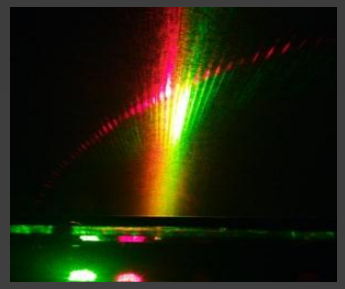
Water: A tale of two surfaces

Professor Glen McHale
Northumbria University

11th October 2012

Public Understanding website: http://www.naturesraincoats.com/



The World Around Us

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In The Garden

The Man-made World

channels

clothes

windows & roofs

plants & leaves

ponds & insects

soil

grass

The Natural World

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Walking on Water

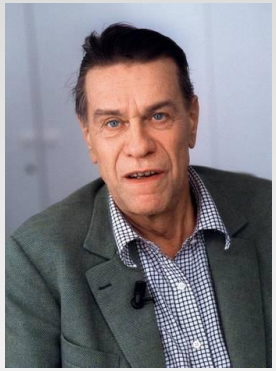
Microcosmos (Copyright: Allied Films, 1996)

Winners and Losers: Understanding provides a competitive advantage

The Great Empires and their Borders

"*The borders between great empires are often populated by the most interesting ethnic groups. Similarly, the interfaces between two forms of bulk matter are responsible for some of the most unexpected actions*"

Pierre Gilles de Gennes
(Nobel Laureate in Physics , 1991)
Dirac Memorial Lecture, 1994



Acknowledgement: Le Figaro

"*Of course, the border is sometimes frozen (the Great Chinese Wall). But in many areas, the overlap region is mobile, diffuse, and active (the Middle East border of the Roman empire, disputed states between Austria and the Russians, or the Italians, …)*"

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The Great Empires of Matter

The Great Empires of Bulk Matter

solids - organic matter, glass, brick, metal, plastic, ...
liquids - water, oil, …

The Two Surfaces

surface of the solid
surface of the liquid

} these are also interfaces (to air)

The Border

solid–to-liquid interface

The border is sometimes frozen. But in many areas, the overlap region is mobile, diffuse, and active.

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Size Matters

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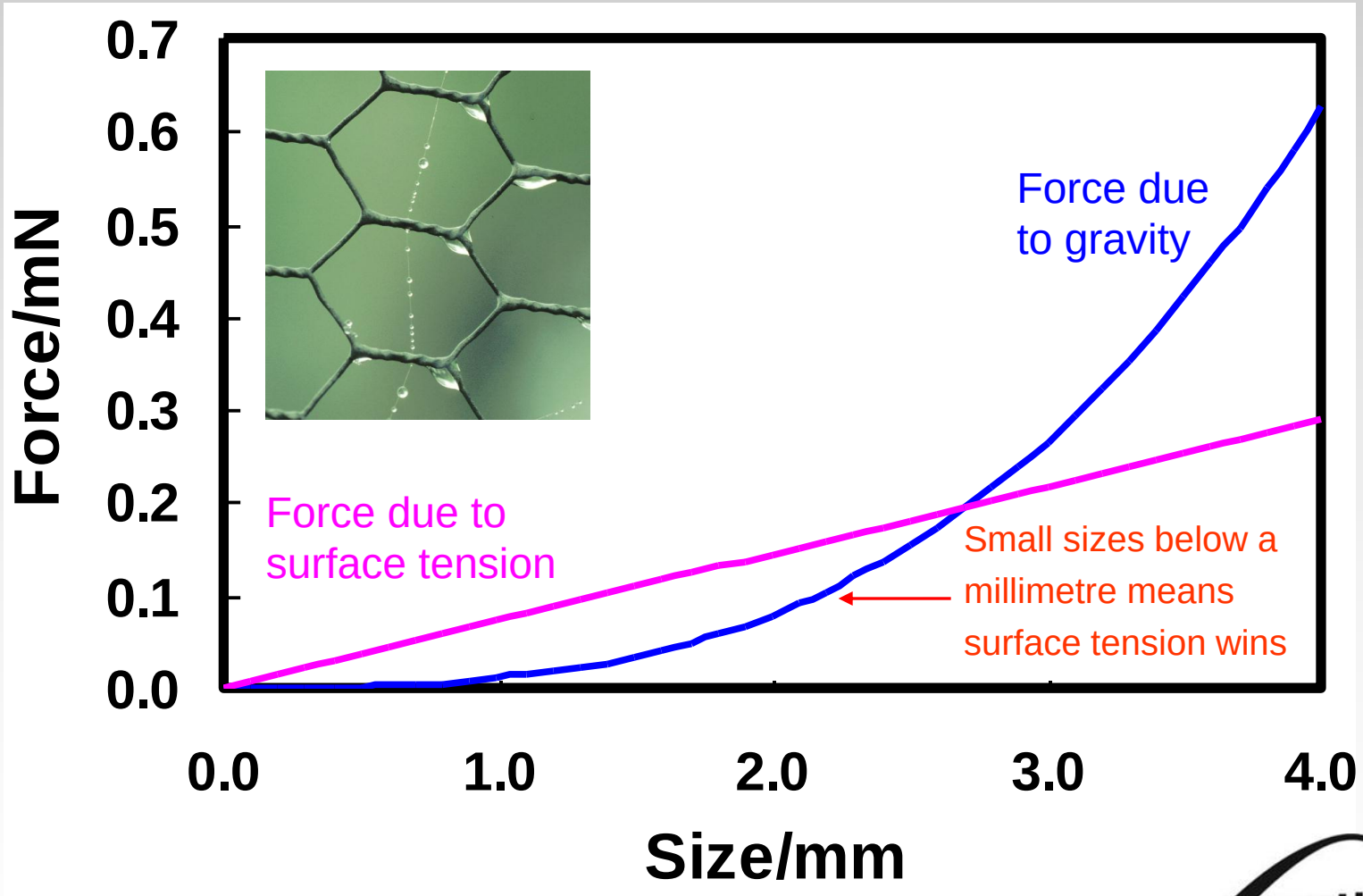
Size Matters: Fact or Fiction?

The Movie – Antz (1998)

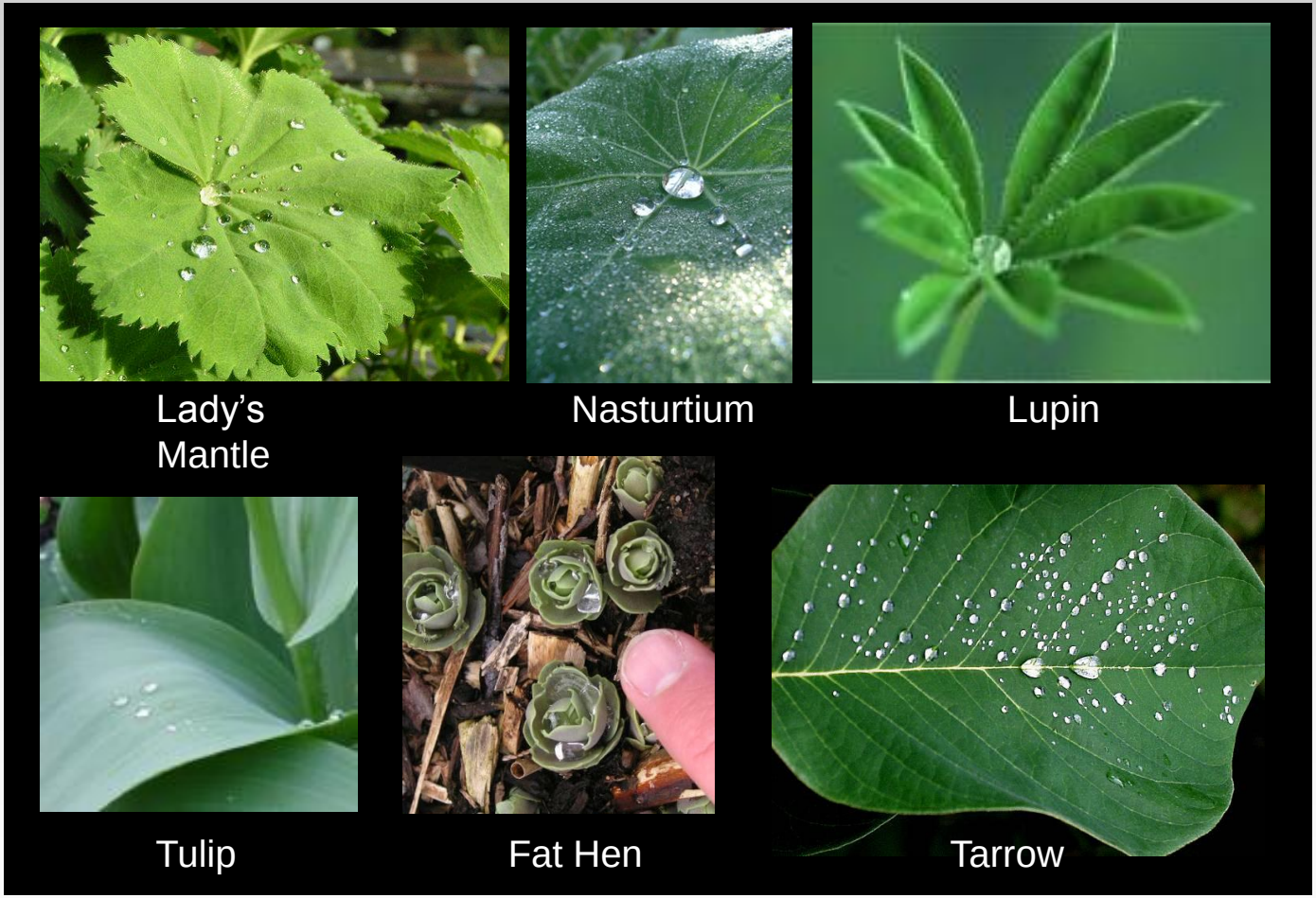
Courtesy: BigWave Productions

Just imagination?

