NOTTINGHAM TRENT UNIVERSITY

Water: A tale of two surfaces

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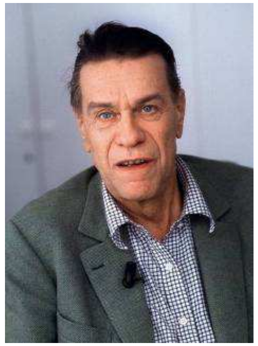
10th November 2008

A DVD of the presentation showing embedded videos and demonstrations is available from the NTU Institutional Repository (http://irep.ntu.ac.uk/). glen.mchale@ntu.ac.uk

The Journey's Origin

"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"



Acknowledgement: Le Figaro

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

A founder of Soft Condensed Matter Physics

"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, …)"

In The Garden

Surfaces and Materials

The Man-made World

channels

clothes

windows & roofs

plants & leaves

ponds & insects

soil

The Natural World

The Great Empires

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.

Insects at the Water's Surface

Walking on Water

Microcosmos (Copyright: Allied Films, 1996)

Winners and Losers: Understanding provides a competitive advantage

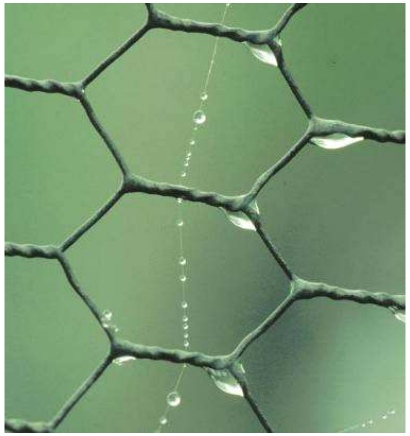
Surface Tension

Liquid Surface

Molecules at a surface have fewer neighbours

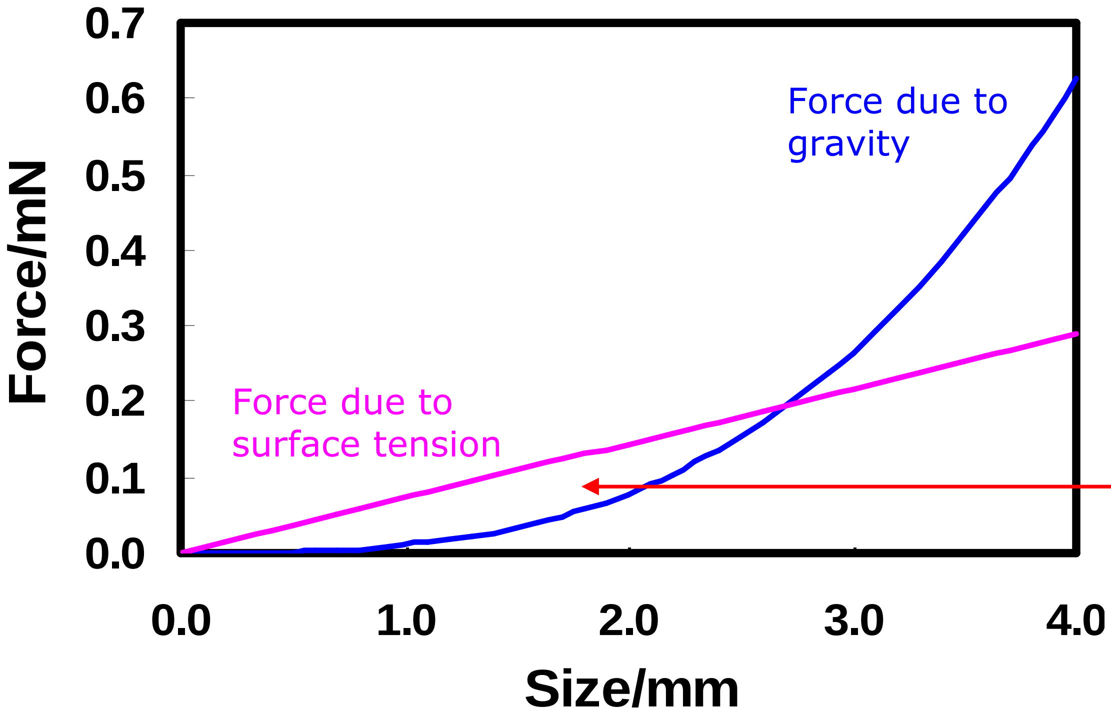
Liquid surface ("skin") behaves as if it is in a state of tension

For a free "blob", the smallest area is obtained with a sphere



http://www.brantacan.co.uk

Surface Tension v Gravity



Small sizes below a millimetre means surface tension wins

Size Matters: Fiction or Fact?

Courtesy: BigWave Productions

The Movie – Antz (1998)

Copyright: DreamWorks Animation (1996)

Is it just imagination?

Or could it happen?

Surface Tension Demonstration

Surfaces of Plants and Leaves

Plants and Leaves

Lady’s Mantle

Nasturtium

Lupin

Tulip

Fat Hen

Tarrow

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

The Sacred Lotus Leaf

Plants

Many leaves are super-water repellent (i.e. droplets completely ball up and roll off their surface)

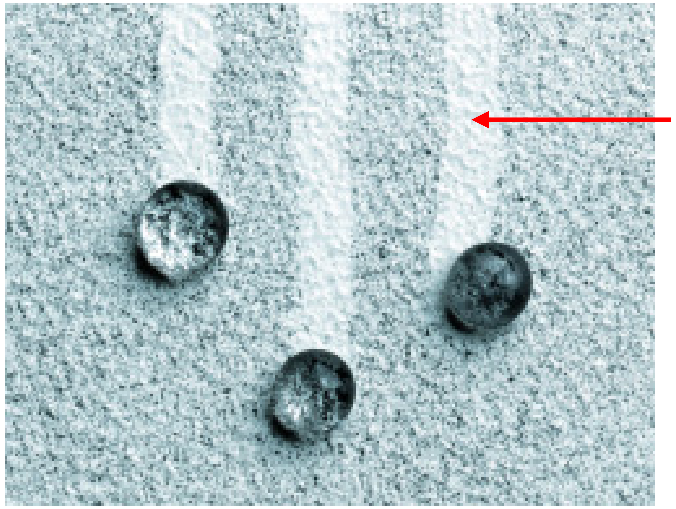
The Lotus plant is known for its purity

Some leaves are self-cleaning (*under the action of rain*)

Microscope Image of Lotus Leaf

Acknowledgement: Neinhuis and Barthlott

Self-Cleaning Glass



Dust cleaned away

Acknowledgement: BASF

Mimicking the Surfaces in Nature

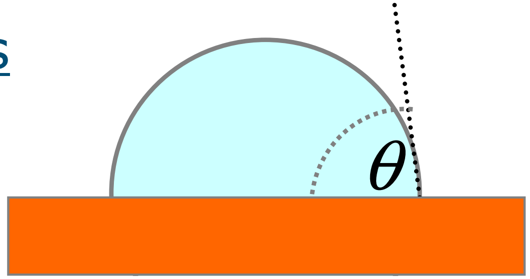
Hydrophobicity and Superhydrophobicity

Surface Chemistry

Terminal group determines whether surface is water hating

Hydrophobic terminal groups are Fluorine (CF_x) and Methyl (CH_3)

