

Water: A tale of two surfaces

Professor Glen McHale

College of Science

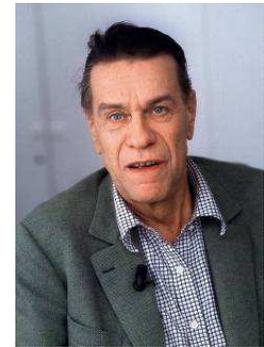
School of Science & Technology

Café Scientifique 2nd March 2009

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”

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



Acknowledgement: Le Figaro

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



plants &
leaves

The Natural
World



ponds &
insects

soil

channels

clothes

windows &
roofs



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

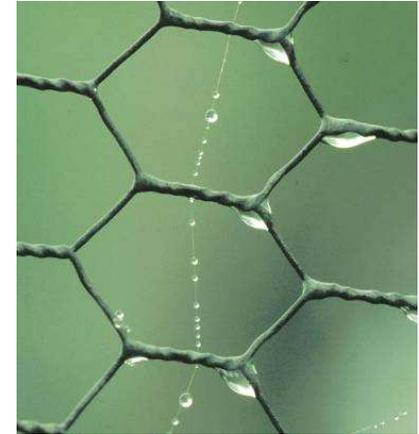
Surface Tension

Liquid Surface

Molecules at a surface have fewer neighbours

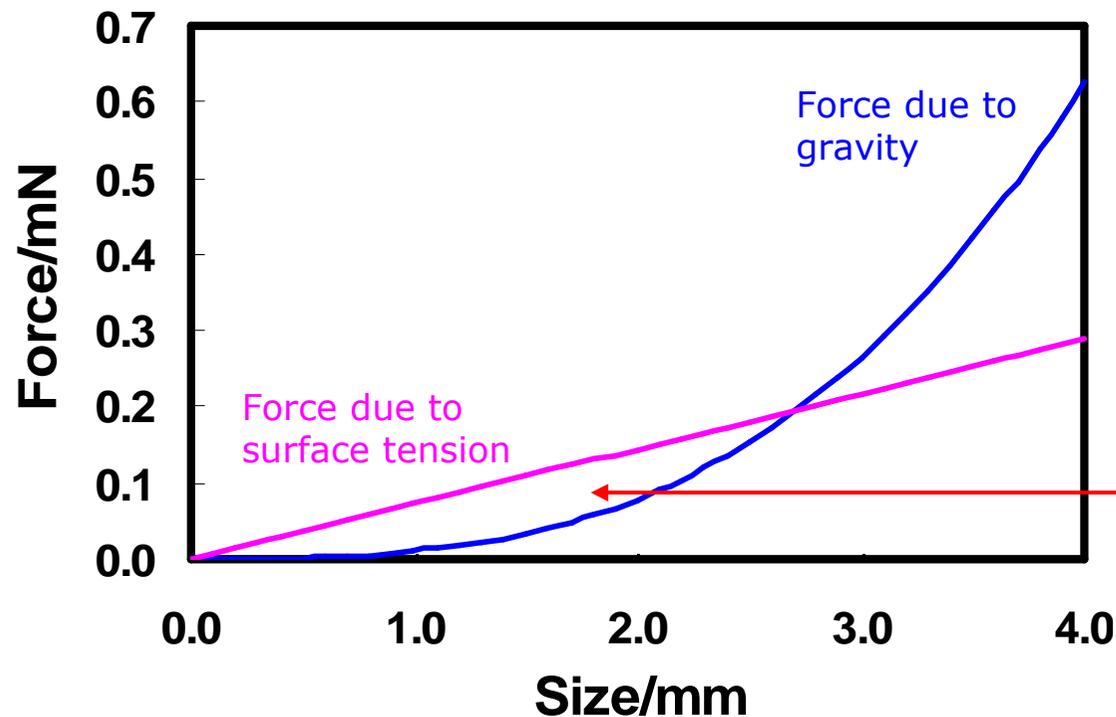
Liquid surface ("skin") behaves as if it is in a state of tension

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?



