

## CPP 44: Micro- and Nanofluidics I

Time: Thursday 14:00–18:00

Location: ZEU 160

CPP 44.1 Thu 14:00 ZEU 160

**Enantioselective separation by an asymmetric flow profile** — ●FLORIAN J. LORENZ<sup>1</sup>, LUKAS BOGUNOVIC<sup>1</sup>, RALF EICHHORN<sup>2</sup>, DARIO ANSELMETTI<sup>1</sup>, and JAN REGTMEIER<sup>1</sup> — <sup>1</sup>Bielefeld University, Bielefeld, Germany — <sup>2</sup>NORDITA, Stockholm, Sweden

The pharmaceutical use of homochiral chemicals is of great interest, because they have different physiological responses in organisms, because of the chiral selectivity in biological systems.

Since abiotic synthesis strategies often render an enantiomeric mixture (so called racemate), the racemate-splitting into pure enantiomers is one of the main challenges. To date, however, this is often realized by chromatography- and electrophoresis-separation-methods, with the great disadvantage that specifically designed chemical selectors are needed.

We present an alternative physical method, selector-free and continuously working, to separate enantiomers at the micrometer scale. It is based on an asymmetric flow profile within a microfluidic Lab-On-a-Chip (LOC) platform with broken spatial symmetry. We could demonstrate that the enantiomers are separated within the micro-channel and can be harvested in different reservoirs at the end.

Currently we explore the possibility to further miniaturize those devices for nanoscale separation of chiral molecules.

CPP 44.2 Thu 14:15 ZEU 160

**AC driven nanopump** — ●KLAUS F. RINNE, STEPHAN GEKLE, DOUWE JAN BONTHUIS, and ROLAND NETZ — Physik Department, TU München, Germany

We present a novel mechanism for pumping water through a (20,0) carbon nanotube (CNT) without requiring external pressure gradients. Using molecular dynamics simulations (with the LAMMPS package) we show that pumping can be achieved through a periodic electric field. The electrical energy of the water dipoles is translated into particle motion via translation-orientation-coupling. We determine the pumping efficiency consistent with thermodynamics. Our system is simple enough that it could be experimentally realizable and might serve as a basis for microscale filtration systems.

CPP 44.3 Thu 14:30 ZEU 160

**A microfluidic ratchet device for the controlled and tuneable separation of microparticles** — ●LUKAS BOGUNOVIC<sup>1</sup>, RALF EICHHORN<sup>2</sup>, JAN REGTMEIER<sup>1</sup>, DARIO ANSELMETTI<sup>1</sup>, and PETER REIMANN<sup>1</sup> — <sup>1</sup>Bielefeld University, Bielefeld, Germany — <sup>2</sup>NORDITA, Stockholm, Sweden

Standard biotechnological separation techniques - such as gel electrophoresis - are often restricted to a separation criterion that is unchangeably implemented during fabrication. Therefore a new microfluidic device, based on a dielectrophoretic (DEP) ratchet design, has been designed and characterized [1]. It allows the dynamic and selective adaption of the separation criterion and direction of migration during operation. As a proof-of-concept, we demonstrate the separation of one arbitrary micro bead species out of three different kinds with freely selectable direction of migration for each species. The device consists of a straight microfluidic channel structured with an array of triangles. Here, DEP traps are created by an alternating voltage  $U_{AC}$  while a constant voltage  $U_{DC}$  drives negatively charged particles with diameters  $d_1=1.1\mu\text{m}$ ,  $d_2=1.9\mu\text{m}$  and  $d_3=2.9\mu\text{m}$  through the channel by electrophoresis (EP). Depending on the relative strengths of EP and DEP forces, a selection of particle types that will be trapped and those, which will still be transported can be archived. Combining these system states to a tailored driving protocol leads to the desired separation task.

