards such an understanding, combining controlled experiments, numerical simulations, and theoretical analysis.

D. Lohse

Time: Monday 15:30–19:15 Location: BH-N 334

DY 17.1 Mon 15:30 BH-N 334

Marangoni Contraction of Evaporating Sessile Droplets of Binary Mixtures — •Stefan Karpitschka[1], Ferenc Liebig[2], and Hans Riegler[3] — [1]Max Planck Institute for Dynamics and Self-Organization, Am Faßberg 17, 37077 Göttingen — [2]Institute of Chemistry, University of Potsdam, Karl-Liebknecht-Straße 24-25, 14476 Potsdam — [3]Max Planck Institute of Colloids and Interfaces, Am Mühlenberg 1, 14476 Potsdam

The evaporation of sessile droplets of mixtures is a ubiquitous natural and industrial process, relevant, e.g., for cleaning/drying of semiconductor surfaces or for ink-jet printing. For binary mixtures, the component with the higher vapor pressure will usually evaporate faster and thus deplete from the contact line region of a droplet. In general, different liquids have different surface tensions. Thus, evaporation causes surface tension gradients and Marangoni flows. Here we investigate the impact of evaporation on the wetting behavior of binary mixtures [Langmuir 33, 4682 (2017)]. We measure non-zero apparent contact angles even if both liquid components individually wet the substrate completely. Simulations show that the interplay of Marangoni flow, capillary flow, diffusive transport, and evaporative losses can establish a quasi-stationary drop profile with an apparent nonzero contact angle. In good agreement with experiments, we reveal a previously unknown universal power-law relation between the apparent contact angle and the relative undersaturation of the atmosphere, which can be inferred from the scaling analysis of the hydrodynamic-evaporative evolution equations.

DY 17.2 Mon 15:45 BH-N 334

Equilibrium versus non-equilibrium positioning of droplets — •Samuel Krüger[1,2], Christoph A. Weber[4], Jens-Uwe Sommer[2,3], and Frank Jülicher[1] — [1]Max Planck Institute for the Physics of Complex Systems — [2]Leibniz Institute of Polymer Research Dresden e.V — [3]Technische Universität Dresden, Institute of Theoretical Physics, Dresden, Germany — [4]Division of Engineering and Applied Sciences, Harvard University, Cambridge, USA

The position of droplets can be controlled by concentration gradients of a component which affect phase separation. A concentration gradient can be generated by an external potential or by boundary conditions. While systems with external potentials belong to the class of equilibrium systems, applying boundary conditions corresponds to a non-equilibrium scenario. We aim to understand what is the difference between these two scenarios and how the positioning is affected. To this end, we consider a ternary system where two components phase separate while a third component regulates their phase separation. We use Monte-Carlo simulations to compare the positioning of droplets between the two scenarios. In both scenarios we find that the droplet is positioned toward the region of low or high regulator concentration depending on their interaction parameters. The essential differences are the set of interaction parameter where the switch of position occurs. The positioning of droplets is relevant in cells prior to cell division or applications in microfluidic devices such as aqueous computing.

DY 17.3 Mon 16:00 BH-N 334

Drying Teardrops — •Alvaro Marin[1], Stefan Karpitschka[2], Christian Diddens[3], Massimiliano Rossi[4], Christian J. Kähler[4], Diego Noguera-Marin[5], and Miguel A. Rodriguez-Valverde[5] — [1]Max Planck + University of Twente Center for Complex Fluid Dynamics, The Netherlands — [2]Max Planck Center for Dynamics and Self-Organization, Germany — [3]Physics of Fluids, University of Twente, The Netherlands — [4]Bundeswehr University Munich, Neubiberg, Germany — [5]Biocolloid and Fluid Physics group, University of Granada, Spain

Salt can be found in different forms in almost any evaporating droplet in nature, our homes and in our own tears. Dried teardrops present an amazing variety of forms, shapes and crystals (even for the same person), but they all have something in common: a ring-shaped stain. In this talk we will address a model teardrop system consisting of an evaporating water sessile droplet with sodium chloride concentrations from 1 mM up to 100 mM. With experimental measurements and numerical simulations we can show that the transport of liquid in this system differs strongly from 'sweet' evaporating water droplets: the liquid flows in the inverse direction due to strong Marangoni stresses at the surface. Such an effect has crucial consequences to the deposition of salt, its crystallization and to the formation of the ring-shaped stains. In summary, our aim is to show that other mechanisms different than the famous "coffee-stain effect" can yield ring-shaped stains in evaporating sessile droplets.

