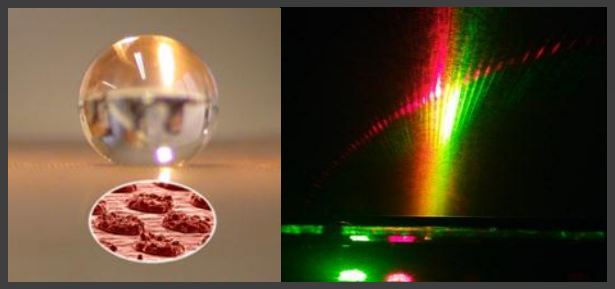
Shaping Liquids, Controlling Surfaces

Professor Glen McHale
Northumbria University

IoP NE Branch, 21st February 2013

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



The World Around Us

northumbria UNIVERSITY

In The Garden

The Man-made World

channels

clothes

windows & roofs

plants & leaves

ponds & insects

soil

grass

The Natural World

northumbria UNIVERSITY

Sinking or Falling?

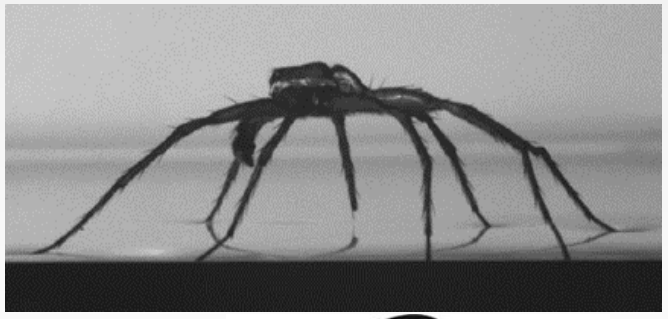
Water-on-Solids

- Liquids sometimes form drops, and sometimes spread over a surface and wet it. Why does this happen?
- Why are raindrops never a metre wide?
- Why don't they run down the window?

Solids-on-Water

- How can pond skaters, and even fishing spiders walk-on-water? Why does this happen?
- How can metal objects "float" on water?

Solids-in-and-Under-Water?



Walking on Water

Microcosmos (Copyright: Allied Films, 1996)

Winners and Losers: Understanding provides a competitive advantage

Size Matters

northumbria UNIVERSITY

Size Matters: Fact or Fiction?

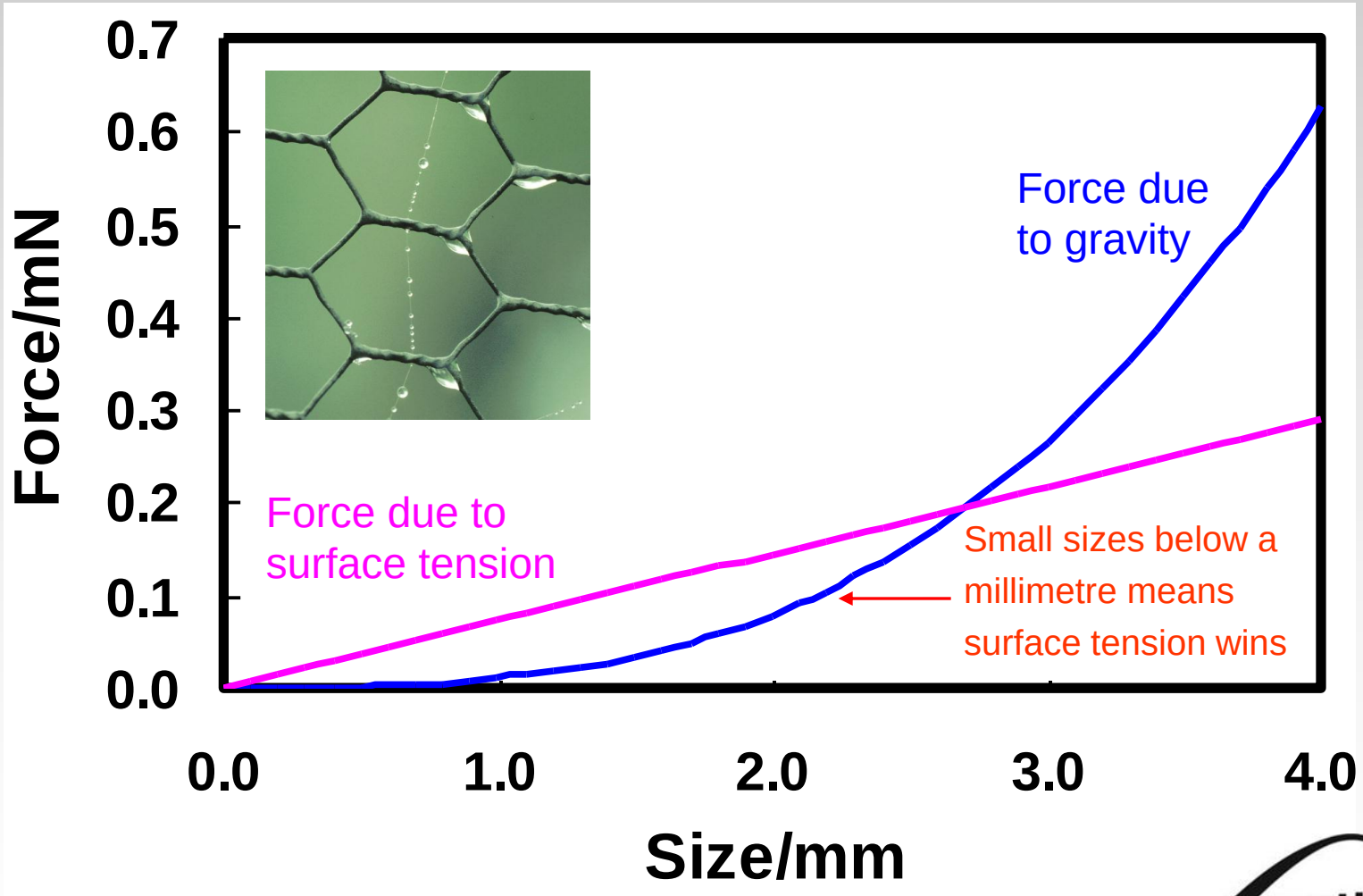
The Movie – Antz (1998)

Courtesy: BigWave Productions

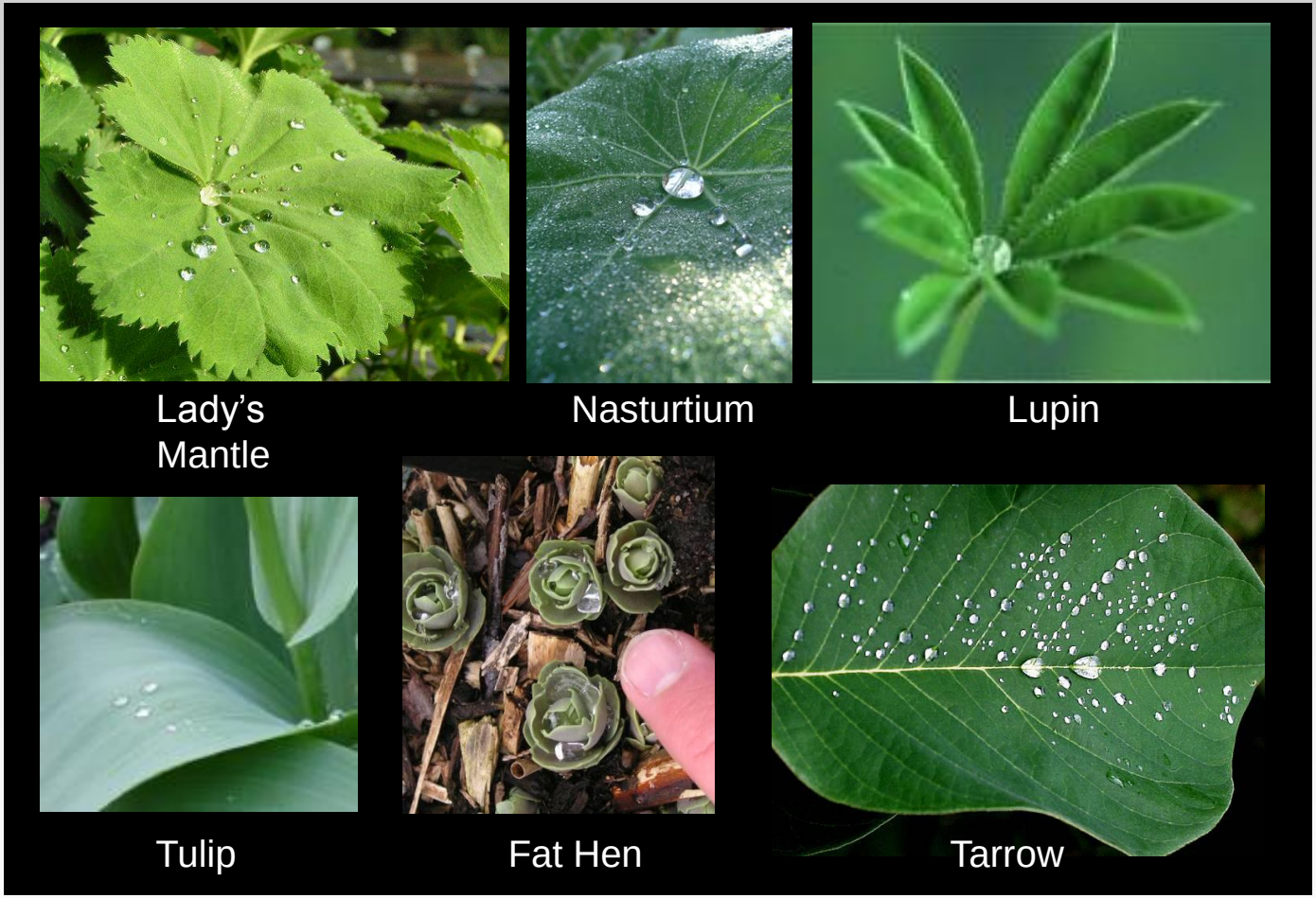
Just imagination?