The Movie – Antz (1998)

Copyright: DreamWorks Animation (1996)



Courtesy: BigWave Productions



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

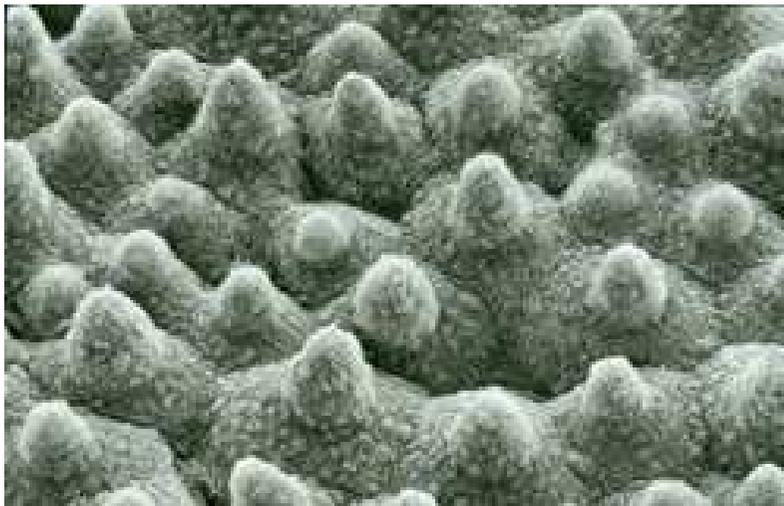
Many leaves are super-water repellent (i.e. droplets completely ball up and roll off their surface)

The Lotus plant is known for its purity

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

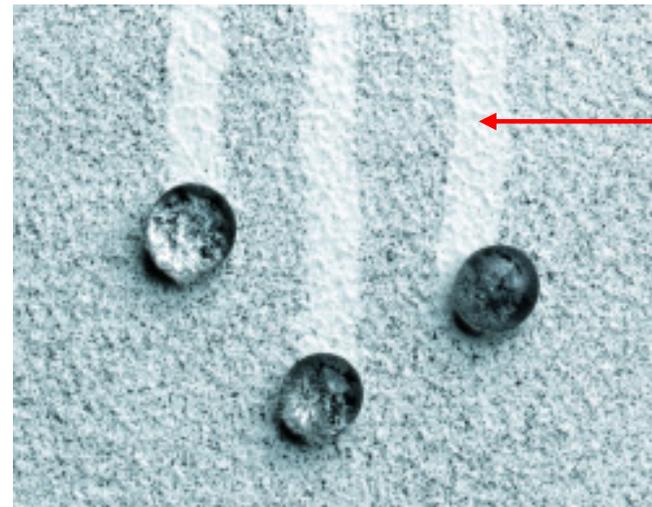


Microscope Image of Lotus Leaf



Acknowledgement: Neinhuis and Barthlott

Self-Cleaning Glass



Dust
cleaned
away

Acknowledgement: BASF

Mimicking the Surfaces in Nature

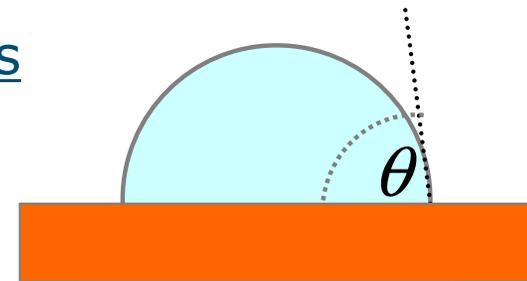
Hydrophobicity and Superhydrophobicity

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

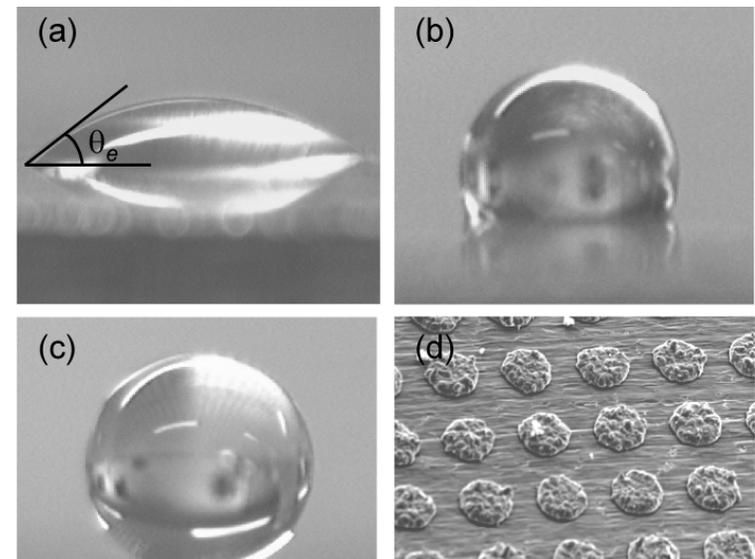
Characterize hydrophobicity
Water-on-Teflon gives $\sim 115^\circ$
The best that *chemistry* can do



