Interplay of Substrate Adaptivity and Wetting Dynamics from Soft Matter to Biology (SYSM)

jointly organised by
the Chemical and Polymer Physics Division (CPP),
the Biological Physics Division (BP), and
the Dynamics and Statistical Physics Devision (DY)

Uwe Thiele
Institut für Theoretische Physik
Westfälische Wilhelms-Universität Münster
u.thiele@uni-muenster.de

Karin John
Laboratoire Interdisciplinaire de Physique
Université Grenoble Alpes, CNRS
karin.john@univ-grenoble-alpes.fr

Stefan Karpitschka
AG Grenzflächen komplexer Flüssigkeiten
Max-Planck-Institut für Dynamik &
Selbstorganisation
Göttingen
stefan.karpitschka@ds.mpg.de

Ralf Seemann
AG Geometrie fluider Grenzflächen,
Experimentalphysik
Universität des Saarlandes
Saarbrücken
ralf.seemann@ds.mpg.de

The basic understanding and practical application of the coupled dynamics of a (de)wetting liquid and adaptive soft substrates is attracting increasing interest in fields spanning chemical and biological physics, material science, and hydrodynamics. Examples of substrates include flexible elastomers or hydrogels that form dissipation-rich wetting ridges, polymer brushes that adapt their wettability and mechanical properties by absorbing liquid, or membraneless organelles in a biological cell whose creation and manipulation involves their adhesion to flexible membranes. Wetting interactions may also be manipulated by spatio-temporally structured external fields allowing, for example, wettability-switching triggered by electric fields or light irradiation. In all these systems, capillary and wetting energies interact with elastic properties, possible decomposition and mixing processes as well as absorption, adsorption and desorption processes resulting in feedback mechanism that influence the static and dynamic behaviour of the liquid-substrate system.

In general, one can say that intricate multiscale dynamics results from the coupling of different non-equilibrium processes, that is various mechanisms of energy dissipation may dominate on different time- and length scales, ultimately determining the dynamic behaviour. Furthermore, the interplay of several degrees of freedom offers new possibilities for a targeted control of dynamic wetting processes, but also poses new challenges for experimental investigation and theoretical description: Recent developments in length-scale-bridging experimental techniques allow for in situ (and in vivo) visualisation enabling quantitative analysis while methods from statistical physics to computational fluid and solid dynamics give unprecedented multiscale insight.

Overview of Invited Talks and Sessions

(Lecture hall H1)

Invited Talks

SYSM 1.1	Wed	15:00–15:30	H1	**Statics and Dynamics of Soft Wetting** — •Bruno Andreotti
SYSM 1.2	Wed	15:30–16:00	H1	**Droplets on elastic substrates and membranes - Numerical simulation of soft wetting** — •Sebastian Aland
SYSM 1.3	Wed	16:00–16:30	H1	**Wetting of Polymer Brushes in Air** — Lars Veldscholte, Guido Ritsema van Eck, Liz Mensink, Jacco Snoeijer, •Sissi de Beer
SYSM 1.4	Wed	16:45–17:15	H1	**Elastocapillary phenomena in cells** — •Roland L. Knorr
SYSM 1.5	Wed	17:15–17:45	H1	**Active contact line depinning by micro-organisms spreading on hydrogels** — Marc Hennes, Julien Tailleur, Gaëlle Charron, •Adrian Daerr

Sessions

SYSM 1.1–1.5	Wed	15:00–17:45	H1	**Interplay of Substrate Adaptivity and Wetting Dynamics from Soft Matter to Biology**

SYSM 1: Interplay of Substrate Adaptivity and Wetting Dynamics from Soft Matter to Biology

Time: Wednesday 15:00–17:45 Location: H1

Invited Talk SYSM 1.1 Wed 15:00 H1

Statics and Dynamics of Soft Wetting — •Bruno Andreotti — LPENS, 24 rue Lhomond, 75005 Paris

The laws of wetting are well-known for drops on rigid surfaces, but these change dramatically when the substrate is soft and deformable. The combination of wetting and the intricacies of soft polymeric interfaces has provided many rich examples of fluid-structure interaction, both in terms of phenomenology as well as from the fundamental perspective. In this colloquium, I will discuss experimental and theoretical progress on the statics and dynamics of soft wetting. In this context, I will critically revisit the foundations of capillarity, such as the nature of solid surface tension, the microscopic mechanics near the contact line, and the dissipative mechanisms that lead to unexpected spreading dynamics.

