

DY 48: Wetting, Nano- and Microfluidics I (joint session CPP/DY)

Time: Thursday 9:30–12:45

Location: H42

Invited Talk

DY 48.1 Thu 9:30 H42

Provoking liquids to dewet and to slide: About concave drops and hungry droplets — ●KARIN JACOBS — Experimental Physics, Saarland University, D-66041 Saarbrücken

Usually, liquids exhibit a 'no-slip' boundary condition to a solid substrate, i.e. the atoms or molecules of a liquid that are the closest to the solid substrate are at rest. However, a polystyrene film that moves over hydrophobized (by a self-assembled monolayer of silanes) Si wafers can be provoked to slide, i.e. there is a non-zero interfacial velocity of the fluid in contact with the solid, and friction occurs [1,2]. This implies variations in the energy dissipation mechanisms in these systems and leads to a strikingly different behaviour of fluids in different geometric situations [3-5]: With slip, the dewetting of flat films is faster on solid surfaces (A), Rayleigh-Plateau-type instabilities exhibit an increased dynamics (B) and droplets that were prepared in a non-equilibrium situation can reach equilibrium via a stadium where their topology is concave (C). Yet, why does a liquid slide? Possible explanations including recent findings by scattering methods will be reviewed. Moreover, if more liquids were sliding, would that change things in our everyday life?

[1] O. Bäümchen et al., PRL 113 (2014) 014501; [2] J. D. McGraw et al., Colloid and Interface Science 210 (2014) 13; [3] S. Haefner et al., Nature Comm. 6 (2015) 7409; [4] S. Haefner, O. Bäümchen, K. Jacobs, Soft Matter 11 (2015) 6921; [5] J. McGraw et al., (submitted)

DY 48.2 Thu 10:00 H42

Soft Levelling: Capillary Relaxation of Thin Liquid Films on Elastic Substrates — ●MARCO RIVETTI¹, THOMAS SALEZ², CHRISTINE LINNE¹, MAXENCE ARUTKIN², ELIE RAPHAËL², and OLIVER BÄUMCHEN¹ — ¹Max Planck Institute for Dynamics and Self-Organization (MPIDS), Göttingen, Germany — ²UMR Gulliver, CNRS and ESPCI ParisTech, PSL University, Paris, France

A thin liquid film with non-zero curvature at its free surface spontaneously relaxes towards a flat configuration. The flow of this liquid film is driven by Laplace pressure gradients and it is resisted by viscosity. In the last few years the dynamics of this system has been studied experimentally, numerically and analytically. Inspired by recent progresses on the wetting behaviour of liquid droplets on soft substrates, we here consider the relaxation of a thin viscous film supported by an elastic foundation. We present experiments involving thin polystyrene films on polydimethylsiloxane substrates, where the dynamics of the liquid-air interface is monitored using an atomic force microscope. In this system, Laplace pressure gradients not only drive the flow but they also induce elastic deformations on the substrate. These deformations affect the flow and the shape of the liquid-air interface itself, giving rise to an original example of elasto-capillary interaction that is not mediated by the presence of a contact line. We show that the width of the profile scales with the time to the power 1/6, rather than 1/4 which we consistently observed on rigid substrates. A theoretical model that describes the coupled evolution of the elastic-liquid and liquid-air interfaces is also presented.

DY 48.3 Thu 10:15 H42

Rayleigh-Plateau Instability and Capillary Droplet Propulsion on a Fiber — ●SABRINA HAEFNER^{1,2}, MICHAEL BENZAQUEN³, OLIVER BÄUMCHEN^{2,4}, THOMAS SALEZ³, ROBERT PETERS², JOSHUA MCGRAW¹, ELIE RAPHAËL³, KARI DALNOKI-VERESS^{2,3}, and KARIN JACOBS¹ — ¹Saarland University, Dept. of Experimental Physics, D-66041 Saarbrücken, Germany — ²McMaster University, Dept. of Physics & Astronomy, Hamilton, ON, Canada — ³PCT Lab, UMR CNRS 7083 Gulliver, ESPCI ParisTech, PSL Research University, Paris, France — ⁴Max-Planck Institute for Dynamics & Self-Organization (MPIDS), 37077 Göttingen, Germany