Physical Enhancement

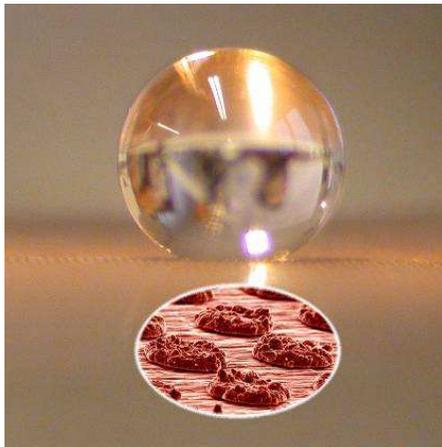
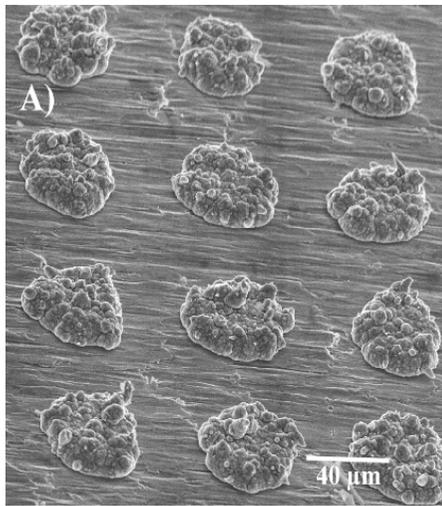
- (a) is water-on-copper
- (b) is water-on-fluorine coated copper
- (c) is a super-hydrophobic surface
- (d) "chocolate-chip-cookie" surface

Superhydrophobicity is when $\theta > 150^\circ$
and a droplet easily rolls off the surface



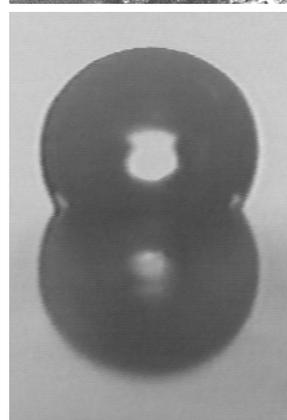
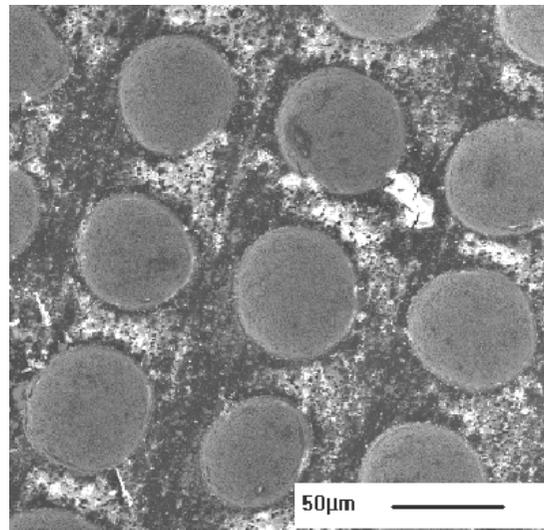
Mimicking Superhydrophobic Surfaces

