CPP 44: Wetting, Micro- and Nanofluidics

Time: Thursday 15:00–18:45 Location: H39

Invited Talk CPP 44.1 Thu 15:00 H39

Dynamic reorganization of droplets: from Foams to Phonons
— •Ralf Seemann[1,2], Jean-Baptiste Fleury[1], Ulf D. Schiller[3], Shashi Thutupalli[2], Ohle Claussen[2], Stephan Herminghaus[2], Gerhard Gompper[3], and Martin Brinkmann[1,2] — [1]Experimental Physics, Saarland University, Germany — [2]MPI for Dynamics and Self-Organization, Göttingen, Germany — [3]Theoretical and Soft Matter Biophysics, FZ Jülich, Germany

The stability and the mechanical response of monodisperse droplet packing in quasi 2d micro-channels are discussed for different packing density under static and dynamic conditions: Very dense droplet arrangements are analogous to foam and can be described by geometrical means provided the friction with the side walls is low. At reduced droplet fraction where the droplets are still in mechanical contact, the resulting droplet arrangements are stabilized by virtue of the Laplace pressure. Depending on the exact choice of parameter a droplet packing can have a negative compressibility separating into stable domains of higher and lower packing fraction. When flowing along a microfluidic channel these unstable droplet arrangements develop complex non-equilibrium re-arrangements similar to avalanches. Reducing the droplet fraction even further so that the droplets do not touch each other, the flowing droplets experience each other by dipole-like hydrodynamic interactions and can be excited to show collective oscillations which can be described by a phonon-type behavior.

CPP 44.2 Thu 15:30 H39

Optimal Particle Separation in Microfluidic Systems Using Inertial Lift Forces — •Christopher Prohm and Holger Stark — Institut für Theoretische Physik, TechnischeUniversität Berlin, D-10623 Berlin, Germany

At intermediate Reynolds numbers, particles in a microfluidic channel assemble at fixed distances from the channel axis and bounding walls [1]. This Segré-Silberberg effect can be described in terms of an effective lift force acting on the particles.

Devices utilizing inertial lift forces for the separation of bacteria and red blood cells have recently been demonstrated [2]. The separation is most efficient for large size differences since the inertial lift force scales with the third power of the particle radius.

Here, we show that one can use external forces generated, for example, by optical tweezers to separate particles similar in size. We determine the inertial lift force by mesoscopic simulations [3] and use it to set up a Smoluchowski equation which describes the particle motion in lateral direction. We then employ the formalism of optimal control [4] to determine profiles of the external force, which help to steer particles and thereby maximize particle separation.

[1] G. Segré and A. Silberberg, *Nature*, **189**, 209 (1961).
[2] A. J. Mach and D. Di Carlo, *Biotechnol. Bioeng.*, **107**, 302 (2010).
[3] C. Prohm, M. Gierlak, and H. Stark *EPJE*, **35**, 80 (2012).
[4] F. Tröltzsch, Optimal Control of Partial Differential Equations, American Mathematical Society, first edition (2010).

CPP 44.3 Thu 15:45 H39

Microfluidic Rocking ratchet for the separation of magnetically labeled cells — •Lars Helmich[1], Matthias Schuermann[2], Alexander Auge[1], Frank Wittbracht[1], Christian Kaltschmidt[2], and Andreas Huetten[1] — [1]Thin films and Physics of Nanostructures, Department of Physics, Bielefeld University — [2]Department of Cell Biology, Bielefeld University

The aim of so called lab-on-a-chip devices is to integrate all laboratory tasks on one microfluidic chip. Employing magnetic materials particularly magnetic beads in these systems has gained great interest during the last decades [1,2].

One way of controlling and directing the motion of magnetically functionalized particles is the use of Rocking ratchet structures [3].

We present a separation device consisting of a micro structured spatially periodic array of conduction lines beneath a microfluidic channel and an additional external magnetic gradient field. Human embryonic kidney cells were labeled with magnetic beads. Depending on the choice of field strengths and switching times it is possible to separate cells by diffusivity and magnetic moment. Parameter optimization studies were carried out by means of finite element method based numerical simulations.

