DY 25: Posters - Soft Particles, Microswimmers, Microfluidics

Time: Tuesday 18:15–21:00 Location: P3

DY 25.1 Tue 18:15 P3

2D simulation of Red Blood Cells in Capillaries. — •Zakaria Boujja[1], Chaouqi Misbah[2], and Christian Wagner[1] — [1]Saarland University, Experimental Physics, Saarbrücken, Germany — [2]Grenoble Alpes University, LIPHY, Grenoble, France

Blood at physiologic conditions is a dense suspension of cells, dominated in terms of its dynamics by red blood cells, they make up over approximately 40% of the blood volume, they are the blood component principally responsible for its rheology. RBCs are made of a two dimensional fluid bilayer of phospholipids, having underneath a network of proteins conferring to them shear elasticity. Simplified systems, like vesicles (made of a pure bilayer of phospholipid) and capsules (made of an extensible polymer shell) are used as models for RBCs, both systems reproduce several features known for RBCs under flow, the general problem is to understand the movement of cells under different flows and geometries.
The model used in our 2D simulation is the Giant Unilamellar Vesicle (GUV) model, the membrane curvature force will be calculated with the Helfrich elasticity theory. The numerical resolution will give us the vesicle shape as function of two carasteristic numbers the Capillary number (C_k) and the Confinement (C_n). A large number of studies were devoted to finding the equilibrium shapes of a RBCs in Poiseuille flow. We focused our study in a particularly interesting shape which has a motion like flagella, and called "Snaking Shape".

DY 25.2 Tue 18:15 P3

Tracking of PEG nanoparticles flowing around red blood cells inside microchannels — •François Yaya, Thomas John, and Christian Wagner — Experimental Physics, University of Saarland

During their life span in our body, red blood cells (RBC) travel through capilaries within a few microns in diameter. In this study, we reproduce these conditions using microfluidic chips with microchannels. Microchannels of 10 μm are built in polydimethylsiloxane (PDMS). Blood was drawn from a single donor from the fingertip and RBC were washed by standard protocol in a solution of Phosphate Buffered Saline (PBS) in which they were resuspended. Nanoparticles of polyethylene glycol (PEG) with a diameter of 250 nm were added at different concentrations. We use a high speed camera to record the particles flow at different pressure drops, flow velocities respectively, to monitor the particles displacements. We track these particles by image processing and we analyse the particles' trajectory. We show the behaviour of PEG nanoparticles around the RBC in different reference frames and different conditions (e.g. concentration, pressure). We give an overview on the parameters having an influence on the flow, vorticity and the nanoparticles distribution around the RBC.

DY 25.3 Tue 18:15 P3

Reduced-order hybrid multiscale method combining the regularized data from MD simulations with the macroscopic flow solver — Nehzat Emamy[1], Leonid Yelash[1], Mária Lukácová[1], •Stefanie Stalter[2], and Peter Virnau[2] — [1]Institut für Physik, JGU Mainz, Staudingerweg 7, 55128 Mainz — [2]Institut für Mathematik, JGU Mainz, Staudingerweg 9, 55128 Mainz

We introduce a reduced-order method to simulate the dynamics of complex materials (e.g. polymer/colloid systems) combining the continuum and atomistic descriptions. We follow the framework of heterogenuous multi-scale method (HMM), separating the scales to macro- and micro-levels. On the macro-level, the governing equations of the incompressible flow are the continuity and momentum equations, which are solved using a high-order accurate discontinuous Galerkin Finite Element Method (dG) and implemented in the BoSSS code. The missing information on the macro-level to solve the momentum equation is the stress tensor, which is computed from molecular Dynamics (MD) simulations on the micro-level. The data obtained from the MD simulations underlie relatively large stochastic errors, which can be controlled by means of the least square approximation. In order to reduce a large number of MD runs for the coupled simulations, we split the computations into an offline phase of expensive training and an online phase of fast multiple queries. In the training phase, we use the Greedy sampling algorithm as a model reduction technique to replace the nonlinear functionality of the stress tensor on the strain by a smooth low-dimensional reliable approximation.