“Floating” Paperclip – Surface Tension

Surface Tension versus Gravity



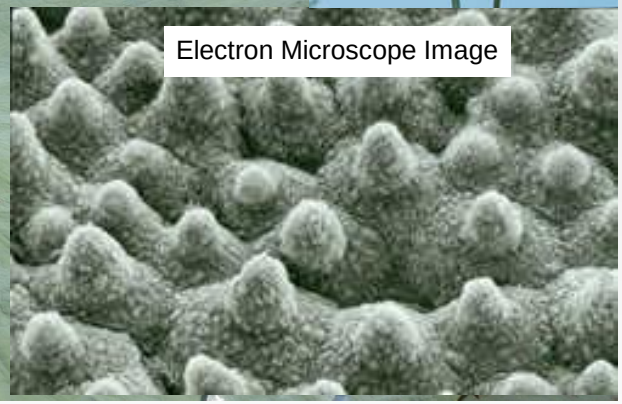
The Surfaces of Leaves



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

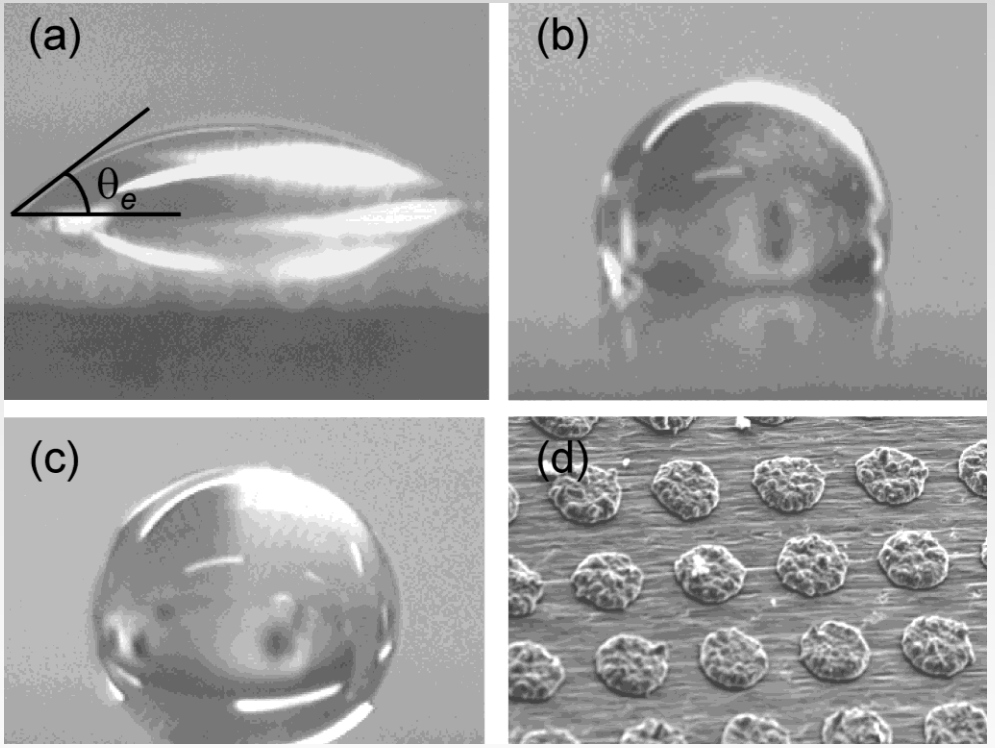
Acknowledgement: Neinhuis & Barthlott

[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



northumbria UNIVERSITY

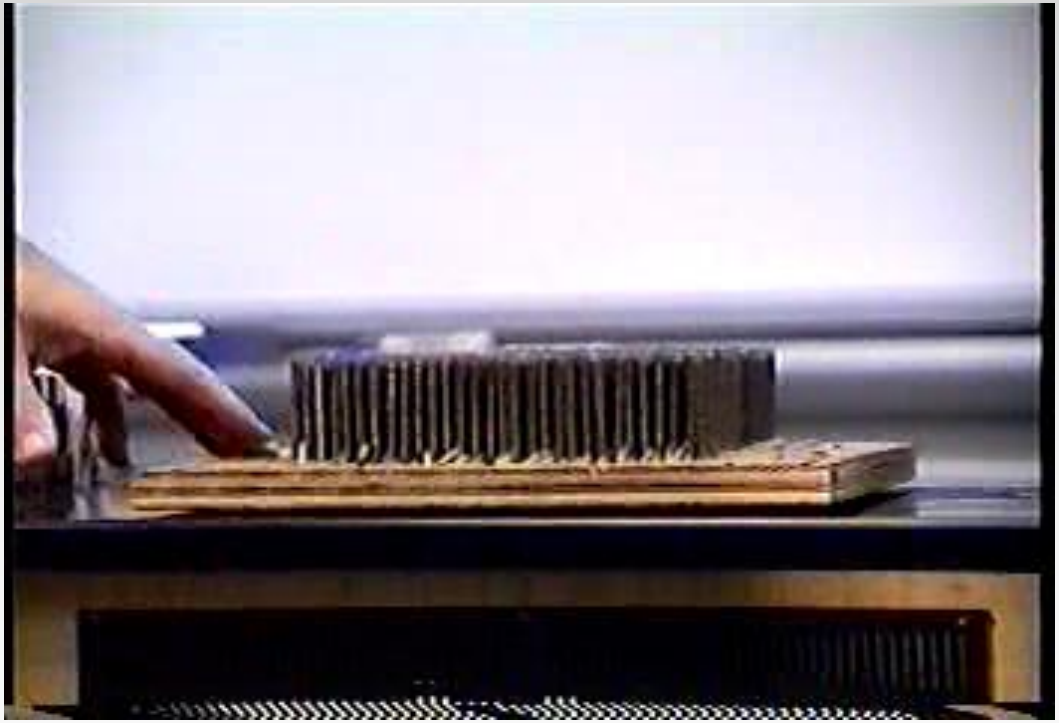
Beds of Nails

northumbria UNIVERSITY

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.