DY 17.4 Mon 16:15 BH-N 334

Protein Interactions Control Dynamics Of Liquid Compartments — •Tyler S. Harmon[1,2], Anthony A. Hyman[2], and Frank Jülicher[1] — [1]Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany — [2]Max Planck Institute for the Physics of Molecular Cell Biology, 01307 Dresden, Germany

Membraneless organelles form in cells due to liquid-liquid phase separation and have been implicated in a range of functions. The physical properties of these compartments are important for their function and thus should be tuned to match their intended purpose. Multiple diseases are associated with a hardening transition where these liquid compartments transition from a functional liquid-like state to an aberrant solid-like state over a long period of time. Other compartments appear to be designed to mature naturally from a liquid into a more solid compartment. Therefore, the physical mechanism controlling the liquid to solid transition is at the heart of how cells regulate and control these compartments.

We designed a three-dimensional polymer lattice model to investigate mechanisms for hardening in liquid compartments. We explore several mechanisms affecting the time dependence of protein dynamics. This allows us to test which protein properties are important for controlling the slowing of the dynamics of the liquid compartments. We analyzed the transition to a solid-like state by quantifying the time dependence of diffusion rates, density, and reversibility of dissolution. These results are a promising first step to reach a molecular picture of the hardening process.

DY 17.5 Mon 16:30 BH-N 334

Oscillatory wetting under drops impacting on a hot plates — •Kirsten Harth, Michiel A. J. van Limbeek, Chao Sun, Andrea Prosperetti, and Detlef Lohse — Physics of Fluids, Max Planck Center for Complex Fluid Dynamics and University of Twente, The Netherlands

The Leidenfrost phenomenon, where an evaporating drop levitates above a layer of its vapour on sufficiently hot plates is well-known for gently deposited drops. For impacting drops, the additional impact pressure can cause much thinner vapour layers in the nanometer range,

and conventional side or bottom view imaging is incapable of detecting substrate contact. Using frustrated total internal reflection (FTIR), three main regimes were distinguished: contact, nucleate boiling at low temperatures (drop spreads in contact with substrate), Leidenfrost (film) boiling without contact and a broad transition regime. Then, the outer parts of the spreading lamella levitate, while the central region of the drop touches the substrate. However, the wetted locations and the drop's partially levitated bottom surface increasingly fluctuate with increasing temperature. Most striking are periodic waves travelling from the lamella tips toward the centre of the wetted region. We analyze and discuss this currently unresolved phenomenon.

DY 17.6 Mon 16:45 BH-N 334

Spontaneous jumping, bouncing and trampolining of hydrogel drops on a heated plate — •Doris Vollmer[1], Jonathan Pham[1], Sanghyuk Wooh[1], Tadashi Kajiya[1,2], and Hans-Jürgen Butt[1] — [1]Max Planck Institute for Polymer Research, Mainz, Germany — [2]Analysis Technology Center, Fujifilm, Nakanuma, Japan

We study the dynamics of hydrogel drops, i.e. sold drops containing up to 97% of water. Using high speed video microscopy, we demonstrate that hydrogel drops, initially at rest on a surface, spontaneously jump upon rapid heating and continue to bounce with increasing amplitudes. Jumping is governed by the surface wettability, surface temperature, hydrogel elasticity, and adhesion. A combination of low adhesion impact behavior and fast water vapor formation supports continuous bouncing and trampolining. Our results illustrate how the interplay between solid and liquid characteristics of hydrogels results in intriguing dynamics, as reflected by spontaneous jumping, bouncing, trampolining, and extremely short contact times.

J.T. Pham, M. Paven, S. Wooh, T. Kajiya, H.-J. Butt, D. Vollmer, Nat. Comm., 2017, 8, 905

15 min. break

DY 17.7 Mon 17:15 BH-N 334

Droplets in moist Rayleigh-Bénard convection — Prasanth Prabhakaran, Alexei Krekhov, •Stephan Weiss, and Eberhard Bodenschatz — Max Planck Institute f. Dynamics and Self-Organisation, Göttingen, Germany

We report experiments on condensation patterns in a moist Rayleigh-Bénard convection experiment. We use Sulphur Hexaflouride (SF_6) at high pressure as the working fluid and the experiment is operated across the liquid-vapor coexistence line close and far from the critical point. A layer of liquid SF_6 forms at the warm bottom of the cell. From its surface, vapor evaporates and condenses at the cold top plate, where it forms a thin film that undergoes a Rayleigh-Taylor like instability. As a result droplets form due to pinch-off that fall back into the liquid layer. Depending on the pressure and the temperature difference between bottom and top, locations where droplet form can lie on an almost stationary hexagonal grid with a well defined wavelength. When the liquid level at the bottom plate is eliminated the droplets falling from the top plate levitate above the bottom plate due to Leidenfrost effect. Under appropriate conditions the Leidenfrost drops form large domains with multiple chimneys (multi-connected domains).