DY 25.4 Tue 18:15 P3

blood crystal: shear-induced ordering in confined suspensions of red blood cells — •zaiyi shen[1], thomas m fischer[2], alexander farutin[1], jens harting[3,4], and chaouqi misbah[1] — [1]Universite Grenoble Alpes/CNRS, Laboratoire Interdisciplinaire de Physique/UMR5588, Grenoble F-38041, France — [2]Laboratory for Red Cell Rheology, 52134 Herzogenrath, Germany — [3]Helmholtz Institute Erlangen-Nürnberg for Renewable Energy (IEK-11), Forschungszentrum Jülich, Fürther Strasse 248, 90429 Nürnberg — [4]Department of Applied Physics, Eindhoven University of Technology, P.O. Box 513, 5600MB Eindhoven, The Netherlands

We report on numerical simulations and experiments which reveal that red blood cells (RBCs) submitted to a shear flow between two parallel walls spontaneously show order, in the Stokes regime, in the form of a 2D crystalline pattern of purely hydrodynamic origin. Order appears as a subtle interplay between (i) the wall-induced migration requiring RBCs deformability, and driving cells away from walls towards the mid-plane and (ii) the intercellular hydrodynamic interaction which has both attractive and repulsive contributions depending on RBC interdistance. Various crystal-like orders arise depending on RBC concentration and confinement. The equilibrium distance between RBCs is shown to be a linear and universal function of confinement. Hardened RBCs in experiments, and rigid particles in simulations adopt a disordered pattern, highlighting the intimate link between particle deformability and the emergence of order.

DY 25.5 Tue 18:15 P3

blood crystal: shear-induced ordering in confined suspensions of red blood cells — •zaiyi shen[1], thomas m fischer[2], alexander farutin[1], jens harting[3,4], and chaouqi misbah[1] — [1]Universite Grenoble Alpes/CNRS, Laboratoire Interdisciplinaire de Physique/UMR5588, Grenoble F-38041, France — [2]Laboratory for Red Cell Rheology, 52134 Herzogenrath, Germany — [3]Helmholtz Institute Erlangen-Nürnberg for Renewable Energy (IEK-11), Forschungszentrum Jülich, Fürther Strasse 248, 90429 Nürnberg, Germany — [4]Department of Applied Physics, Eindhoven University of Technology, P.O. Box 513, 5600MB Eindhoven, The Netherlands

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DY 25.6 Tue 18:15 P3

Transport of ring polymers in microfluidic channels: A comparison to their linear counterparts — •Lisa Weiss[1], Arash Nikoubashman[2], and Christos N. Likos[1] — [1]Faculty of Physics, University of Vienna, Boltzmanngasse 5, A-1090 Vienna, Austria — [2]Institute of Physics, Johannes Gutenberg University, Mainz, Staudingerweg 7, 55128 Mainz, Germany

Ring polymers are an important class of biological and synthetic macromolecules. Due to the lack of free ends, they are expected to show distinct behaviour compared to their linear counterparts, as for example with respect to migration mechanisms, rheology or disentanglement. This simulation study aims at addressing the question, whether those two are transported distinctly in microfluidic devices. Since many biological ring polymers are in aqueous solution hydrodynamics is taken into account by a simulation method called Multi-Particle Collision Dynamics while the polymer itself is treated via Molecular Dynamics. We establish the existene of marked differences in the density profiles between linear chains and their cyclic counterpart in a Hagen-Poiseuille flow profile. In addition, we investigate the effects of polymer rigidity on their transport properties, which lead to a pronounced difference regarding depletion close to walls. On this basis we suggest possibilities to utilise these features as a means to separate the two architectures in microfluidic devices.