Contact Angles on Teflon Coated Frying Pans

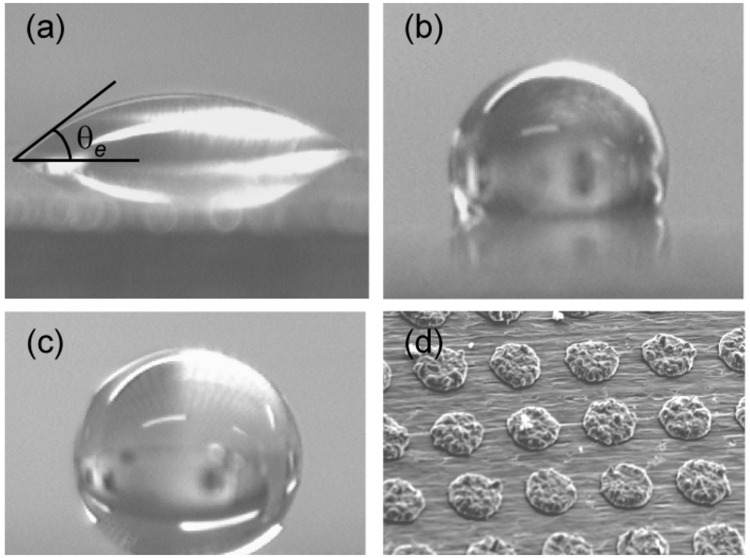


Characterize hydrophobicity

Water-on-Teflon gives ~ 115°

The best that *chemistry* can do

Physical Enhancement



(a) is water-on-copper

(b) is water-on-fluorine coated copper

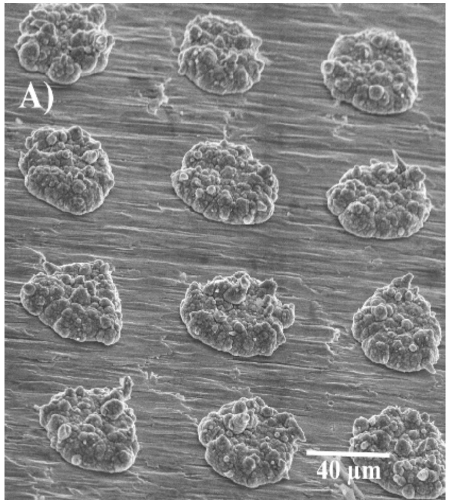
(c) is a super-hydrophobic surface

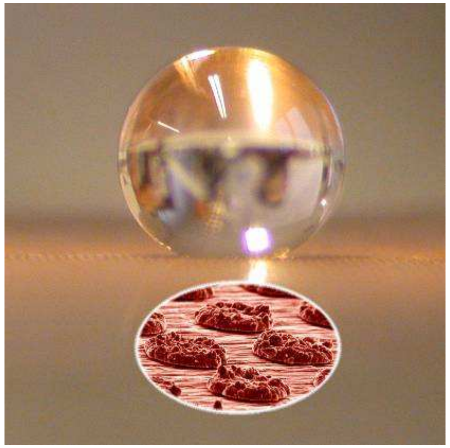
(d) "chocolate-chip-cookie" surface

Superhydrophobicity is when θ>150°
and a droplet easily rolls off the surface

Mimicking Superhydrophobic Surfaces

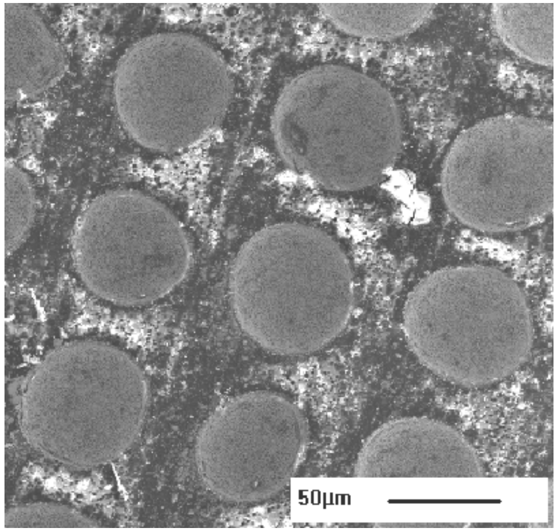
Deposited Metal

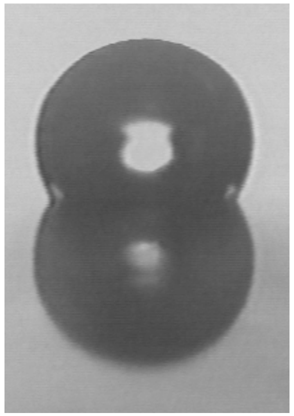




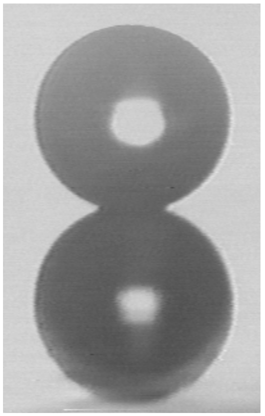
Patterned & hydrophobic

Etched Metal



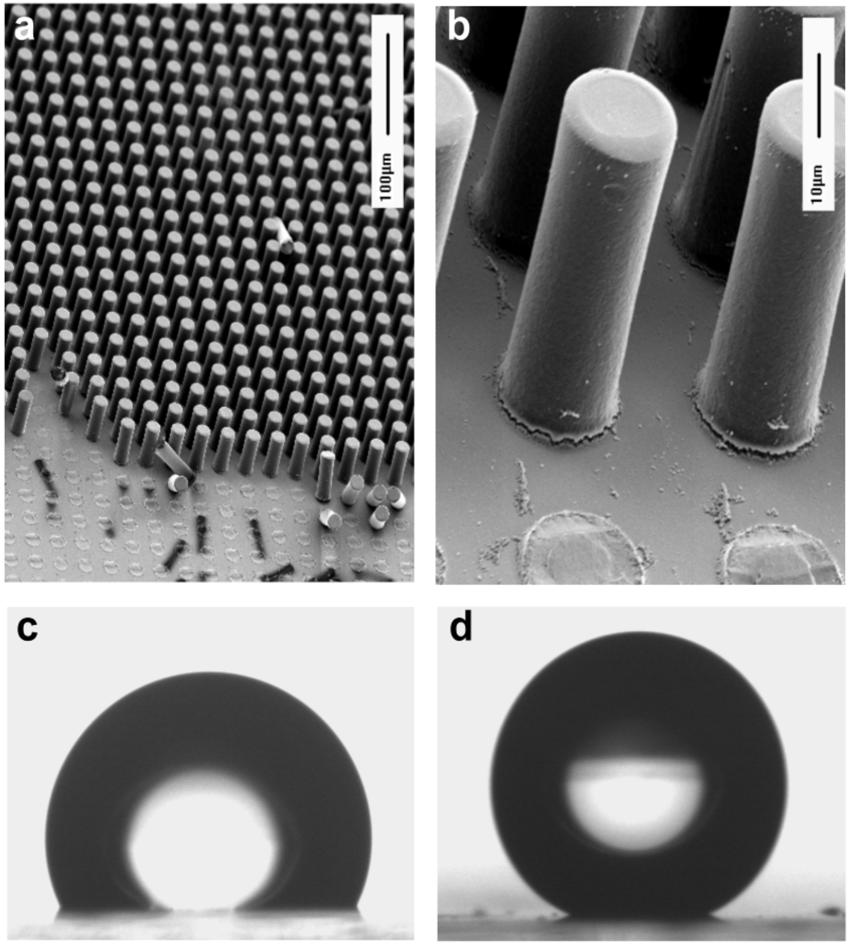


Flat & hydrophobic



Patterned & hydrophobic

Polymer Microposts



Flat & hydrophobic

Patterned & hydrophobic

NTU Superhydrophobic Materials Demonstration

The Fakir’s Carpet

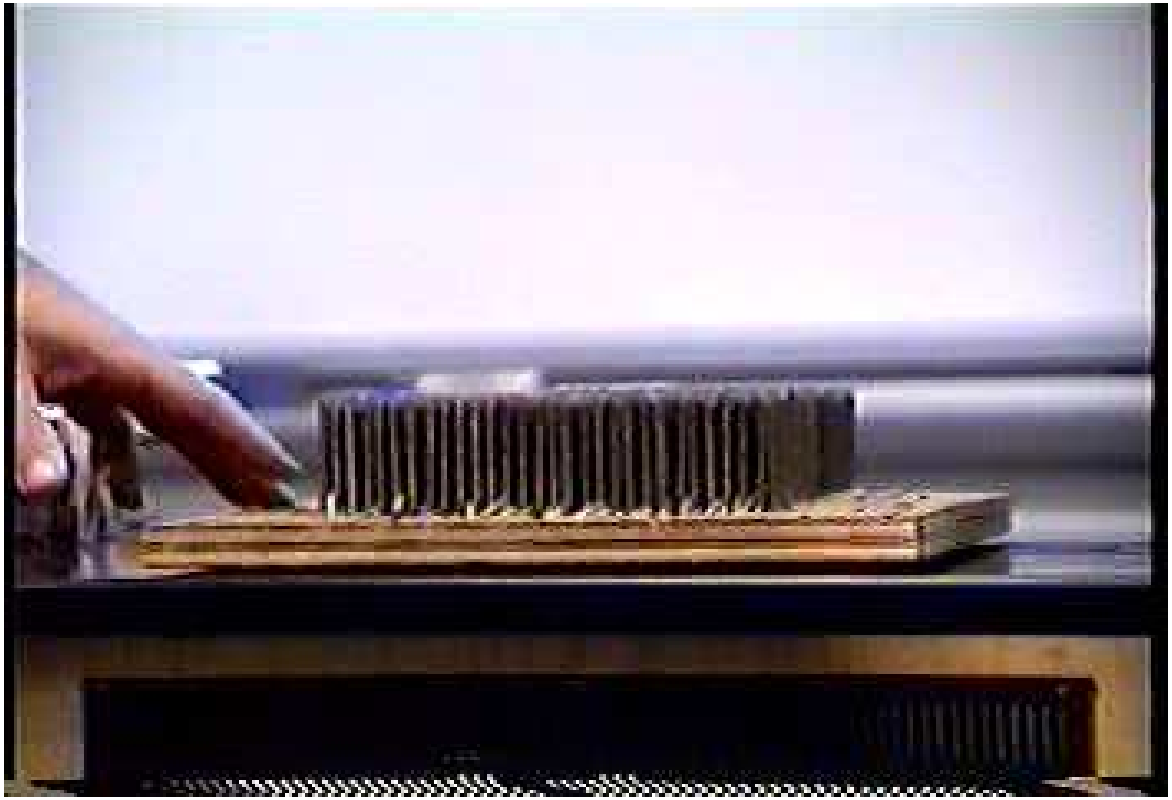
Bed of Nails

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

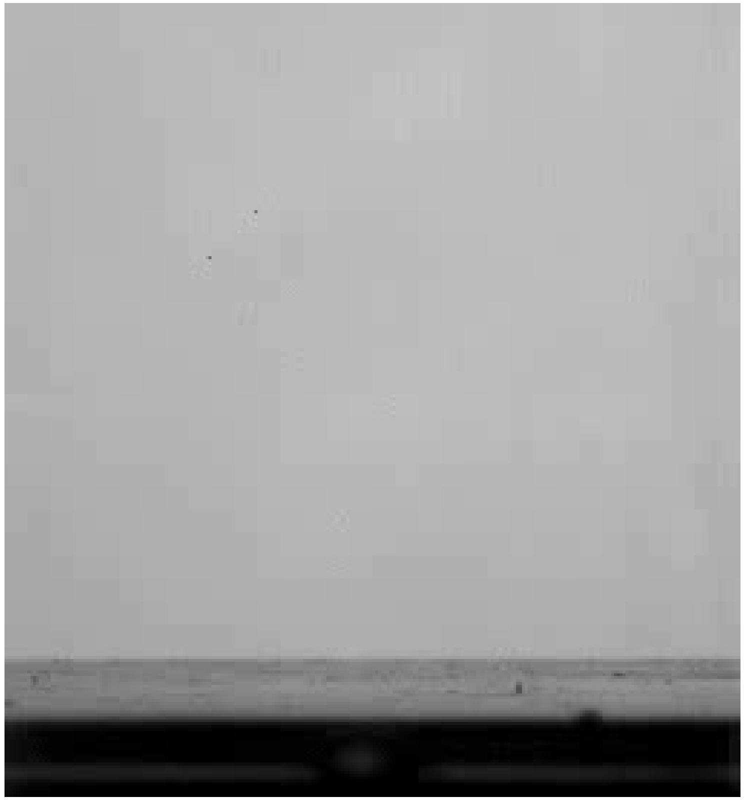
Acknowledgement: Physics, UCLA

Fakir’s Carpet Demonstration

Fakir's Carpet and Bouncing Droplets

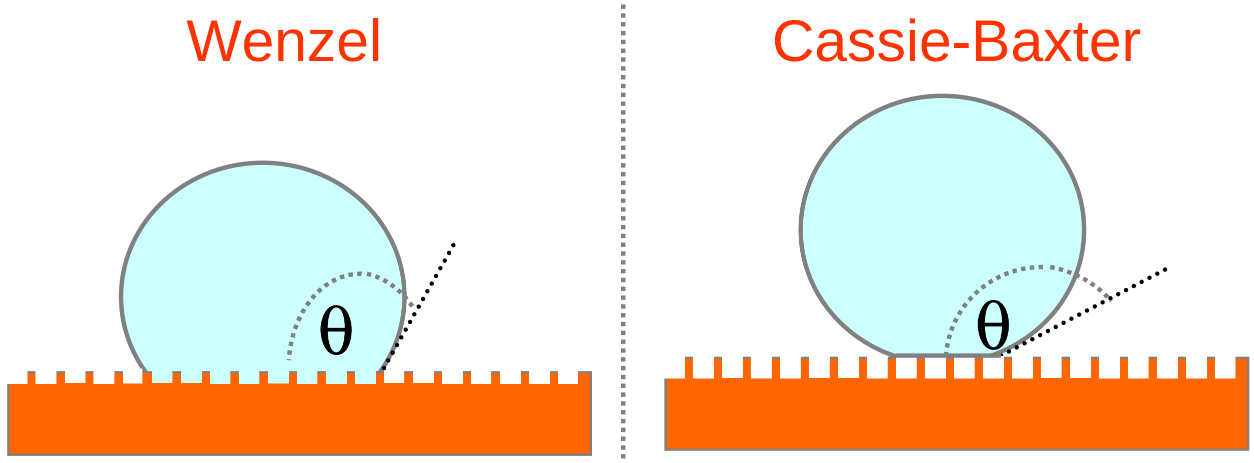


