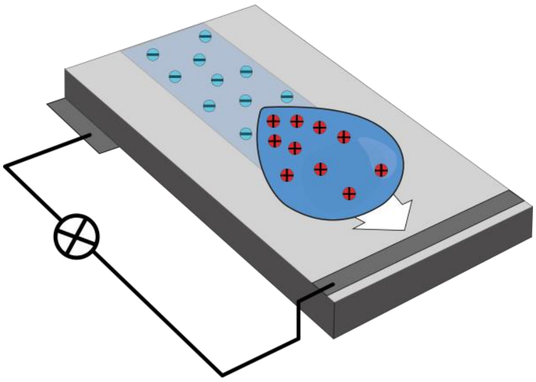
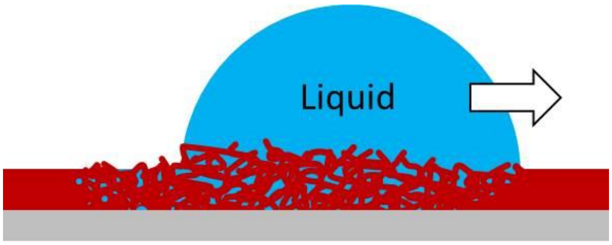
Scientific CV Hans-Jürgen Butt

2019 Slide electrication: Charging of surfaces by moving water drops

We establish a protocol of reproducibly measure the charge gained by water drops sliding down a substrate. Furthermore we outline an analytical theory to describe this charging process. We explain charging, by assuming that some fraction of the charge in the Debye layer is transferred to the surface rather than being neutralized as the drop passes. This fraction, or "transfer coefficient", is dependent on the electric potentials of surface and drop. Given that nearly every surface in our lives comes in contact with water, this water-dependent surface charging may be a ubiquitous process that we can begin to understand through the proposed theory. A.Z. Stetten, D.S. Golovko, S.A.L. Weber, H.-J. Butt, *Soft Matter* 2019, ***15***, 8667-8679.

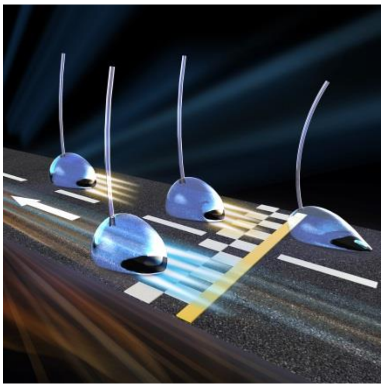


2018 Adaptive wetting – adaptation in wetting



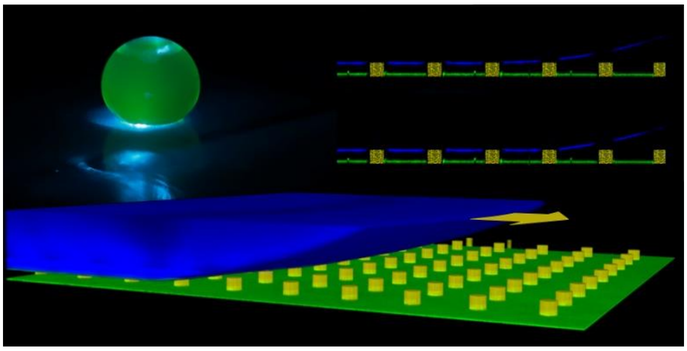
Many surfaces change their structure and interfacial energy upon being in contact with a liquid. Such surfaces adapt to the specific liquid. We propose a first order kinetic model to describe dynamic contact angles of such adaptive surfaces. The model is general and does not refer to a particular adaptation process. The aim of the proposed model is to provide a quantitative description of adaptive wetting and to link changes in contact angles to microscopic adaptation processes. H.-J. Butt, R. Berger, W. Steffen, D. Vollmer, S.A.L. Weber, *Langmuir* **2018**, *34*, 11292-11304

2017 How drops start sliding over solid surfaces



It has been known for more than 200 years that the maximum static friction force between two solid surfaces is usually greater than the kinetic friction force. In contrast to solid–solid friction, there is a lack of understanding of liquid–solid friction, i.e. the forces that impede the lateral motion of a drop of liquid on a solid surface. We found that the lateral adhesion force between a liquid drop and a solid can be divided into a static and a kinetic regime. This striking analogy with solid–solid friction is a generic phenomenon that holds for liquids of different polarities and surface tensions on smooth, rough and structured surfaces. Gao, N., F. Geyer, D.W. Pilat, S. Wooh, D. Vollmer, H.-J. Butt & R. Berger, *Nature Physics* **2018**, *14*, 191-196.

