CPP 30: Poster: Micro and Nanofluidics

Time: Wednesday 17:30–19:00 Location: Poster C

CPP 30.1 Wed 17:30 Poster C

Limits of DDFT for sheared suspensions — •Markus Rauscher[1,2] and Laura Almenar[1,2] — [1]Max-Planck-Institut für Metallforschung, Stuttgart, Germany — [2]ITAP, Universität Stuttgart, Stuttgart, Germany

Dynamic density functional theory (DDFT) has developed into a versatile tool for modeling the dynamics of interacting Brownian particles. We demonstrate that for the stationary transport of particles advected in straight channel DDFT fails to capture essential features of the system: the density distribution across the channel is changed by the solvent flow, as a result the particle throughput is non-linear in the flow velocity, and the throughputs different particles have to be equal if the particles are so big that they cannot pass each other. We mainly attribute this deficiency of DDFT to the equilibrium approximation for the two-body correlation functions used as a closure relation. And in addition to the grand canonical nature of the density functional.

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Evidence for the Absence of the Shear Viscosity Minimum of the Confined Liquid Crystal 8OCB — •Dominik Gerstner, Simon Gruener, and Patrick Huber — Physics of Mesoscopic Systems, Saarland University, Saarbruecken

We present measurements on the capillary rise (spontaneous imbibition) of the lqiuid crystal 8OCB into silica monoliths (porous Vycor) permeated by tortuous pores with radii of 5 nm. The invasion dynamics have been recorded measuring the sample's mass increase $m(t)$ due to the liquid uptake. All obtained curves obey the classical Lucas-Washburn law, thus corroborating bulk-like flow behavior even in such extreme spatial confinement. However, the shear viscosity minimum characteristic of the flow of a nematic liquid crystal is found to be absent. This behavior corroborates the assumption of a paranematic phase beyond the I-N-transition temperature caused by an orientational ordering of the molecules induced by the confining cylindrical pore walls. Optical birefringence measurements on 8OCB in aligned silica nanochannels further support this hypothesis. This work has been supported within the DFG priority program 1164, Nano- & Microfluidics (Grant No. Hu 850/2).

CPP 30.3 Wed 17:30 Poster C

Wetting of hydrophobic periodic nanotemplates on Si-surfaces — •Stefan Wiedemann[1], Stefan Heindl[1], Kay Egloff[2], Alfred Plettl[1], Sabine Hild[3], and Paul Ziemann[1] — [1]Institut für Festkörperphysik, Universität Ulm, 89069 Ulm, Germany — [2]Institut für Experimentelle Physik, Universität Ulm, 89069 Ulm, Germany — [3]Institut für Polymerwissenschaften, Universität Linz, A-4040 Linz, Austria

To influence the wetting behavior of a Si surface, periodically ordered nanomasks were prepared by a micellar[1] and photoseeding technique and used to fabricate extended arrays of nanopillars on a Si wafer by RIE etching[3]. These methods allow a systematic variation of the height (<180nm), density (70-500 $1/\mu m^2$) and diameter (10-40nm) of the pillars. After removing the etching mask hydrophobicity of the samples was additionaly modified by coating with HMDS (Hexamethyldisilane), OTMS (Octadecyltrimethoxysilane) or a fluorcarbon-film fabricated by plasma-deposition. Wetting of water was studied by measuring advancing, static and receeding contact angles. First results demonstrate either the Wenzel or Cassie-Baxter-state of water drops on the nanostructured surfaces.