Deposited Metal

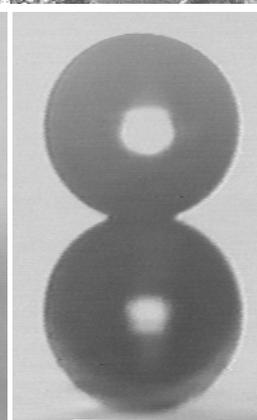


Patterned & hydrophobic

Etched Metal

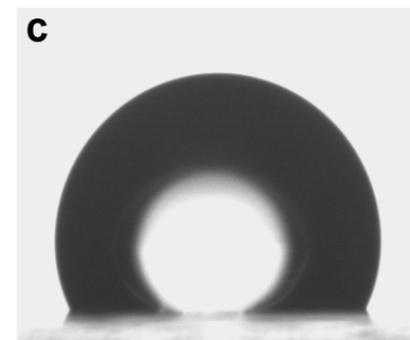
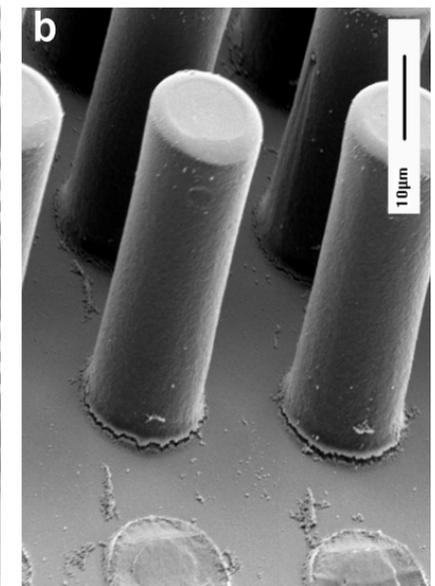
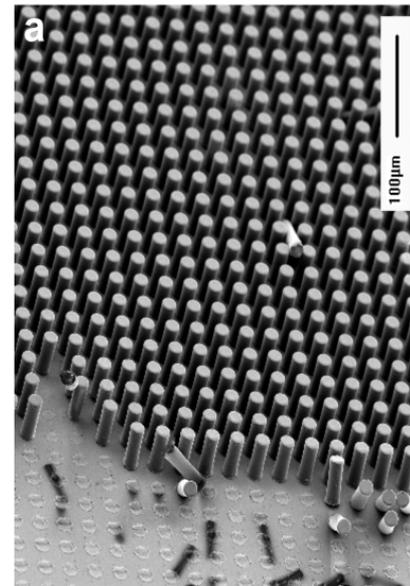


Flat & hydrophobic

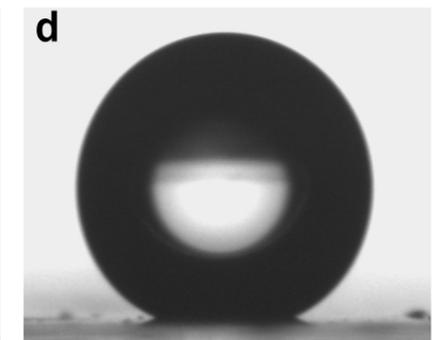


Patterned & hydrophobic

Polymer Microposts



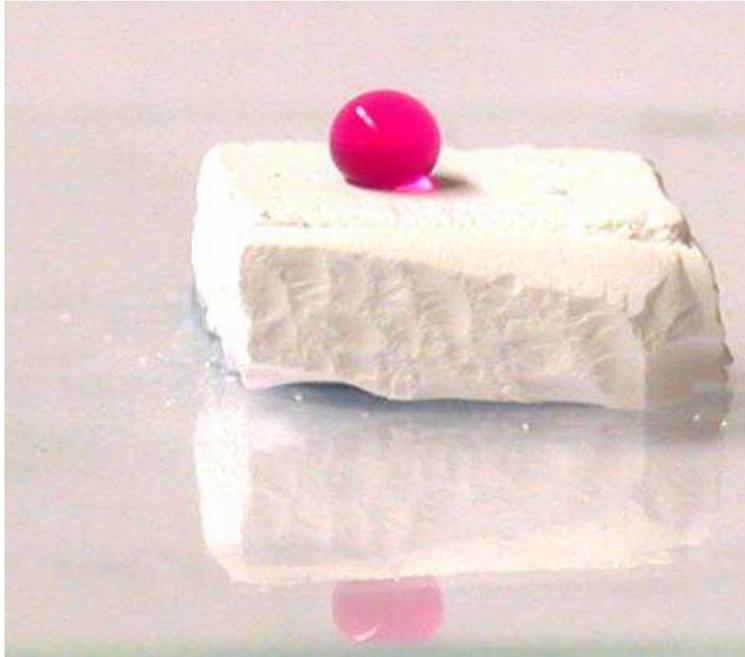
Flat & hydrophobic



Patterned & hydrophobic

Superhydrophobicity: 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, ...)