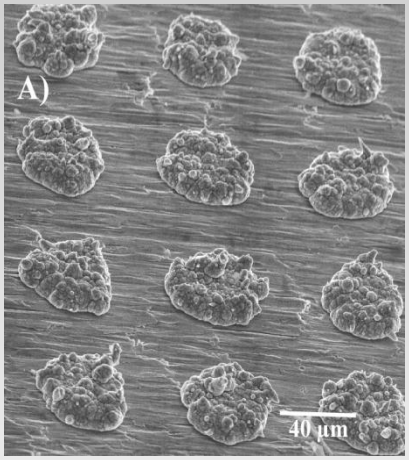
Acknowledgement: Physics, UCLA

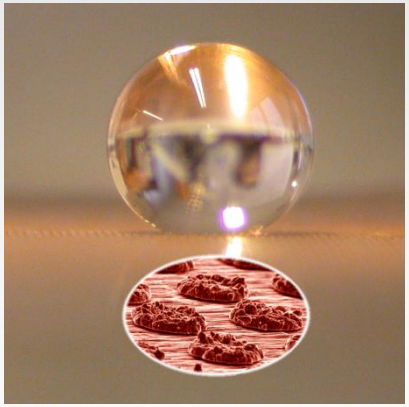


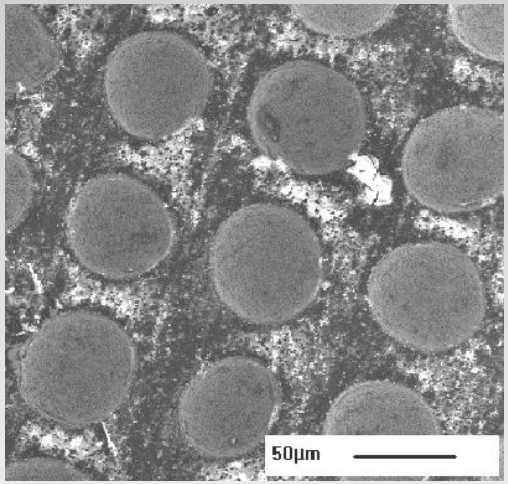
Acknowledgement: Wake Forest University

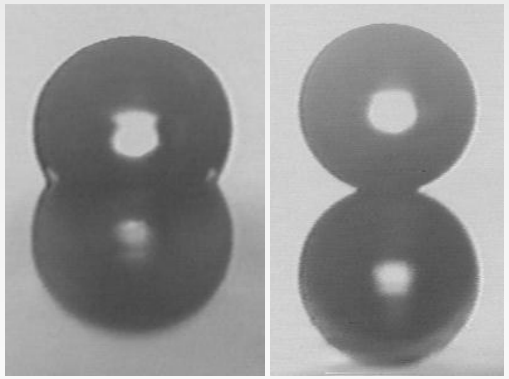
Do Professors Believe Their Science?

Man-made Superhydrophobic Surfaces









Depositing metal
"Choc-chip cookies"

Etching metal
"Lunar landscapes"

Courtesy: Prof. David Quéré, ESPCI
"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

northumbria UNIVERSITY

Sensors - Foams that Switch

Do foams always absorb liquids?

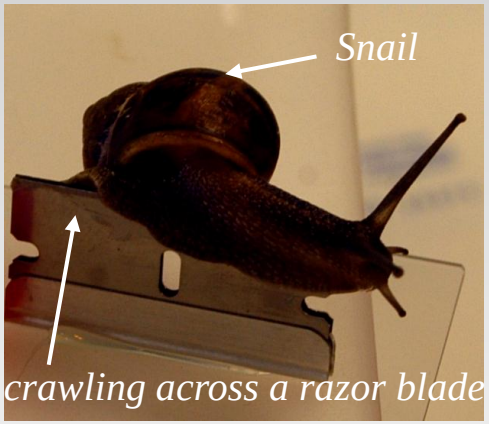
Foam heated (and cooled) prior to droplet deposition

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).

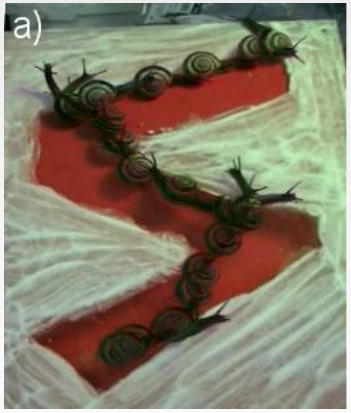
Adhesion - Snails that Slip

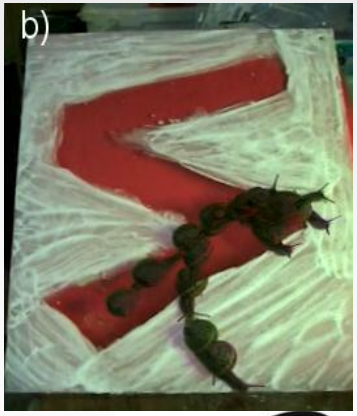
In the battle between super-slippy surfaces and super sticky snails, who wins?



Snail Video

Snail Film.mov



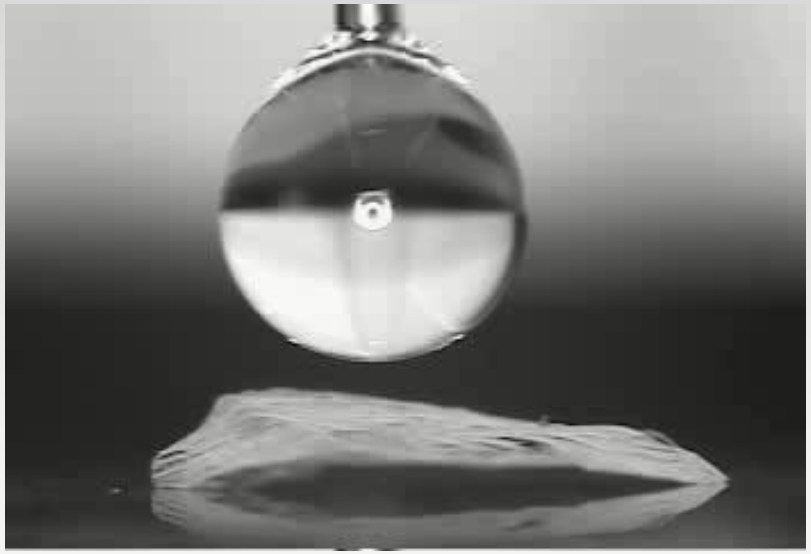


Shirtcliffe, McHale, Newton, Wet adhesion and adhesive locomotion on anti-adhesive non-wetting surfaces, PLoS ONE 7, 2012.

Is Teflon Hydrophobic or Hydrophilic?

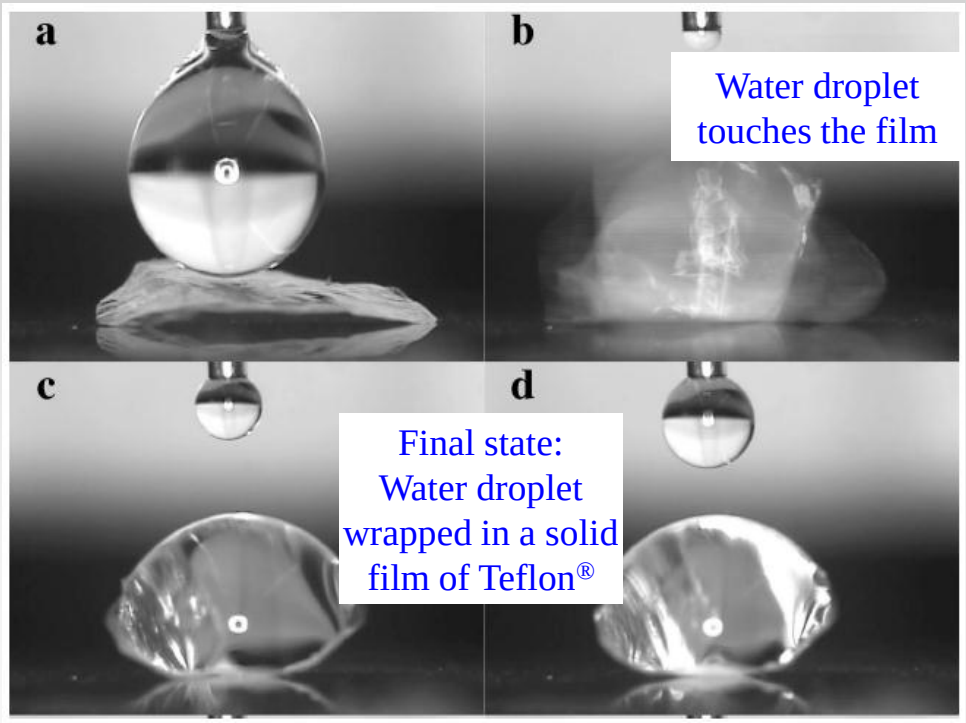
Droplet Wrapping Video

Water drop brought into contact with a film of Teflon



Courtesy: Prof. Tom McCarthy (UMass, Amherst)

Stills from Video



If a droplet wraps itself up in Teflon® ... is this consistent with Teflon® being hydrophobic?

Adhesive Hydrophobicity - Capillary Origami

Can we construct 3D shapes using surface tension?