Acknowledgement: Wake Forest University



Courtesy: Prof. David Quéré, ESPCI

Penetrating versus Skating



<u>Surface Chemistry and Surface Structure</u>

Provided our “nails” are tall, thin and close enough and we make them hydrophobic (water-repellent), water can skate across their tips

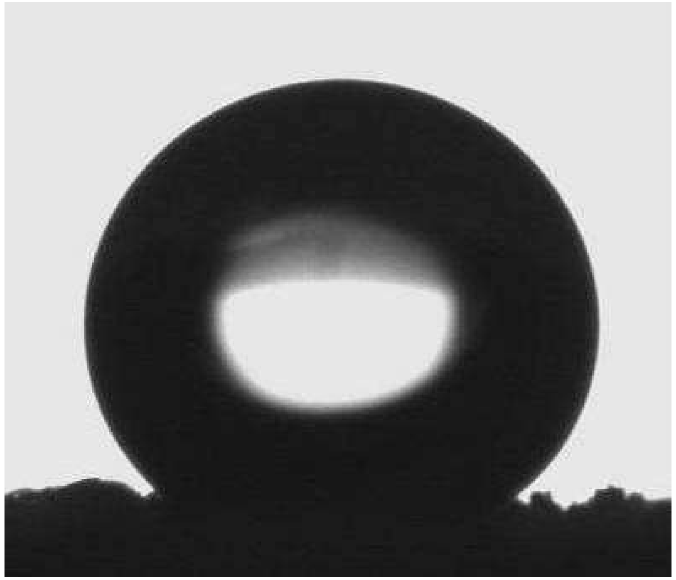
A droplet of water sitting on a composite air-solid interface balls up

The Surface of Hydrophobic Soil

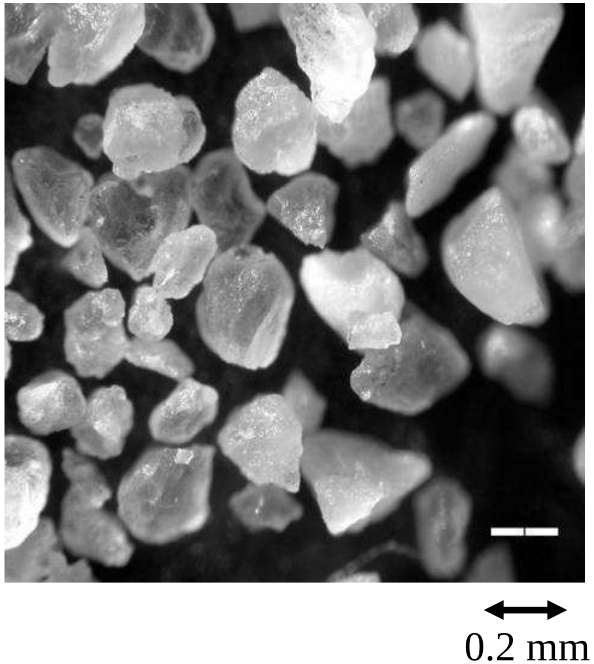
Sand Demonstration

Super Water-Repellent Sand/Soil

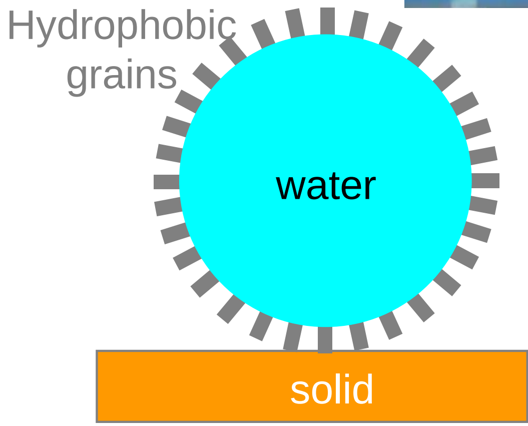
Sand with 139°



Shape and Packing



Liquid Marbles



Hydrophobic sand occurs naturally, but can also be reproduced in the lab

Hydrophobic sand sticks to the surface of water to form a liquid marble

Hydrophobic Soil - Occurrence

Forests

Farmland

Golf courses

Overland flow,
soil erosion and
land remediation

Gray water and irrigation

Localized dry spots

<u>Courtesy</u>: Dr Stefan Doerr (Swansea),
Dr Pete Robinchaud (USDA- Forest Service), Dr Margaret Roper (CSIRO, Australia).

Forest Fire and Debris Slide

Courtesy: Dr P. Robinchaud USDA- Forest Service. Video footage courtesy, Devore resident, Mr. Davis showing Greenwood Ave. Devore CA. 25/12/2003.