Invited Talk SYSM 1.2 Wed 15:30 H1

Droplets on elastic substrates and membranes - Numerical simulation of soft wetting — •Sebastian Aland — TU Freiberg, Germany

Wetting of flexible substrates plays a major role in a broad variety of phenomena. The interaction between droplets and their surrounding is at small length scales dominated by surface tension forces. These forces may lead to significant deformation of the surrounding structure if either very soft or very thin (e.g. a biological membrane). The interplay between wetting dynamics and structure mechanics leads to a range of fascinating phenomena from stick-slip motion to droplet-mediated remodeling of membranes.

In this talk, we present a computational model which is capable to shed some light on such elastocapillary phenomena. The model captures the interaction between two immiscible fluids and a soft structure or membrane. The discretization is based on a combination of a phase-field model with a moving finite-element grid. In numerical tests we demonstrate that this novel method is robust, flexible and accurate. We confirm analytical theory of droplet surfing on Kelvin-Voigt substrates and find an explanation for the experimentally observed stick-slip phenomenon. Finally, we present first simulations of droplet-mediated membrane remodeling.

Invited Talk SYSM 1.3 Wed 16:00 H1

Wetting of Polymer Brushes in Air — Lars Veldscholte, Guido Ritsema van Eck, Liz Mensink, Jacco Snoeijer, and •Sissi de Beer — Sustainable Polymer Chemistry Group, Department of Molecules & Materials, MESA+ Institute for Nanotechnology, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands

For the development of brush-based functional surface-coatings, it is critical to understand their properties, because they will determine their performance and user-experience. Polymer brush wetting is a key parameter in this. In this presentation we will show that brushes can display counter-intuitive wetting properties. We aim to unravel those by combining molecular dynamics simulations, contact angle goniometry and ellipsometry laboratory experiments.

15 min. break

Invited Talk SYSM 1.4 Wed 16:45 H1

Elastocapillary phenomena in cells — •Roland L. Knorr — Interfacial Cell Biology Lab, Integrative Research Institute for the Life Sciences, Humboldt-Universität zu Berlin, Germany — Graduate School and Faculty of Medicine, The University of Tokyo, Japan

Compartmentalisation is essential for eukaryotic cell function, allowing the division of processes into membrane-bound, specialised compartments, such as organelles. In recent years, intracellular phase separation has garnered much attention as a non-membrane means of organising components through the formation of droplet-like compartments, which are functionally implicated in both health and disease. Evidence suggests that droplet clearance involves autophagy, a highly-conserved cellular recycling system in which membrane sheets expand and bend to isolate and degrade portions of the cell interior.

Here, we investigate the mechanisms of droplet sequestration by membrane sheets in both living and synthetic cells. A minimal theoretical model shows that the surface tension of wetting droplets determines whether membrane sheets isolate the droplet phase in a whole or piecemeal fashion. We also find that wetting droplet induce local membrane spontaneous curvature changes, resulting in the reversal of the bending direction of membrane sheets and, thus, in cytosol sequestration [Nature 2020, 2021]. Further, we demonstrate that the morphogenesis of protein storage vacuoles in plants underlies similar physical principles [PNAS, JCB 2021]. I propose that droplet-mediated autophagy and vacuole remodelling represent a novel class of cellular processes driven by elastocapillary.

Invited Talk SYSM 1.5 Wed 17:15 H1

Active contact line depinning by micro-organisms spreading on hydrogels — Marc Hennes[1,2], Julien Tailleur[1,3], Gaëlle Charron[1], and •Adrian Daerr[1] — [1]Université Paris Cité, UMR 7057 Matière et Systèmes Complexes, Frankreich — [2]Universität zu Köln, Institut für Biologische Physik — [3]CNRS, Frankreich

Capillary forces, capable of pinning millimetre-sized water droplets on inclined surfaces, become enormous at the bacterial scale, exceeding typical propulsion forces of microbes by several orders of magnitude. It is thus fascinating to explore the tricks that micro-organisms have evolved to overcome contact line pinning and spread across substrates. I will discuss specifically the spreading of bacteria (*Bacillus subtilis*) across agar hydrogels.

Recently we discovered a mode of collective bacterial motility in humid environment through the depinning of bacterial droplets[1]. Bacteria harness a variety of phenomena, drawing both on the porosity and the softness of the substrate, that result in unpinning the contact line, hence inducing a collective slipping of the colony across surfaces at slopes that can be as small as 0.5°. The exploited microscopic mechanisms could play a role in other contexts, including biofilm formation and flagella dependent migration modes like swarming, and highlight the possibilties of tuning the wetting dynamics on soft porous substrates.

[1] M. Hennes, J. Tailleur, G. Charron, A. Daerr, Proc. Nat. Acad. Sc. USA **114**, 5958–5963, (2017), doi: 10.1073/pnas.1703997114