DY 25.7 Tue 18:15 P3

Cross-stream transport of asymmetric particles driven by oscillating shear — •M. Laumann[1], P. Bauknecht[2], A. Förtsch[1], S. Gekle[2], D. Kienle[1], and W. Zimmermann[1] — [1]Theoretische Physik I, Universität Bayreuth, 95440 Bayreuth, Germany — [2]Biofluid Simulation, Physikalisches Institut, Universität Bayreuth, 95440 Bayreuth, Germany

We study the dynamics of asymmetric, deformable particles in oscillatory, linear shear flow. By simulating the motion of a dumbbell, a ring polymer, and a capsule we show that cross-stream migration occurs for asymmetric elastic particles even in linear shear flow if the shear rate varies in time. The migration is generic as it does not depend on the particle dimension. Importantly, the migration velocity and migration direction are robust to variations of the initial particle orientation, making our proposed scheme suitable for sorting particles with asymmetric material properties.

DY 25.8 Tue 18:15 P3

Active Brownian particles moving in a random Lorentz gas — •Maria Zeitz and Holger Stark — Institut für Theoretische Physik, Technische Universität Berlin, 10623 Berlin, Germany

Biological microswimmers often inhabit a porous or crowded environment such as soil. In order to understand how such a complex environment influences their spreading, we numerically study noninteracting active Brownian particles (ABPs) in a two-dimensional random Lorentz gas. Close to the percolation transition in the Lorentz gas, they perform the same subdiffusive motion as ballistic and diffusive particles. However, due to their persistent motion they reach their long-time dynamics faster than passive particles and also show superdiffusive motion at intermediate times. While above the critical obstacle density η_c the ABPs are trapped, their long-time diffusion below η_c is strongly influenced by the propulsion speed v_0. With increasing v_0, ABPs are stuck at the obstacles for longer times. Thus, for large propulsion speed, the long-time diffusion constant decreases more strongly in a denser obstacle environment than for passive particles.

Moreover, we present first results how a constant gradient in obstacle density influences the dynamics of the system. We expect an induced drift along the gradient, similar to the *durotaxis* of motile cells which move along the stiffness gradient of the substrate.

DY 25.9 Tue 18:15 P3

Active Swimmers and convection — •Jérémy Vachier, Stephan Herminghaus, and Marco G. Mazza — Max-Planck-Institute for Dynamics and Self-Organization, Göttingen, Germany

Active matter systems are driven out of thermodynamic equilibrium because the particles are able to convert energy into motion. Suspensions of self-propelled microscopic particles, such as swimming bacteria (*E. Coli*) or swimming algae (*Chlamydomonas*), exhibit collective motion. Describing the motion of these swimmers has an august place in the history of fluid mechanics. The small scale of our system implies that the hydrodynamics governing the motion are at low Reynolds numbers. We use the Stokes equation to describe the fluid, and we describe the swimmers as force dipoles, the swimmers are represented as spheroids, under Weeks-Chandler-Anderson (WCA) potential. We investigate the collective behaviour under mass convection due to a density mismatch. In order to simulate our system numerically, we use a hybrid method composed to Molecular Dynamics and Stochastic Rotation Dynamics. In this approach the fluid and the particles are represented with a particle based, coarse grained description. We study the dimensionless numbers, such as Péclet, Galilei and Sherwood numbers, characterizing the dynamics.

DY 25.10 Tue 18:15 P3

Controlled motion of L-shaped microswimmers — •Tobias Bäuerle[1], Julia Riede[1], Daniel Häufle[2], Jakob Steiner[1], Keyan Ghazi-Zahedi[3], Syn Schmitt[1], Christian Holm[1], and Clemens Bechinger[1,4] — [1]Universität Stuttgart, Deutschland — [2]Eberhard Karls Universität, Tübingen, Deutschland — [3]Max-Planck-Insitut für Mathematik in den Naturwissenschaften, Leipzig, Deutschland — [4]Max-Planck-Institut für Intelligente Systeme, Stuttgart, Deutschland