[1] L. Bogunovic et al. "A tuneable microfluidic ratchet for particle sorting", submitted 2010

CPP 44.4 Thu 14:45 ZEU 160

**Directed transport of DNA polymer molecules in micro- and nanochannels** — ●RONNY SCZECH<sup>1</sup>, STEFFEN HOWITZ<sup>2</sup>, and MICHAEL MERTIG<sup>1</sup> — <sup>1</sup>Technische Universität Dresden, 01062 Dresden, Germany — <sup>2</sup>GeSiM, Bautzner Landstrasse 45, 01454 Großerkammendorf, Germany

DNA molecules can be transported in a nanochannel with help of both electrophoretic and hydrodynamic flow. Transport experiments

and theoretical considerations suggest an interaction of electrophoresis, electro-osmosis, and the unique statistical properties of confined polymers. Besides that, the confinement of the device is crucial since it influences the electric field in the nanochannel.

Nanofluidic channels in polydimethylsiloxane (PDMS) were formed by classical nanoimprinting technology combining micro- and nanofluidic features. The feasibility of those hybrid micro- and nanofluidic structures for single molecule observation and manipulation was demonstrated by introducing single molecules of  $\lambda$ -DNA into the channels using optimized parameters for the applied potential and flow.

It was possible to show the manipulation of  $\lambda$ -DNA molecules in PDMS nanochannels with a cross section  $\leq 1\mu\text{m}$  using epifluorescence microscopy. Once stabilized inside a nanochannel the free diffusion of individual  $\lambda$ -DNA molecules were observed. Diffusivity was compared with previous studies that concentrated on nanoslits and checked for adaptability to blob theory and reflecting rod theory. In this context, electrokinetic concentration of the  $\lambda$ -DNA were observed during the application of an sufficient electrical field.

CPP 44.5 Thu 15:00 ZEU 160

**Omniphobicity Scrutinized with a Phase-Field Approach** — ●WALTER MICKEL<sup>1,2</sup> and THIERRY BIBEN<sup>1</sup> — <sup>1</sup>Université de Lyon, F-69000, Lyon, France; Université Lyon 1, F-69622, Villeurbanne, France; CNRS, UMR5586, Laboratoire PMCN — <sup>2</sup>Institut für Theoretische Physik, Friedrich-Alexander Universität Erlangen-Nürnberg, Staudtstr. 7, 91058 Erlangen, Germany

Spreading liquids on a rough surface with pillars may result in a penetrated Wenzel-state where liquid enters the grooves or a fakir state with air-pockets suspending the liquid above. On micronic scales this behavior is very well described with the Wenzel- and Cassie-Baxter laws. According to this theory hydrophobic materials are needed to obtain superhydrophobic states due to the roughness induced amplification of the hydrophobicity. An inversion of the wetting behavior due to roughness, could not be explained by the theory. However experiments from Ramos[1] and simulations from Daub[2] showed that intrinsic hydrophilic materials could render hydrophobic with appropriate surface structures. Such materials are called omniphobic.

We study the mechanisms which lead to omniphobic substrates with a phase-field model[3] coming from mesoscale to nanoscale wetting. With this model we investigate the free energy landscape to quantify metastabilities and dynamic transitions. Further we report the impact of several roughness parameters on the wetting inversion. We discuss the capillary filling of grooves and show a mesoscopic wetting theory.

[1] S. Ramos, Langmuir 26 (2010) 5141-6 [2] C.D. Daub, Faraday Discussions 146 (2010) 67-77 [3] T. Biben, PRL 100 (2008) 186103

CPP 44.6 Thu 15:15 ZEU 160

**Electrical switching of wetting states on superhydrophobic surfaces: a route towards reversible Cassie-to-Wenzel transitions** — GOR MANUKYAN, OH JUNG MIN, VAN DEN ENDE DIRK, LAMMERTINK ROB, and ●MUGELE FRIEDER — University of Twente, MESA institute, Enschede, The Netherlands

We demonstrate that the equilibrium shape of the composite interface between superhydrophobic surfaces and drops in the Cassie state under electrowetting is determined by the balance of the Maxwell stress and the Laplace pressure. Energy barriers due to pinning of contact lines at the pillar edges control the transition from Cassie to the Wenzel state. Barriers due to the narrow gap between adjacent pillars control the lateral propagation of the Wenzel state. Suitable engineering of surface and electrode geometries allows for reversible local switching between the two wetting states.