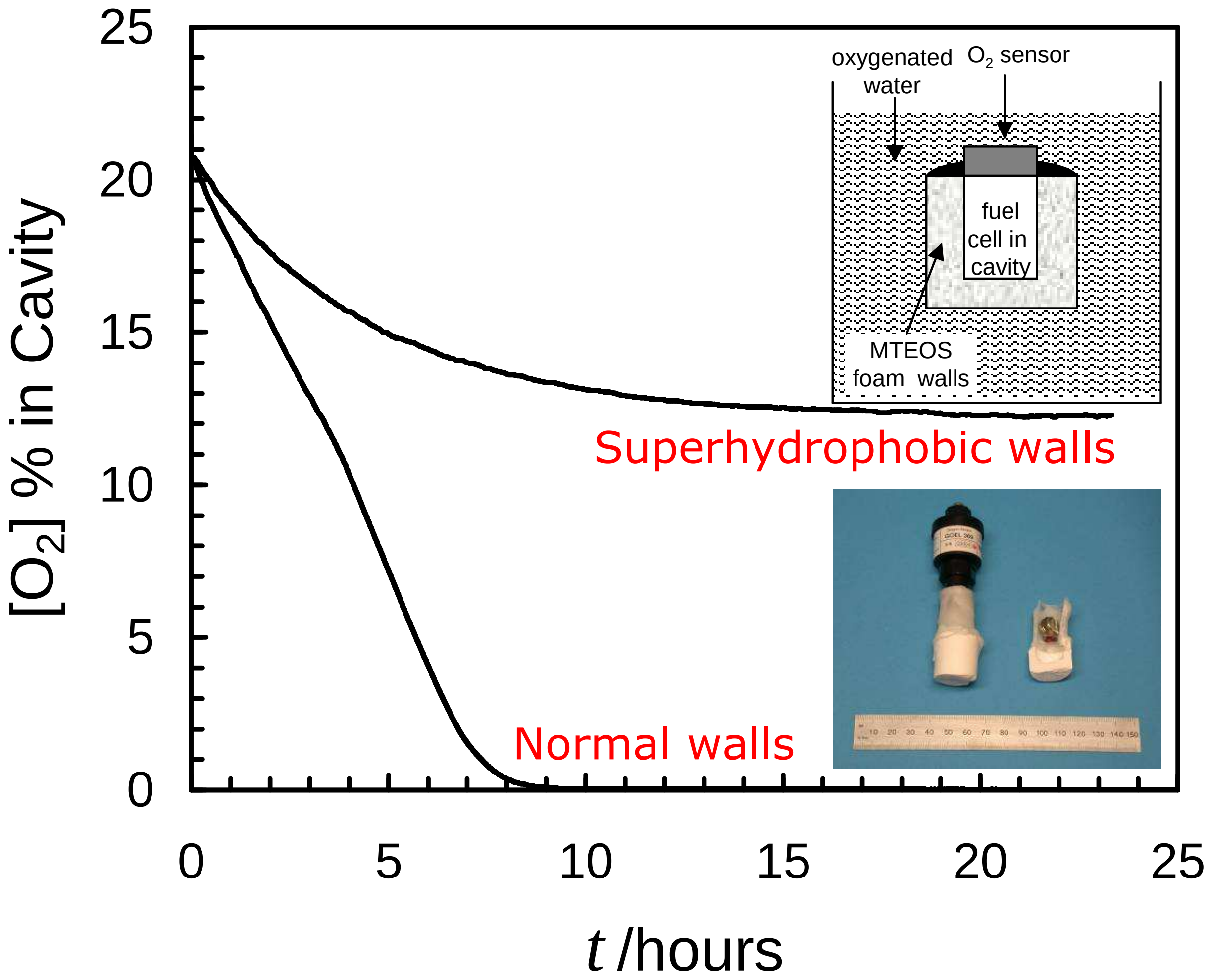
Ponds, Plastrons and Pipes

Plastron Demonstration

Breathing without Gills: Plastron Respiration

Water ("Diving Bell") Spider – but not bubble respiration

The Movie – Microcosmos



Superhydrophobicity: Plastron Respiration

Similar to super gas exchange membranes

Edward Cussler

Underwater Breathing:

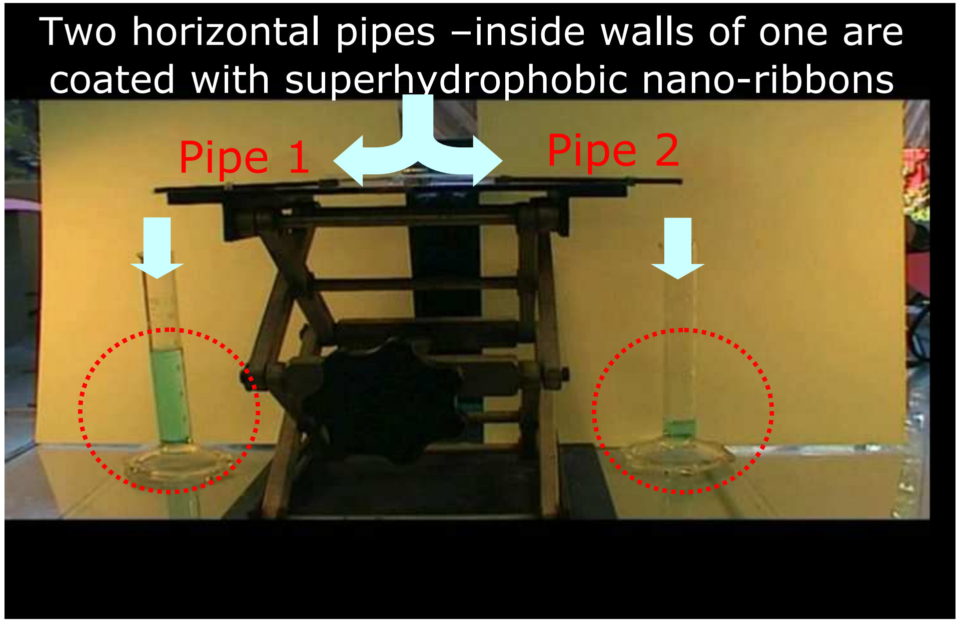
BBC Radio 4 Broadcast

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

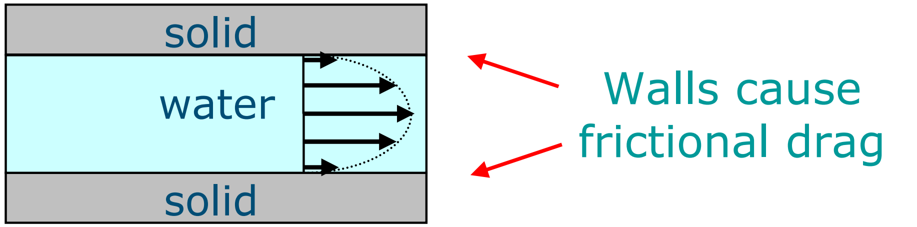
Speaking 9th February 2006

Flow in Pipes with Superhydrophobic Walls

Hosepipe



Closed-channel



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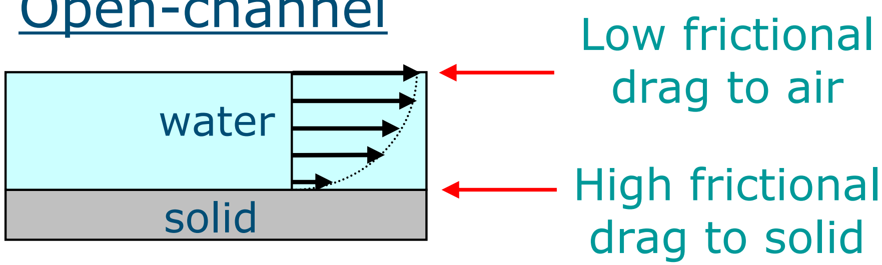
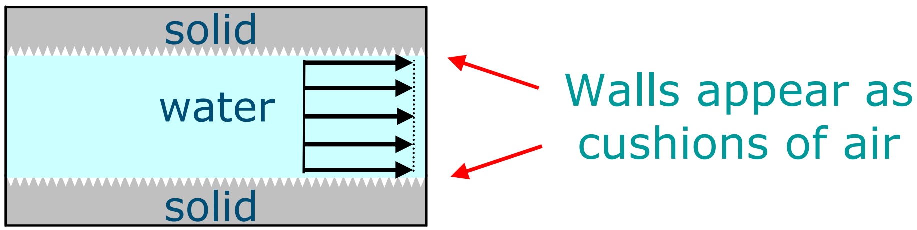


Super-channel



Falling Objects

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

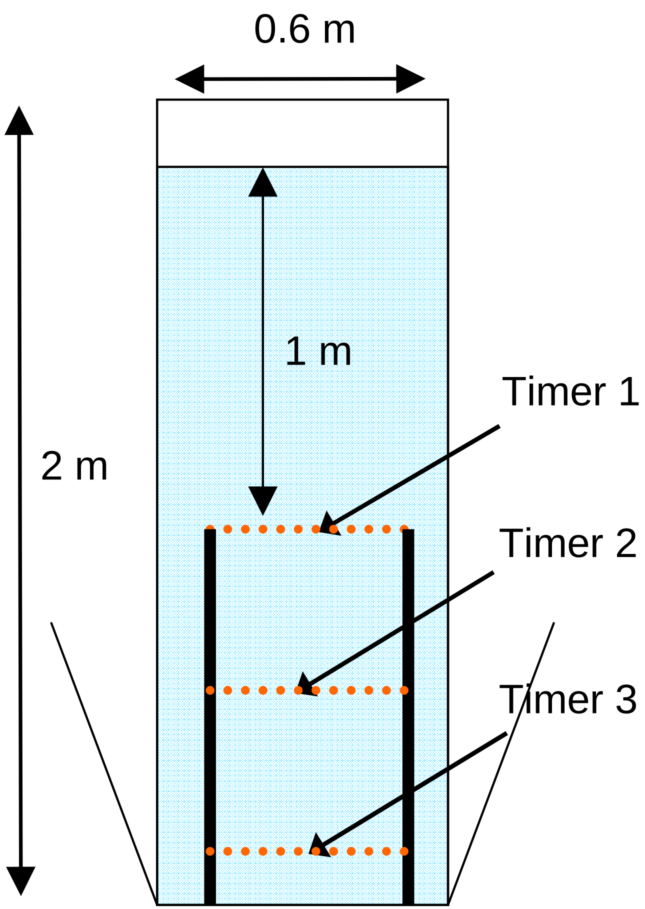
Apollo 15 moon walk, Commander David Scott