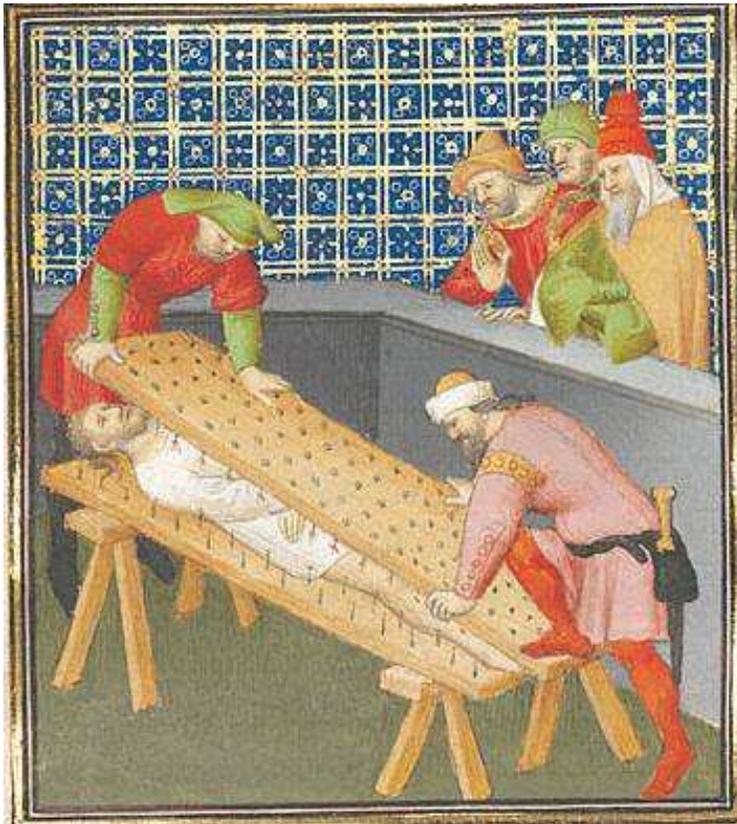
“Operating point” for switch is chosen by intelligent materials design → Sensor