CPP 44.7 Thu 15:30 ZEU 160

**MD simulation of polymer droplets on super-hydrophobic substrates** — ●NIKITA TRETYAKOV and MARCUS MÜLLER — Georg-August Universität, Göttingen

We study coarse-grained polymer liquids on super-hydrophobic substrates by Molecular Dynamics simulation. The systems under investigation consist of a polymer droplet on a spatially structured corrugated substrate. The temperature is controlled by DPD thermostat which locally conserves the momentum. The values of the contact an-

gle are dictated by the substrate-liquid interaction and the geometry of the substrate corrugation. Cassie and Wenzel states are observed by changing the amplitude of Lennard-Jones interaction between polymer chains and substrate's atoms.

Applying the body force onto droplet's molecules we study dynamical properties of the system. Spatial corrugation of the substrate initiate the pinning of the droplet's contact line. The energy barriers needed to be overcome for depinning are estimated. The fluctuations of the contact line providing information on capillary waves on the droplet's surface are explored. The energy dissipations due to the presence of the substrate are calculated. Directed motion caused by asymmetry of the substrate corrugation is studied.

CPP 44.8 Thu 15:45 ZEU 160

**Anisotropic wetting behavior on groove patterns** — ●CIRIO SEMPREBON<sup>1</sup>, CARSTEN HERRMANN<sup>2</sup>, RALF SEEMANN<sup>2</sup>, STEPHAN HERMINGHAUS<sup>1</sup>, and MARTIN BRINKMANN<sup>1</sup> — <sup>1</sup>MPI for Dynamics and Self-Organization, Goettingen — <sup>2</sup>Universitat des Saarlandes, Saarbrücken

We investigate theoretically and experimentally the shape of small liquid droplets condensing on a substrate decorated with periodic micro-patterns of parallel grooves. Depending on the pattern geometry and substrate wettability these droplets may either grow solely in the direction of the grooves forming elongated filaments, or spread anisotropically in both directions. In the spreading regime the droplet eccentricity oscillates as the number of wet grooves increases, ultimately reaching a scale invariant shape with a well defined anisotropy. The boundaries of the stability of filaments can be computed from an analytical model and depend on the number of grooves which are wet. Generally we find that the region of stability of filaments is smaller for filaments wetting a larger number of grooves. For the particular case of V-grooves the filaments may undergo either a Rayleigh-Plateau instability or lateral depinning of the contact line. The scale invariant shape can be described with a numerical model for liquid droplets confined to a single wettable stripe.

## 15 min. break

CPP 44.9 Thu 16:15 ZEU 160

**Colloidal flow and transport in micro structured porous media** — ●FRANK WIRNER<sup>1</sup>, CHRISTIAN SCHOLZ<sup>1</sup>, YUJIE LI<sup>1,2</sup>, and CLEMENS BECHINGER<sup>1,2</sup> — <sup>1</sup>Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — <sup>2</sup>Max-Planck-Institut für Metallforschung, Heisenbergstrasse 3, 70569 Stuttgart, Germany

Transport and flow phenomena in porous media occur in various fields of science and engineering, ranging from agricultural, biomedical, chemical and petroleum engineering to soil sciences. Although the literature on porous media has been growing rapidly over the last decades it is still unclear, how transport properties of liquids through porous materials can be related to their structure.

We study transport and flow properties of fluids and colloidal suspensions in a quasi 2D microporous system, created using soft lithography, over a wide range of flow regimes. The colloids act as tracer particles and visualize the flow field. A camera system with a temporal resolution of 2 ms and a spatial resolution of 0.4  $\mu\text{m}$  is used to analyze the particle trajectories. The porous structures are artificially designed and therefore the structural parameters like Minkowski functionals and pore size distributions are fully known and can be related to dynamical flow variables, such as permeability or dispersion coefficients. We discuss the relationship between permeability and porosity near and far off the percolation threshold of different random structures.