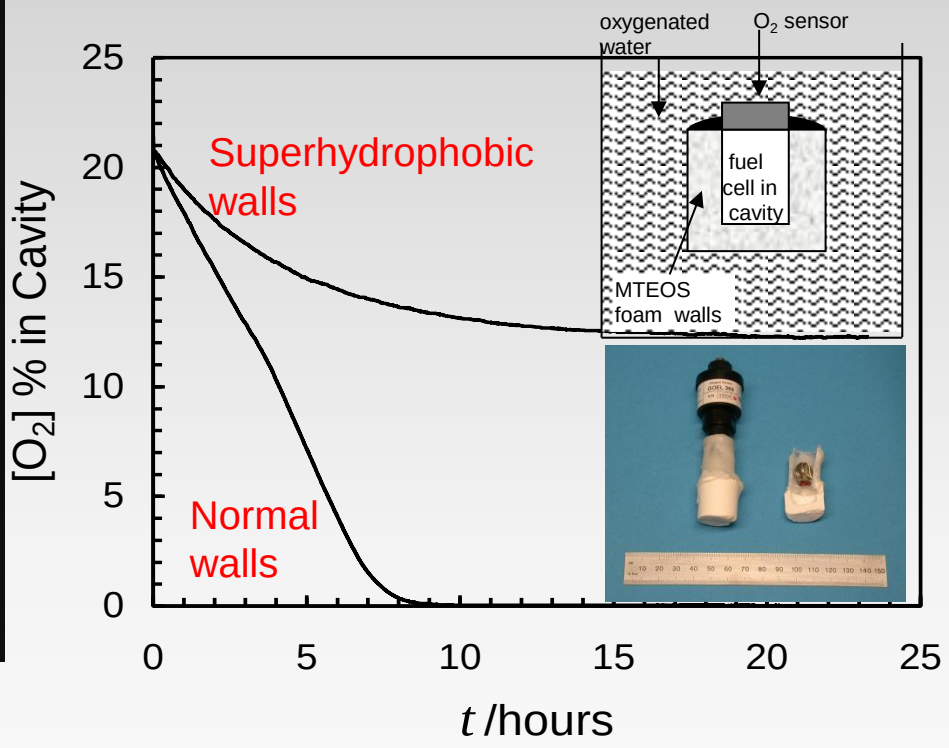
We can design surfaces that cannot feel the adhesive capillary forces

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

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)

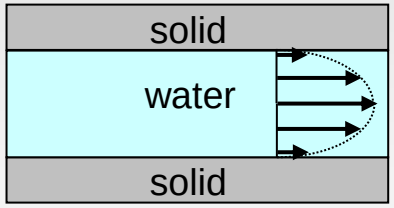
Speaking 9th February 2006

Going with the Flow

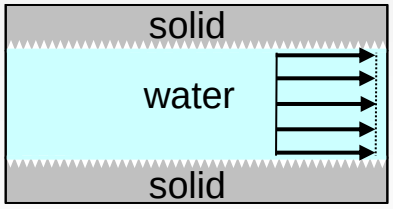
northumbria UNIVERSITY

Liquid Transport - Pipes without Walls

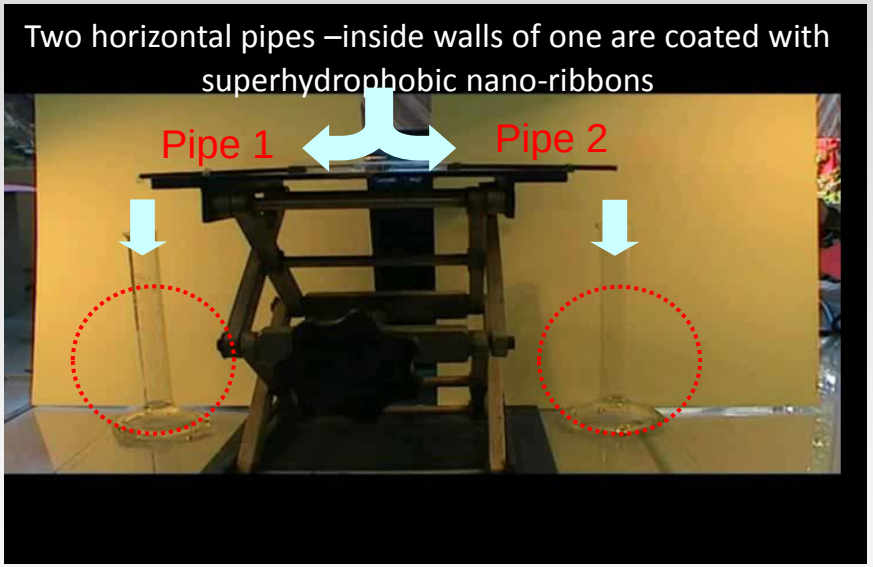
Does water flow through a hydrophobic pipe faster or slower?



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.

Galileo and Apollo 15

In the absence of a fluid, objects of different masses fall under the action of gravity fall at equal rates of acceleration

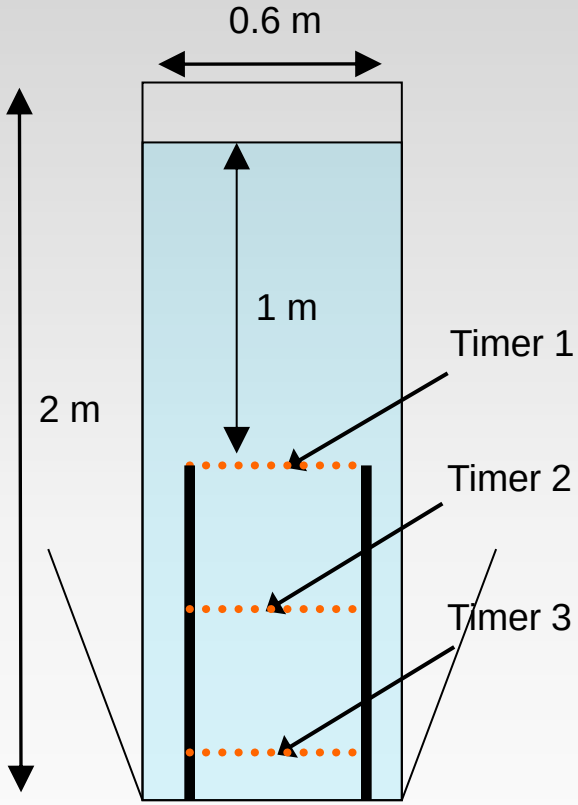
Apollo 15 moon walk, Commander David Scott

Acknowledgement: Wikipedia

Acknowledgement: http://nssdc.gsfc.nasa.gov/planetary/lunar/

Settling Objects – Anti-Buoyancy

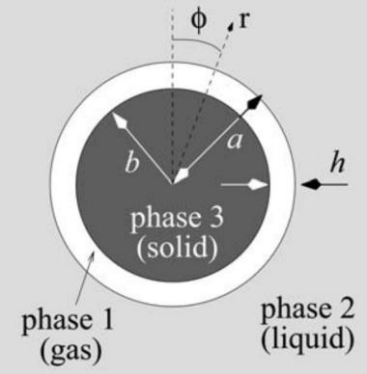
Is the terminal velocity of a sphere settling in water increased or decreased when it carries air?

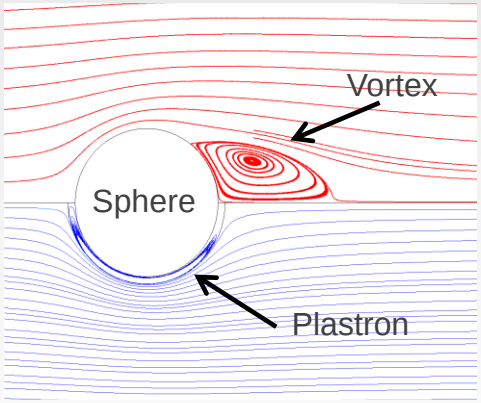


McHale, et al, Terminal velocity and drag reduction measurements on superhydrophobic spheres, Appl. Phys. Lett. 94, 2009.

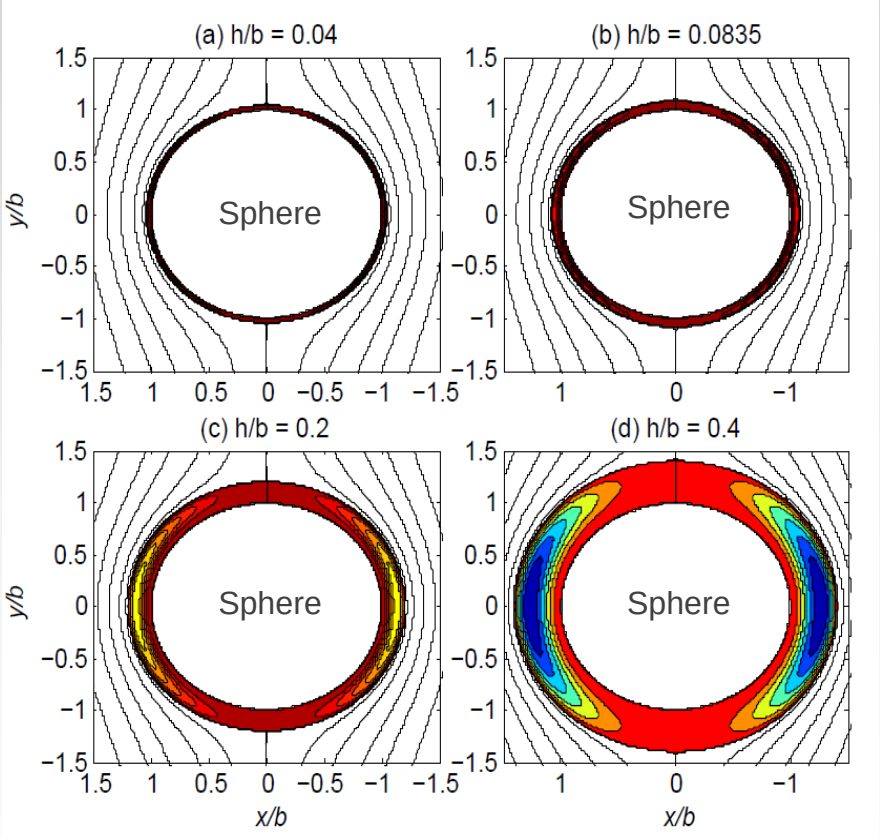
Drag Reduction – Lubricating Flow

Can air lubricate the flow of water past an object?





