CPP 26: Micro and Nanofluidics I

Time: Wednesday 14:00–17:30

Location: H39

CPP 26.1 Wed 14:00 H39

Sorption in elastically coupled microporous media: Equilibrium and dynamics — •KRISTIAN MÜLLER-NEDEBOCK — Stellenbosch University, Stellenbosch, Südafrika

Microporous materials in which small guest molecules can be sorbed and where pores are coupled elastically are studied. We show how multiple state models with elastic interactions can account for experimentally determined adsorption isotherms. We also present a simple theoretical model for an auxetic medium, consisting of counter-rotating hinged elements, that permits selective sorption of molecules in dependence of shape and size. This tuning can be achieved through the application of external hydrostatic pressure on the host. A mean-field treatment of the model indicates both continuous and first-order phase transitions. Finally, we study simple dynamics of filling of medium of one-dimensional, yet elastically coupled pores, which pose extremely interesting and mathematically challenging problems beyond that of slow single-file diffusion. Here we develop a Langevin equation approach in order to understand better the subdiffusive regime.

CPP 26.2 Wed 14:15 H39

Pore-scale investigations of multiphase fluid systems subject to freeze-thaw — •KAMALJIT SINGH[1,2,3], ROBERT K. NIVEN[1], TIMOTHY J. SENDEN[4], MICHAEL L. TURNER[4], ADRIAN P. SHEPPARD[4], JILL P. MIDDLETON[4], and MARK A. KNACKSTEDT[4] — [1]School of Aerospace, Civil and Mechanical Engineering, The University of New South Wales at ADFA, Northcott Drive, Canberra, ACT, 2600, Australia — [2]Max Planck Institute for Dynamics and Self-Organization, D-37018 Göttingen, Germany — [3]Experimental Physics, Saarland University, 66123 Saarbrücken, Germany — [4]Department of Applied Mathematics, Research School of Physics and Engineering, Australian National University, ACT, 0200, Australia

The pore scale behavior of non-aqueous phase liquid (NAPL) contaminants in porous media undergoing freeze-thaw cycles is studied by conducting various experiments, including two-dimensional micromodels, containing residual NAPL in a monolayer of glass beads; and three-dimensional glass-bead cell using X-ray micro-computed tomography. It is shown that freeze-thaw cycles have a substantial impact on the distribution of residual NAPL (in initially water saturated porous media), including the rupture and remobilization of trapped NAPL due to freezing-induced pressure forces, and ganglion fragmentation into singlet ganglia. The results of these experiments are interpreted by developing pore-scale models. The findings have important implications for the behavior of subsurface NAPL contamination in cold climate regions.

CPP 26.3 Wed 14:30 H39

Invasion Kinetics of Hydrocarbons into Networks of Silica Mesopores — •SIMON GRUENER[1], HELEN E. HERMES[2], STEFAN U. EGELHAAF[2], and PATRICK HUBER[1] — [1]Physics of Mesoscopic Systems, Saarland University, Saarbruecken — [2]Soft Matter Physics, Heinrich-Heine University, Duesseldorf

We present measurements on the capillary rise (spontaneous imbibition) of liquids into silica monoliths (porous Vycor) permeated by tortuous pores with radii of about 5 nm. The invasion dynamics have been recorded by standard gravimetric measurements, but also by means of neutron radiography experiments. The latter method provides detailed information on the spatial distribution of the liquid within the sample. For one thing this allows for the determination of the liquid's rise height $h(t)$ complementary to the sample's mass increase $m(t)$. Furthermore, insights into the invasion kinetics of the liquid front into the mesoporous network can be gained. Based on these results the occurrence of light scattering at the advancing front can be conclusively traced back to the non-negligible pore size distribution of the applied Vycor glass. This work has been supported within the DFG priority program 1164, Nano- & Microfluidics (Grant No. Hu 850/2).