Microswimmers can be steered by controlling the propulsion velocity depending on their orientation and position with respect to a target [1]. For spherical particles the orientation and, hence, the direction of motion changes only due to rotational diffusion. However, L-shaped particles, subjected to a gravitational force field, reorient depending on their orientation and swimming velocity [2]. In this sense, the shape of the particle, i.e. its morphology, significantly influences the swimming behavior. We investigate, numerically and experimentally, how this behavior can be exploited for steering these particles to reach a target position or follow a desired path. The resulting strategies are quantitatively compared by different figures of merit, such as energy expenditure, time to reach the target, deviation from an ideal path, or morphological computation [3].

1 D. Haeufle et al., Physical Review E, 94, 012617 (2016)
2 Ten Hagen et al., Nature Communications, 5, 4829 (2014)
3 K. Ghazi-Zahedi et al., Frontiers in Robotics and AI, 3, 1 (2016)

DY 25.11 Tue 18:15 P3

Random Shaped Magnetic Micropropellers — •Felix Bachmann[1], Peter Vach[1], Agnese Codutti[1], Stefan Klumpp[2], Peter Fratzl[1], and Damien Faivre[1] — [1]Department of Biomaterials, Max Planck Institute of Colloids and Interfaces, Science Park Golm — [2]Theoretical Biophysics, Georg-August-University Göttingen

Swimming at low Reynolds number is a difficult task that diverges from our day by day experience. At the micrometer scale viscous forces play a dominant role and inertia can be neglected. Nature provides us with fascinating solutions for motion at low Reynolds numbers, e.g. swimming *E.coli* bacteria: moving their flagella in a cork screw manner, they overcome the hindrance of symmetry. Trying to mimic this mechanism, many achievements in designing and producing micro swimmers have been made over the last couple of years. Now the task is to optimize the motion process in this regime: moving fast and being able to control the moving pattern precisely.

In a step towards these goals, experiments with random shaped micropropellers allow exploring new avenues [1]. The characteristics and understanding of those random shaped micropropellers is subject of this work. Of particular interest are the very fast propellers and their morphology visualized through optical microscopy and tomography. Together with propelling characteristics like velocity-frequency dependence and direction pattern, this will help to create design guidelines for future task specific micropropellers.

[1] Vach PJ, Fratzl P, Klumpp S, Faivre D., Fast Magnetic Micropropellers with Random Shapes. Nano Letters. 2015;15(10):7064-7070.

DY 25.12 Tue 18:15 P3

Collective Dynamics of Squirmers in Poiseuille Flow — •Shahajhan Sorathiya and Holger Stark — Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin,Germany.

For their immense importance and impact on human health and ecology, we aim at understanding the collective behaviour of organisms like sperms, bacteria, and algae using the squirmer model. We present numerical simulations of a large number of squirmers confined in a channel and subjected to Poiseuille flow using multi-particle collision dynamics (MPCD). Building upon our understanding how a single microswimmer behaves near the wall and in Poiseuille flow [1,2], we report on results of a parametric study varying squirmer concentration, swimming speed, and strength of background flow.

We first verified the single-squirmer motion of tumbling and swinging trajectories as derived in Ref. [1]. Increasing density we then observe different types of clustering patterns formed by pushers and pullers in Poiseuille flow. We also report on the lateral density profile, which shows a depletion in the channel center according to experiments [3]. Finally, we investigate the average squirmer orientation close to walls, which heavily depends on concentration and background flow.

[1] A. Zöttl and H. Stark, Phys. Rev. Lett **108**, 218104 (2012).
[2] K. Schaar, A. Zöttl, and H. Stark, Phys. Rev. Lett **115**, 038101 (2015).
[3] R. Rusconi, J. S. Guasto, and R. Stocker, Nature Phys. **10**, 212 (2014).