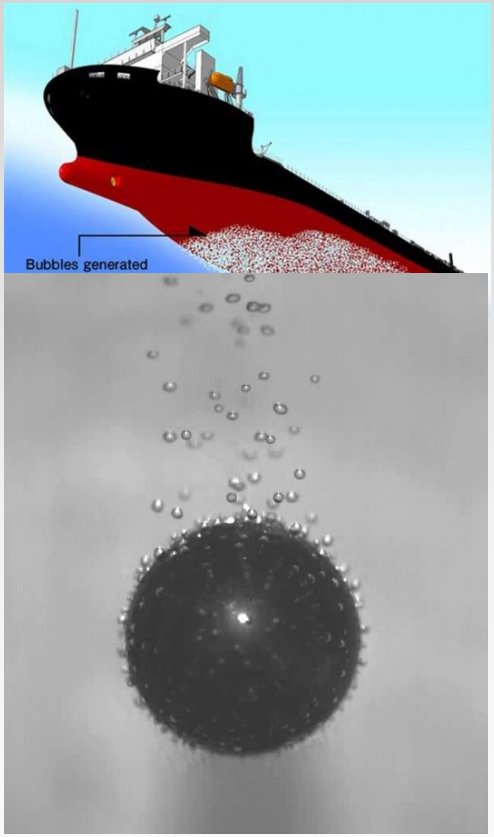
Sandham & Gruncell (Southampton)

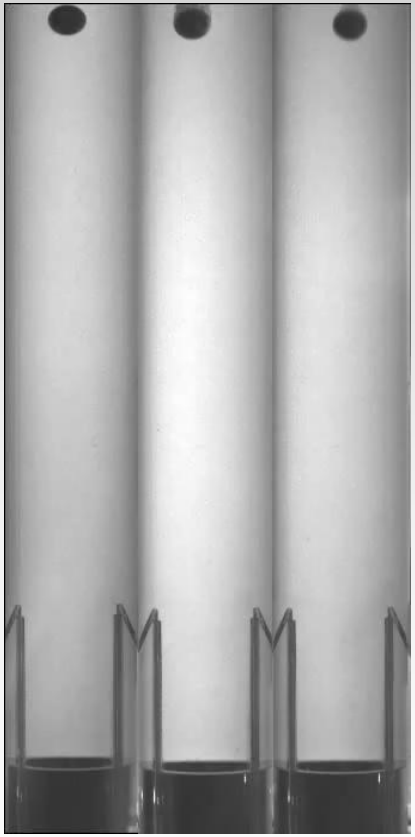


McHale, et al, Plastron induced drag reduction and increased slip on a superhydrophobic sphere, Soft Matter 7, 2011.

Efficient Transport - Futuristic Ships

Can bubbles help ships go faster?





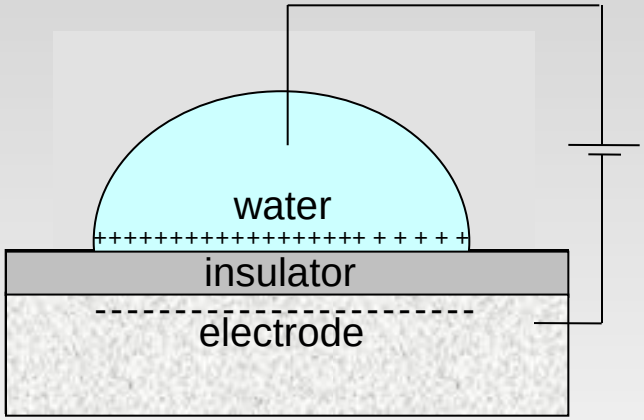
Acknowledgements: Vakarelski et al. Phys. Rev. Lett. 106, 2011. Mitsubishi Air Lubrication Concept.

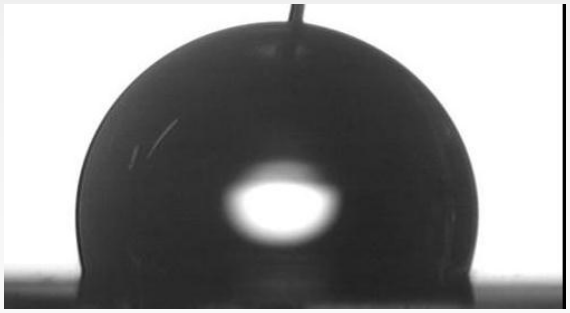
Water-Based Devices

northumbria UNIVERSITY

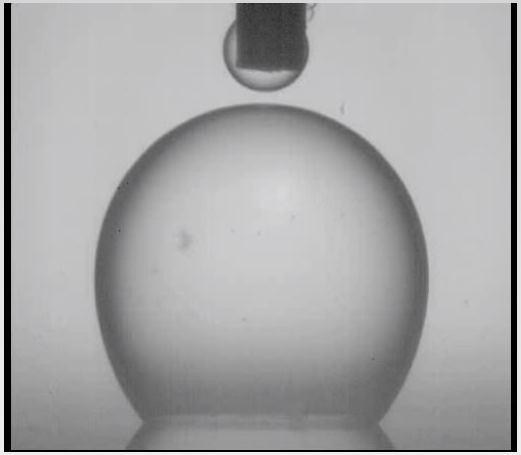
Electrowetting - Shaping Droplets

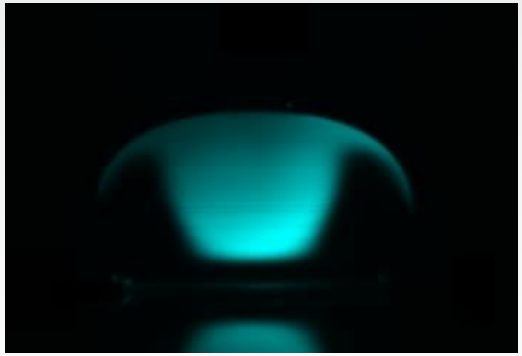
Electrowetting: Droplet in Air





Electrowetting: Water in Oil



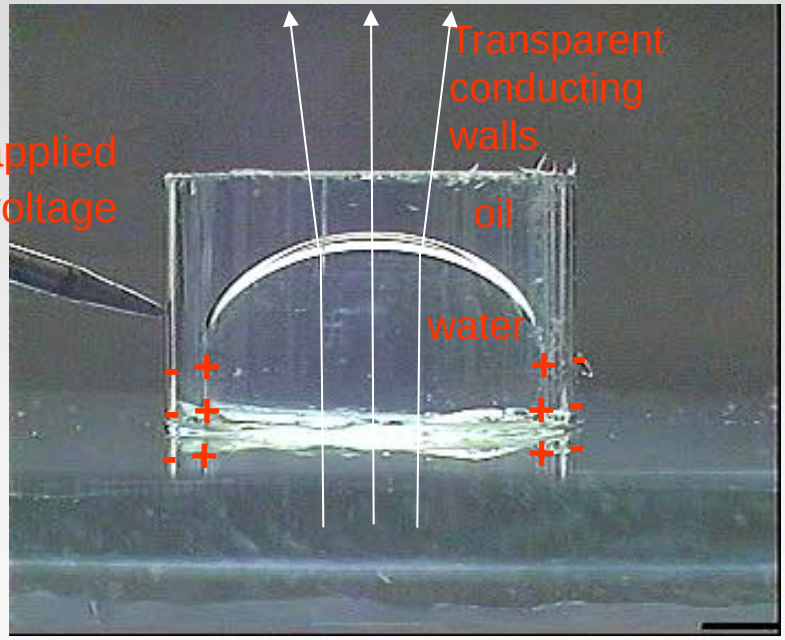


Courtesy: Prof. F. Mugele (Twente)