[1] A. Auge et al., Appl. Phys. Lett 94, 183507 (2009)
[2] N. Pamme, Lab On A Chip, 6(1) 24-38 (2006)
[3] P. Reimann, Physics Reports, 361 57-265 (2002)

CPP 44.4 Thu 16:00 H39

Fluctuating Boundary Conditions in Hydrodynamics — •Martin Reichelsdorfer and Klaus Mecke — Institut für Theoretische Physik, Universität Erlangen-Nürnberg, Staudtstraße 7, 91058 Erlangen

Fluctuating internal stresses are ubiquitous in the hydrodynamics of small systems. The correlations of these 'noise' terms are closely related to the viscosities, which is an example of a fluctuation dissipation relation. Here, we extend this fundamental principle to fluid interfaces with slip boundary conditions. We demonstrate that fluid-fluid and fluid-substrate interactions can be treated consistently in a unified way by introducing a fluctuating boundary force. In the spirit of Bocquet and Barrat [1] the correlations of the latter give rise to the friction coefficient between fluid and substrate. Moreover, we show that cross-correlations with the fluctuating stresses inside the liquid can lead to even strongly enhanced slip, described by an effective slip length. As an application we study the dewetting dynamics of thin liquid films [2].

[1] L. Bocquet and J.-L. Barrat. *Physical Review E*, 49(4):3079, 1994.
[2] R. Fetzer et al. *Physical Review Letters*, 99:114503, 2007.

CPP 44.5 Thu 16:15 H39

Influence of Slip on the Rayleigh-Plateau Rim Instability in Dewetting Polymer Films — •Sabrina Haefner[1], Oliver Bäumchen[1,2], Ludovic Marquant[1], Matthias Lessel[1], Ralf Blossey[3], Andreas Münch[4], Barbara Wagner[5], and Karin Jacobs[1] — [1]Saarland University, Experimental Physics, D-66041 Saarbrücken, Germany — [2]McMasters University, Dept. of Physics & Astronomy, Hamilton, ON, Canada — [3]Interdisciplinary Research Institute (IRI), CNRS USR 3078, Villeneuve — [4]Mathematical Institute, University of Oxford, Oxford OX1 3LB, UK — [5]Technical University of Berlin, Institute for Mathematics, 10623 Berlin, Germany

A dewetting polymer film develops a characteristic fluid rim at its receding edge due to mass conservation. In the course of the dewetting process the rim becomes unstable via an instability of Rayleigh-Plateau type. An important difference exists between this classic instability of a liquid column and the rim instability in the thin film as the growth of the rim is continuously fueled by the receding film. We explain how the development and macroscopic morphology of the rim instability are controlled by the slip of the film on the substrate. A single thin-film model, valid for all slip lengths, captures quantitatively the characteristics of the evolution of the rim observed in our experiments.

CPP 44.6 Thu 16:30 H39

Self-Similarity and Energy Dissipation in Stepped Polymer Films — •Joshua D. McGraw[1], Thomas Salez[2], Oliver Bäumchen[1], Elie Raphaël[2], and Kari Dalnoki-Veress[1] — [1]Department of Physics & Astronomy and the Brockhouse Institute for Materials Research, McMaster University, Hamilton, ON, Canada — [2]Laboratoire de Physico-Chimie Theorique, UMR CNRS Gulliver 7083, ESPCI, Paris, France

We have recently learned how to prepare polymer films whose only feature is a step in the height profile [1]. In the melt, Laplace pressure drives a flow that levels the topography, with the excess energy of the height step being dissipated by viscosity. It has been observed that the profiles are self-similar in time for a variety of molecular weights and geometries. Given the surface tension, this simple observation allows a precise measurement of the viscosity by comparison with numerical solutions [2] of the thin film equation. It is also possible to derive a master expression for the time dependence of the excess surface energy as a function of the material properties and film geometry. Thus, all geometries and molecular weights fall on a single temporal curve. The material parameter allowing this collapse is the capillary velocity: the ratio of the surface tension to the viscosity.

[1] McGraw et al., PRL (2012).
[2] Salez et al., EPJE (2012).