Surface Tension versus Gravity



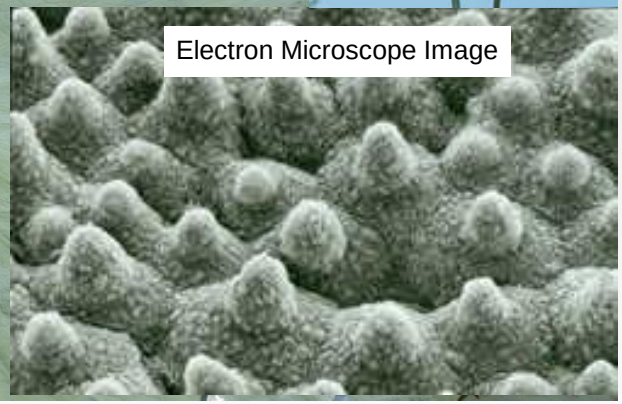
The Surfaces of Leaves



Lady's Mantle, Honeysuckle, Fat Hen, Tulip, Daffodil, Sew thistle (Milkweed), Aquilegia, Nasturtium, Cabbage/Sprout/Broccoli (Image Sources: Various)

The (Superhydrophobic) Sacred Lotus Leaf

Courtesy: Professor Julie McLeod (Dal Lake, Srinagar)



Electron Microscope Image

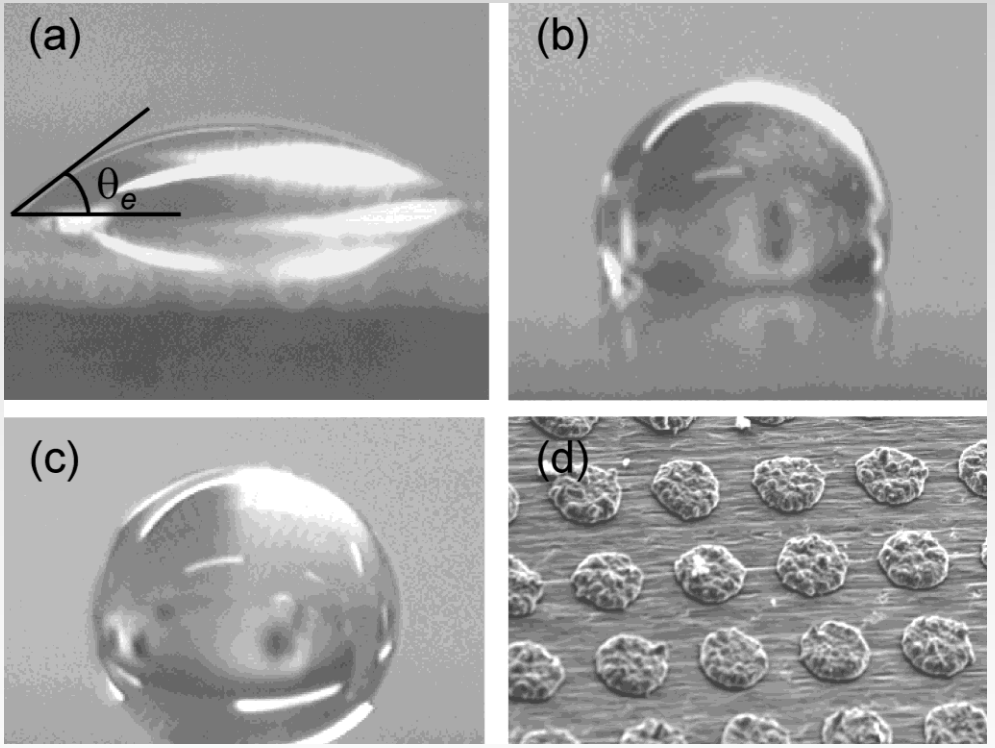
Acknowledgement: Neinhuis & Barthlott

[Youtube Lotus Effect Video]

Chemistry and Physics of Surfaces

Physical Enhancement of Chemistry

(a) is water-on-copper
(b) is water-on-fluorine coated copper
(c) is a super-hydrophobic surface
(d) “chocolate-chip-cookie” surface



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Beds of Nails

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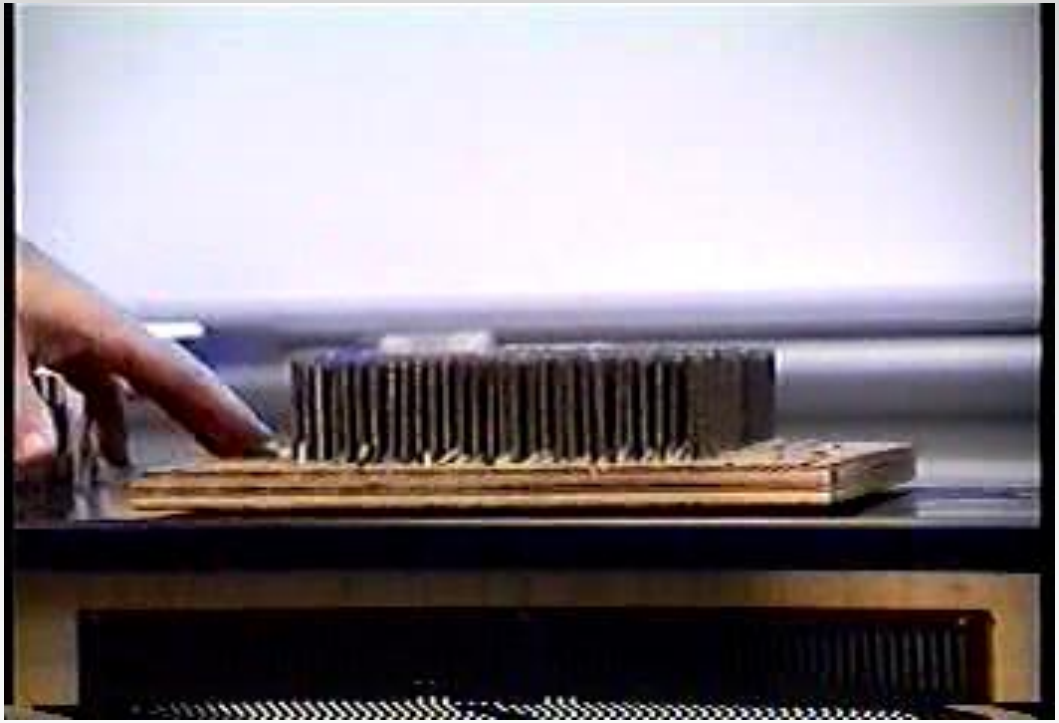
Bed of Nails and Fakir Carpet

Roman consul Marcus Atilius Regulus is tortured to death by Carthaginians in about 255 BC. The illustration was painted in about 1415 in Paris.