CPP 26.4 Wed 14:45 H39

Charge transport and diffusion of ionic liquids in nanoporous silica membranes — •CIPRIAN IACOB, JOSHUA SANGORO, SERGEJ NAUMOV, RUSTEM VALIULLIN, JÖRG KÄRGER, and FRIEDRICH KREMER — Institute of Experimental Physics I, University of Leipzig, Linnéstr. 5, 04103, Leipzig, Germany

Charge transport in 1-hexyl-3-methylimidazolium hexafluorophosphate ionic liquid in oxidized nanoporous silicon membranes - prepared by electrochemical etching of (100) p-type silicon- is investigated in a wide frequency and temperature range by a combination of broadband dielectric spectroscopy and pulsed field gradient nuclear magnetic resonance (PFG NMR). By applying the Einstein-Smoluchowski relation to the dielectric spectra, diffusion coefficient is obtained in quantitative agreement with independent PFG NMR measurements. More than 10-fold systematic decrease in the diffusion coefficient from the bulk value is observed in silica nanopores. This is explained within the framework of a model taking into account decreased mobility at the interface of the pore and the nanoporous membrane due to the ability of the hydrogen-bonded ionic liquid to attach to SiO2 surfaces. By that, it becomes possible to probe the size of the adsorption layer and its temperature dependence. This has direct technological implications to the use of ionic liquids in fuel cells and nanobatteries.

CPP 26.5 Wed 15:00 H39

Polymer Flow in Homogeneous and Structured Microchannels — •RAGHUNATH CHELAKKOT, ROLAND G. WINKLER, and GERHARD GOMPPER — Institut für Festkörperforschung, Forschungszentrum Jülich, 52425 Jülich

The flow properties of polymers in microfluidic channels are governed by confinement effects and hydrodynamic interactions. We study this interplay by mesoscale hydrodynamic simulations of confined flexible and semiflexible polymers using multiparticle collision dynamics (MPC). The simulations reveal a pronounced bi-directional cross-channel migration, despite the stiffness of the polymer, governed by surface hydrodynamic interactions and anisotropies in the diffusion, respectively. Increasing polymer stiffness enhances surface induced migration. Semiflexible polymers exhibit tumbling dynamics which resembles that of a polymer in shear flow. Simulations of the transport of flexible polymers through a nanopore show that even at weak flow rates the polymers pass through the narrow region of the channel within a finite simulation time. The translocation time distribution for various flow strength has been calculated. Flow induced properties such as asymmetric stretching, relative velocities of the leading and trailing end of the polymers have also been quantified.

CPP 26.6 Wed 15:15 H39

Flow of microliter and submicroliter droplets on inclined surfaces — •DAVID MAGERL, VOLKER KÖRSTGENS, and PETER MÜLLER-BUSCHBAUM — TU München, Physik-Department LS E13, James-Franck-Str. 1, 85747 Garching (Germany)

Theory predicts that very small droplets under an external body force show a different behavior than larger drops. The velocity of large drops is dominated by dissipation in the volume, that of small droplets by friction at the substrate. The aim of our work is to find experimental proof to this interesting phenomenon. Therefore we investigate the gravity-driven movement of microliter and submicroliter droplets on inclined surfaces. We measure the velocity of these small droplets as a function of their size. In these experiments both, the surface treatment and the liquid of the droplets have been varied. The experiments are conducted in a saturated atmosphere of the according liquid. First, the droplet size on a horizontally oriented surface is measured by optical means, then the surface is tilted and the velocity of the flowing droplet is determined by the optical investigation of the droplet movement on the incline. We present experiments with toluene and water on silicon surfaces of different surface energies and compare the results to the theoretical simulations.

15 min. break

CPP 26.7 Wed 15:45 H39

The microscopic origin of surface slip: A neutron scattering study of hexadecane at solid interfaces — •PHILIPP GUTFREUND[1,2], MAX WOLFF[3], MARCO MACCARINI[2], STEFAN GERTH[4], and HARTMUT ZABEL[1] — [1]Ruhr-University Bochum, 44780 Bochum, Germany — [2]Institut Laue-Langevin, 38042 Grenoble, France — [3]Uppsala University, 75121 Uppsala, Sweden — [4]University Erlangen-Nuernberg, 91058 Erlangen, Germany

A non-sticking contacting layer of a flowing liquid at solid boundaries,

called surface slip, is nowadays observed in a wide range of studies exploring microscopic flow. However, the fundamental origin of boundary slip remains unclear. Different mechanisms were proposed like the formation of a thin depletion layer or a molecular ordering in the liquid near the interface, both changing the interfacial velocity profile and, thus, manifesting in apparent slip. Neutron Reflectometry (NR) and Grazing Incident Neutron Diffraction (GIND) are excellent tools for the investigation of buried boundary layers at solid/liquid interfaces in the nm regime. In this contribution we will show a combined NR and GIND study on in situ sheared hexadecane in contact with differently coated solid interfaces. In the case of an attractive interface a depleted layer is observed which is influenced by shear as well as by temperature. For the low interfacial energy substrate no depletion layer is observed. Thus the depletion layer cannot be the origin of surface slip, as for hexadecane slip was observed in both cases.