15 min. break

Invited Talk CPP 44.7 Thu 17:00 H39

Wetting behaviour in inkjet printed droplets — •Patrick Smith and Jonathan Stringer — University of Sheffield, Kroto Research Institute, Broad Lane, Sheffield, S3 7HQ, England

Understanding how droplets behave is essential to using inkjet printing if inkjet is to be successful as a manufacturing process. This talk discusses the lifetime of droplets from when they are ejected from a nozzle, their impact with a substrate and their drying behaviour.

In this contribution I will discuss how, by varying the height of a printhead nozzle above a substrate, the final dried droplet diameter of a polymer ink can be decreased. I will also show that at higher concentrations of polymer, the solute forms a skin on the surface of the inkjet printed droplet, which inhibits the in-flight evaporation of the solvent. I will also discuss a study into the spreading of inkjet printed droplets of a polystyrene/toluene solution with varied molar masses on solid dry surfaces. The experimental results were compared to theoretical models and found to have a good fit. The spreading factor was found to decrease as molar mass increased, which is explained in terms of increased viscosity. Finally, I will discuss how the size of a suspended particle can influence the size of the final dried morphology of a printed feature.

CPP 44.8 Thu 17:30 H39

Marangoni Modified Drop Fusion and Drop Motion — •Stefan Karpitschka and Hans Riegler — MPI für Kolloid- und Grenzflächenforschung, Potsdam, Germany

Sessile droplets on solid surfaces will fuse due to capillary forces. The droplet fusion can be delayed if the droplets consist of different (but still completely miscible) liquids. Quite unexpected, even after initial contact at the three phase line, the main droplet bodies remain separated. The droplets are connected only through a neck via a thin liquid film and move together over the substrate surface [1]. This non-coalescing state can last up to minutes. Its origin are the different surface energies of the liquids: The difference induces a Marangoni flow between the droplets which keeps them separate [2]. Based on new experiments, we present – for the first time – an analytical treatment in the framework of a thin film description. The key ingredient is a balance of advective and diffusive transport mechanisms in the vicinity of the neck, which induces a Marangoni flow. By piece-wise asymptotic matching of meso- and microscopic solutions we determine the global free surface topology and the capillary number [3]. We find traveling wave solutions in quantitative agreement with the experimental observations. The findings are generally relevant for (shallow, steady-state) free surface flows that involve (are caused by) surface tension gradients (e.g. due to local compositional variations).

[1] H. Riegler, P. Lazar, Langmuir 24, 6395 (2008).
[2] S. Karpitschka, H. Riegler, Langmuir 26, 11823 (2010).
[3] S. Karpitschka, H. Riegler, PRL 109, 066103 (2012).

CPP 44.9 Thu 17:45 H39

Droplet morphologies in a cylindrical tube — •Ciro Semprebon, Stephan Herminghaus, and Martin Brinmann — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

Equilibrium conformations of droplets on cylindrical fibers and their transitions during changes of volume and contact angle have been studied for almost a century. Liquid morphologies in a tube, however, have received only little attraction. Here, we present the results of a combined analytical and numerical study of droplet shapes wetting the inside of a cylinder at zero buoyancy. For any contact angle the liquid forms a plug bounded by two spherical surfaces if the volume is sufficiently large. In the opposite limit of small volumes, the liquid interface adopts the shape of a spherical cap which is slightly deformed by the curved surface. At intermediate volumes and small contact angle an annular morphology is observed which can be described as the analog to the barrel droplet on a fiber. In contrast to the barrel droplets the mechanical stability of this morphology is limited by the appearance of either an axisymmetric or a non-axisymmetric soft mode. Stability with respect to the latter type of mode can be related to the existence of an inflection point in the droplet contour as already demonstrated for barrel droplets [1]. Based on our findings a complete morphology diagram is constructed in terms of contact angle and volume.