Acknowledgement: Physics, UCLA



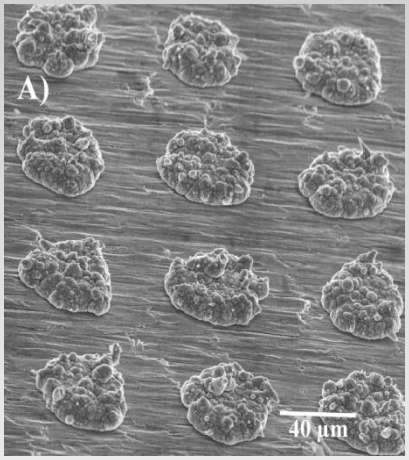
Acknowledgement: Wake Forest University

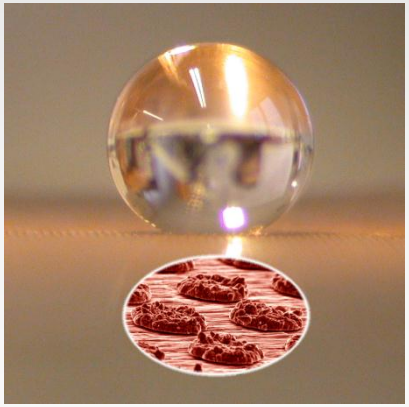
Nature's Raincoats

[Nature's Raincoats at The Royal Society Summer Science Exhibition](#) (at 1min 40 seconds)

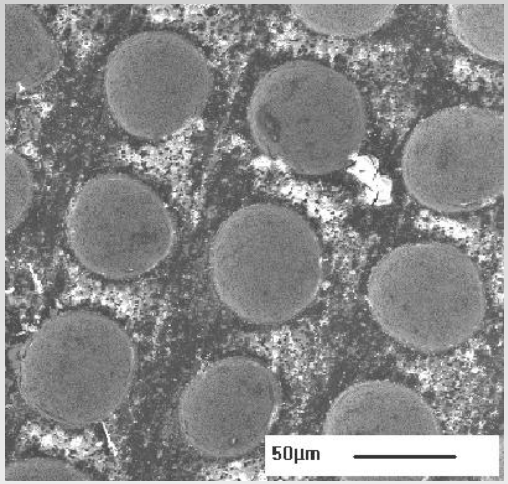
Nature's Raincoats website: http://www.naturesraincoats.com/

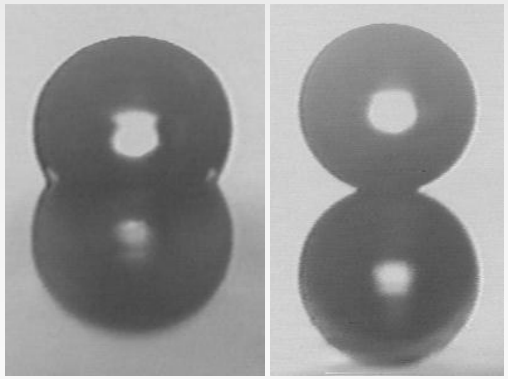
Man-made Superhydrophobic Surfaces



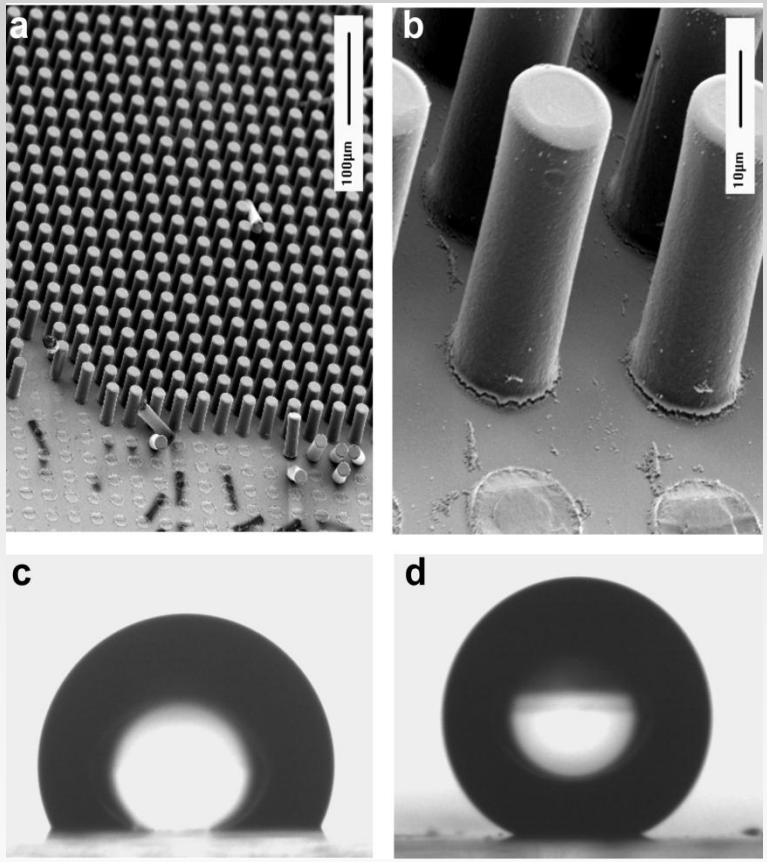


Depositing metal
"Choc-chip cookies"





Etching metal
"Lunar landscapes"



Polymer microposts
"Beds of nails"

e.g. Shirtcliffe, McHale, et al.,, Adv. Maters. 16, 2004; Langmuir 21, 2005. McHale, et al. Phys. Rev. Lett. 93, 2004.

Smart Surfaces and Materials

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Sensors - Foams that Switch

Do foams always absorb liquids?

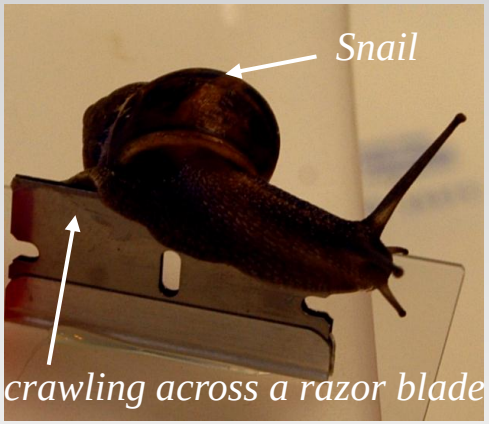
Foam heated (and cooled) prior to droplet deposition

Nature called this “Superhydrophobic to Super-slurp”

Shirtcliffe, McHale, Newton, et al, Porous materials show superhydrophobic to superhydrophilic switching, Chem. Comm. (25) (2005) 3135-3137. (Nature Highlight/News “Quick change for super sponge” Published on-line 20/7/05). (Front cover image).

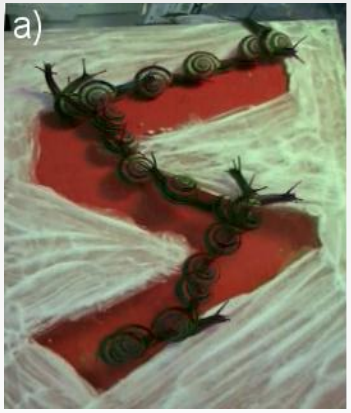
Adhesion - Snails that Slip

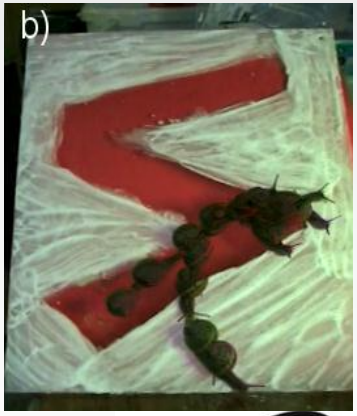
In the battle between super-slippy surfaces and super sticky snails, who wins?



Snail Video

Snail Film.mov





Shirtcliffe, McHale, Newton, Wet adhesion and adhesive locomotion on anti-adhesive non-wetting surfaces, PLoS ONE 7, 2012.

Adhesive Hydrophobicity - Capillary Origami

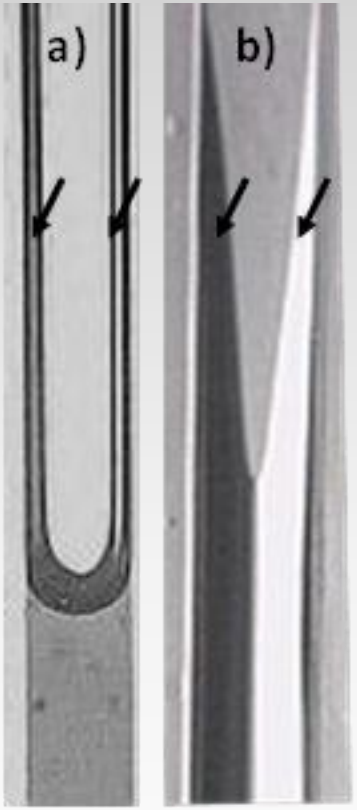
Are hydrophobic surfaces really water-fearing?