[1] G. Kästle et al., Adv. Funct. Mat. 13, 853 (2003)
[2] A. Seidenstücker et al., submitted
[3] F. Weigl et al., Diamond and rel. Mat. 15 1689 (2006)

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Wetting of grooved elastic substrates — •Carsten Herrmann[1], Dominik Michler[1], Konstantina Kostourou[2], Stefan Bommer[1], and Ralf Seemann[1] — [1]Experimental Physics, Saarland University, D-66041 Saarbrücken — [2]MPI for Dynamics and Self-Organisation, Bunsenstraße 10, D-37073 Göttingen

The wetting morphologies on grooved viscoelastic substrates are considered experimentally. Due to their elastic properties, the geometry of rubber substrates is changed in the presence of wetting morphologies by the virtue of the capillary forces. Depending on geometry and wettability of the substrate an attractive or repulsive force between neighboring grooves respectively neighboring ridges emerge. This leads to different wetting scenarios and a lateral ordering of the wetting morphologies. The substrates are fabricated from Polydimethylsiloxane (PDMS) rubber and consist of straight parallel grooves having a rectangular shaped cross section. The wetting morphologies are generated by gas phase deposition and observed in situ by optical microscopy. We explore the lateral order and the shape of the emerging liquid morphologies as function of wettability and geometry.

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Visualizing Forced Imbibitions in Porous Media. — •Michael Jung, Kamaljit Singh, and Ralf Seemann — Universität des Saarlandes, Saarbrücken, Germany

As a simple model for forced liquid imbibitions into porous media, we study two-dimensional flow experiments in microfluidic devices, developed from oil-resistant UV-curable glue using a softlithography technique. These devices were first saturated with oil (silicon oils or alkanes). The oil was then displaced by flushing water. We observe the dynamic behavior of liquid front using a CCD camera. The effect of various parameters, such as fluid densities, viscosities, water flow velocities and the size and geometry of the pore space, on the position and the behavior of the liquid front as well as the remaining fraction of trapped oil was investigated in detail.

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Wetting of grooved elastic substrates - a theoretical study — •Dominik Michler[1,2], Ralf Seemann[1,2], and Martin Brinkmann[1] — [1]Max Planck Institute for Dynamics and Self-Organization, D-37073 Göttingen — [2]Experimental Physics, Saarland University, D-66123 Saarbrücken, Germany

The wetting of an elastic substrate decorated with a periodic pattern of parallel ridges of rectangular cross section is considered theoretically. A high aspect ratio of the ridges separating two neighbouring grooves allows us to employ Krichhoff's theory for the elastic deformation of thin plates to compute their deformations due to interfacial tension and Laplace pressure. We start our investigation with liquid structures of constant cross section perpendicular to the ridges. On this basis a complete morphology diagram of the liquid can be derived, where the appearance of certain morphologies is given depending on the groove geometry, substrate elasticity, and wettability. Using this quasi-2D approach we first calculate the deformation of the ridges of a single groove filled by liquid. For the case of an array of parallel ridges we predict an ordering of liquid structures in neighbouring grooves. This ordering effect is due to the deformation of the ridges, which leads to changes in the cross section of neighbouring grooves. The theoretical predictions will be compared with experimental results.

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Liquid Morphologies in wet granulates with large contact angle — •Marc Schaber[1], Mario Scheel[3], Marco Di Michiel[3], Stephan Herminghaus[2], and Ralf Seemann[1] — [1]Experimental Physics, Saarland University, D-66041 Saarbrücken — [2]MPI for Dynamics and Self-Organisation, Bunsenstraße 10, D-37073 Göttingen — [3]ESRF, 6 rue Jules Horowitz, F-38000 Grenoble

Adding liquid to dry granulates causes the formation of a network of capillary bridges and complex liquid morphologies inside the granulate and typically a stiffening of the granulate is observed. Depending on wettability of the granulate different liquid morphologies are formed. We explore the three dimensional liquid distribution within granulates composed of glass microspheres with a low contact angle and basalt microspheres with a large contact angle using X-ray micro-tomography. The emerging liquid morphologies are analyzed and compared for different liquid contents, contact angles and bead sizes. Using time resolved X-ray tomography we furthermore explore the liquid equilibration process as function of wettability.