Acknowledgement: Wikipedia

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

Stokes and Terminal Velocity

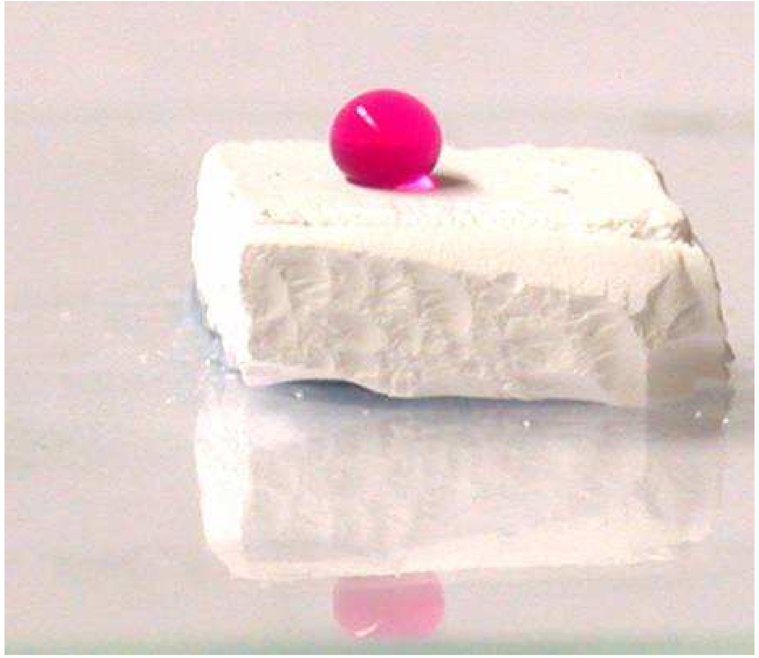
In the presence of a fluid, a falling object eventually reaches a terminal velocity. Textbooks tell us that in water the terminal velocity does not depend on the surface chemistry …. But is that true?



Sensing at Surfaces

Example 1: Triggering Changes

Superhydrophobic Foam



Foam heated (and cooled) prior to droplet deposition

Super-Slurp

Mechanisms for Switching

Temperature history of substrate

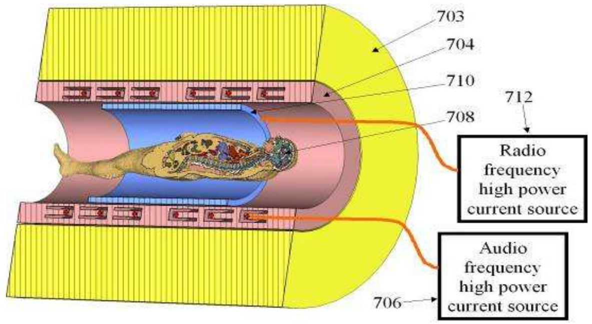
Contamination of a liquid (alcohol content, surfactant, …)

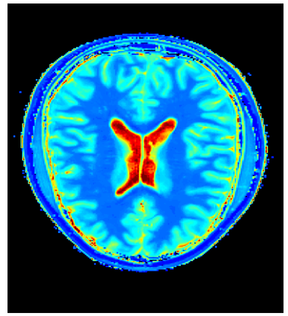
"Operating point" for switch is chosen by intelligent materials design → Sensor

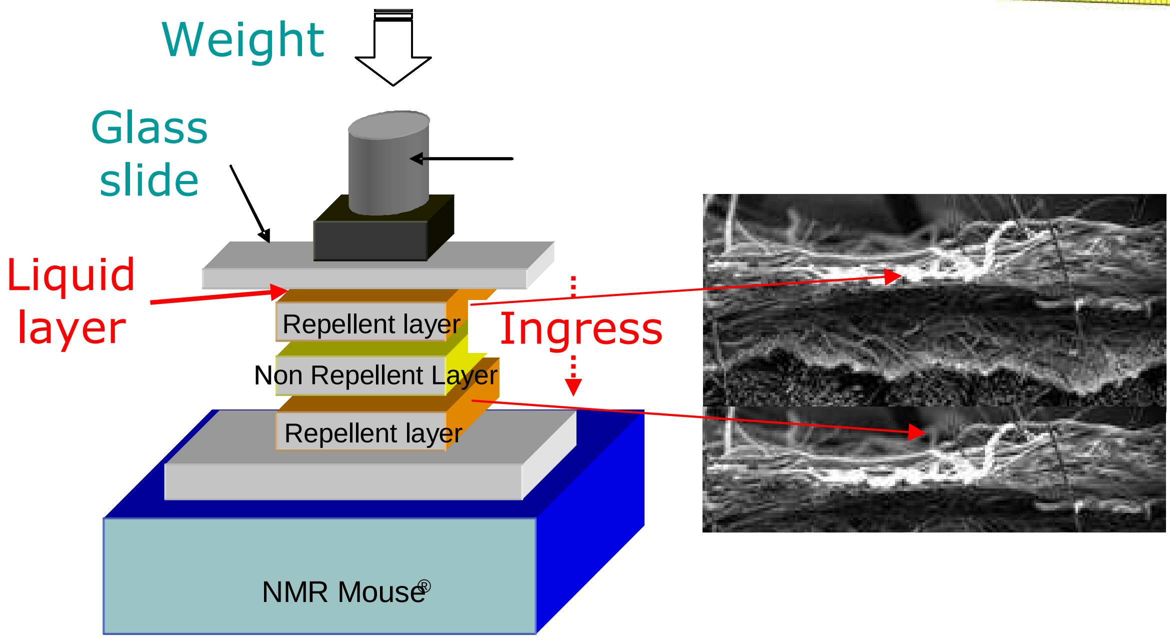
Example 2: MRI of Protective Textiles

Textiles can be made super-repellent, e.g. two repellent and one wicking layer

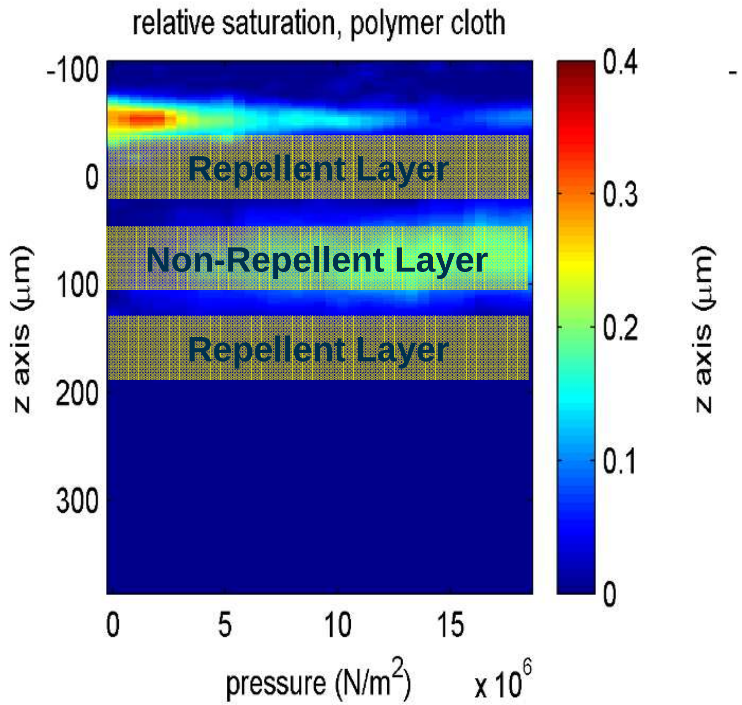
How can we know how much pressure is needed to drive liquid into them?







MRI microscope



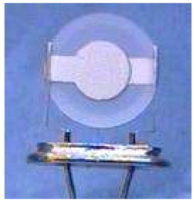
Acknowledgement: Dr Martin Bencsik with Hans Adraiensen and Dr Stuart Brewer

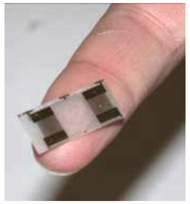
Example 3: Weighing Small Masses

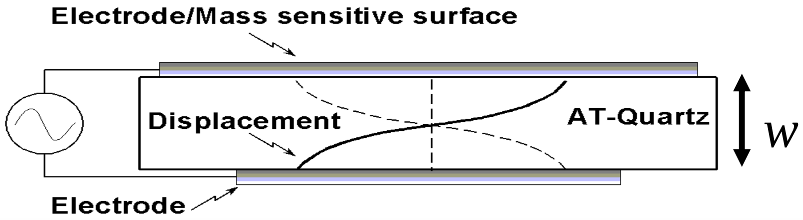
Quartz Crystals and Surface Acoustic Waves

Timing elements in watches,

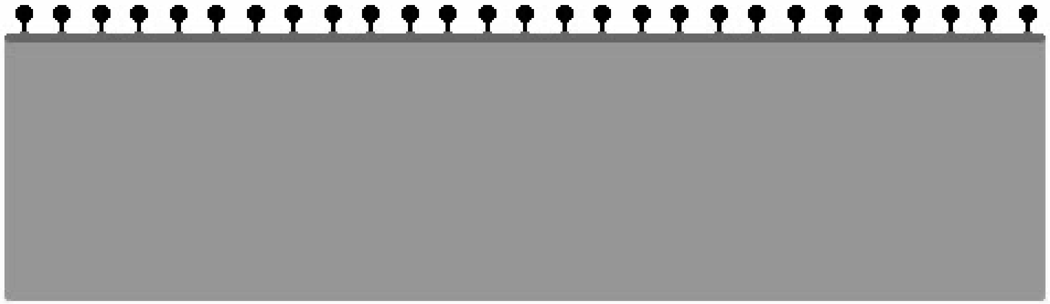
Filters in TVs, mobile phones, ...