CPP 44.10 Thu 16:30 ZEU 160

**Dynamics of Forced-Imbibition in Porous Media** — ●KAMALJIT SINGH<sup>1,2</sup>, HAGEN SCHOLL<sup>2</sup>, MARCO DI MICHIEL<sup>3</sup>, MARIO SCHEEL<sup>3</sup>, STEPHAN HERMINGHAUS<sup>1</sup>, and RALF SEEMANN<sup>1,2</sup> — <sup>1</sup>Max Planck Institute for Dynamics and Self-Organization, D-37073 Goettingen, Germany — <sup>2</sup>Saarland University, D-66041 Saarbrücken, Germany — <sup>3</sup>European Synchrotron Radiation Facility, BP 220, F-38043 Grenoble, France

We used ultrafast X-ray micro-tomography at the European Synchrotron Radiation Facility (ESRF, ID15) to observe the three-dimensional dynamic behaviour of water-oil fronts during a water flood into an initially oil filled porous medium. This type of multiphase flow is similar to a situation which can be found for oil recovery or soil

decontamination. We characterised the pore and throat parameters of the porous media, and analysed the water-oil front behaviour at pore scale for various factors, including wettability of porous matrix, flow velocity and porosity. The dynamic experiments reveal that in an oil-wet medium, the water-oil front is more compact, however the front in a water-wet porous medium progresses in elongated fingers. The fingering in water-wet porous medium results in a higher final residual oil saturation after a complete water flood due to by-passing of several oil-filled pore pockets. We will compare the experimental results for various parameters with models developed from pore-throat characteristics.

CPP 44.11 Thu 16:45 ZEU 160

**Phase behaviour and rheology of the liquid crystal 8OCB in confinement** — ●DOMINIK GERSTNER, SIMON GRUENER, and PATRICK HUBER — Experimental Physics, Saarland University, Saarbrücken, Germany

To examine the hydrodynamic properties of the liquid crystal 8OCB in nanoscale confinement, we measured the time dependence of its capillary rise into porous Vycor glass. Porous Vycor is a monolithic silica glass, permeated by a random network of pores with a mean diameter of approximately 7 nm. The capillary rise was monitored by the mass uptake  $m(t)$  of the system. We observed the typical Lucas-Washburn behaviour for all our measurements, which suggests the validity of bulk hydrodynamics even in such strong confinement. However, the shear viscosity minimum, appearing at the bulk isotropic-nematic transition of 8OCB, is found to be absent. We explain this with the formation of a paranematic phase, i.e. the continuous evolution of molecule alignment due to the ordering effects of the narrow pores. The evolution of the paranematic order can also be seen in <sup>13</sup>C neutron magnetic resonance spectroscopy and differential scanning calorimetry measurements on 8OCB in a porous Vycor host.

CPP 44.12 Thu 17:00 ZEU 160

**Wetting of liquid-crystals on flat surfaces. The role of substrate anchoring.** — ●MANUEL GRESCHKE<sup>1</sup> and MARTIN SCHOEN<sup>1,2</sup> — <sup>1</sup>Stranski-Laboratorium für Physikalische und Theoretische Chemie, Fakultät für Mathematik und Naturwissenschaften, Technische Universität Berlin, Straße des 17. Juni 135, 10623 Berlin, GERMANY — <sup>2</sup>Department of Chemical and Biomolecular Engineering, Engineering Building I, Box 7905, North Carolina State University, 911 Partners Way, Raleigh, NC 27695, USA

Predicting the behaviour of liquid crystals in confinement plays an important role in developing novel nanotechnological devices such as biosensors. Using grand canonical Monte Carlo simulations we investigate the impact of different anchoring scenarios on the wetting behaviour of a model liquid-crystal confined by a mesoscopic slit-pore. The intermolecular fluid-fluid interaction is modeled by a modified Lennard-Jones potential with an orientation-dependent attractive term. Different anchoring scenarios are described by an anchoring function  $g(\hat{\mathbf{u}})$ , that discriminates energetically between different orientations of a molecule with respect to the substrate plane. Depending on the specific anchoring scenarios the fluid may or may not wet the solid substrate where wetting may involve an orientation dependent prewetting transition. The thickness of the wetting layer is shown to depend on the anchoring function as well.