DY 25.13 Tue 18:15 P3

Self-Chemotactic Properties of Active Droplets — •Mahmoud Hosseinzadeh[1], Leonard Li[1], Martin Brinkmann[1], Ignacio Pagonabarraga[2], Ralf Seemann[1], and Jean-Baptiste Fleury[1] — [1]Saarland University, 66123 Saarbrücken, Germany — [2]University of Barcelona, 08028 Barcelona, Spain

We explore the self-chemotactic properties of a new type of water/solvent emulsion droplets, which self-propel in a continuous oil/surfactant solution. Depending on solvent concentration the droplets evolve in up to three stages finally forming Janus droplets. We concentrate on the first stage, where the propulsion is generated by a Marangoni flow originating from the solvent solubilization into the oily phase. During active motion, the droplets additionally absorb a large amount of surfactant, which is preferentially soluble in the solvent phase. An increasing ethanol concentration in the continuous phase and a decreasing surfactant concentrations leads to repulsive chemotactic interactions. By adjusting the initial ethanol and surfactant concentration in the continuous phase we vary the chemotactic interactions of the droplets. In particular, we explore the consequences of the self-chemotactic properties in terms of flow properties (squirmer modes).

DY 25.14 Tue 18:15 P3

Active microrheology of dense microswimmer suspensions — •Alexander Liluashvili[1] and Thomas Voigtmann[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Köln, Germany — [2]Heinrich-Heine-Universität, Düsseldorf, Germany

The dynamics of self-propelled particles like microswimmers in dense environments are studied using the mode coupling theory of the glass transition. The theory is developed to investigate the glassy dynamics of active suspensions out-of-equilibrium, violating the fluctuation-dissipation-theorem relations.

As starting point of mathematical calculations the Mori-Zwanzig equations with orientational degrees of freedom in two dimensions are used. The final equations for the density two-point function in the time domain are solved numerically for the full model including the orientational degrees of freedom, as well as the spatial fluctuations.

DY 25.15 Tue 18:15 P3

Particle inertia induced passive swimming in oscillatory flows — •M. Laumann[1], I. Jo[2], Y. Huang[3], E. Kanso[3], D. Kienle[1], and W. Zimmermann[1] — [1]Theoretische Physik I, University of Bayreuth, 95440 Bayreuth, Germany — [2]Electrical Eng., University of Southern California, Los Angeles, California 90089, USA — [3]Aerospace and Mechanical Eng., University of Southern California, Los Angeles, California 90089, USA

Microswimmers are often actuted via active shape deformations. Here we describe a mechanism of passive swimming of soft particles in oscillatory homogenous flows, that is based on an interplay between their inertia and elasticity. This actuation strategy is demonstrated by analyzing a simple Λ shaped model analogous to Purcell's scallop, but passively deformed in homogeneous oscillatory flows [1]. In addition this actuation strategy is investigated for asymmetric bead-spring models in oscillatory flow by using a established hydrodynamic description of accelerated particles in flows [2]. We determine optimal parameters which maximize passive swimming. We also examine the stability of swimming motions and observe a transition from stable to unstable swimming. These results suggest that one can tune the background flow properties to control the swimmer motion, and thus, they may have profound implications on design and employment of artificial swimmers in oscillatory flows.

[1] I. Jo, Y. Huang, W. Zimmermann, E. Kanso, Phys. Rev. E **94**, 063116 (2016); [2] M.R. Maxey, J.J. Riley, Phys. Fluids **26**, 883 (1983).

DY 25.16 Tue 18:15 P3

Hydrodynamic ratchet — •František Slanina — Institute of Physics ASCR, Na Slovance 2, CZ-18221 Prague, Czech Republic

We investigate analytically a microfluidic device consisting of a tube with a nonuniform but spatially periodic diameter, where a fluid driven back and forth by a pump carries colloidal particles. Although the net flow of the fluid is zero, the particles move preferentially in one direction due to the ratchet mechanism, which occurs due to the simultaneous effect of inertial hydrodynamics and Brownian motion. We show that the average current is strongly sensitive to particle size, thus facilitating colloidal particle sorting.