CPP 12: Focus: Soft Particles in Flows II (joint focus session CPP/DY)

Organized by S. Gekle, G. Gompper, C. Wagner

Time: Monday 15:00–18:00 Location: ZEU 160

Invited Talk CPP 12.1 Mon 15:00 ZEU 160

Particle alignment in microchannels and microjets — •Stephan Foerster[1], Mathias Schlenk[1], Susanne Seibt[1], Martin Trebbin[3], Josef Breu[1], and Stephan Roth[2] — [1]University of Bayreuth, Bayreuth, Germany — [2]DESY, Hamburg, Germany — [3]University of Hamburg, Hamburg, Germany

The flow orientation of particles in microflows is of high relevance in many areas ranging from synthetic fiber production to streams of cells and proteins in blood capillaries. With current advances in device miniaturization in microfluidics, X-ray optics and high-resolution optical microscopy, it has become possible to study the flow orientation of anisometric colloids in-situ with unprecedented precision.

We investigated the flow orientation of Au-nanorods, wormlike polymer micelles and hectorite nanosheets in curved and tapered microchannels. We surprisingly find that all anisometric particles align perpendicular to the flow orientation in the widening section of tapered microchannels. This is caused by strong extensional forces that reorient the particles. This phenomenon is even observed during the formation of microdroplets from microjets, resulting in biaxial orientations of particles in the free droplets. These findings have important consequences for the production of high performance fibers and the agglomeration of particles in blood capillary stenoses.

CPP 12.2 Mon 15:30 ZEU 160

Intricate dynamics and morphology of red blood cells under physiological flow conditions — Johannes Mauer[1], Luca Lanotte[2], Simon Mendez[3], Viviana Claveria[2], Franck Nicoud[3], Manouk Abkarian[2], Gerhard Gompper[1], and •Dmitry A. Fedosov[1] — [1]Institute of Complex Systems, Forschungszentrum Juelich, 52425 Juelich, Germany — [2]Centre de Biochimie Structurale, CNRS UMR 5048, University of Montpellier, 34090 Montpellier, France — [3]Institut Montpellierain Alexander Grothendieck, UMR5149, University of Montpellier, 34095 Montpellier, France

Red blood cells (RBCs) constitute the major cellular part of blood. They have a biconcave shape with a membrane consisting of a lipid bilayer with an attached cytoskeleton formed by a network of the spectrin proteins. The RBC membrane encloses a viscous cytosol (hemoglobin solution), so that RBCs possess no bulk cytoskeleton and organelles. Despite this simple structure, RBCs exhibit fascinating behavior in flow showing complex deformation and dynamics. Current simplified understanding of RBC behavior in shear flow is that they tumble or roll at low shear rates and tank-tread at high shear rates. This view has been mainly formed by a number of experiments performed on RBCs dispersed in a viscous solution, which is several times more viscous than blood plasma. However, under physiological conditions with increasing shear rates, RBCs successively tumble, roll, deform into rolling stomatocytes, and finally adopt highly-deformed poly-lobed shapes. This behavior is governed by RBC elastic and viscous properties and it is important to consider it under relevant physiological conditions.

CPP 12.3 Mon 15:45 ZEU 160

Red blood cells in high shear and strain rates: how numerical simulation can contribute — •Simon Mendez, Etienne Gibaud, and Franck Nicoud — IMAG, UMR CNRS 5149, University of Montpellier. 34095 Montpellier. France

Red blood cells (RBCs) constitute 99 percent of the formed elements present in blood. The dynamics of RBCs controls the complexity and the behavior of blood itself, as red blood cells constitute approximately 40 percent of the whole blood volume. The individual dynamics of a RBC is still a topic of research. This is particularly the case at high shear and strain rates, for which experimental data are scarce, due to the difficulty of visualizing the RBC dynamics in high-speed flows.

Although computing the RBCs dynamics in flows with high shear/strain rates is challenging, numerical simulation does not suffer from the same limitations as in vitro experiments of high-speed flows. This talk will illustrate how computations can be used in this context to gain new insight in the dynamics of red blood cells.

Two examples will be used: the behavior of RBCs at high shear rate in a low-viscosity fluid and the dynamics of RBCs during their counting and sizing in industrial blood analyzers, where strain dominates.