DY 17.8 Mon 17:30 BH-N 334

Growing drops on an inclined plate: Onset of sliding — •Simeon Völkel, Jonas Landgraf, and Kai Huang — Experimentalphysik V, Universität Bayreuth, 95440 Bayreuth, Germany

Liquid drops sitting on or running down an inclined plane are ubiquitous in our daily lives. Their sliding can be triggered by tilting the surface at a fixed drop volume or by increasing the drop volume at a fixed inclination angle. Here, we present experiments on the latter protocol. Therefore we employ a conventional inkjet printhead, which provides a volume resolution of 23 picoliters, high repeatability, as well as the flexibility of following the drop's development by selecting different nozzles. Based on an analysis of both top view and side view images, we explore the evolution of the drop shape in the vicinity of the depinning transition and compare our results with numerical simulations.

DY 17.9 Mon 17:45 BH-N 334

Contact angle saturation in electrowetting of nanodrops — •Nicolas Rivas and Jens Harting — Forschungszentrum Jülich GmbH, Helmholtz Institute Erlangen-Nürnberg for Renewable Energy (IEK-11)

The wetting angle of a drop in contact with a substrate can be modified by applying an external electric field, a phenomenon referred to as electrowetting. The degree of wetting most commonly increases with the applied electric field, although in many cases only until a certain angle, after which the electric field has little or no influence on the wetting properties of the drop. This limit behavior is referred to as contact angle saturation (CAS). The origin of CAS is unknown, with numerous possible explanations present in the literature. In the following work we investigate electrowetting and CAS at the nanoscale. A model is proposed that takes into account the hydrodynamics of two fluids and the diffusion of charged solutes (ions). The numerical methodology used to solve this model is presented together with validation cases. The model is used to study electrowetting of conductive sessile drops as a function of the overall ion concentration and the relative conductivity of the two fluid phases. The variations of the contact angle are consistent with previous studies. We also observe CAS in regions of low salt concentration. A mechanism for CAS is proposed based on the progressive loss of ions from the drop as the electric field increases. This is discussed in relation to previously proposed mechanisms for CAS, which in general involve physics which our model does not intend to capture.

DY 17.10 Mon 18:00 BH-N 334

Oblique Impact onto a Spherical Target — •Vignesh Thammanna Gurumurthy, Daniel Rettenmaier, Ilia V. Roisman, and Cameron Tropea — Insitute for Fluid Dynamics and Aerodynamics, Technical University of Darmstadt, Darmstadt,Germany

Drop impact onto spherical targets can be found in applications such as coating of particles in pharmaceutical products, spray encapsulation or agglomeration of particles in fluidized bed, etc. The chances of the drop impinging on the target asymmetrically are high which necessitates the understanding of its hydrodynamics. In this work, we investigate the drop impact onto spherical targets using numerical simulations. We use a modified version of volume of fluid method available in the open source code OpenFOAM for the simulations, with adaptive mesh refinement on the liquid-gas interface. Reynolds number and the off-axis distance between the target and the drop are the two parameters varied while the drop to target size ratio is kept constant. The impact is characterized by measuring the thickness of the film at the point of impact over time. Finally, an empirical correlation based on the Reynolds number for the residual film thickness will be presented.

DY 17.11 Mon 18:15 BH-N 334

Morphological evolution of microscopic dewetting droplets with slip — Tak S. Chan[1], Joshua D. McGraw[1,2], Thomas Salez[3], Ralf Seemann[1], and •Martin Brinkmann[1] — [1]Experimental Physics, D-66123 Saarland University — [2]Département de Physique, Ecole Normale Supérieure/PSL Research University, CNRS, 24 rue Lhomond, 75005 Paris, France — [3]Laboratoire de Physico-Chimie Théorique, UMR CNRS Gulliver 7083, ESPCI Paris, PSL Research University, Paris, France