Frequency accuracy to better than 1 part in 10 million



Detects molecular layers less than one monolayer thick

Can also detect changes in liquid properties

Examples of NTU Acoustic Wave Sensors

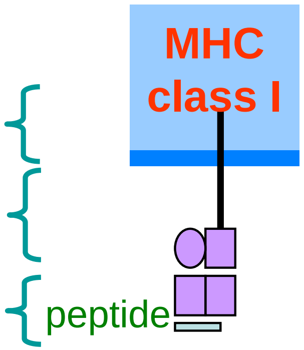
1. Particulates/PAHs/Terpenes	Pollution Monitoring
2. MHC-peptide screening	Cancer Vaccines
3. Steroid detection (nandrolone, testosterone)	Drug Detection
4. Sperm quality and detection device	Vet AI
5. Microfluidic chip for properties of ionic liquids	Green Chemistry

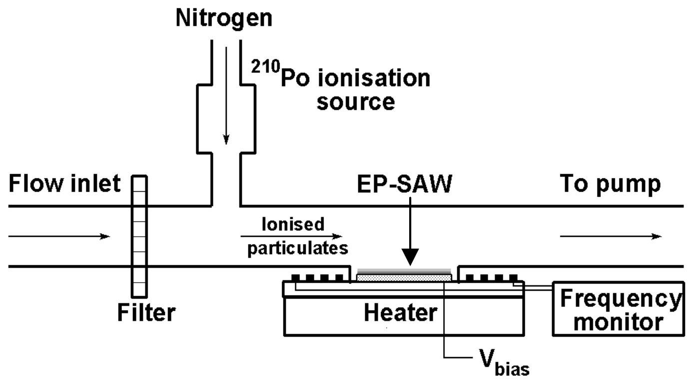
Sensor Strategy

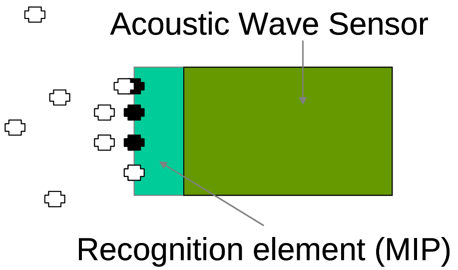
Make this the acoustic wave sensor

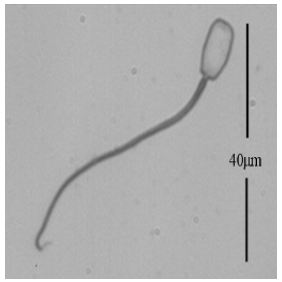
Recognition layer is MHC protein

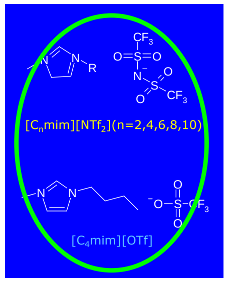
Detect peptide specific binding











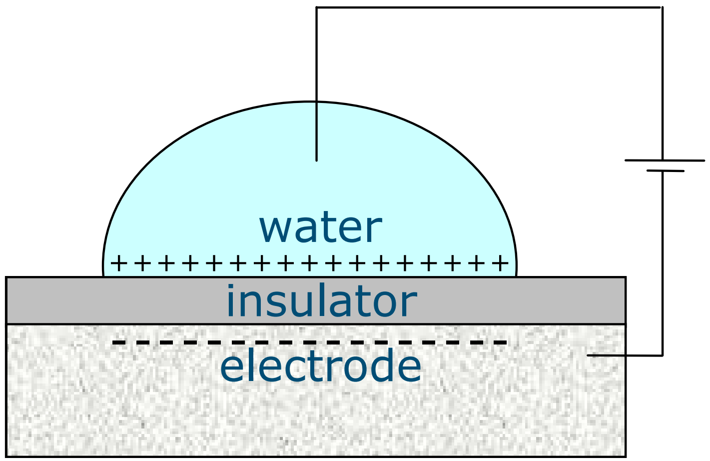
Almost all involve the solid-liquid interface

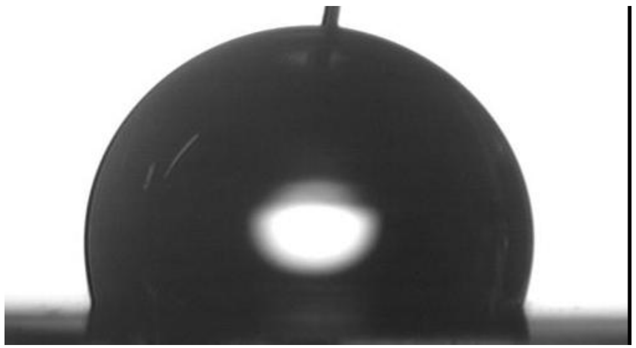
New Liquid Based Devices

The Principle of Electrowetting-on-Dielectric

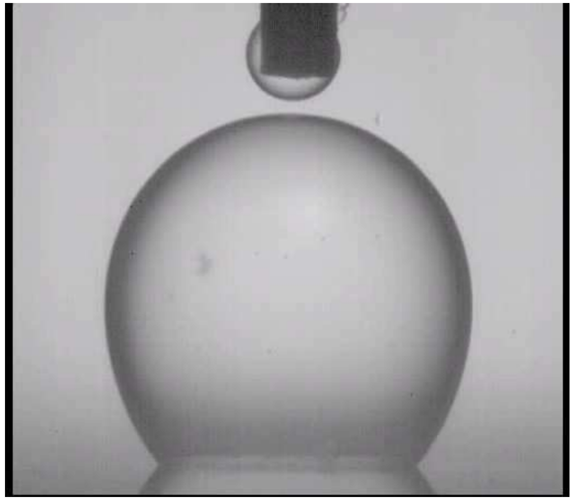
Use a droplet of water as an electrode – charge up water-solid interface

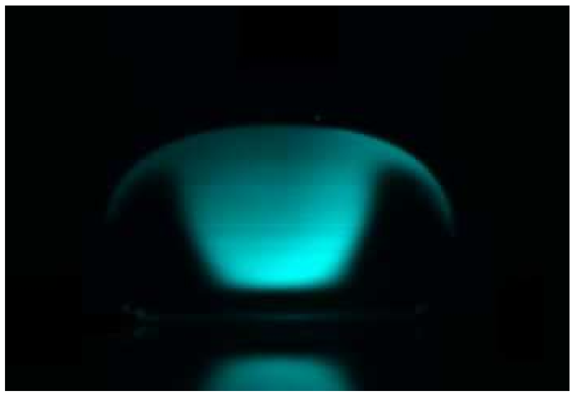
<u>Electrowetting in Air</u>





<u>Electrowetting: Water in Oil</u>



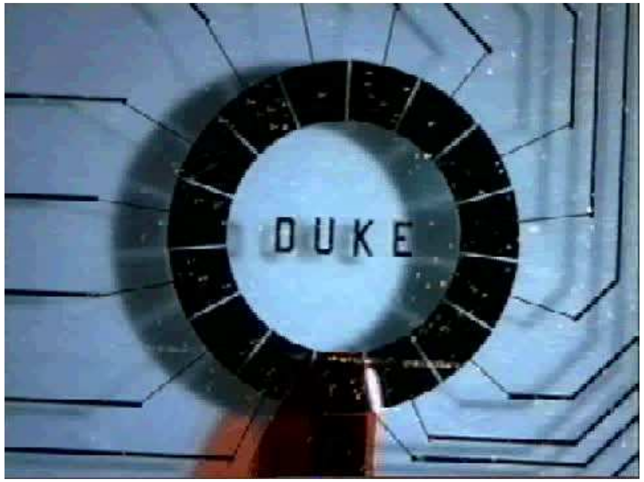


<u>Courtesy</u>: Prof. Frieder Mugele (Univ. Twente)

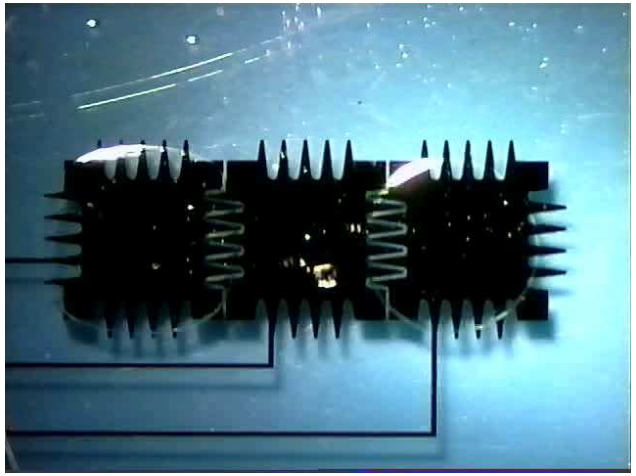
Example 1: Chemical Factories in Droplets