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Static Wetting Morphologies in Topographically Structured Substrates — •Stefan Bommer[1], Dominik Michler[1], Martin Brinkmann[2], and Ralf Seemann[1] — [1]Saarland University, Experimental Physics,D-66041 Saarbrücken — [2]MPI for Dynamics and Self-

Organisation,Bunsenstrasse 10, D-37073 Göttingen

The different wetting morphologies of liquid confined to micron sized trapezoidal grooves are studied experimentally and theoretically. We explore the emerging equilibrium morphologies as function of groove wettability and groove aspect ratio, i.e. the ratio of the groove depth to the groove width. For big aspect ratio the qualitative wetting behavior is expected to be similar to triangular grooves, whereas for decreasing aspect ratio the wetting behavior of rectangular grooves or even individual topographic steps is expected. The grooves are fabricated in silicon by wet etching, whereas the slope of the side walls is given by the crystal lattice of the silicon. The wettability of the substrate is controlled by various self-assembly monolayers and fine tuned with a subsequent oxygen plasma treatment. The wetting morphologies consist of polystyrene deposited from the gas phase and imaged by scanning force microscopy in an intermitted. A morphological diagram is derived analytically by minimizing the surface free energies and using the available software package "Surface Evolver" and compared to the experimental results.

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Forced imbibition in porous media using in-situ X-ray microtomography — •Hagen Scholl[1], Marco Di Michiel[2], Kamaljit Singh[1], Mario Scheel[2], Stephan Herminghaus[3], and Ralf Seemann[1] — [1]Saarland University, Experimental Physics, D-66041 Saarbrücken, Germany — [2]European Synchrotron Radiation Facility, F-38000 Grenoble, France — [3]MPI for Dynamics and Self-Organization, D-37073 Göttingen, Germany

The high energy beamline ID15 at the European Radiation Facility (ESRF) allows acquiring full 3D tomograms with micron scaled spatial resolution in less than 2 s. This time resolution is sufficient for an in-situ insight into the dynamics of driven multiphase flow in porous media. We investigate the motion of a water-oil front advancing into an oil filled granular pile composed of glass or basalt microspheres. We analyse the flow velocity of the aqueous phase, shape of the liquid front, the residual oil saturation on a pore size level. An initially straight liquid front roughens extremely quickly and a dynamic and repeatedly filling and draining of individual pore volumes is observed.

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On the shape of surface nanobubbles — Bram Borkent[1], •Sissi de Beer[2], Frieder Mugele[2], and Detlef Lohse[1] — [1]University of Twente, PoF, Enschede, the Netherlands — [2]University of Twente, PCF, Enschede, the Netherlands

In recent years the puzzling appearance of surface nanobubbles on hydrophobic surfaces has attracted a lot of attention. On the one hand, stable Atomic Force Microscope (AFM) imaging of the bubbles should not be possible. Due to the large Laplace-pressure inside these small bubbles, they should dissolve immediately and therefore not exist at all. On the other hand, previous AFM experiments of surface nanobubbles suggested an anomalously large contact angle of the bubbles (i.e. much larger then the macroscopic contact angle) and a possible size dependence. We present precise measurements of the contact angle for nanobubbles of various sizes on smooth highly orientated pyrolytic graphite (HOPG) with cantilevers of different shape, spring constant and surface properties. We find that for all cantilevers the contact angle is constant, within the experimental error, down to of a size 20 nm, and its value is equal to 119o. This result, which is the lowest contact angle for surface nanobubbles found so far, is very reproducible and moreover independent of the cantilever type used, provided that the cantilever is clean and the HOPG surface is smooth. In contrast we find that, for a particular set of cantilevers, the surface can become relatively rough (probably due to precipitated matter from the cantilever onto the substrate). In this case much larger contact angles show up, similar to values reported in literature.