A liquid drop sitting on a smooth substrate will contract or spread depending on the equilibrium contact angle and the initial shape of the drop. One well known example is that of drops spreading over a completely wetting surface, which follow Tanner's law. In this study, we numerically compute the dynamics of contracting microscopic droplets where the slip-length b on the substrate is comparable to the intial drop height H. As quantified by the asphericity of the drop shape, we find a cross-over between two different dynamic regimes at slip length $b \ll H$ and $b \gg H$. These findings are explained from a competition between viscous dissipation in elongational flows for $b \gg H$, friction at the substrate for $b \approx H$, and viscous dissipation in shear flows for $b \ll H$. Following the changes between the dominant dissipation mechanisms, our study not only indicates two universal rescalings of the evolution of asphericity, but also a cross–over to the quasi-static shape evolution when b is many orders of magnitude smaller than the slip length b_m where the asphericity assume its maximum value.

DY 17.12 Mon 18:30 BH-N 334

Role of hydrodynamics in chemically driven droplet division — •Rabea Seyboldt and Frank Jülicher — Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany

Macromolecular phase separation and droplet formation have long been proposed as key elements in the formation of protocells during the origin of life. A simple model of a protocell consists of a droplet, where droplet material is produced outside the droplet, and chemical reactions inside the droplet play the role of a simple metabolism. Our previous theoretical study showed that such chemically active droplets can have a flux-driven shape instability that leads to a symmetric droplet division. Here we study the role of hydrodynamic flows on the chemically driven droplet division. In the deformed droplet, gradients of Laplace pressure create the hydrodynamic flows that have a tendency to relax the droplet to a spherical shape. We find that despite these stabilizing flows, droplet division can still occur. We analyze the dependence of the instability on the droplet viscosity and parameters that characterize the metabolism and material production. A comparison with protein/RNA droplets suggests that the droplet division could be observable in experimental systems. This highlights the possibility that chemically driven shape instabilities could play a role for the organization of membrane-less organelles in biological cells. Additionally, our work provides a physical mechanism for the division of early protocells before the appearance of membranes.

DY 17.13 Mon 18:45 BH-N 334

Content of secondary droplets formed by drop impact onto a solid wall wetted by another liquid — •Hannah M. Kittel, Ilia V. Roisman, and Cameron Tropea — Institute of Fluid Mechanics and Aerodynamic, Technische Universität Darmstadt, 64287 Darmstadt, Germany

Drop impact onto a wetted substrate is of importance in many engineering applications, for example in a combustion chamber, during spray coating or airframe icing.. The impact outcome s determined by the inertia, viscous and capillary forces. If the drop and wall film are of different fluids, the miscibility and the interfacial forces also influence the outcome. The composition of secondary drops resulting from such an impingement, and the state of the liquid film influence significantly the mixture preparation in either the engine or the catalytic converter. In the case of non-miscible fluids, the distribution of both fluids during and after the impact is important in order to understand the mechanism behind the drop impact of different liquids.

The main focus of this experimental work is on the impact of a single drop onto a thin, horizontal wall film of dif-ferent fluids. The liquids of drop and wall film are non-miscible in order to have a phase interface between both liquids. A dye is added to the liquid of the drop in order to distinguish both phases during and after the drop impact. The composition of the secondary droplets resulting from splashing, as well as the content of the partial rebound are characterized.

DY 17.14 Mon 19:00 BH-N 334

Breakup of a stretching liquid bridge — •Sebastian Brulin, Ilia V. Roisman, and Cameron Tropea — Institute of Fluid Mechanics and Aerodynamics, Technische Universität Darmstadt, Darmstadt, Germany

Liquid bridge stretching occurs in many industrial applications like gravure printing, granulation of fine powders or fiber spinning. One industrial process where the phenomenon plays an important role is the ink transfer in gravure printing. This technique is used for the production of electrical circuits. The liquid is transferred from the printing role onto the printable substrate. During this transferring process the liquid forms a liquid bridge with the two substrates. In this work, the dynamics of a stretching liquid bridge between two solid plates, one of which moves with a constant acceleration, is studied using a high-speed video system. Experiments on fast bridge stretching and breakup were performed with the aim to measure the breakup time and the residual liquid volume at various initial gape thicknesses.

The measurements involve different non-dimensional initial gap heights (d= 0.1-0.4) for a wide range of accelerations (10 m/s2 -180 m/s2). The distilled water and water-gylcerol mixtures are used for the liquid bridge formation to investigate the effect of the viscosity and surface tension on the breakup time and breakup length. A semi-empirical model is developed in this study to predict these values.