CPP 12.4 Mon 16:00 ZEU 160

Structure and dynamics of colloidal short range repulsive interacting suspensions with weak attractive interactions. — Clara Weis and •Norbert Willenbacher — Karlsruhe Institute for Technology, Karlsruhe, Germany

The effect of weak attractive interactions on structure and dynamics of aqueous polymer dispersions is investigated using Multiple Particle Tracking (MPT) and classical rotational rheology. This allowed us to correlate microstructure, structural heterogeneities and local particle mobility in fluid, fluid/crystalline, glassy and gel like samples with the corresponding macroscopic flow behavior. For volume fractions $\phi < 0.5$ good agreement between micro- and macro-viscosity was found. As weak attractive interactions were induced by adding non-adsorbing polymer, an enormous broadening of the fluid-crystalline co-existence regime was observed. MPT allowed for retrieving the phase composition, i.e. the fraction of the fluid and crystalline regions as well as the respective particle concentration, completely. In addition, the size of the crystals as well as their shear modulus could be determined. Further increasing attraction strength a gel state occurred and MPT disclosed a heterogeneous structure resembling a percolating network. At $\phi > \phi_{glass}$, the introduction of weak attractive interactions leads to a much broader fluid regime than predicted by MCT. At a given ϕ, stronger attractive interaction is required to form an attractive gel than for true hard sphere systems. MPT enables to study particle localization and structural heterogeneities on feasible, short time scales since a large number of dispersed particles are in the field of view.

CPP 12.5 Mon 16:15 ZEU 160

An iterative solution algorithm for actively and passively swimming elastic capsules — •Horst-Holger Boltz[1,2] and Jan Kierfeld[2] — [1]Institut für nichtlineare Dynamik, Fakultät Physik, Georg-August-Universität Göttingen, Göttingen, Deutschland — [2]Fakultät Physik, Technische Universität Dortmund, Dortmund, Deutschland

Soft elastic capsules which are subject a viscous fluid flow undergo shape deformation coupled to their motion. We introduce an iterative solution scheme which couples hydrodynamic boundary integral methods and elastic shape equations to find the stationary axisymmetric shape and the velocity of an elastic capsule moving in a viscous fluid at low Reynolds numbers. We use this approach to systematically study dynamical shape transitions of capsules with Hookean stretching and bending energies and spherical rest shape sedimenting under the influence of gravity or centrifugal forces [Phys. Rev. E **92**: 033003 (2015)]. Additionally, we discuss the application to actively swimming ("squirming") capsules.

15 min. break

CPP 12.6 Mon 16:45 ZEU 160

Shapes and interaction of microcapillary RBC flow — •Alexander Kihm[1], Achim Guckenberger[2], Stephan Gekle[2], and Christian Wagner[1] — [1]Saarland University, Saarbrücken, Germany — [2]Bayreuth University, Bayreuth, Germany

We try to establish the phase diagram of Red Blood Cells (RBC's) flowing through a capillary, i.e. characterize their shape and position as a function of capillary dimensions and imposed flow rate (pressure drop).

Therefore, we perform microfluidic experiments, either with a simple inverted brightfield microscope or with a recently developed 3-D confocal spinning disk technique. In most cases we find a migration of cells towards the center, but above a critical flow rate off-centered positions are observed as well. In addition, we classify the shapes of flowing cells, and as categories we distinguish between slippers, croissants and other (ambiguous) shapes. The experimental data is compared to predictions obtained from numerical simulations using a boundary-integral method.

CPP 12.7 Mon 17:00 ZEU 160

Red blood cells dynamics in biomimetic submicron splenic slits — •Annie Viallat[1], Emmanuele Helfer[1], Anne Charrier[1],

Priya Gambhire[1], Scott Atwell[1], Catherine Badens[2], and Cecile Iss[1] — [1]Aix Marseille Univ, CNRS CINAM, Marseille, France — [2]Aix Marseille Univ., INSERM, GMGF, Marseille, France

In drug delivery, cancer cell dissemination and red blood cells (RBCs) splenic filtration, nanoparticles and cells have to deform and pass through the submicron and high aspect ratio gaps between the endothelial cells lining blood vessels. The dynamics of passage of particles/cells remain poorly understood because costly technologies are required to reproduce gaps of physiological dimensions in devices suitable for in-vitro optical-microscopy observations. Here, novel microfluidic PDMS devices containing high aspect ratio slits with submicron width were molded on silicon masters by using a simple, inexpensive, and highly flexible combination of standard UV lithography and anisotropic wet etching. These devices revealed novel modes of deformations of healthy and sick RBCs squeezing through slits replicating splenic slits (0.8x2x5 microns) under physiological interstitial pressures. At the slit exit the cytoskeleton of spherocytic RBCs was spectacularly detached from the lipid membrane whereas RBC shapes from healthy donors and patients with sickle cell disease exhibited peculiar tips at their front. These tips disappeared much slower in patients cells, allowing to estimate a threefold increase in RBC cytoplasmic viscosity in sickle cell disease. Measurements of both time and rate of RBC sequestration in the slits allowed quantifying the massive spherocytic RBCs trapping.