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Optimized Droplet Microfluidics for Complex Sol-Gel Reactions — •VENKATACHALAM CHOKKALINGAM[1,2], BORIS WEIDENHOF[3], WILHELM MAIER[3], STEPHAN HERMINGHAUS[2], and RALF SEEMANN[1,2] — [1]Experimental Physics, Saarland University, 66123-Saarbruecken, Germany — [2]Max Planck Institute for Dynamics and Self-Organization, Bunsenstr. 10, 37073-Goettingen, Germany — [3]Technical Chemistry Saarland University, 66123-Saarbrücken, Germany

Droplet based microfluidics is used to produce silica particles using a sol-gel synthesis route. The chemicals are stoichiometrically dispensed, mixed, and pre-processed inside a microfluidic device allowing for long operation times without any clogging. Using this approach and optimizing all reaction and processing parameters we generate mesoporous silica particles with a very high surface area of 820 sq.m/g and a narrow pore radius distribution of around 2.4 nm. The sol-gel process developed here for pure silica spheres can easily be modified to produce a large variety of mixed oxides.

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Self-Synchronizing Microfludiic Droplets — •Venkatachalam Chokkalingam[1,2], Stephan Herminghaus[2], and Ralf Seemann[1,2] — [1]Experimental Physics, Saarland University, 66123-Saarbruecken, Germany — [2]Max Planck Institute for Dynamics and Self-Organization, Bunsenstr. 10, 37073-Goettingen, Germany

An easy to handle device for the synchronized in-situ production of two types of emulsion droplets in a microfluidic device with high dispersed phase volume fraction (up to about 96 %) and excellent monodispersity (variance of the droplet diameter < 1.2 %) is introduced. For this device we combined two single step-emulsification units into one device whereas the droplet production of each individual unit self synchronizes with the other to produce droplets in a strictly alternating way. This double step-emulsification mechanism is very robust and even allows producing two distinct families of droplets with variable size in a fixed number ratio of 1:1 upto 1:4, with each family having identical droplets while maintaining excellent monodispersity (variance always < 1.2 %).

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Deriving elastic properties of rubber substrates by analyzing the shape of nanodroplets on their surface — •Konstantina Kostourou[1], Stephan Herminghaus[1], and Ralf Seemann[1,2] — [1]Max Planck Institute for Dynamics and Self-Organization, D-37073 Göttingen, Germany — [2]Experimental Physics, Saarland University, 66041 Saarbrücken, Germany

We study the shape of polystyrene (PS) nanodroplets generated by the complete dewetting of a PS thin film on rubber elastic substrates of cross-linked Polydimethylsiloxane (PDMS). We are interested in the full shape of the droplet, i.e. the shape of the air/PS interface, the deformation at the dry side of the three phase contact line (TPCL) and the deformation below the droplet. The exact position of the TPCL is determined by scanning the air/PS interface with Harmonix^{TM} AFM, a tool which allows us to extract the elasticity of the material. Thus, overlapping the topography and elasticity signals, we identify the crossover from PDMS to PS, i.e. the TPCL. In parallel, the deformation at the dry side of the TPCL is compared to the one calculated by existing theories. Using the theoretical model as a fitting function with the Elastic modulus being the only free parameter, we can extract the elasticity of the substrate. Finally, the PS/PDMS interface is also imaged by AFM. Quantifying the deformation below the droplet and applying a nanoindentation model, we can extract the substrate Elastic modulus, which is compared and found in very good agreement with the one calculated by the fitting of the dry side of the TPCL.