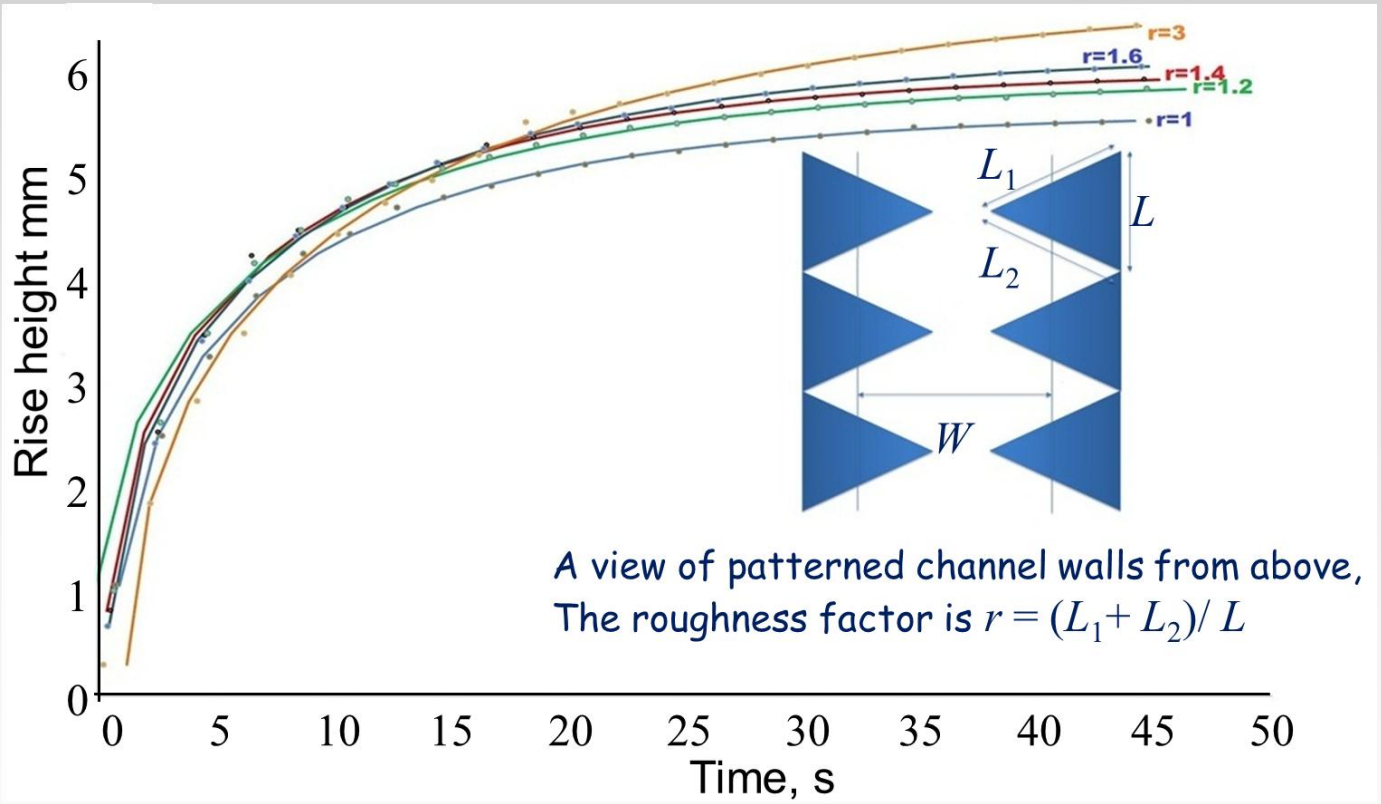
We can design surfaces that cannot feel the adhesive capillary forces

McHale et al, Capillary origami: superhydrophobic ribbon surfaces and liquid marbles, Beilstein J. Nanotechnol., 2, 2011.

Rising Threads – Capillary Imbibition

Do sharp corners on walls of channels impede or enhance imbibing liquids?



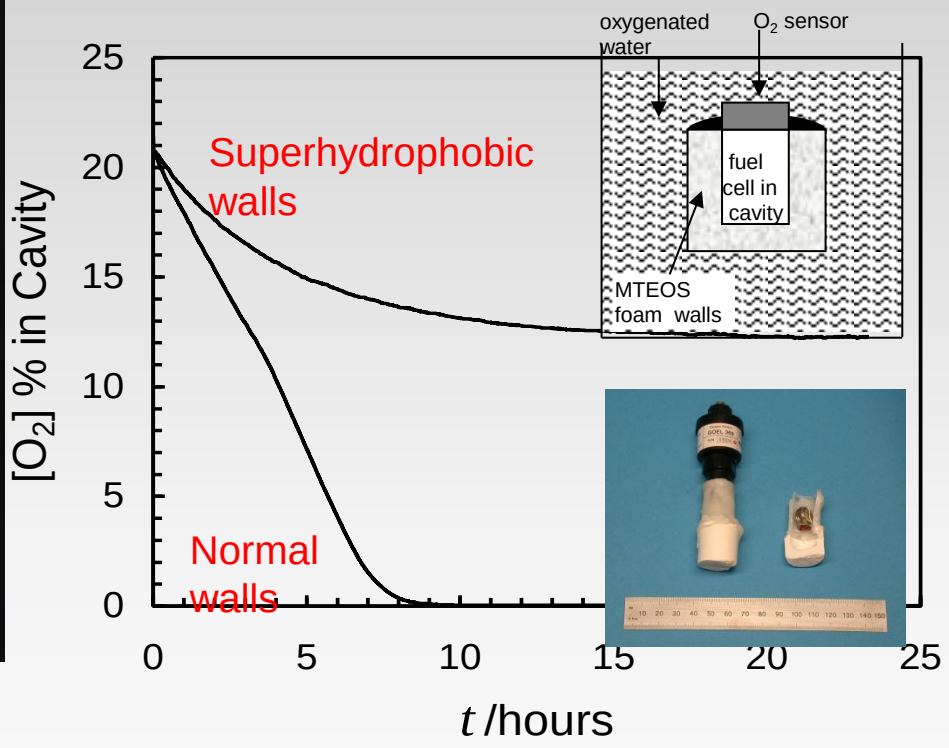


Ouali, McHale, et al, Wetting considerations in capillary rise and imbibition in closed square tubes and open rectangular cross-section channels, ubmitted (2012).

Gas Exchange - Spiders that Dive

Do we need gills to breathe underwater?

The Movie – Microcosmos



Shirtcliffe, McHale, Newton, et al, Plastron properties of a super-hydrophobic surface, Appl. Phys. Lett. 89, 2006.

Respiration - “Dogs” that Survive

How long can a dog be kept underwater in a sealed box?

Underwater Breathing

BBC Radio 4 Material World Broadcast

Edward Cussler, Professor of Chemical Engineering (University of Minnesota)

Speaking 9th February 2006

Going with the Flow

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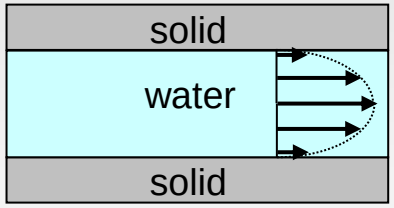
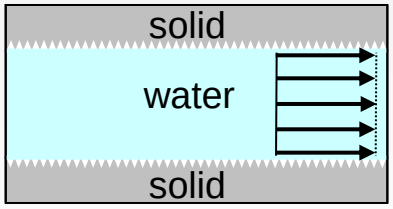
Liquid Transport - Pipes without Walls

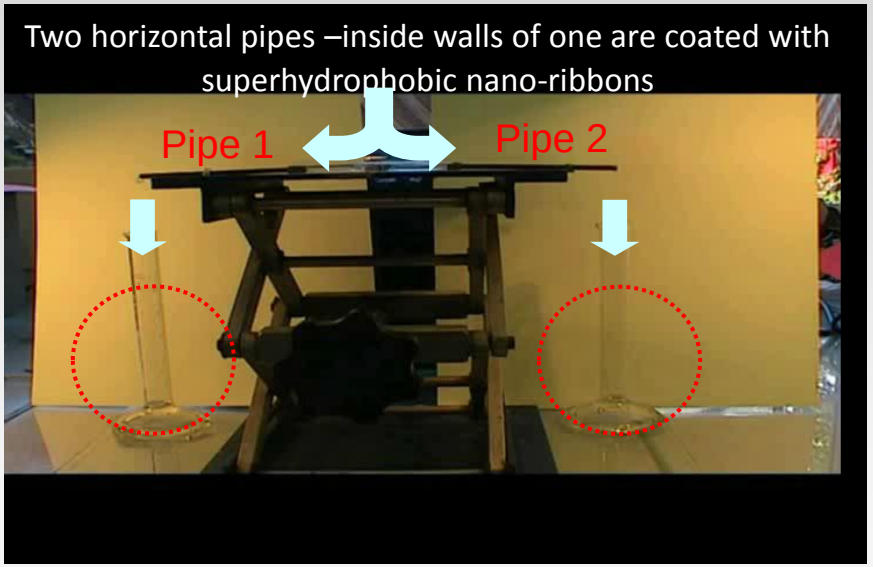
Does water flow through a hydrophobic pipe faster or slower?