Electrowetting to dispense, merge/split/mix and move

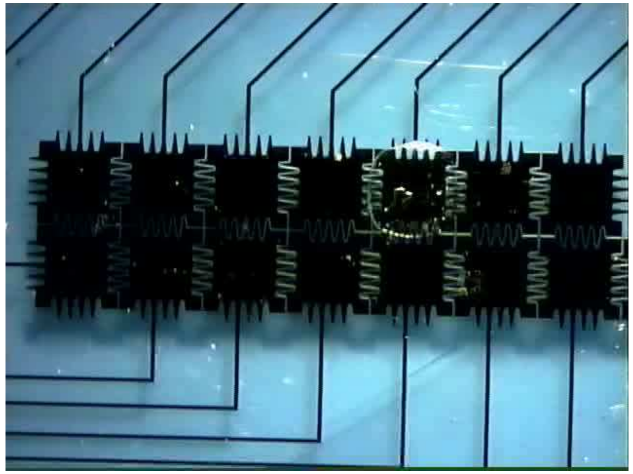
Dispense



Combine/Split



Digital Motion

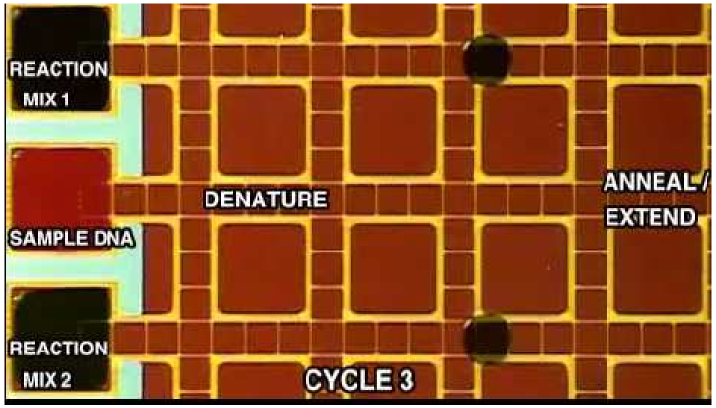


Courtesy: Dr Mike Pollack (Duke University – co-founder Advanced Liquid Logic, USA)

Assays on the size of a credit card

Immunoassays, clinical chemistry, …

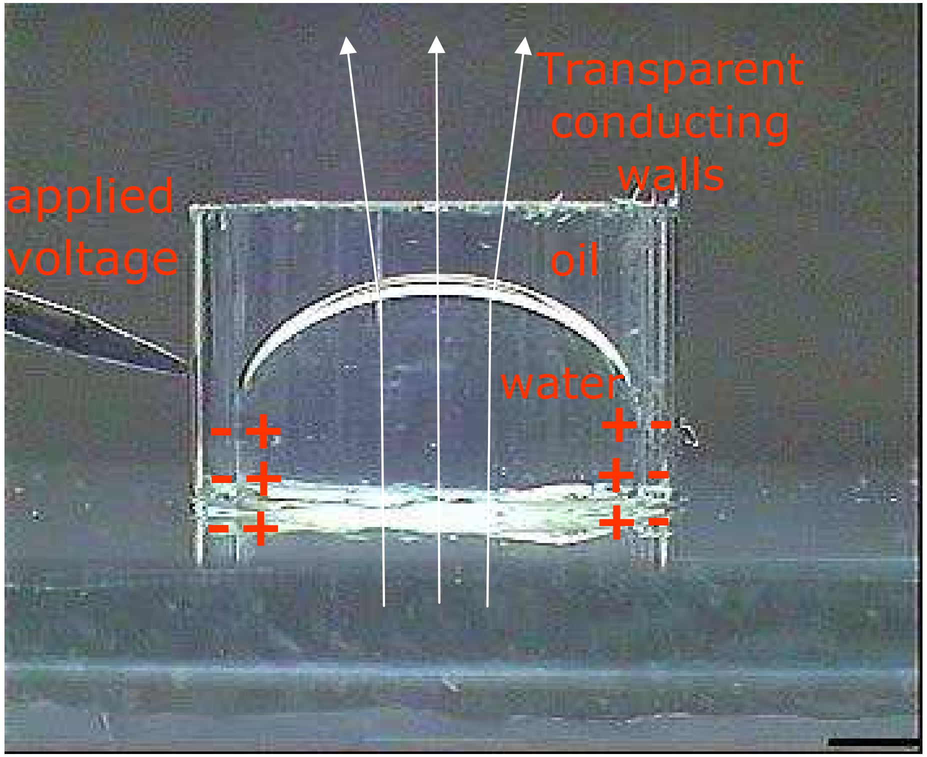
Acknowledgement: Advanced Liquid Logic



Example 2: 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



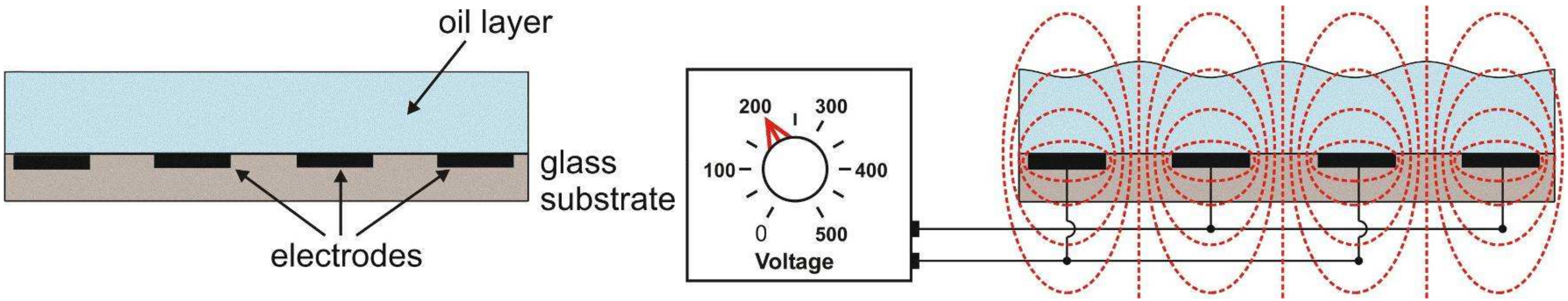
Courtesy: Dr Stein Kuiper (Philips Research Labs, Eindhoven)

Example 3: Liquid Photonics

1. A diffraction grating uses surface structure to split light into its constituent colours
2. Can also redirect path of ray of light of a single colour – photonic devices

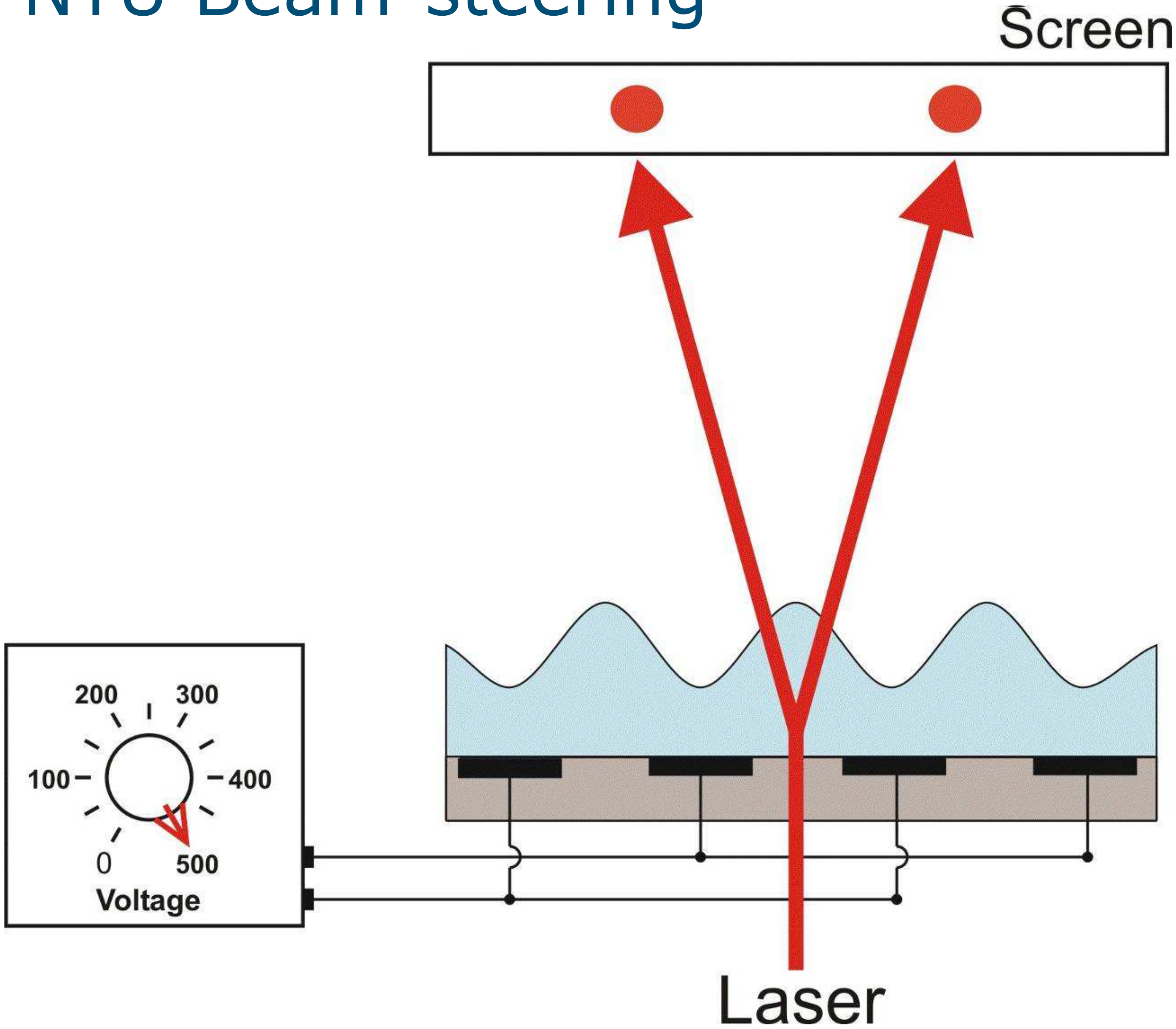
Edge of a CD under white light

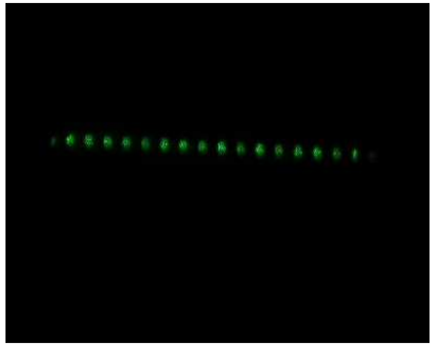
Diffraction using programmable electrical control of oil-air interface