CPP 12.8 Mon 17:15 ZEU 160

Non-inertial lift and its application to label-free microfluidic cell separation and sorting — T M Geislinger[1,2], M Stamp[1], B Eggart[1], S Braunmüller[1], L Schmid[1], S Chan[2], M Koll[2], M Wahlgren[2], A Wixforth[1], and •T Franke[1,3] — [1]Experimental Physics I, University of Augsburg, 86159 Augsburg, Germany — [2]Department of Microbiology, Tumor and Cell Biology, Karolinska Institutet, Box 280, S-171 77 Stockholm, Sweden — [3]Chair of Biomedical Engineering, University of Glasgow, Oakfield Avenue, G12 8LT, Glasgow, Scotland

Reliable cell separation and sorting are important tasks in everyday's laboratory work and of increasing importance in various medical diagnoses. Widely used methods like fluorescence or magnetically activated cell sorting (FACS, MACS), however, require labelling of samples with adequate markers and/or the generation of external fields. Apart from the dimensions and the costs of such devices, any unwanted alterations of the cells by the markers potentially interfere with subsequent processes such as genetic analyses. Here, we present a simple and cheap microfluidic approach for continuous, passive and label-free cell sorting that relies on the exploitation of a hydrodynamic effect for separation: the non-inertial lift effect. The non-inertial lift effect is a repulsive cell-wall interaction of purely viscous origin that acts on non-spherical and deformable objects in laminar flow fields. Generally, the lateral drift becomes stronger for larger and more deformable objects. We examine this effect for separation of different cells including circulating tumor cells and malaria infected red blood cells.

CPP 12.9 Mon 17:30 ZEU 160

Jammed capsules as a model system for soft glassy matter — •Othmane Aouane[1], Andrea Scagliarini[1], and Jens Harting[1,2] — [1]Forschungszentrum Jülich, Helmholtz Institute Erlangen-Nürnberg, Nürnberg, Germany — [2]Department of Applied Physics, Eindhoven University of Technology, Eindhoven, The Netherlands

Soft-glassy materials describe materials exhibiting a solid-like behavior at rest and local yielding when subject to a high enough stress. While systems like foams, emulsions[1], colloidal and polymer gels have been widely studied in the last decades; still a little is known about the flow behavior of deformable microgels. We investigate numerically the rheology of microgels formed by dense suspensions of capsules under mechanical stress in an athermal system. In a first step, the packing of capsules is done by increasing the size of the scaled deformable particles until reaching the desired size meanwhile the dynamical evolution of the system follows a molecular dynamics-like approach. After the initialization stage and the formation of the microgel structure, we use the lattice Boltzmann method to resolve the fluid motion and the immersed boundary method to couple between the finite element capsules and the fluid [2]. We investigate the existence or not of local yield points by varying the concentration of capsules from 60 to 90%. The effect of elasticity and mechanical forcing are also considered in our study.

[1] Benzi, R., *et al.* Europhysics Letters, 104.4 (2013): 48006

[2] Krüger, T., *et al.* Journal of Fluid Mechanics, 751 (2014): 725-745

CPP 12.10 Mon 17:45 ZEU 160

Dynamics of microcapsules in elongational and shear flows — •Clement de Loubens[1], Kaili Xie[2], and Marc Leonetti[3] — [1]Laboratoire Rheologie et Procedes, Grenoble, France — [2]M2P2, Marseille, France — [3]IRPHE, Marseille, France

A capsule is a drop bounded by a thin solid membrane providing specific mechanical properties. The interfacial rheological properties of these soft microparticles are deduced from their dynamics of deformation in elongational and shear flows.

In elongational flow, the surface shear modulus of the membrane is measured and related to the kind of biopolymer used and to the main parameters of the process of fabrication. In the regime of large deformations, the microcapsules can present a non-linear elastic response or plastic deformations. Non-linear elastic constitutive law is deduced by comparison of the evolution of the shape of the microcapsule in the two main planes of deformation of the capsule with numerical simulations.

In shear flow, the rotation of the membrane, i.e. the tank-treading, is visualised and quantified by decorating the membrane of microcapsules with particles. The tracking of the distance between two close microparticles showed membrane contraction at the tips and stretching on the sides. This dynamics of deformation induce viscous dissipation inside the membrane. The order of magnitude of membrane viscosity is determined by comparison with numerical simulations.

We will conclude the talk by some examples of breakdown of microcapsules in elongational flow.