Walls cause frictional drag



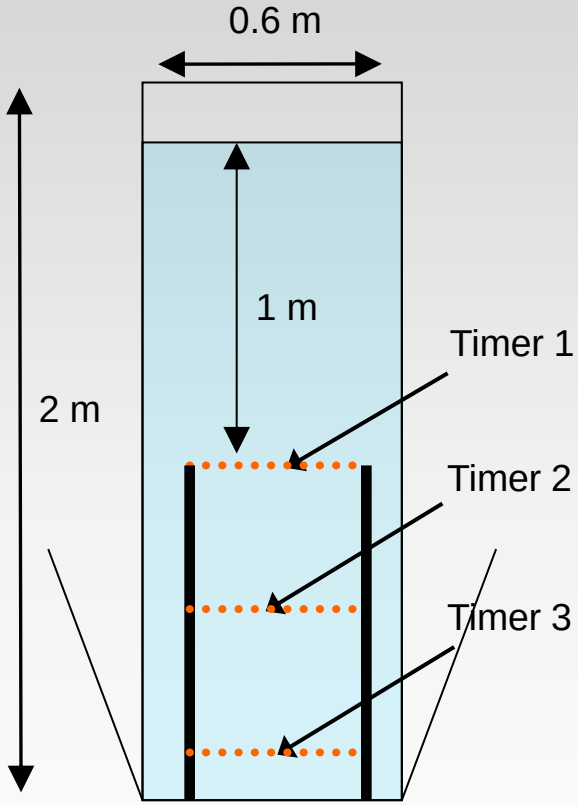
Walls appear as cushions of air



Shirtcliffe, McHale, et al, Superhydrophobic copper tubes with possible flow enhancement and drag reduction, ACS Appl. Mater. Interf. 1, 2009.

Settling Objects – Anti-Buoyancy

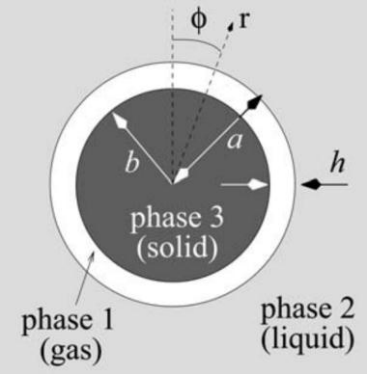
Is the terminal velocity of a sphere settling in water increased or decreased when it carries air?

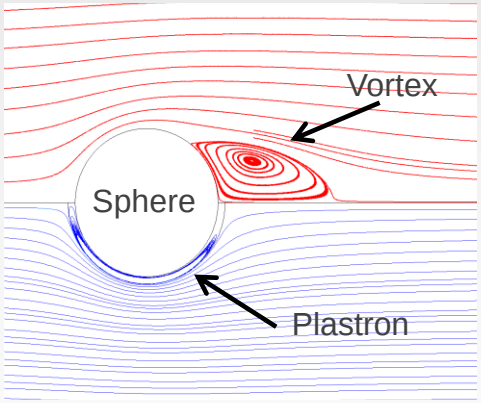


McHale, et al, Terminal velocity and drag reduction measurements on superhydrophobic spheres, Appl. Phys. Lett. 94, 2009.

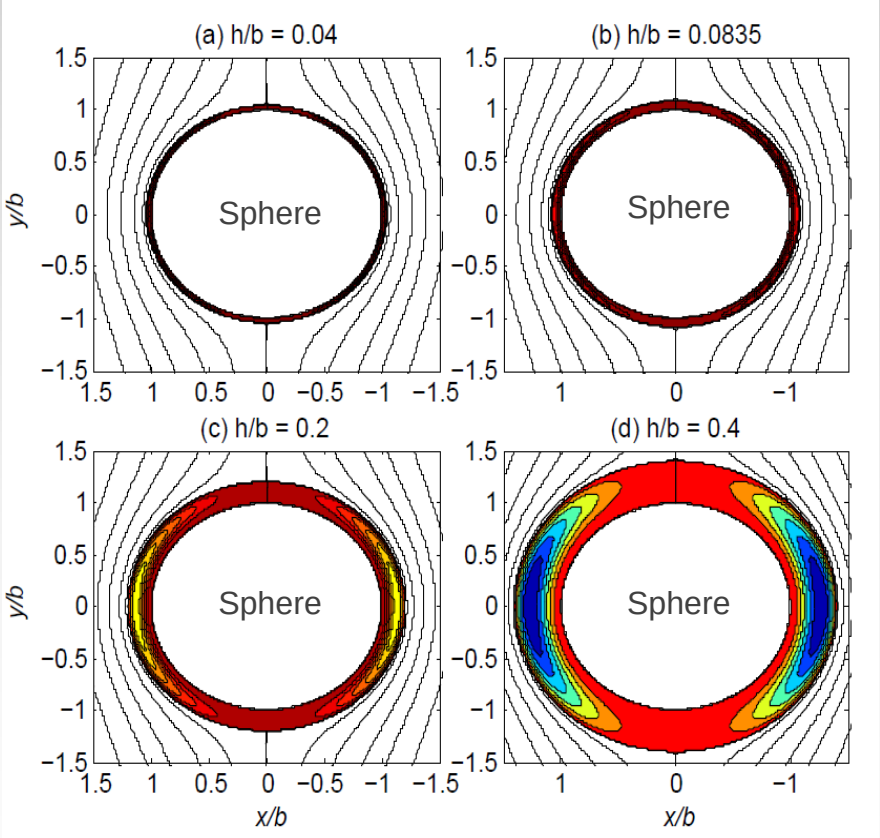
Drag Reduction – Lubricating Flow

Can air lubricate the flow of water past an object?





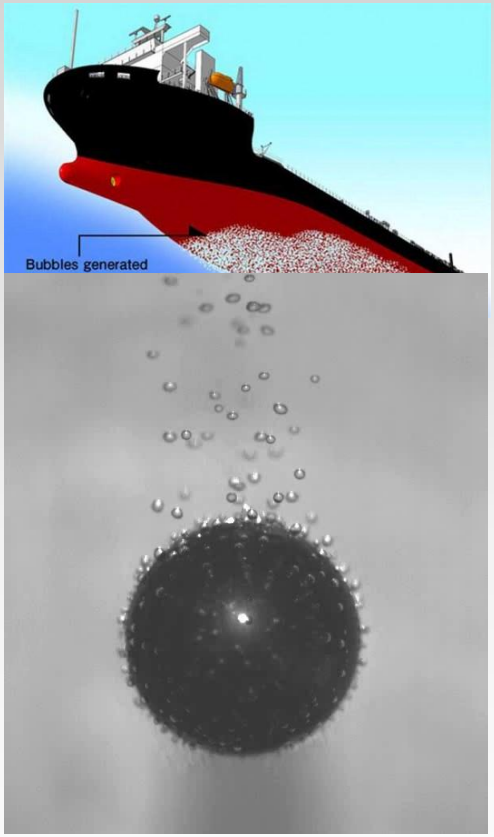
Sandham & Gruncell (Southampton)

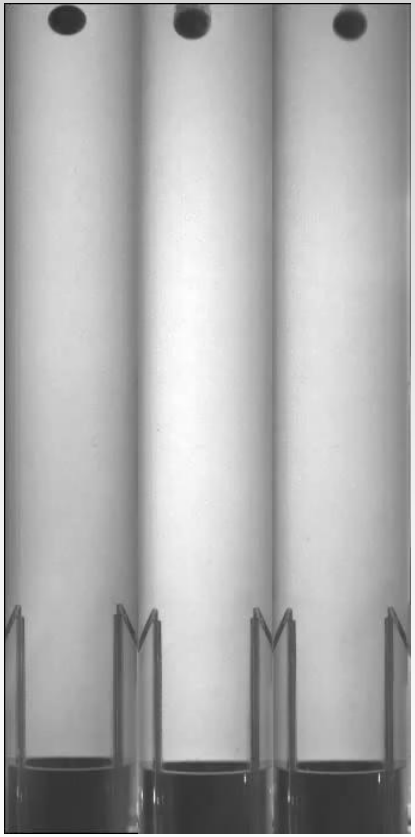


McHale, et al, Plastron induced drag reduction and increased slip on a superhydrophobic sphere, Soft Matter 7, 2011.

Efficient Transport - Futuristic Ships

Can bubbles help ships go faster?





Acknowledgements: Vakarelski et al. Phys. Rev. Lett. 106, 2011. Mitsubishi Air Lubrication Concept.