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 and Bouncing Droplets

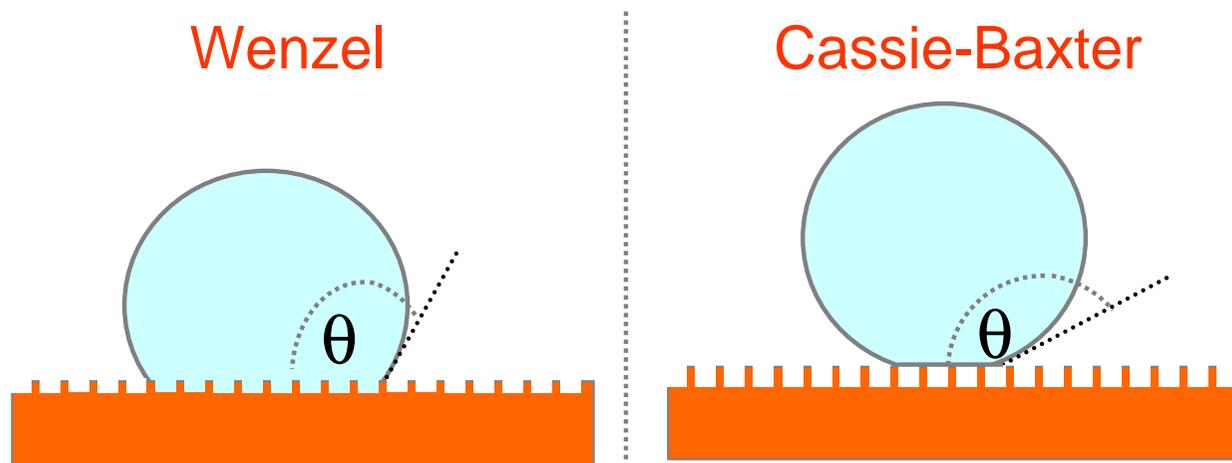


Acknowledgement: Wake Forest University



Courtesy: Prof. David Quéré, ESPCI

Penetrating versus Skating



Surface Chemistry and Surface Structure

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

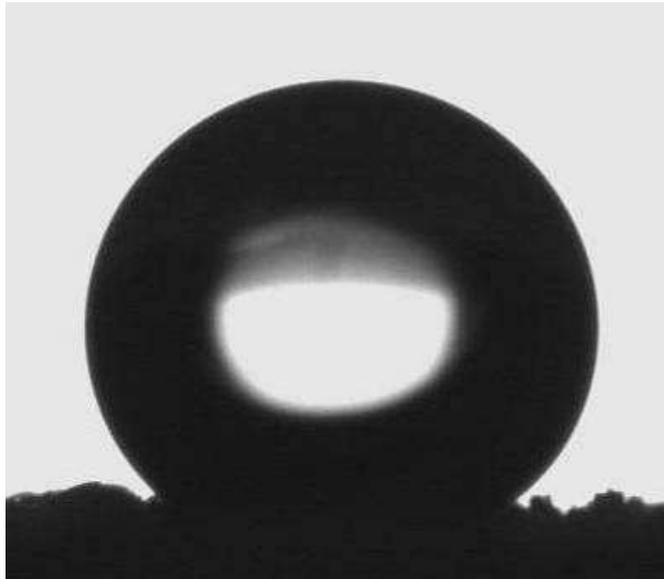
A droplet of water sitting on a composite air-solid interface balls up

The Surface of Hydrophobic Soil

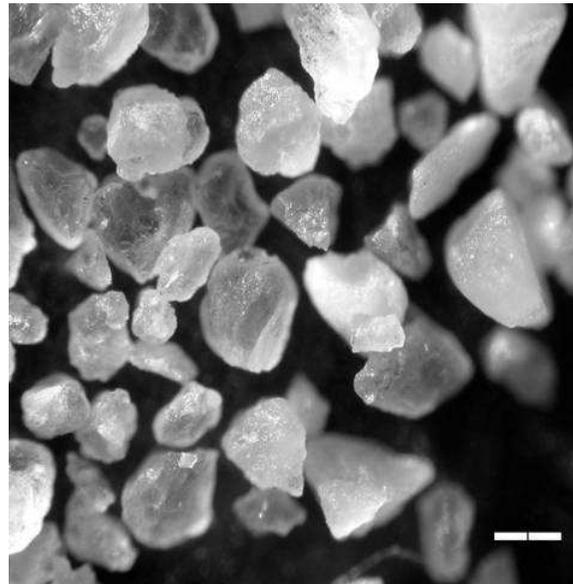
Sand Demonstration

Super Water-Repellent Sand/Soil

Sand with 139°

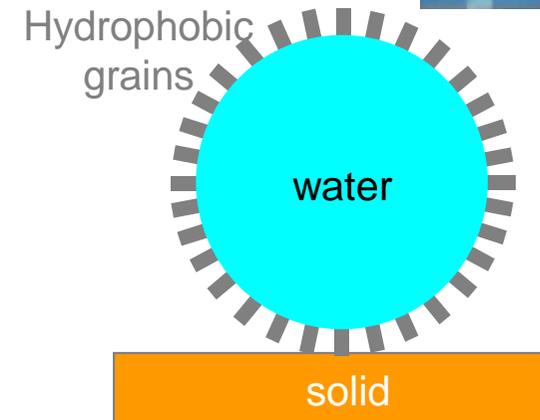


Shape and Packing



0.2 mm

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



Overland flow,
soil erosion and
land remediation

Farmland



Gray water and irrigation



Golf courses



Localized dry spots

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

Forest Fire and Debris Slide

Grand Pri
October 21 - Nove
Acres: 69
Cost: \$1
Firefighters assi
Homes los
Other structure
Lives los
Cause: Hu