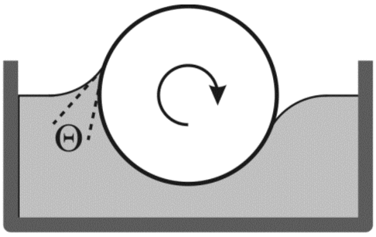
2016 How water advances on superhydrophobic surfaces



Using confocal microscopy we image water drops advancing on a superhydrophobic array of micropillars. In contrast to common belief, the liquid surface gradually bends down until it touches the top face of the next micropillars. The apparent advancing contact angle is 180°. On the receding side, pinning to the top faces of the micropillars determines the apparent receding contact angle. We propose that the apparent *receding* contact angle should be used for characterizing superliquid-repellent surfaces rather than the apparent *advancing* contact angle and hysteresis (Schellenberger, Encinas, Vollmer, Butt, *Phys. Rev. Lett.* **2016**, *116*, 096101. Highlighted by *Nature Materials* **2016**, *15*, 376).

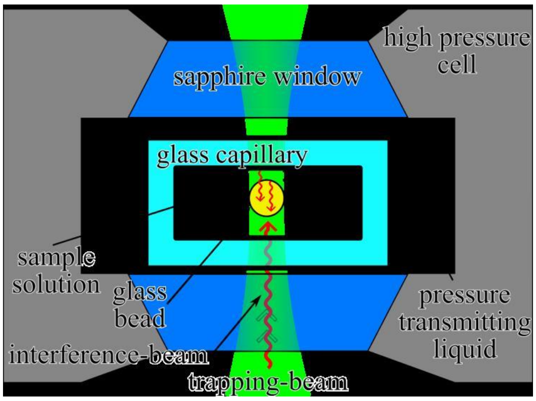
2016 Surfactants reduce dynamic receding contact angle

We demonstrate that even low amounts of surfactants (<10% CMC) drastically reduce the dynamic receding contact angle of aqueous solutions. The effect is independent on the type of surfactant and primarily depends on the concentration scaled by the critical micelle concentration (CMC) (Henrich, Truszkowska, Weirich, Anyfantakis, Nguyen, Wagner, Auernhammer & Butt. *Soft Matter* **2016**, *12*, 7782-7791).



2016 Surface force at high pressure

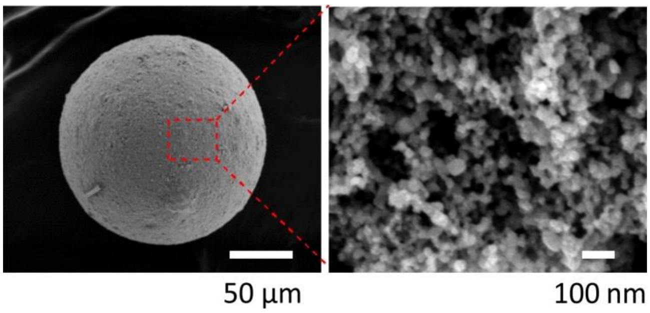
To measure surface forces at a pressure which exists in deep sea, we designed an optical trapping setup that allowed us to explore the interaction of a micrometer-sized glass bead and a solid glass wall up to 1 kbar. We demonstrated that the Debye length in aqueous electrolyte remained constant within approximately ±1 nm for salt concentrations of 0.1 and 1 mM (Pilat, Pouligny, Best, Nick, Berger & Butt, *Phys. Rev. E.* **2016**, *93*, 022608).