Water-Based Devices

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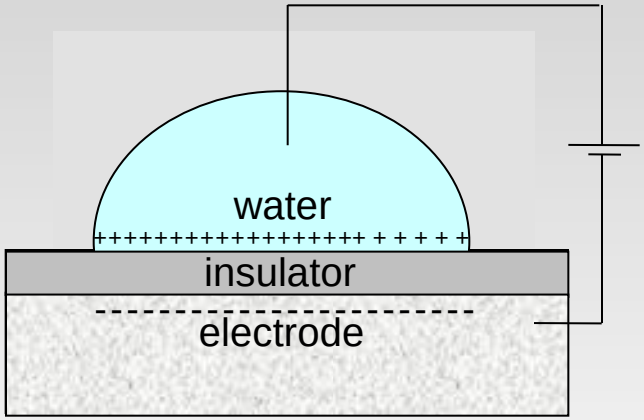
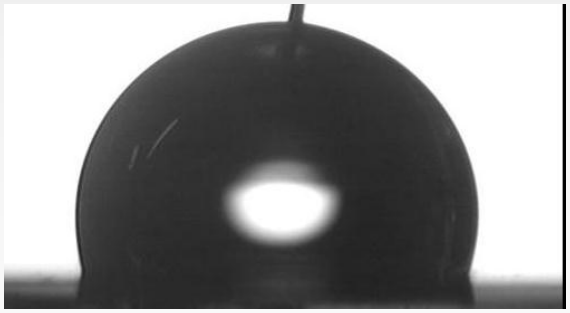
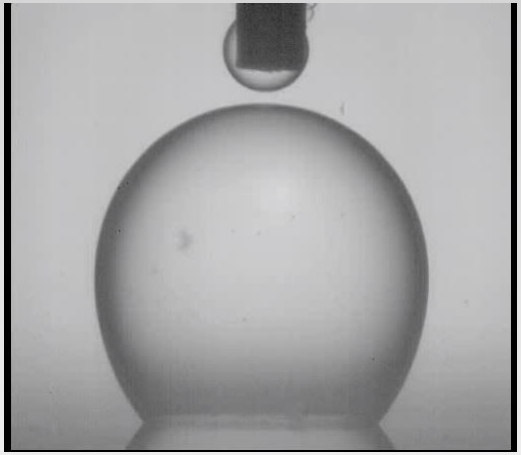
Electrowetting - Shaping Droplets

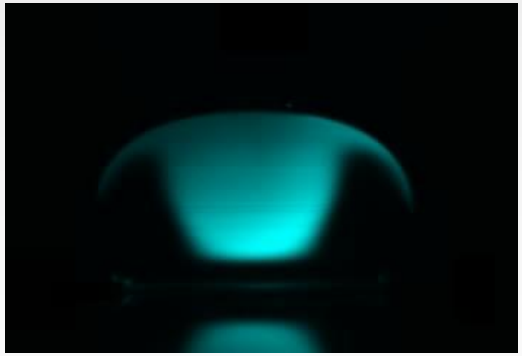
Electrowetting: Droplet in Air





Electrowetting: Water in Oil



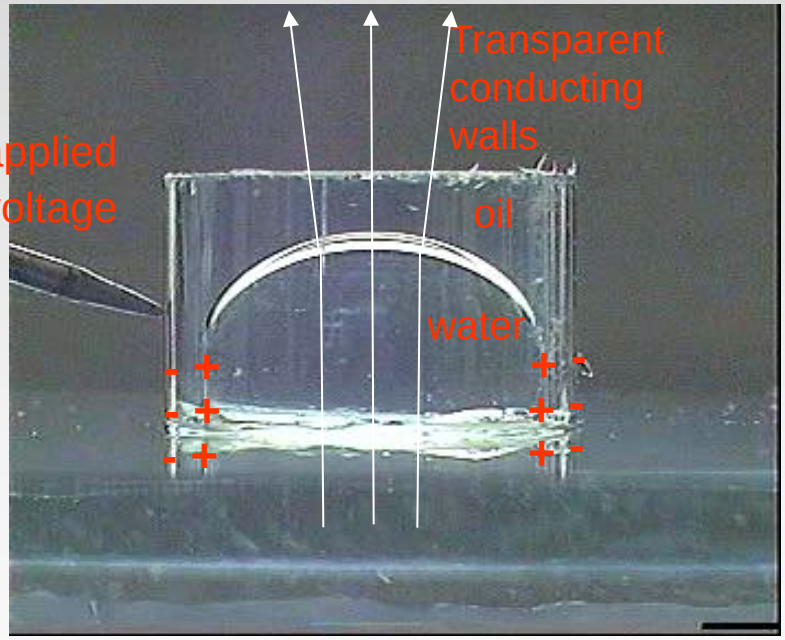


Courtesy: Prof. F. Mugele (Twente)

Example 1: Varioptic's Liquid Lenses

Voltage Control of Liquid-Oil Interface (Varioptics and Philips)

- Electrically charge the solid-water interface to cause shape changes
- Electrowetting uses capacitance of a liquid-insulator-conducting solid structure

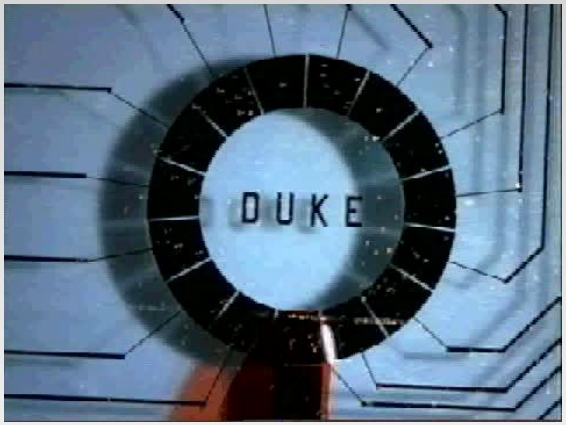


Courtesy: Dr S. Kuiper (Philips Res. Labs, Eindhoven)

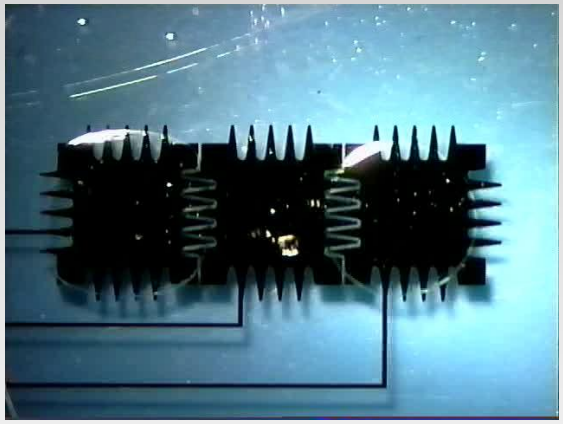
Example 2: Duke's Droplet Microfluidics

Electrowetting to dispense, merge/split/mix and move

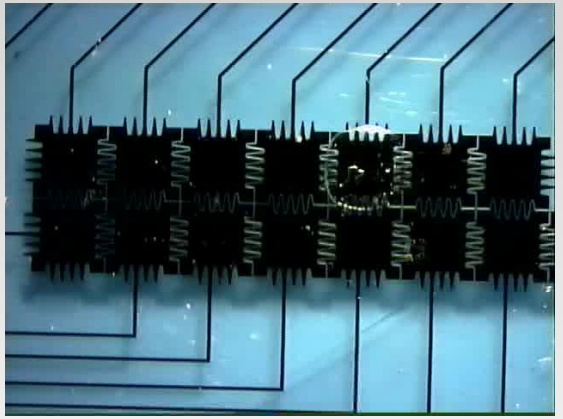
Dispense



Combine/Split



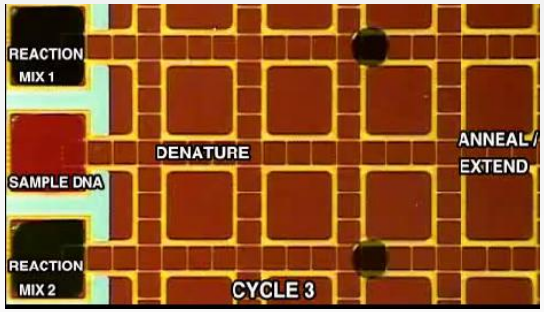
Digital Motion



Courtesy: Dr Mike Pollack (Duke University – co-founder Advanced Liquid Logic, USA)

Assays on the size of a credit card

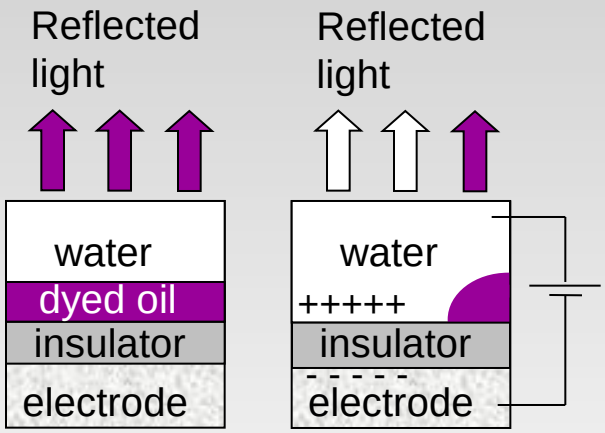
Immunoassays, clinical chemistry, three-enzyme pyrosequencing, enzyme assays for screening newborns, PCR for detecting M pneumonmiae DNA ….