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

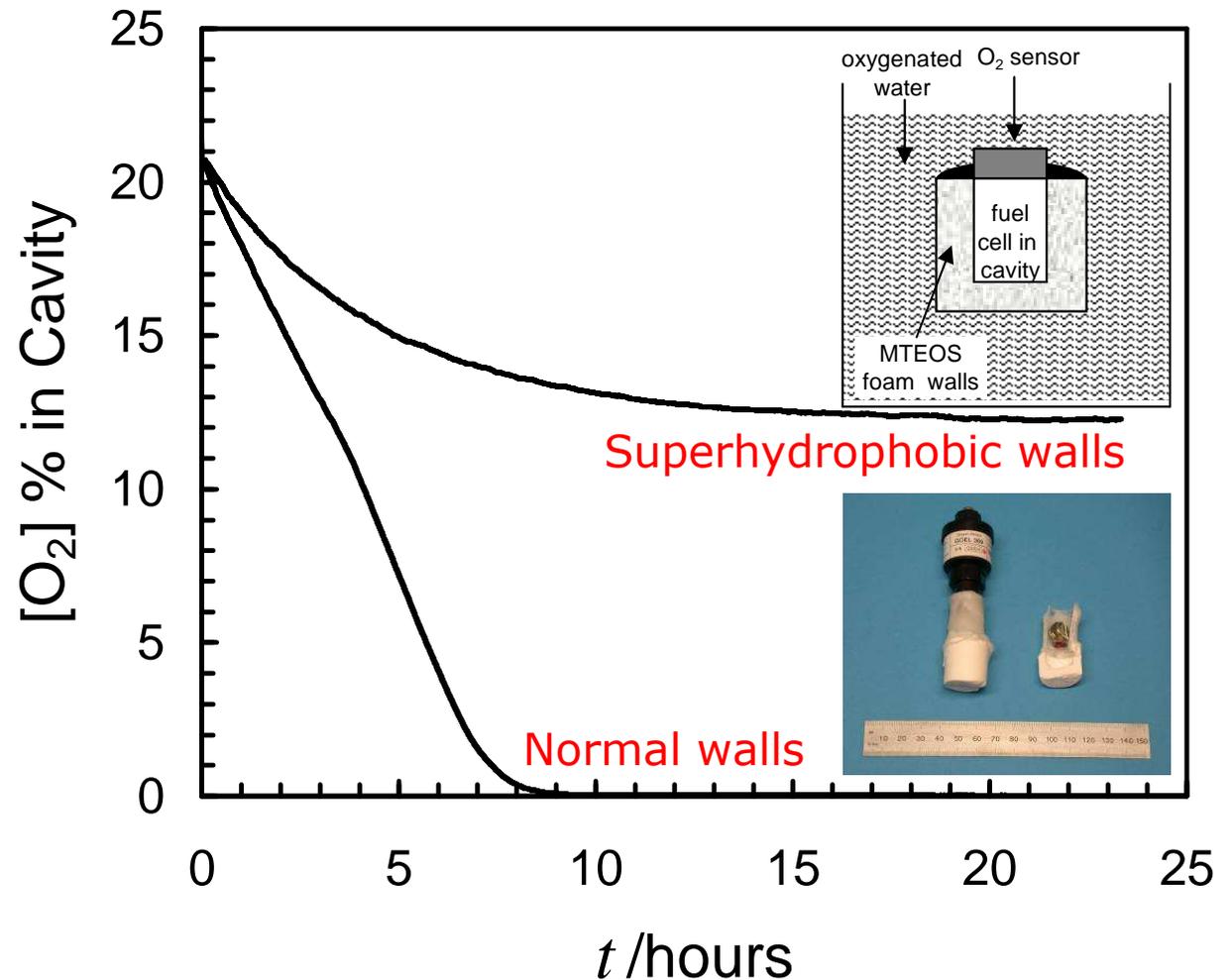
Plastron Demonstration

Breathing without Gills: Plastron Respiration

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



The Movie – Microcosmos
Copyright: Allied Films Ltd (1996)



Superhydrophobicity: Plastron Respiration

Similar to super gas exchange membranes

Edward Cussler

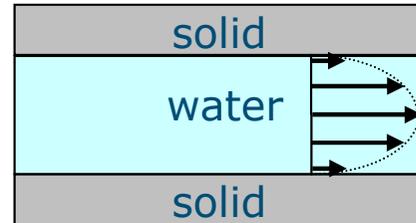
Underwater Breathing:
BBC Radio 4 Broadcast
Edward Cussler, Professor of Chemical
Engineering (University of Minnesota)
Speaking 9th February 2006