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

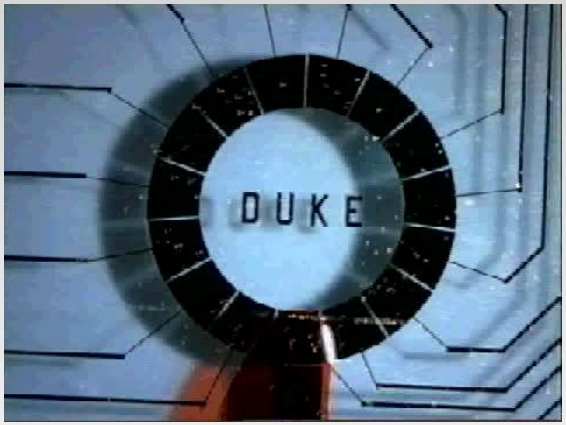


Courtesy: Dr S. Kuiper (Philips Res. Labs, Eindhoven)

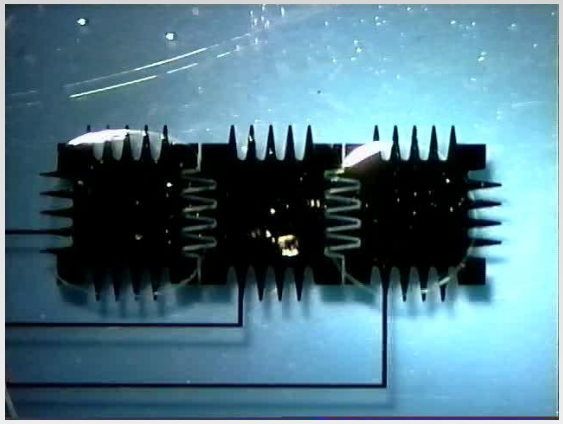
Example 2: Duke's Droplet Microfluidics

Electrowetting to dispense, merge/split/mix and move

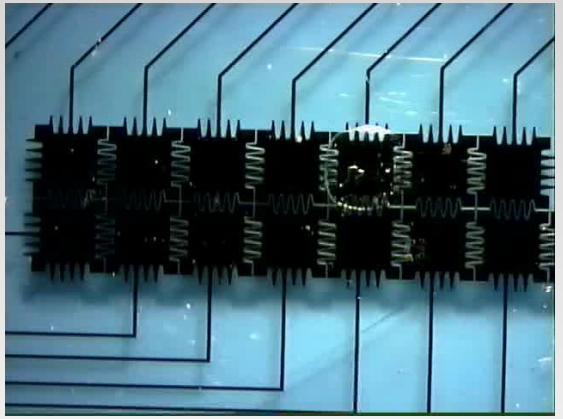
Dispense



Combine/Split



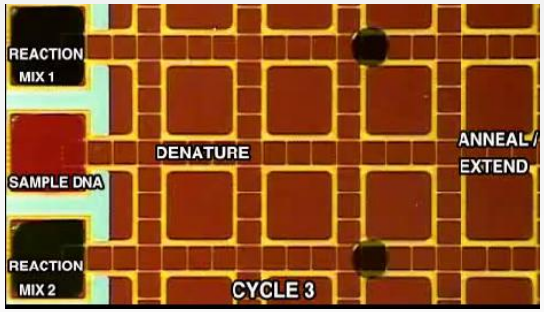
Digital Motion



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

Assays on the size of a credit card

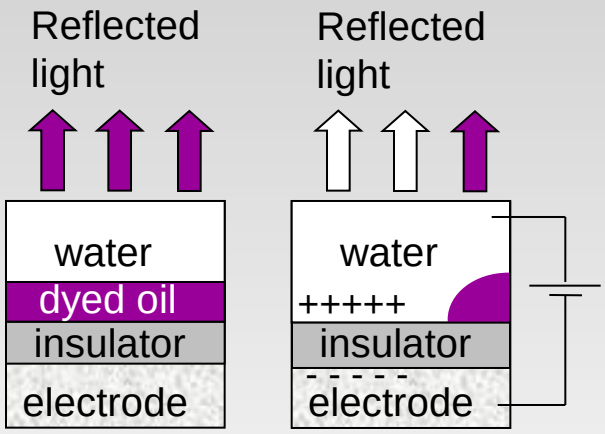
Immunoassays, clinical chemistry, three-enzyme pyrosequencing, enzyme assays for screening newborns, PCR for detecting M pneumonmiae DNA ….



Acknowledgement: Advanced Liquid Logic

Example 3: LiquaVista's Liquid Paper

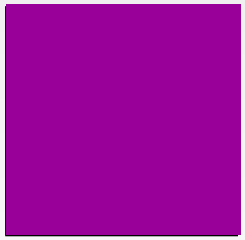
Oil layer-to-droplet transition



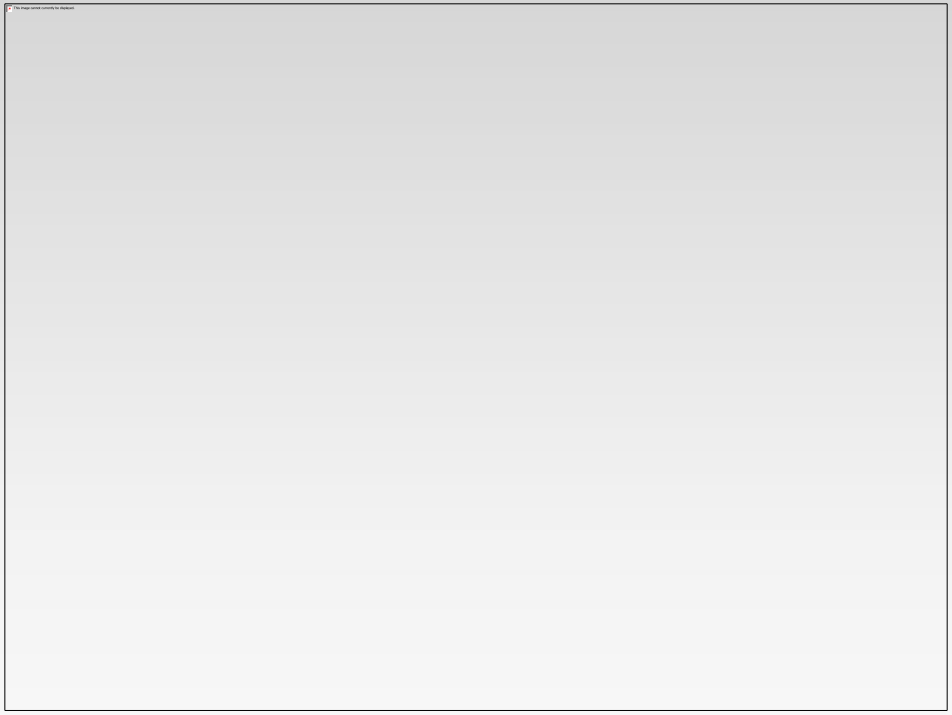
dyed oil

Pixel

(from above)



LiquaVista's Sunlight readable displays



Courtesy: Dr Romaric Massard (LiquaVista, USA)