Acknowledgement: Advanced Liquid Logic

Example 3: LiquaVista's Liquid Paper

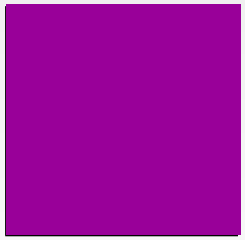
Oil layer-to-droplet transition



dyed oil

Pixel

(from above)



LiquaVista's Sunlight readable displays

Courtesy: Dr Romaric Massard (LiquaVista, USA)

Oil-Based Devices

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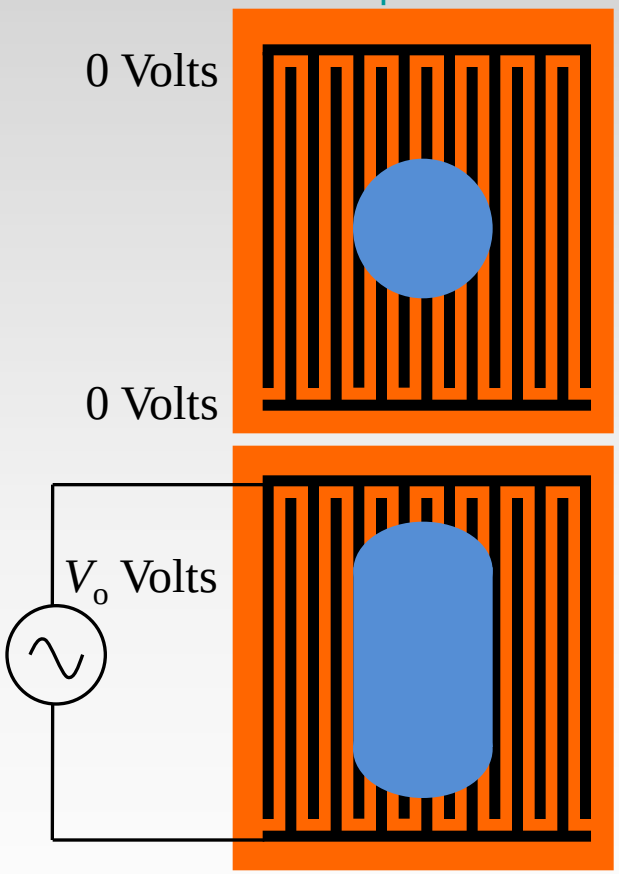
Oil Replaces Water - Liquid Dielectrophoresis

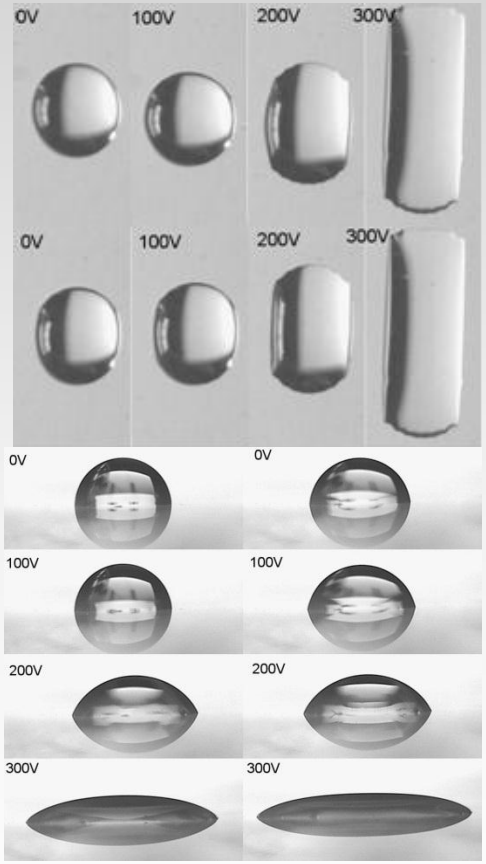
Interdigital Transducers

Top view



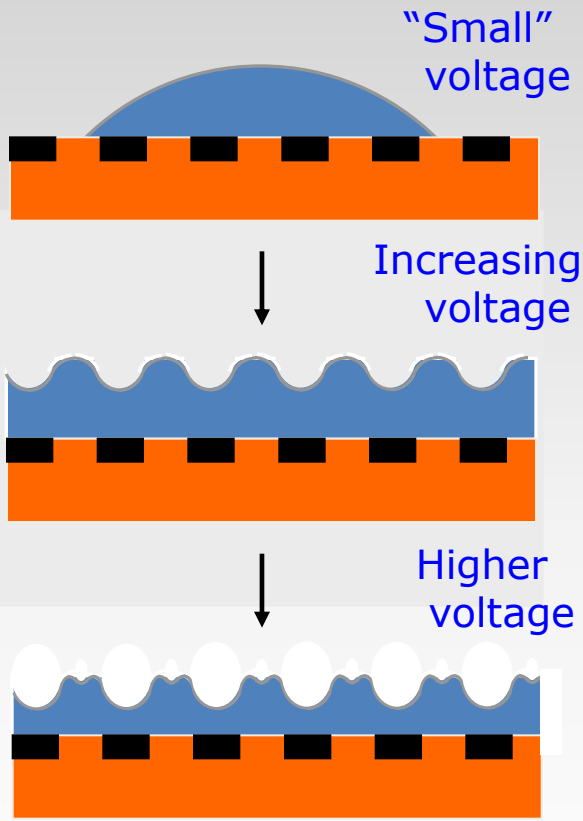
1,2 PPG Droplet

Top and side views*



Droplet to Wrinkled Film

Side view



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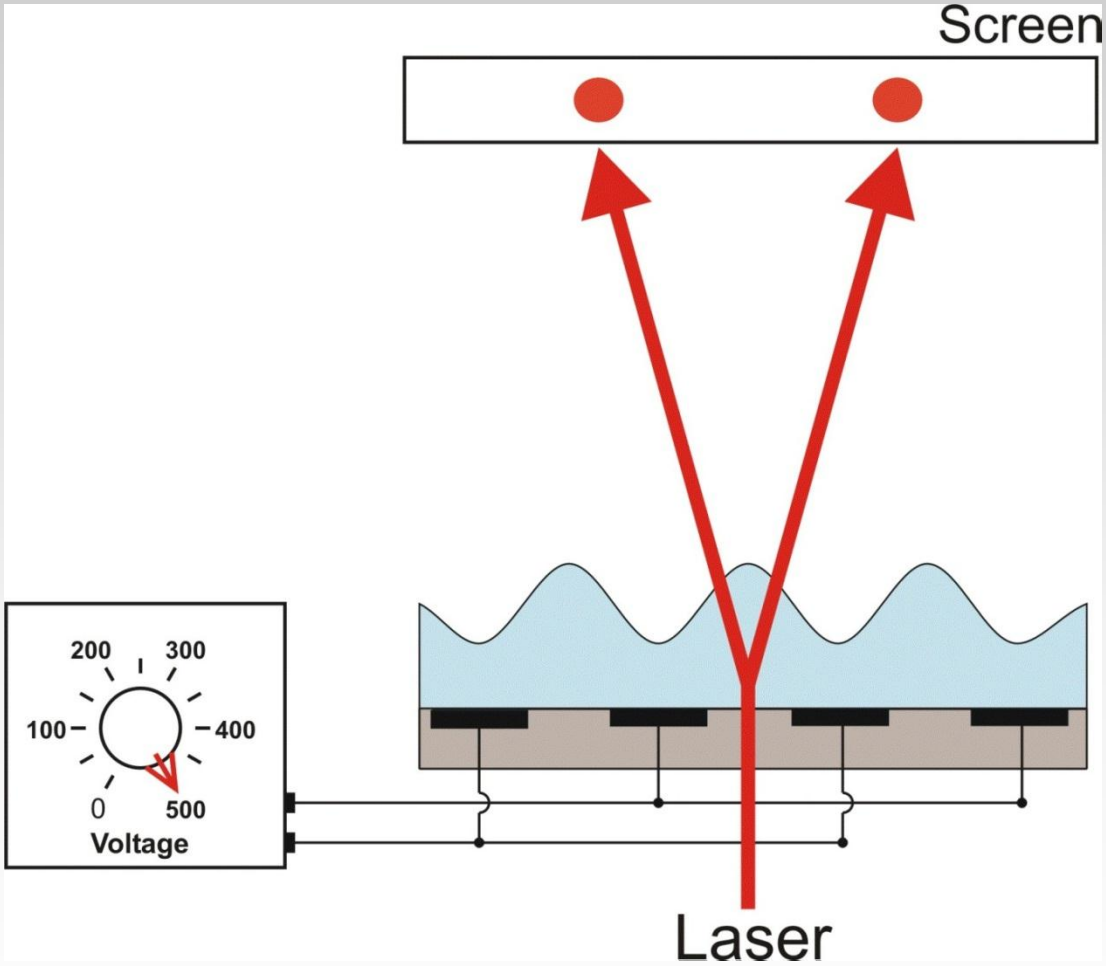
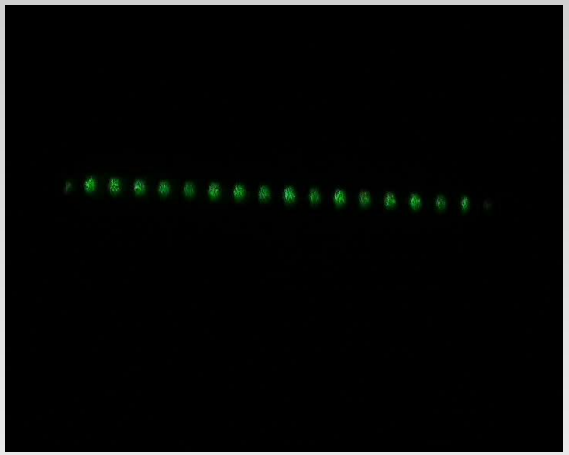
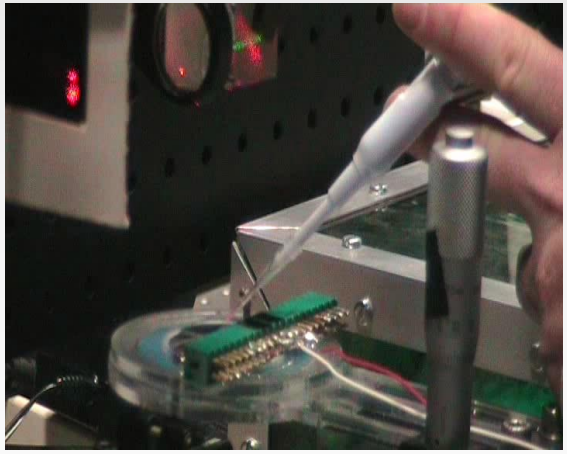
Beam Steering Using Films of Oil