2015 Homogeneous nucleation of ice confinement

When cooling water confined in nanoporous alumina it crystallizes by homogeneous rather than heterogeneous nucleation. The nucleation mechanism of water can be regulated by confinement within nanoporous alumina. We found a transition from heterogeneous nucleation of ice to homogeneous nucleation with decreasing pore diameter. Homogeneously nucleated ice in confinements seems to have a cubic rather than the usual hexagonal structure (Suzuki, Duran, Steinhart, Kappl, Butt & Floudas, *Nano Letters* **2015**, *15*, 1987-1992).

2015 Fabricating supraparticles

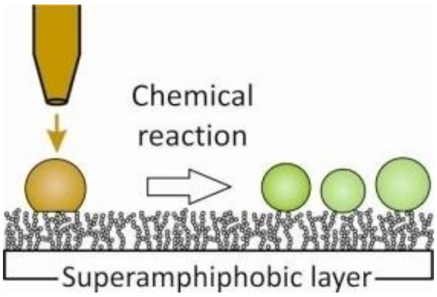


We use superamphiphobic surface to fabricate supraparticles by drying dispersions of nano-particles. Such supraparticles can be used to photocatalysis (Wooh, Huesmann, Nawaz Tahir, Paven, Wichmann, Vollmer, Tremel, Papadopoulos & Butt, *Adv. Mater.* **2015**, *27*, 7338).

2014 Superamphiphobic particles

We fabricate superamphiphobic particles and find a fundamental limit of how small one can go and still keep superamphiphobicity (Ye, Deng, Ally, Papadopoulos, Schellenberger, Vollmer, Kappl & Butt, *Phys. Rev. Lett.* **2014**, 112, 016101).

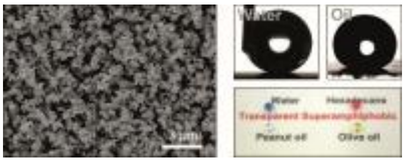
2013 Gas exchange membranes and solvent-free synthesis with superamphiphobic surfaces



Polymeric and composite microspheres can be synthesized without solvents or process liquids by using superamphiphobic surfaces. In this method, the repellency of superamphiphobic surfaces to monomers and polymer melts and the extremely low adhesion to particles are taken advantage of. (Deng, Paven, Papadopoulos, Ye, Wu, Schuster, Klapper, Vollmer & Butt, Angewandte Chemie Intl. Ed. 2013, 52, 11286-11289.)

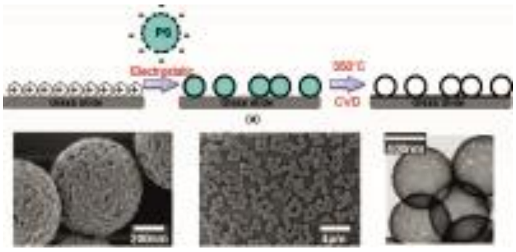
We demonstrate that superamphiphobic gas membranes can be used to exchange CO2 and oxygenate blood. Human blood stored in a superamphiphobic well for 24h can be poured off without leaving cells or adsorbed protein behind. (Paven, Papadopoulos, Schöttler, Deng, Mailänder, Vollmer & Butt, Nature Communications 2013, 4, 2512.)

2012 Transparent superamphiphobic layers from candle soot



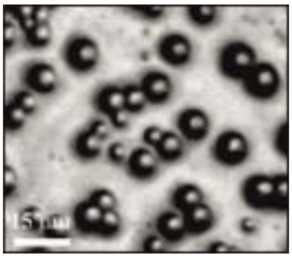
Using candle soot as a template we produce transparent robust superamphiphobic coating. They not only repel water but also oils and surfactant solutions (Deng, Mammen, Butt & Vollmer, Science 2012, 335, 67-70).