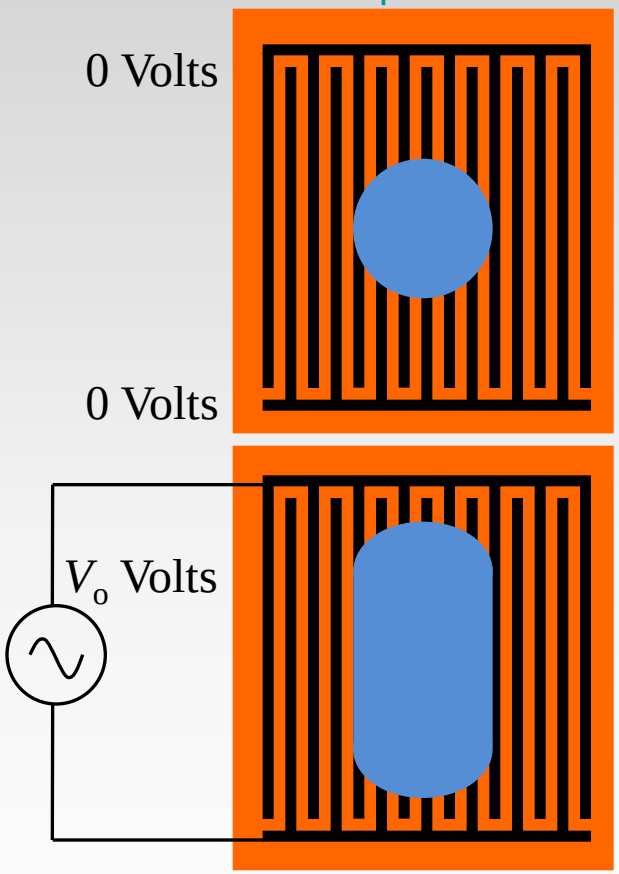
Oil-Based Devices

northumbria UNIVERSITY

Oil Replaces Water - Liquid Dielectrophoresis

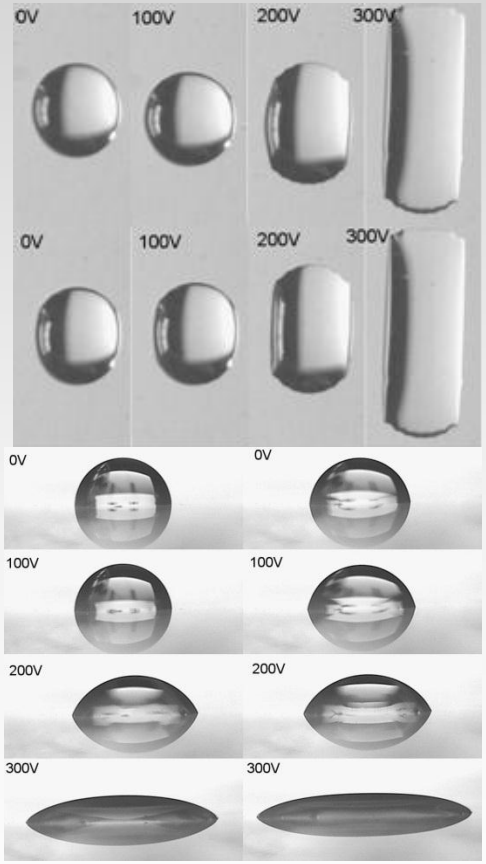
Interdigital Transducers

Top view



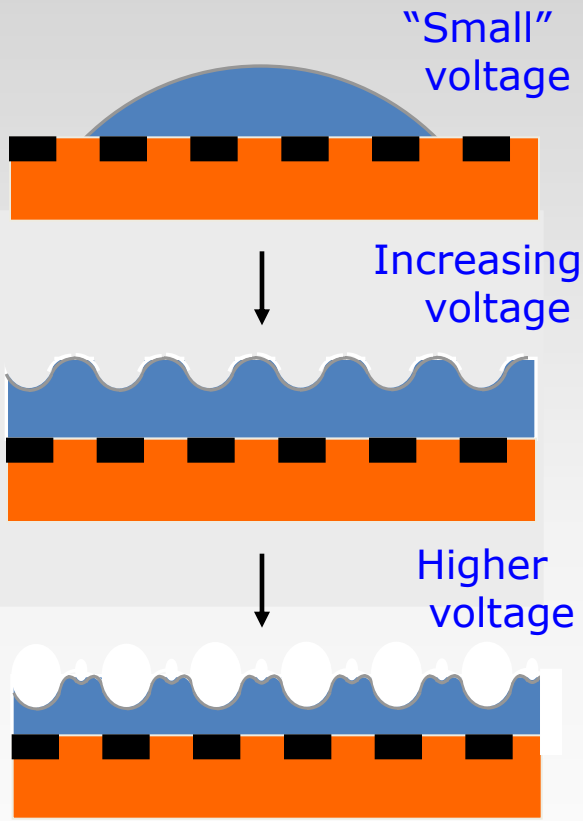
1,2 PPG Droplet

Top and side views*



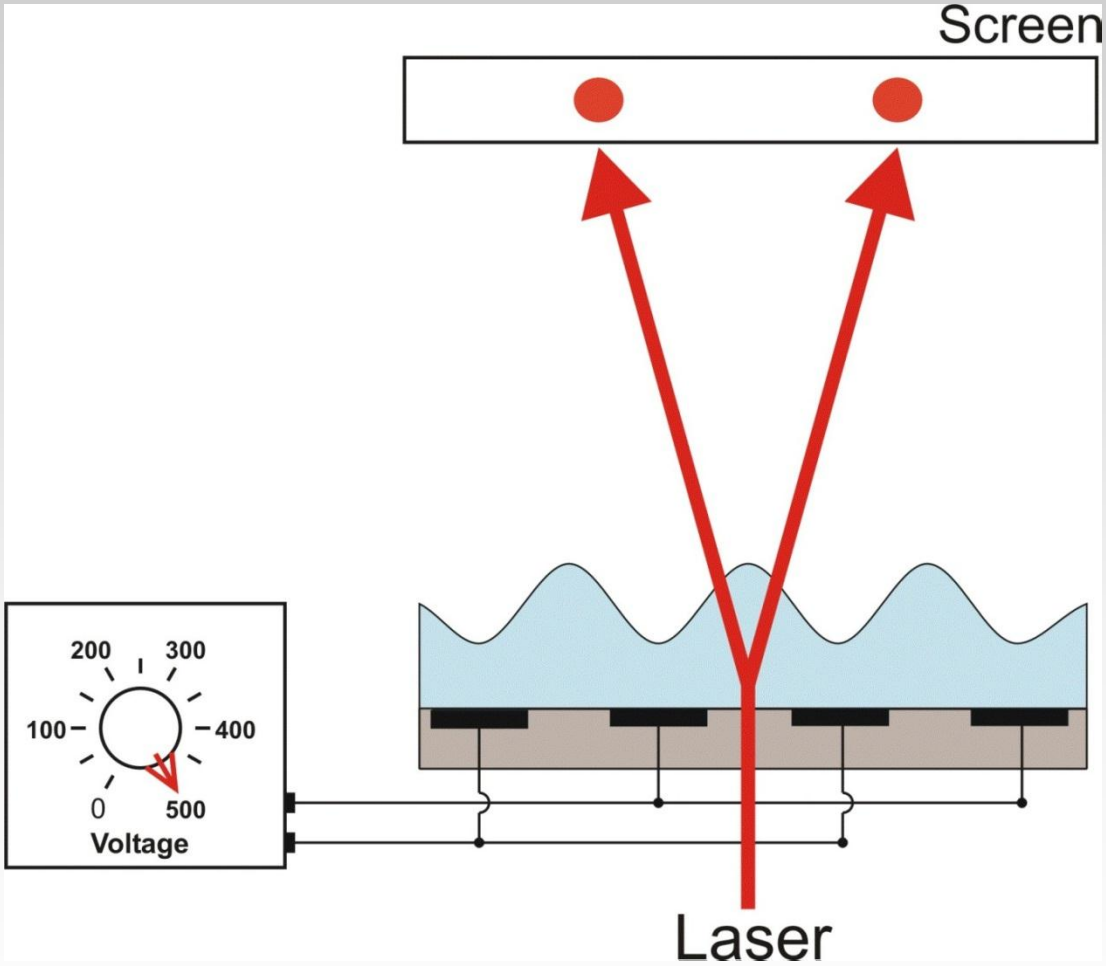
Droplet to Wrinkled Film

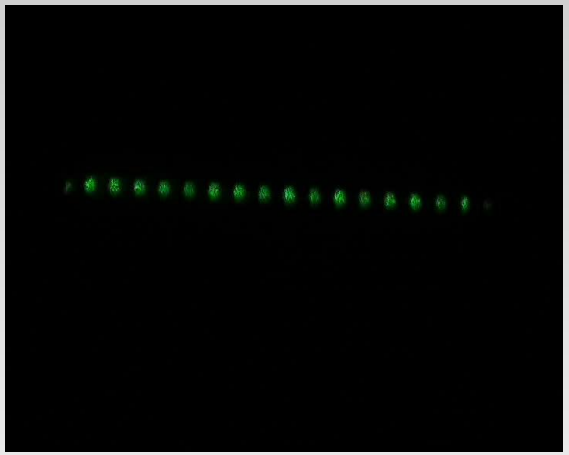
Side view

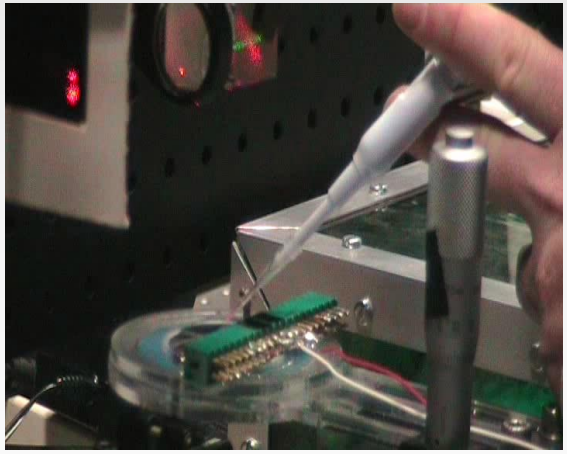


northumbria UNIVERSITY

Beam Steering Using Films of Oil

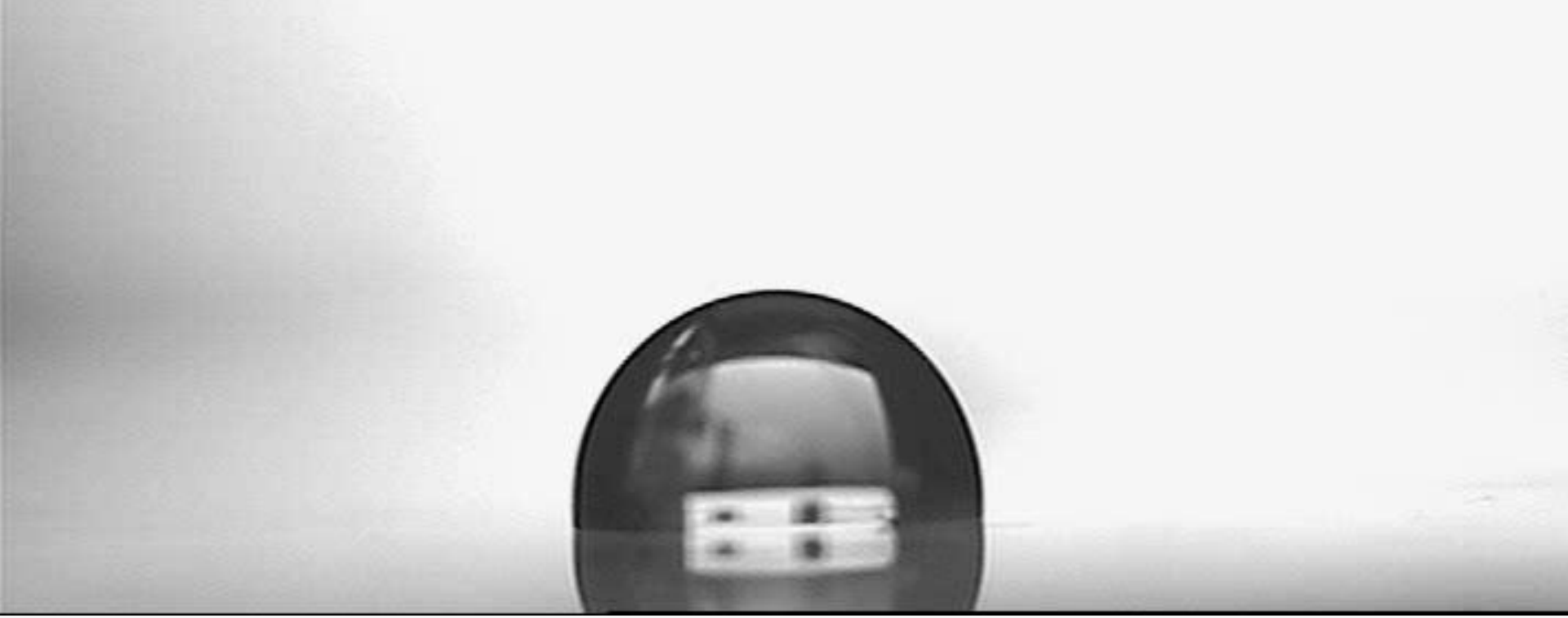






Brown, McHale, et al, Voltage-programmable liquid optical interface, Nature Photonics 3, 2009.

Super-spreading without Surfactants

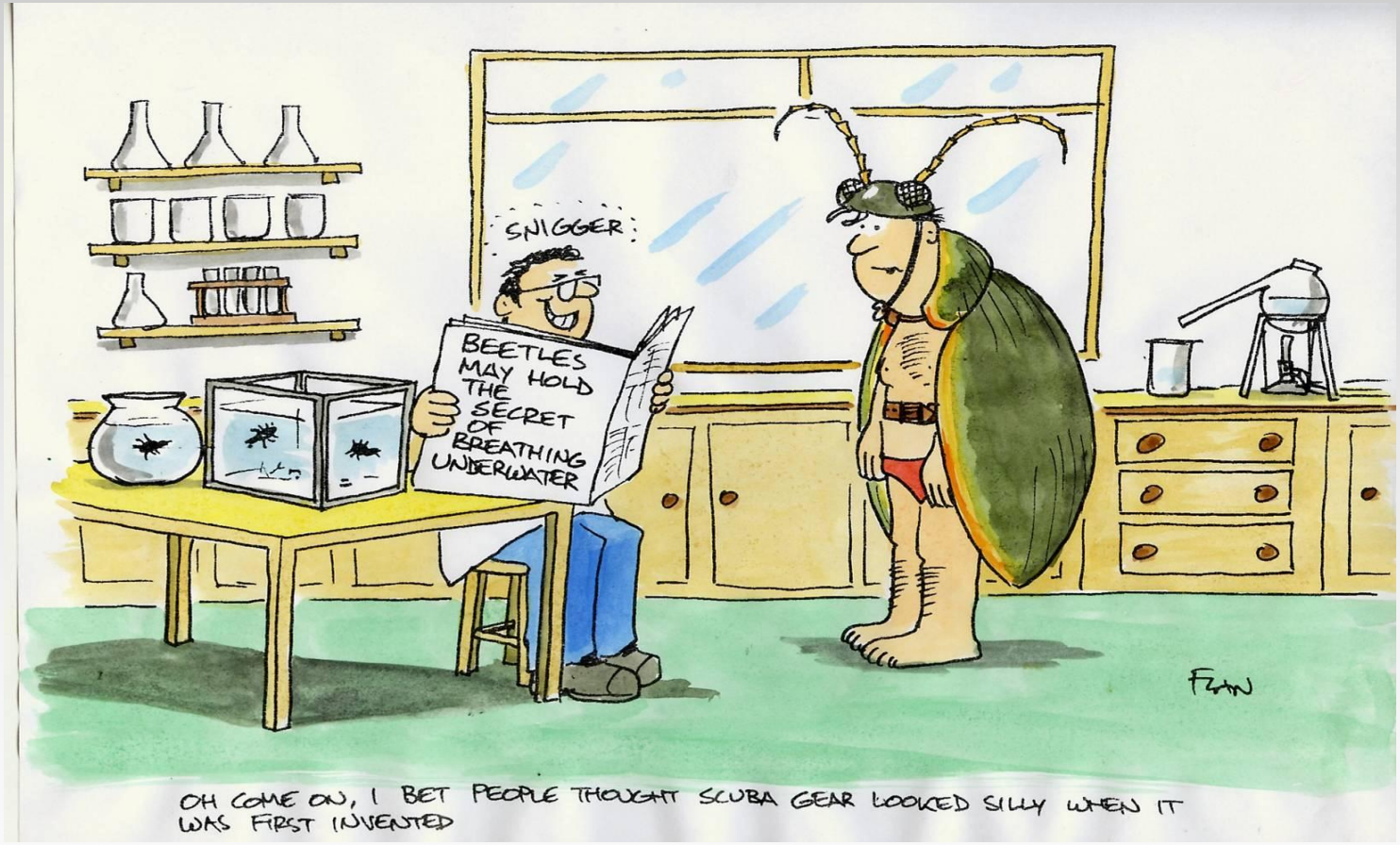


Isotropic material

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

McHale, Brown, et al, Voltage-induced superspreading, Nature Communications 2013.

Appreciation of Science & Engineering?



The End

Acknowledgements

Collaborators