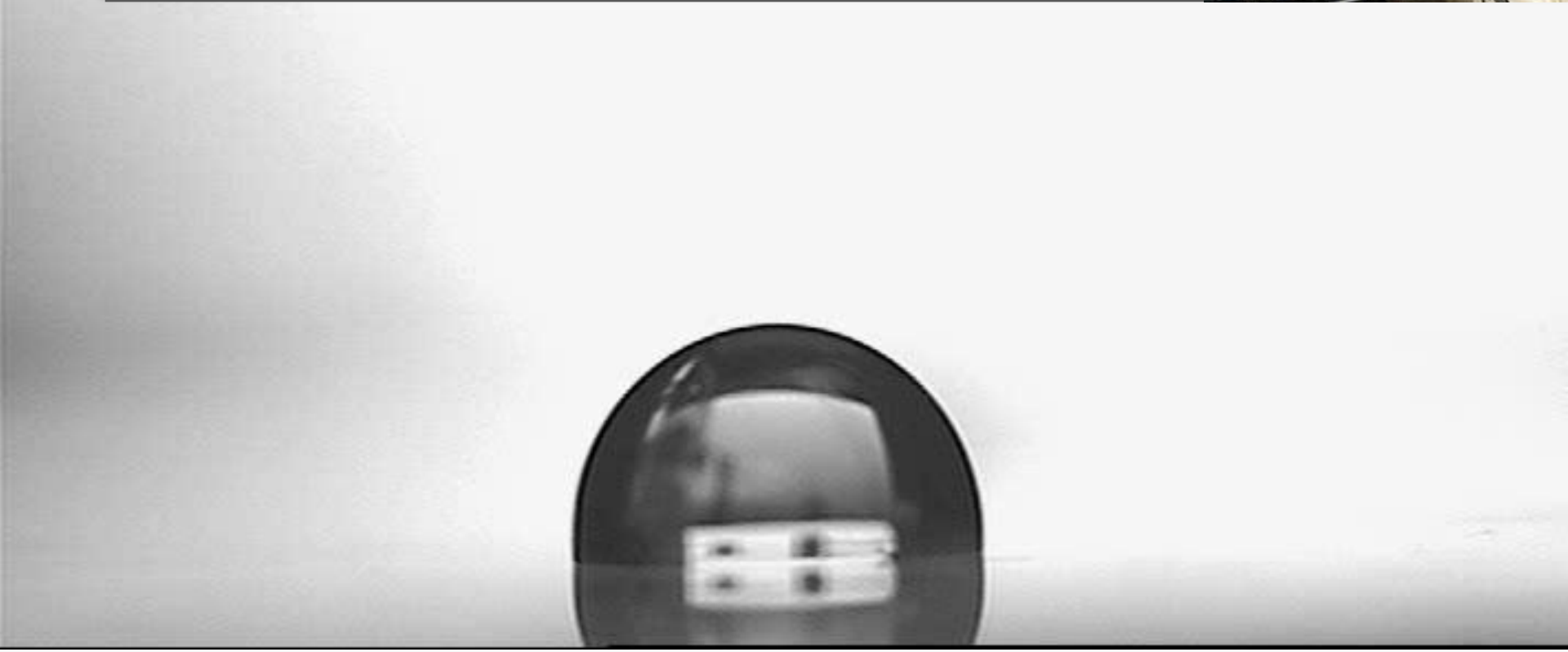






Brown, McHale, et al, Voltage-programmable liquid optical interface, Nature Photonics 3, 2009.

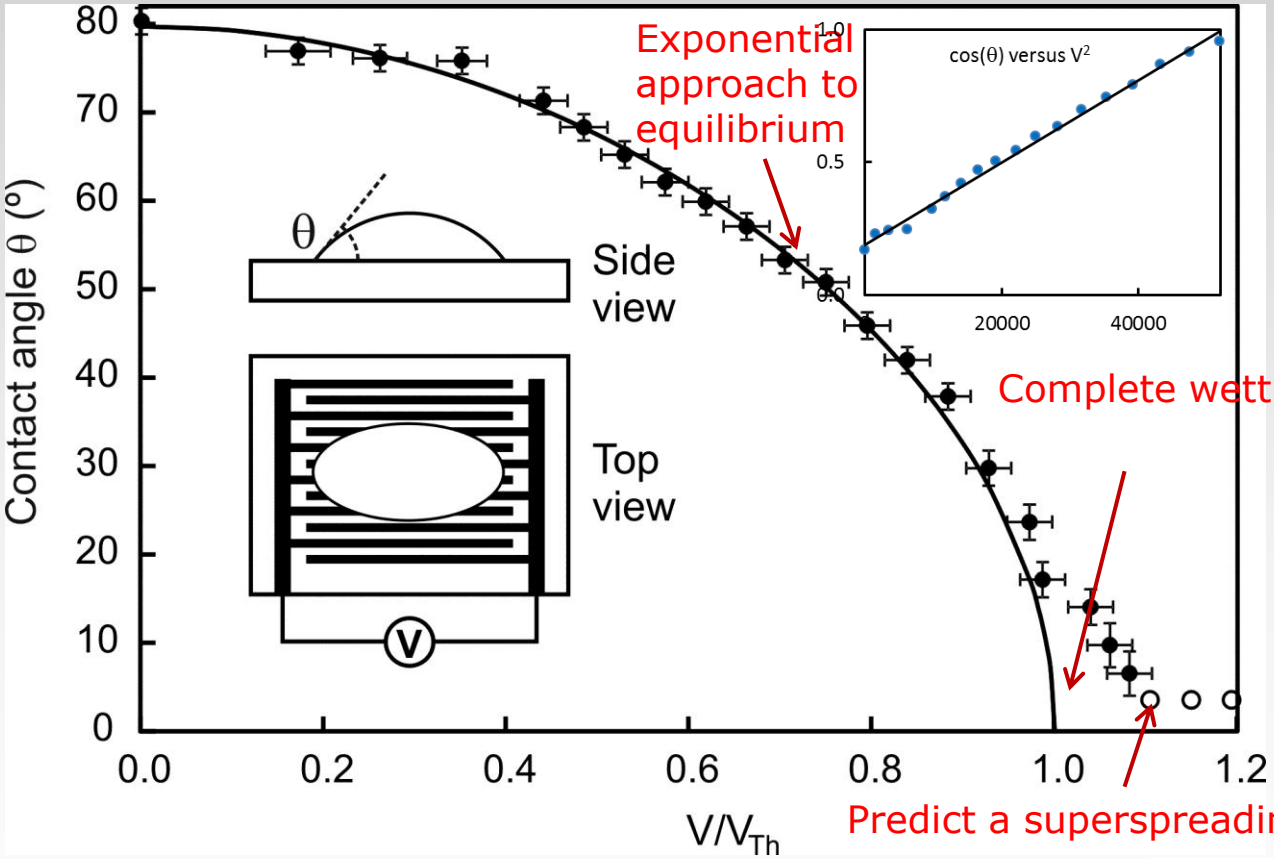
Forcing Spreading without Surfactants



Isotropic material

10 kHz sinewave, 1, 2 propylene glycol, electrode pitch p = 160 μm, initial contact angle 95°

The Dynamics of Wetting



McHale, Brown, et al, Voltage-induced superspreading, submitted 2012.

The Meaning of “A Tale of Two Surfaces”?

What is Research for me?

A means to understand the world around us

A way to develop new tools

An application of imagination, but one that requires us to work within constraints …

In my Empires of solids and liquids with their surfaces

Known scientific principles are both guides and boundaries

And experiments provide paths and roads

But the unspoken Queen and Servant of Science is …… Mathematics

$$v_E \approx k\left(\frac{\gamma_{LV}}{\eta}\right)\theta\left\{\left[1-\cos\theta(t)\right]-\left[1-\cos\theta_Y\right]\left(\frac{V}{V_{Th}}\right)^2\right\}$$

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