The Rayleigh-Plateau instability (RPI) of a liquid column underlies a variety of hydrodynamic phenomena. Compared to the classical case of a free liquid column, the description of a liquid layer on a fiber requires the consideration of the solid/liquid interface in addition to the free surface. We revisit the RPI of a liquid layer on a solid fiber by varying the hydrodynamic boundary condition at the fiber/liquid interface from no-slip to slip. We find that the growth rate depends on the system geometry and the boundary condition, which is in agreement with theory [1]. In the late stages of liquid column breakup on

slip-fibers, a three-phase contact line can be formed on one side of the droplet. The resulting capillary imbalance leads to droplet propulsion, which is studied as a function of temperature and molecular weight [2].

- [1] S. Haefner et al., Nat. Commun., 6 (2015), 7409.
[2] S. Haefner et al., Soft Matter, 11, (2015), 6921.

DY 48.4 Thu 10:30 H42

Rayleigh-Plateau instability of slipping viscous filaments in v-shaped grooves — ●MARTIN BRINKMANN^{1,3}, TAK SHING CHAN¹, RALF SEEMANN¹, KRISHNA KHARE², and STEPHAN HERMINGHAUS³ — ¹Experimental Physics, Saarland University, Saarbrücken — ²Indian Institute of Technology Kanpur — ³Max Planck Institute for Dynamics and Self-Organisation, Göttingen

Since the seminal works of Rayleigh and Plateau on the break-up of free-standing liquid jets, a large number of studies have addressed the instability of cylindrical interfaces in various experimental settings. The most unstable wavelength λ of a viscous liquid filament wetting the bottom of a v-shaped groove is mainly governed by the slope angle ψ , the contact angle θ of the interface on the solid, and the initial width w of the filament. A linear stability analysis using the method of boundary elements reveals that the characteristic timescale of the decay is affected not only by viscosity, interfacial tension, and geometry. Slip has a substantial effect on the wavelength λ of the fastest growing mode whenever the transverse dimension w of the filaments is comparable or smaller than the Navier slip-length b . In this limit $b/w \rightarrow \infty$ we find $\lambda/w \rightarrow \infty$ while the timescale τ saturates to a finite lower bound, similar to the case of a free-standing viscous liquid cylinder. In the opposite limit $b/w \rightarrow 0$ the corresponding timescale τ of the decay increases only logarithmically with b/w while λ tends to $\sqrt{2}$ times the neutrally stable wavelength λ^* . A linear stability analysis based on long wavelength approximations of the flows agree with the numerical results only for 'flat' filaments $0 < \theta - \psi \ll 1$ with $\lambda^* \gg w$.

DY 48.5 Thu 10:45 H42

Waves at viscoelastic surfaces — ●JULIAN KAPPLER and ROLAND R. NETZ — Institut für Theoretische Physik, Freie Universität Berlin, 14195 Berlin, Germany

Waves on water, whose properties depend on gravity and surface tension, are a well-known phenomenon. If there is a surfactant that reacts viscoelastically under compression, like e.g. a biomembrane on water, also another type of surface wave, called longitudinal capillary wave, can exist. On the other hand, on viscoelastic solids there exist Rayleigh waves. These are surface waves which, on a large scale, can be excited by earthquakes, or, on a small scale, can be excited on materials to measure their mechanical properties non-destructively.

We present a unified treatment of all the above waves: We consider a viscoelastic medium covered by a viscoelastic interface and derive a general equation characterizing localized waves at the interface. We show how the aforementioned waves can be derived from this general equation, identify a new surface wave, and discuss how all these waves are interrelated.

Reference: J. Kappler, R. R. Netz. Multiple surface wave solutions on linear viscoelastic media. EPL, 112(1):19002, 2015.