CPP 30.14 Wed 17:30 Poster C

Micro-rheology on polymer-grafted colloids — •Christof Gutsche[1], Matthias Krüger[2], Markus Rauscher[3], Rudolf Weeber[4], Jens Harting[4], Yong Woon Kim[5], Roland R. Netz[6], and Friedrich Kremer[1] — [1]Institute of Experimental Physics I, Leipzig University, Germany — [2]Fachbereich Physik, Universität Konstanz, Germany — [3]Max-Planck-Institut für Metallforschung, Stuttgart, Germany — [4]Institut für Computerphysik, Universität Stuttgart, Germany — [5]School of Physics, Korea Institute for Advanced Study, Korea — [6]Physics Department, Technical University Munich, Germany

Optical Tweezers are ideal tools to carry out microfluidic and microrheological experiments with micrometer-sized objects. They enable one to measure without any mechanical contact forces acting on a particle with the extraordinary resolution of up to 5 fN. Experiments are presented on (i) the interaction between two single colloids in media of varying ionic strength [1], (ii) the flow resistance of one blank colloid in a polymer solution [2] and (iii) the flow resistance of single DNA-grafted colloids in different media [3,4].

[1] C. Gutsche et al. Phys. Rev. E 76, 031403 (2007) [2] C. Gutsche et al. J. Chem. Phys. 129, 084902 (2008) [3] C. Gutsche et al. Microfluidic Nanofluidic 2(5), 381 (2006) [4] Y.W. Kim et al. Macromolecules 42, 3650 (2009)

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Hydrodynamic effects between rotating objects and chains grafted at a wall — •Steffen Schreiber[1], Thomas Tischer[2], and Walter Zimmermann[1] — [1]Theoretische Physik I, Universität Bayreuth, D-95440 Bayreuth, Germany — [2]Experimentalphysik V, Universität Bayreuth, D-95440 Bayreuth, Germany

We investigate two asymmetric, rotating and hydrodynamically interacting dumbbells. When the dumbbells have different asymmetries they rotate asynchronously in an external field. The angle between the dumbbell axes oscillates around a non-vanishing mean value. So the symmetry with respect to time reversal is broken. Depending on the dumbbells' shapes this causes either attraction or repulsion between them as we show in selected phase diagrams.

Secondly we investigate the motion of an ensemble of paramagnetic beads in a rotating magnetic field. After aligning the beads in a linear chain by a static magnetic field we rotate the field. Depending on its rotation frequency and on the field strength we find two regimes: For high rotation frequencies and for low field strengths the ensemble of beads forms spiral structures, whereas for low rotation frequencies and high field strengths the chain breaks up into smaller chains.

Furthermore we examine the hydrodynamic interaction between a semiflexible bead-spring chain and a plane no-slip wall, to which the chain is attached. The chain is exposed to different flow profiles. We find that the hydrodynamic interactions between the chain and the wall cause the chain to bend towards the wall. In oscillating flow fields we find an interesting asymmetric motion of the chain.

CPP 30.16 Wed 17:30 Poster C

Slip length of thin polymer films on substrates with different hydrophobic layers — •Mischa Klos, Matthias Lessel, and Karin Jacobs — Saarland University, Experimental Physics, D-66123 Saarbrücken

The typical volume-to-surface fraction in fluid channels of modern microfluidics is getting smaller and smaller, so the solid/liquid interface becomes more and more important. In classic hydrodynamics, the velocity of a liquid at a channel wall is zero. Yet, a non-zero velocity at the interface could greatly enhance the throughput. This phenomenon is known as 'slippage' with the slip length characterizing its strength. For polymer melts, slippage can be achieved by a hydrophobic coating on, e.g., a Si wafer. The slip length can be inferred from the profile of the liquid front during dewetting of the film. We show the impact of different hydrophobic coatings on silicon substrates on the slip length. As coatings we use an amorphous Teflon (AF1600) layer and silanes with different chain lengths. The Teflon induces nearly no slip whereas the silanes (Octadecyltrichlorosilane (OTS), Dodecyltrichlorosilane (DTS)) provoke slip lengths in the range of micrometers (OTS) to tens of micrometers (DTS). The open question is why a difference between 12 (DTS) and 18 (OTS) carbon atoms on the backbone of the silane molecule can be responsible for the different slip lengths. To answer this question we investigate the dewetting on Hexadecyltrichlorosilane (HTS) with 16 carbon atoms on the back bone.