Academics: Dr Mike Newton (NTU: Physics), Prof. Carl Brown (NTU: Physics), Dr Fouzia Ouali (NTU: Physics), Prof. Carole Perry (NTU: Chemistry), Prof. Brian Pyatt (NTU: Bio Sci.), Prof. Stefan Doerr (Swansea: Geography), Dr Rob Bryant (Swansea, Geography), Prof. Neil Sandham (Southampton: Engineering), Dr Martyn Prince (Southampton: Wolfson Unit), Mr Ian Campbell (Southampton: Wolfson Unit), Prof. Julia Yeomans (Oxford: Physics), Dr Morris Flynn (Alberta), Prof. Jorg Bachmann (Hannover: Soil Physics)

Industry: Dr Stuart Brewer (Dstl), Dr Andrew Clarke (Kodak/Schlumberger), John Fyson (Kodak), Dr Scott Drawer (UK Sport)

PDRA's Dr Neil Shirtcliffe, (Rhien-Waal), Dr Carl Evans, Dr Gary Wells, Dr Yong Zhang, Dr Chris Hamlett, Dr Simon Stanley, Dr Rob Morris, Dr Christophe Trabi, Dr Angela Busse, Dr Paul Roach, Dr Dale Herbertson

PhD's Dr Sanaa Aqil, Dr Steve Elliott, Dr Nicola Doy, Dr Shaun Atherton, Dr Gary Wells, Mr Naresh Sampara, Mr Jo Brennan, Mr Nic Geraldi, Mr Haadi Javed, Mr Brian Gruncell, Ms Sujung Ahn

+ Collaborators, former colleagues, students and research fellows whose joint work has not been mentioned today.

Group website and reprints: http://www.naturesraincoats.com/