15 min. break

DY 48.6 Thu 11:15 H42

Non-equilibrium interfacial tension during relaxation — ●MARKUS BIER — Max Planck Institute Int. Sys. and University of Stuttgart, Germany

The concept of a non-equilibrium interfacial tension, defined via the work required to deform the system such that the interfacial area is changed while the volume is conserved, is discussed in the context of the relaxation of an initial perturbation of a colloidal fluid towards the equilibrium state. It is shown that the non-equilibrium interfacial tension is not necessarily positive, that negative non-equilibrium interfacial tensions are consistent with strictly positive equilibrium interfacial tensions and that the sign of the interfacial tension can influence the morphology of density perturbations during relaxation.

References:

- [1] M. Bier and D. Arnold, Phys. Rev. E **88**, 062307 (2013).
 [2] M. Bier, Phys. Rev. E **92**, 042128 (2015).

DY 48.7 Thu 11:30 H42

Hydrodynamic cavitation in Stokes flow of anisotropic fluids — ●TILLMANN STIEGER¹, HAKAM AGHA², MARTIN SCHOEN¹, MARCO G. MAZZA², and ANUPAM SENGUPTA³ — ¹TU Berlin — ²MPIDS Göttingen — ³Massachusetts Institute of Technology

Cavitation is ubiquitous in fluid dynamics, and has significant effects on a wide range of industrial and biomedical applications. Investigations in anisotropic fluids are scarce, and till date, no systematic attempt has been made to study them. Here we report flow-induced cavitation in an anisotropic fluid, studied by combining microfluidic experiments and nonequilibrium molecular dynamics (MD) simulations. Cavitation domains nucleate due to sudden drop in pressure upon flow past a micron-sized obstacle in microchannels, which over time, progressively grows in volume after attaching at the downstream obstacle surface. The inception and growth of cavitation domain ensue in Stokes flow regime. Using MD simulations we study the physical principles governing the cavitation phenomena in nematic liquid crystals (LC), and identify a critical value of Reynolds number Re_{cr} for the cavitation inception that scales inversely with the characteristic order parameter of the LC. Strikingly, the critical Re_{cr} can be as low as $\sim 50\%$ of the cavitation threshold in isotropic fluids. Corresponding results for the LC in the isotropic phase and for a Lennard–Jones fluid reveal that the drop in Re_{cr} is a consequence of the long range ordering in anisotropic fluids. The findings suggest that long range ordering, and its tunability, can be potentially applied as a novel control parameter to modulate cavitation inception in anisotropic fluids.

DY 48.8 Thu 11:45 H42

Sliding Drops - stationary states and large-scale dynamics — ●SEBASTIAN ENGELNKEMPER, MARKUS WILCZEK, SVETLANA GUREVICH, and UWE THIELE — Institut für Theoretische Physik, Westfälische Wilhelms Universität Münster, Corrensstr. 2, 48149 Münster

The long-wave evolution equation for a liquid film (or Thin-Film-Equation) describes structures including drops and ridges. Including a lateral driving force (e.g., inclined substrate) all structures begin to move and change their shapes. Experiments show this and, in addition, a further instability where large drops emit small satellite drops [1]. Implementing the Thin-Film-Equation in the continuation-toolbox PDE2PATH [2], we analyze the primary bifurcations from a flat film in the case without driving using the mean film height as bifurcation parameter. Then, with lateral driving forces we track sliding drops in dependence of either drop volume or substrate inclination. We analyze the shape changes and compare them to previous 1d results [3]. Finally, we focus on the bifurcation that is responsible for the satellite drops and relate the results of continuation to direct numerical simulations for single drops and ensembles of many drops. [1] T. Podgorski, J.-M. Flesselles, L. Limat, Phys. Rev. Lett. **87**, 036102 (2001); [2] H. Uecker, D. Wetzel, J.D.M. Rademacher, arXiv:1208.3112v2 (2012); [3] U. Thiele et al., Phys. Rev. E, **64**, 061601 (2001).