CPP 26.8   Wed 16:00   H39

Reduced Interfacial Entanglement Density Affects Boundary Condition of Polymer Flow — Oliver Bäumchen[1], •Matthias Lessel[1], Renate Fetzer[1,2], and Karin Jacobs[1] — [1]Saarland University, Experimental Physics, D-66041 Saarbrücken, Germany — [2]Ian Wark Research Institute, University of South Australia, Mawson Lakes, SA 5095, Australia.

Hydrodynamic boundary conditions play a crucial role in the flow dynamics of thin films [1] and can be probed by the analysis of liquid front profiles [2]. For long-chained polymer films it was reported that a deviation from a symmetric profile is a result of viscoelastic effects. In this study [3], however, evidence is given that merely a slip boundary condition at the solid/liquid interface can lead to an asymmetric profile. Variation of molecular weight shows that slippage is directly linked to chain entanglements. We find a reduced entanglement density at the solid/liquid interface (factor 3 to 4), which stresses the importance of considering non-bulk polymer properties in the vicinity of an interface.

[1] O. Bäumchen et al., J.Phys.: Condens. Matter 21 (2009, in press).

[2] O. Bäumchen et al., in IUTAM Symposium on Advances in Micro- and Nanofluidics, edited by M. Ellero, X. Hu, J. Fröhlich, N. Adams (Springer, 2009).

[3] O. Bäumchen et al., Phys. Rev. Lett. (2009, in press).

CPP 26.9   Wed 16:15   H39

The influence of thermal noise and slippage on the dynamics of spinodally dewetting polymer films — •Matthias Lessel, Oliver Bäumchen, and Karin Jacobs — Saarland University, Experimental physics, 66123 Saarbrücken

We investigate the dewetting dynamics of liquid films with thicknesses in the range of a few nanometers. Our experiments focus on spinodally dewetting films [1]. Thermal fluctuations (capillary waves) lead to a variation in film thickness and induce dewetting.

The morphology of the dewetting film can be captured by simulations. Catching the experimental system, the interaction potential, the surface tension and the film thickness are needed [2]. In case of thin polymer films, spinodally dewetting can be monitored in situ by AFM, which reveals the power spectrum of the film thickness variation over time. For the theoretical description, however, experimental viscosity and thermal noise have to be taken into account [3].

Our study now concentrates on the impact of the boundary condition at the liquid/solid interface on the power spectrum. Recently, Rauscher et al. [4] predicted a shift in the power spectrum in case of a slip-boundary condition. To test that prediction, dewetting experiments have been performed on surfaces which provoke strong slippage. First results show the influence of the boundary condition.

[1]:R. Seemann, R. Herminghaus, K. Jacobs, PRL, 86 (2001)
[2]:J. Becker et al., Nat. Mat., 2 (2003)
[3]:R. Fetzer et al., PRL, 99 (2007)
[4]:R. Rauscher et al., Langmuir, 24 (2008)

CPP 26.10   Wed 16:30   H39

Instability of confined water films between elastic surfaces — •Sissi de Beer, Dieter 't Mannetje, Sietske Zantema, and Frieder Mugele — University of Twente, Enschede, the Netherlands

We investigated the dynamics of nanometer thin water films at controlled ambient humidity adsorbed onto two atomically smooth mica sheets upon rapidly approach of the two surfaces into contact. Using a Surface Forces Apparatus (SFA) in the imaging mode, we found that the water films break up into a distribution of small drops with

a typical thickness of few nanometers and a characteristic lateral size and spacing of several micrometers. While the characteristic length of the drops is found to be independent of the ambient humidity, the characteristic time of the break-up decreases from ~1s to 0.01s with increasing humidity. The existence, of characteristic length and time scales shows that this break-up is controlled by an instability rather than a * for SFA experiments conventional * nucleation and growth mechanism. These findings cannot be explained by a dispersion-driven instability mechanism like e.g. spinodal dewetting. In contrast, a model incorporating the elastic energies for the deformation of both the mica sheets and the underlying glue layer (i.e. wrinkling) slowed down by the hydrodynamic resistance correctly reproduces the scaling of the characteristic length and time with humidity.