2011 Robust, transparent superhydrophobic surfaces



We develop a method to produce transparent, thermally stable and mechanically robust superhydrophobic surfaces made from porous silica capsules (Deng, Mammen, Zhao, Lellig, Müllen, Butt & Vollmer, Adv. Mater. 2011, 23, 2962)

2010 Liquids condense faster on soft surfaces than on hard ones



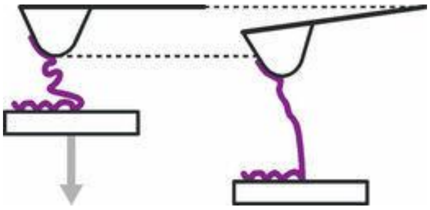
Sokuler, Auernhammer, Roth, Liu, Bonaccurso, Butt, Langmuir 2010, 26, 1544-1547

Sokuler, Auernhammer, Liu, Bonaccurso, Butt, Europhys. Lett. 2010, 89, 36004.

2009 Nanoadhesion at high separation speeds

Using a modified atomic force microscope we were able to measure adhesion forces at 100 times faster separation velocities. Different regimes of the separation limiting step could be identified on various thiol monolayers (Ptak, Kappl, Moreno-Flores, Gojzewski, Butt, Langmuir 2009, 25, 256-261; Gojzewski, Kappl, Ptak, Butt Langmuir 2010, 26, 1837-1847).

2008 Wet bioadhesion - towards a universal adhesive



The adhesion of a biomimetic DOPA-containing polymer is largely independent on the density of functional groups. This finding should allow designing universal adhesion polymers (Wang et al., Adv. Materials 2008, 20, 3872)

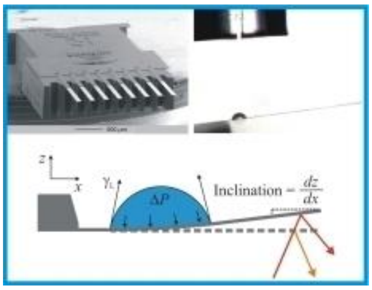
2007 Stress and failure at mechanical contacts of microspheres

Measurement of the stress distribution in hard microcontacts. Hertz theory describes the stress distribution adequately. Failure by the formation of nano- and microcracks (Chen, Koynov, Butt, J. Mater. Res. 2007, 22, 3196).

2006 Capillary forces

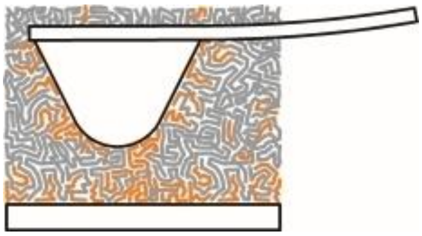
The surface structure on the sub-1 nm scale can explain adhesion forces measured between particles at different humidity (Farshchi, Kappl, Cheng, Gutmann, Butt, Langmuir 2006, 22, 2171). A simple way to take surface roughness into account is described (Butt, Langmuir 2008, 24, 4715).

2005 Drop evaporation



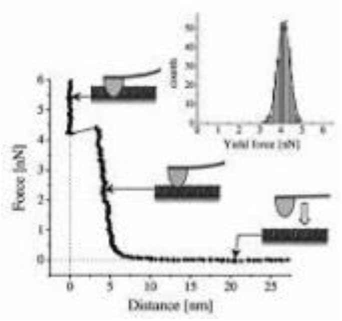
First measurements of the evaporation of liquid drops with a size much smaller than 100 µm. Therefore microcantilevers were applied (Bonaccurso, Butt, J. Phys. Chem. B 2005, 109, 253; Golovko, Butt, Bonaccurso, Langmuir 2009, 25, 75).

2004 Surface forces across polymer melts



Surface forces across polymer melts are dominated by slow processes at the polymer-solid interface (Langmuir 2004, 20, 8030; Macromolecules 2004, 37, 6086; Macromolecules 2007, 40, 2520; J. Phys. Chem. B 2008, 112, 2001).