DY 48.9 Thu 12:00 H42

Autophobic drops, fuelled by oil/water interfacial chemistry — BIJOYENDRA BERA, ●MICHAEL DUIJS, DIRK VAN DEN ENDE, MARTIEN COHEN STUART, and FRIEDER MUGELE — University of Twente, Enschede, The Netherlands

We report a hitherto not observed wetting phenomenon, namely the retraction of a drop after deposition on a solid substrate, caused by an interfacial reaction between cations in the aqueous drop and fatty acids in the ambient oil. We investigate how this process depends on the concentrations of the reactants, the chain lengths of fatty acid and alkane solvent, and the solid substrate material. We demonstrate with

contact angle and AFM measurements that deposition of amphiphilic molecules on the solid takes place only after assembly at the oil-water interface. Deposition of material by the moving contact line leads to an increasingly hydrophobic local substrate and a concomitant increase in contact angle, which we call autophobic. This phenomenon is observed both on mica and on silica substrates, for several fatty acids and alkane solvents. The time-dependent contact angle can be described with a theoretical model in which the adsorption reaction at the oil-water interface is rate-limiting, and transfer to the solid is determined by a mass flux balance (similar to a Langmuir Blodgett transfer). The ensuing time-dependent oil-water and solid-oil interfacial tensions then produce the evolution of the contact angle.

DY 48.10 Thu 12:15 H42

Compact nanosensors probe microdroplets — ●JULIAN SCHÜTT¹, FELIX ZÖRGIEBEL^{1,2}, BERGOI IBARLUCEA^{1,2}, SEBASTIAN PREGL^{1,2}, DAIJIRO NOZAKI¹, WALTER WEBER^{2,3}, THOMAS MIKOLAJICK^{2,3,4}, LARYSA BARABAN^{1,2}, and GIANAURELIO CUNIBERTI^{1,2} — ¹Max Bergmann Center of Biomaterials and Institute for Materials Science, Dresden University of Technology, Budapesterstrasse 27, 01069 Dresden, Germany — ²Center for Advancing Electronics Dresden, 01062 Dresden, Germany — ³NamLab GmbH, Nöthnitzerstraße 64, 01187 Dresden, Germany — ⁴Institute for Semiconductors and Microsystems, TU Dresden, 01062 Dresden

Smart combination of nanosensors and droplets based reactors represents a powerful tool for monitoring and high throughput analysis of the kinetics of biological and chemical reactions, staying miniaturized, highly sensitive and optically label-free. Here we present a first demonstration of droplets microfluidics with the compact silicon nanowire field effect transistor (SiNW FET) on a single chip for in flow electrical detection of aqueous reactor-drops. Apart from detection events, we chemically probe the content of numerous droplets in a row as independent events (up to ten thousands), and resolve the pH values and ionic strength of the solution, resulted in a change of a source-drain current through the nanowires. Optic-less and noninvasive measurements of these parameters in aqueous droplets have a great impact on the area of biodetection and bioanalytics as a high throughput screening tool for pathogens, drug assays, and evaluation of the enzymatic activities.

DY 48.11 Thu 12:30 H42

Stability of emulsions against coalescence and transport: Influence of surfactants — ●BIRTE RIECHERS^{1,2}, PHILIPP GRUNER², FLORINE MAES^{1,2}, and JEAN-CHRISTOPHE BARET^{1,2} — ¹CNRS, Univ. Bordeaux, CRPP, UPR 8641, Pessac, France — ²Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

Monodisperse aqueous droplets within emulsions become evermore attractive for use as separate microreactors in pharmaceutical and biotechnological applications [Theberge *et al.*, *Angewandte* 2010]. These applications need constant experimental conditions inside the droplets. To date stabilization against coalescence is mainly obtained using surfactants. Surfactants also affect the solubility of solutes inside the continuous oil phase, thereby restricting their use [Gruner *et al.*, *Curr. Opin. Colloid Interface Sci.* 2015]. Microfluidic tools provide insight into the mechanisms of interfacial stabilization:

Here we perform a complete analysis of the adsorption kinetics of a surfactant typically used in droplet-based microfluidic applications. We combine pH measurements at the micronscale and coalescence experiments in droplet-based microfluidics with bulk measurements to show that the kinetics of the transport of molecules across interfaces directly relates to those of interfacial stabilisation. Combining all information, we derive a simple model of adsorption in the kinetic-limited regime and show that two interfaces are only stabilized against coalescence for surfactant concentrations which are close to or above the critical micellar concentration.