[1] H B Eral et al.: "Drops on functional fibers: from barrels to clamshells and back" Soft Matter 7 (2011) 5138

CPP 44.10 Thu 18:00 H39

Dynamics of Immiscible Fluid Flow through Porous Media — •Kamaljit Singh[1,2,3], Hagen Scholl[3], Alen Kabdenov[2,3], Marco Di Michiel[1], Mario Scheel[1], Stephan Herminghaus[2], and Ralf Seemann[2,3] — [1]European Synchrotron Radiation Facility, BP 220, F-38043 Grenoble, France — [2]Max Planck Institute for Dynamics and Self-Organization, D-37073 Goettingen, Germany — [3]Saarland University, Experimental Physics, D-66041 Saarbruecken, Germany

The pore-scale dynamic behavior of water imbibition into an initially oil filled porous medium was investigated in situ using synchrotron X-ray tomography. We investigated the effect of various factors, including wettability, viscosity and density of fluids, flow velocity and pore structure, on the quantitative and qualitative behaviour of the fronts. The findings reveal that for low capillary numbers the water-oil front behavior is independent of all other factors except for wettability. The wettability decides the nature of the front and the final oil saturation after a complete water flood. The front is more compact for small contact angles of the imbibing water phase. This compact front results in almost no oil trapping after a complete flood. However, the front roughens with increasing contact angle and progresses in elongated capillary fingers for large contact angles. The formation of fingers results in significant oil trapping (10-15%).

CPP 44.11 Thu 18:15 H39

Imbibition of electrolytes into nanoporous gold and electrocapillary effects — •Yahui Xue[1,2], Jürgen Markmann[1,3], Patrick Huber[3], Huiling Duan[2], and Jörg Weissmüller[1,3] — [1]Helmholtz-Zentrum Geesthacht, Institut für Werkstoffforschung, Werkstoffmechanik, 21502 Geesthacht, Germany — [2]State Key Laboratory for Turbulence and Complex System, Department of Mechanics and Aerospace Engineering, College of Engineering, Peking University, Beijing 100871, China — [3]Technische Universität Hamburg-Harburg, Institut für Werkstoffphysik und -technologie, 21073 Hamburg, Germany

Electrocapillary techniques exhibit great advantages in nonmechanical electrofluidic manipulation, e.g., flow actuation in micro-/nanochannels. One issue of interest is the spontaneous imbibition of fluids in bodies with a nanoscale pores size. Contrary to previous studies we here use a metallic nanoporous body. This allows us to control the electrode potential at the solid-fluid interface. Nanoporous gold (NPG) with uniform pore- and ligament size of ~45 nm was fabricated by dealloying an Ag75Au25 alloy. Spontaneous imbibition of aqueous electrolytes obeys the Lucas-Washburn law. Electrocapillary effects were then used to manipulate the imbibition dynamics. Due to the enhanced wetting, the Washburn law predicts an acceleration of the imbibition by ~60%. Yet, imbibition experiments show only ~25% acceleration. A possible explanation is that the ion transport capability through nanopores limits the charging of the double layer at the invasion front, which is confirmed by potential step coulometry experiments.

CPP 44.12 Thu 18:30 H39

Microfluidics of ordered fluids — •Anupam Sengupta, Christian Bahr, and Stephan Herminghaus — Max Planck Institute for Dynamics and Self Organization, Am Fassberg 17, 37077 Göttingen

Flow of ordered fluids (e.g. liquid crystals) is inherently complex due to the coupling between the flow and the long-range orientational order. Experiments carried out at micro scales further reveal the influence of surface properties on the static and dynamic outcomes. We use microfluidics as a platform to tune one or more of the above competing components, and explore the resulting equilibrium states. The delicate but intricate balance between the viscous, elastic and surface forces was consequently used to devise opto-fluidic and micro-scale-transport applications. On one hand the novel applications complement the conventional microfluidic capabilities, and on the other hand, broaden the reach of 'isotropic' microfluidics by offering competitive advantages. Standard microfluidic techniques and a combination of polarizing optical microscopy, fluorescence confocal polarizing microscopy and particle tracking methods were employed for the investigations.

[1] Nematic textures in microfluidic environment by A. Sengupta, U. Tkalec, Ch. Bahr, Soft Matter 7, 6542, 2011.
[2] Functionalization of microfluidic devices for investigation of liquid crystal flows by A. Sengupta, B. Schulz, E. Ouskova, Ch. Bahr, Microfluidics and Nanofluidics, DOI: 10.1007/s10404-012-1014-7, 2012.
[3] Opto-fluidic velocimetry using liquid crystal microfluidics by A. Sengupta, S. Herminghaus, Ch. Bahr, Applied Physics Letters 101, 164101, 2012.