2002 Rupture of molecularly thin films

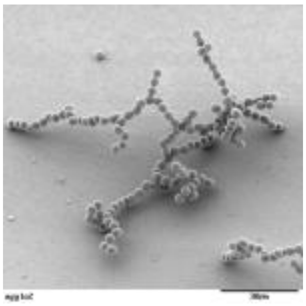


Theory and experiment on the rupture of lipid bilayers and molecular films in atomic force microscopy (Loi, Sun, Franz, Butt, Phys. Rev. E. **2002**, *66*, 031602; Butt & Franz, *Phys. Rev. E.* **2002**, *66*, 031601).

2000 Liquid-like layer on ice

We studied the properties of ice with the atomic force microscope and measured the thickness of the liquid-like layer on top of the solid ice surface (Döppenschmidt, Butt, Langmuir 2000, 16, 6709).

1999 Adhesion and friction between fine particles

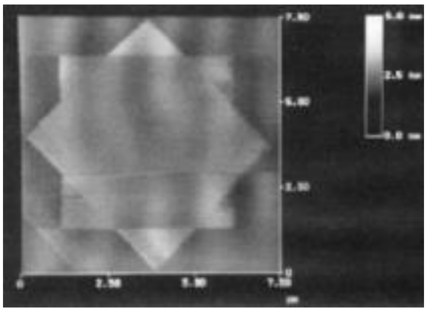


Measuring for the first time the adhesion and rolling friction forces between micron-sized particles (Heim, Blum, Preuss, Butt, Phys. Rev. Lett. 1999, 83, 3328). Latter quantitative measurements of friction acting between individual fine particles were carried out (Ecke, Butt, J. Colloid Interface Sci. 2001, 244, 432).

1996 Microcantilever sensors

Based on earlier work by Thundat (Thundat, Warmack, Chen, Allison, Appl. Phys. Lett. 1994, 64, 2894) and Raiteri, Grattarola, Butt (Raiteri & Butt, J. Phys. Chem. 1995, 99) it was realized that AFM cantilevers can be used to measure changes in the surface tension of solids. This can be applied to build micromechanical sensors (Butt, J. Colloid Interface Sci. 1996, 180, 251). See also Berger (Berger et al., Science 1997, 276, 2021).

1995 Dip-pen lithography



Discovery that an organic monolayer can be deposited by the tip of an AFM with sub 100 nm accuracy by scanning force microscopy (Jaschke, Butt, Langmuir 1995, 11, 1061). Mirkin later applied it to deposit thiols on gold. He coined the term "dip-pen lithography" (Piner, Zhu, Xu, Hong, Mirkin, Science 1999, 283, 661).

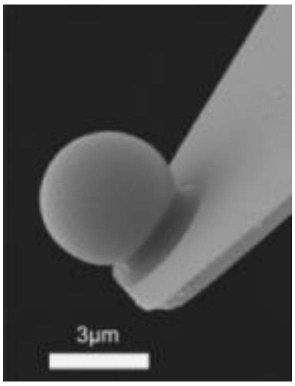
1994 Particle-bubble interaction

First measurements of single micron-sized particles and air bubbles in water (Butt, J. Colloid Interface Sci. 1994, 166, 109; Preuss, Butt, Langmuir 1998, 14, 3164). Ducker, Xu and Israelachvili did similar experiments in the same year with an atomic force microscope (Ducker, Xu, Israelachvili, Langmuir 1994, 10, 3279) followed by Fielden, Hayes & Ralston (Fielden, Hayes, Ralston, Langmuir 1996, 12, 3721).

1992 Local charge density in aqueous electrolyte with the atomic force microscope

Measuring local charge densities in aqueous electrolyte with sub 100 nm resolution with the AFM (Butt, Biophys. J. 1992, 63, 578).

1991 Colloidal Probe Technique



Demonstration that the atomic force microscope can be used for quantitative force-versus-distance experiments; attaching particles to atomic force microscope cantilevers (Butt, Biophys. J. 1991, 60, 1438). This discovery was independent and in parallel to Ducker, Senden and Pashley (Ducker, Senden, Pashley, Nature 1991, 353, 239). Ducker et al. coined the name "colloidal probe technique". Meanwhile the AFM has become the standard instrument to measure surface forces.