CPP 44.13 Thu 17:15 ZEU 160

**Mechanical Properties of Wet Granulates** — ●SOMNATH KARMAKAR<sup>1</sup>, MARC SCHABER<sup>1</sup>, MARIO SCHEEL<sup>2</sup>, MARCO DI MICHIEL<sup>2</sup>, STEPHAN HERMINGHAUS<sup>3</sup>, and RALF SEEMANN<sup>1,3</sup> — <sup>1</sup>Saarland University, Saarbrücken, Germany — <sup>2</sup>ESRF, Grenoble, France — <sup>3</sup>Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

Adding small amounts of a wetting liquid to dry granular matter typically leads to a substantial increase of the mechanical stiffness of the granular media. This arises due to the formation of capillary bridges, exerting an attractive force between individual grains. We study the mechanical properties, i.e. yield stress, tensile strength and critical fluidization acceleration of wet granular materials with different wettability using glass and basalt beads and sand grains at various liquid contents. The mechanical properties are probed for various experimental conditions and surprisingly the wetting liquid might act as a lubricant for a granulate sheared at large absolute pressure. Moreover, we experimentally find for a wetting system a yield stress that is depending on the applied shear frequency. For a granular system with low wettability however, the yield stress is independent of the shear

frequency. By time resolved X-ray tomography experiments we can explain this behavior by a liquid exchange process occurring between the individual liquid morphologies emerging in wetttable granulates but which is not observed in granulates with low wettability.

CPP 44.14 Thu 17:30 ZEU 160

**Dielectric response of interfacial water** — ●STEPHAN GEKLE, DOUWE JAN BONTHUIS, and ROLAND NETZ — Physik Department, TU München, Germany

Water at interfaces or in confinement often exhibits unique properties. In this talk we focus on the dielectric response to an external frequency-dependent electric field and outline possible consequences for dielectric heating and electro-osmotic flow. Using molecular dynamics computer simulations, we further show how the interfacial behavior is related to a nonlocal dielectric function which can be observed even in bulk water.

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**Drop Impact on Free-Standing Surfactant Films** — ●DANIELA FELL<sup>1,2</sup>, MORDECHAI SOKULER<sup>1,2</sup>, ANDREAS N. LEMBACH<sup>2,3</sup>, CHUANJUN LIU<sup>1,2</sup>, ELMAR BONACCURSO<sup>2</sup>, GÜNTER K. AUERNHAMMER<sup>1</sup>, and HANS-JÜRGEN BUTT<sup>1,2</sup> — <sup>1</sup>Max Planck

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We investigate the influence of drop composition on the drop's behavior during impact. The drops of either water or aqueous surfactant solution had a diameter of  $(2.4 \pm 0.4)$  mm and impacted with a velocity up to 1.3 m/s. As surfactants the anionic sodium dodecyl sulfate (SDS) and the cationic cetyl trimethyl ammonium bromide (CTAB) were used. Pure water drops impacting on surfactant films showed coalescence, bouncing, passing, partial bouncing, and partial passing. When surfactant was added to the drop, partial passing was suppressed and coalescence was replaced by (partial) bouncing.

We interpret the different phenomena based on the repulsive hydrodynamic force arising when the air has to flow out of the closing gap between the two liquid surfaces. This repulsion is influenced by the hydrodynamic boundary condition at the air-water interface. For a mobile interface represented by water drops impacting on surfactant films the outflow of air should be faster than for a no-slip boundary condition represented by both liquids containing surfactant. The boundary condition change from mobile to no-slip condition leads to stronger hydrodynamic repulsion in case of impacting surfactant drops.