CPP 26.11   Wed 16:45   H39

Advancing and receding contact ancles on structured topographic surfaces — Ciro Semprebon, •Stephan Herminghaus, and Martin Brinkmann — Max Planck Institute for Dynamics and Self-Organization, Goettingen, Germany

The static advancing and receding contact angles of a liquid in contact to topographically structured substrate is studied numerically using a minimization of the interfacial energy. As surface topographies we consider a square array of posts with circular or square cross section which is fully characterized by the diameter, spacing, and height of the posts. The material contact angle of the wetting liquid on the homogeneous surface, θ_o, is varied between 45° and 135°. Depending on the combination of these three parameters, we find transitions between several possible configurations of the liquid-vapor interface as the apparent contact angle θ_a is increased. During this increase the liquid font passes through a sequence of configurations. The instability of the last configuration triggers the detachment from the row of posts and leads to a jump of the contact line to the next row of posts. The resulting advancing contact angle shows a number of unexpected behaviours depending on the material contact angle and the particular shape of the pillars. For the same systems we determine the corresponding receding angles and the corresponding contact angle hysteresis.

CPP 26.12   Wed 17:00   H39

Dynamics of trapped Brownian particles in shear flows: shear-induced cross-correlations — •Jochen Bammert and Walter Zimmermann — Theoretische Physik I, Universität Bayreuth, 95440 Bayreuth

Shear flow causes cross-correlations between fluctuations along orthogonal directions of Brownian particle motion. This effect has been measured recently in an experiment [1], where one or two polystyrene beads were trapped by optical tweezers in a specially designed shear flow cell (see also the contribution of A. Ziehl et al.). The results coincide with the predictions of a Langevin model as explained by this contribution and in [2], where the dynamics of a Brownian particle trapped by a harmonic potential and simultaneously exposed either to a linear shear flow or to a plane Poiseuille flow is described. In the shear plane of both flows the probability distribution of the particle becomes anisotropic and takes either an elliptical or a parachute shape or a superposition of both depending on the mean particle position in the shear plane. We have also determined the correlations between two trapped and hydrodynamically interacting particles in a linear shear flow. Again, correlations between orthogonal directions in the shear plane are found, even between different particles.

[1] A. Ziehl, J. Bammert, L. Holzer, C. Wagner, W. Zimmermann, arXiv:0909.0401, to appear in Phys. Rev. Lett.

[2] L. Holzer, J. Bammert, R. Rzehak, W. Zimmermann, arXiv:0911.3264, submitted to Phys. Rev. E

CPP 26.13   Wed 17:15   H39

Dynamics of lipid bilayer formation using water in oil emulsions in microfluidic channels — •Shashi Thutupalli[1], Ralf Seemann[1,2], and Stephan Herminghaus[1] — [1]Max Planck Institute for Dynamics and Self Organization, Göttingen, Germany — [2]Experimental Physics, Saarland University, Saarbrücken, Germany

Using lipid stabilized water-in-oil emulsions, we investigate the process of formation of lipid bilayers between emulsion droplets. For sufficiently high lipid concentrations in the oil phase, the oil-water interface is fully covered by a monolayer of lipid molecules. When two such monolayers are brought together, the oil separating them drains away, thus forming a lipid bilayer. We use a combination of high speed microscopy and electrical measurements to follow the dynamics of oil drainage and the subsequent bilayer formation. We find two typical

modes of membrane formation depending on the surfactant concentration: (i) for lower concentrations, a zipper like mechanism where an oil lens rapidly leaves the region between the two lipid monolayers and (ii) at higher concentration the membrane forms as the droplets tend to separate from each other, similar to a decompression effect. In the first case, we find that the oil drainage reaches a typical velocity of 2mm/s, also corroborated by the rise time of the electrical capacitance due to the bilayer. In the latter case, we report on the critical length and time scales of the membrane formation and also the effect of surfactant concentration on the stability of the bilayer formation by decompression.