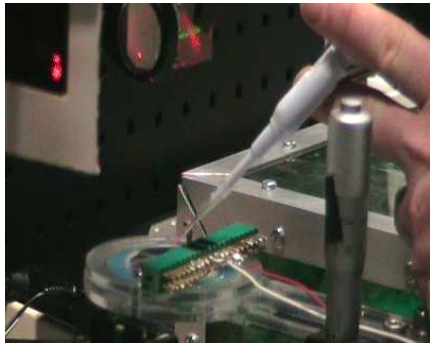


Acknowledgement: Dr Carl Brown, Dr Mike Newton with Gary Wells

NTU Beam-steering







Journey's End

What is Science 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

$$\cos\theta_e^W(x) = r(x)\cos\theta_e^s \qquad \cos\theta_e^{CB}(x) = f_1(x)\cos\theta_1^s + f_2(x)\cos\theta_2^s$$

$$Z_L = \sqrt{i\omega\rho_f\eta_f}\,\tanh\left[\frac{\sqrt{2i}\,d}{\delta}\right] \qquad \left(\frac{\Delta\omega}{\omega}\right) \approx -\frac{1}{\pi}\sqrt{\frac{\omega\rho_f\eta_f}{2\rho_s\mu_s}}$$

Acknowledgements

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Dr Carl Percival (Chemistry), Prof. Carole Perry (Chemistry),
Prof. Brian Pyatt (Bio Sci.), Prof. Bob Rees (Bio. Sci.), Prof. Tony Dodi (ANRI/NTU)

PDRA's — Dr Neil Shirtcliffe, Dr Carl Evans, Dr Paul Roach, Dr Yong Zhang,
Dr Dale Herbertson, Dr Simon Stanley, Mr Rob Morris, Dr Andrew Hall, ….

PhD's — Ms Sanaa Aqil, Mr Steve Elliott, Ms Nicola Doy, Mr Shaun Atherton, Mr Gary Wells,

+ — Former colleagues, students and research fellows

External Collaborators

Dr Electra Gizeli & Dr Kathryn Melzak (Crete/Cambridge), Prof. Mike Thompson (Toronto),
Prof. Yildirim Erbil (Istanbul), Dr Stefan Doerr (Swansea), Dr Stuart Brewer (Dstl),
Dr Andrew Clarke & John Fyson (Kodak), Dr Ralf Lücklum (Magdeburg),
Dr Neil Thomas (UoN), Ms Huey-Jen Fang, Prof. Chris Hardacre (QUB),
Prof. Ray Allen & Dr Jordan MacInnes, …..

Demonstrations/Organization

Drs Newton, Shirtcliffe, Brown & Bencsik, Gary Wells,
Dave Parker, Dr James Hind, Laurice Fretwell, Ian Rogers
Dr Christian Thode + Kerri H, Kathryn P & Lesley A

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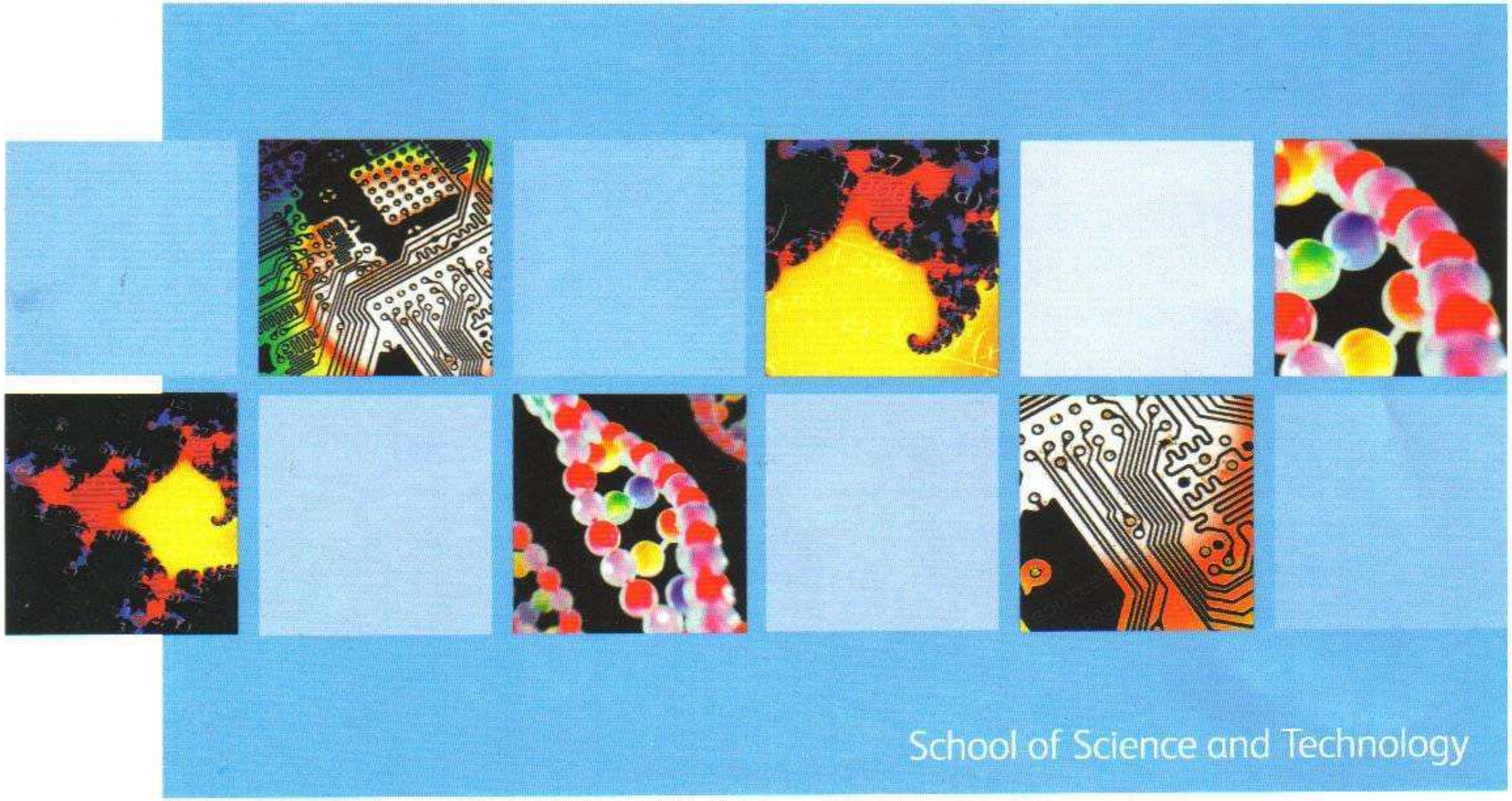
Appendices

Invitation



Professorial Lecture by Professor Glen McHale

Monday 10 November 2008

NOTTINGHAM TRENT UNIVERSITY

Abstract

Water: A tale of two surfaces

"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)

Water is all around us. On a wet day we need coats to keep us dry, windscreen wipers so we can see and reservoirs to collect water to drink. There are few things more essential for life. Nature controls water in a myriad of ways. The lotus leaf cleanses itself of dust when it rains, a beetle in the desert collects drinking water from an early morning fog, some spiders walk on water and others breathe underwater. We understand so little of how to mimic the adaptations to water that nature has evolved, but if we did, we could use this natural resource so much better.

In this tale of two surfaces, the solid and the liquid, Glen McHale will begin in the garden with its soil, plants, ponds and insects. His lecture will touch upon frying pans, clothes and watches. As the journey progresses into the laboratory, we will begin to understand how the interactions at the interface between water and a solid are vital to so many processes. At journey's end, we will glimpse a future prospect of such variety, from better clothes to miniature biochemical factories the size of a credit card, all made possible by a simple understanding of water.

Profile

Professor Glen McHale

Glen completed a PhD in Applied Mathematics in 1986, going on to research the theory of quantum fluids in Nottingham and Paris. He joined NTU in 1990, becoming Professor of Physics in 2002. His research has attracted extensive funding, he regularly speaks at international meetings, and he has published more than 100 journal papers.

Glen is Associate Dean for Research and Graduate Studies at NTU, a Fellow of the Institute of Physics, and a member of the IEEE FCS Technical Programme Committee, the EU COST P21 Management Committee and the Institute of Physics Physical Acoustics Group Committee.