Flow in Pipes with Superhydrophobic Walls

Hosepipe

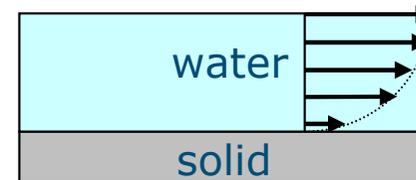


Closed-channel



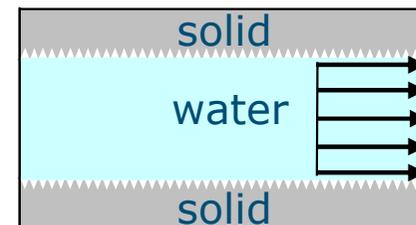
Walls cause frictional drag

Open-channel

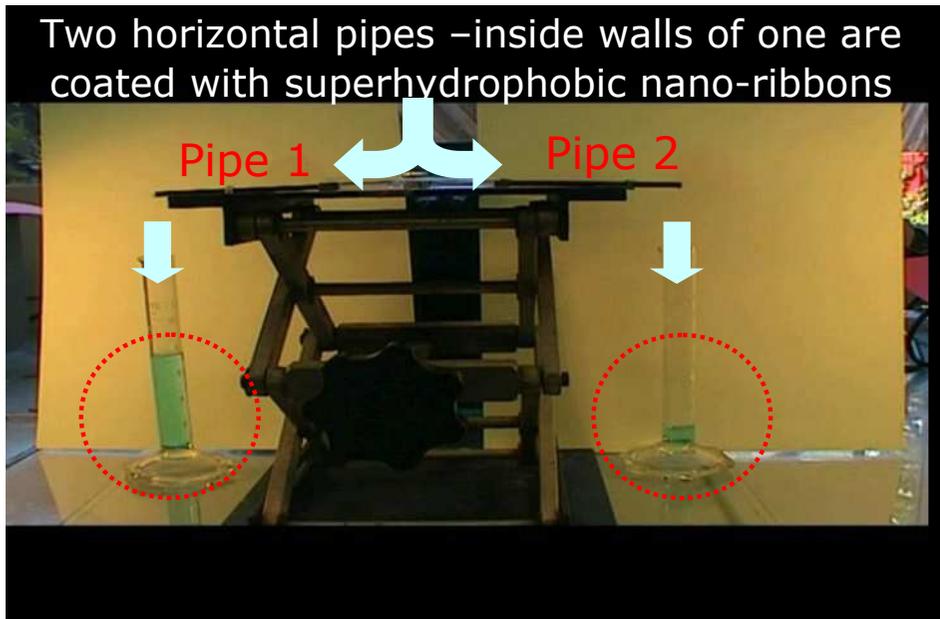


Low frictional drag to air
High frictional drag to solid

Super-channel



Walls appear as cushions of air



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



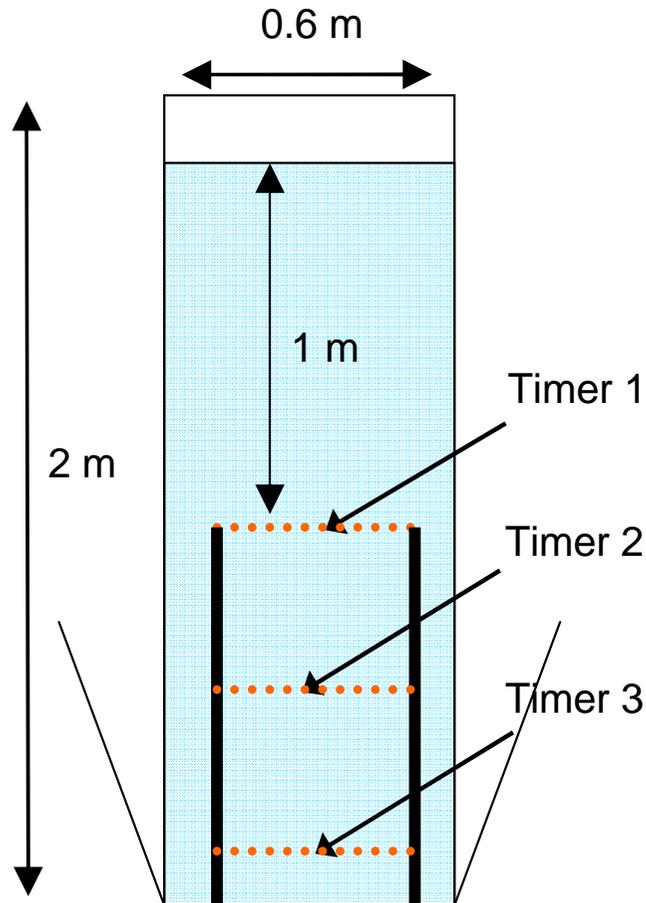
Apollo 15 moon walk, Commander David Scott

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?



Solid sphere
↓
Plastron bearing sphere
↓
Same sphere
↓



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

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

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- 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,
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Prof. Yildirim Erbil (Istanbul), Dr Stefan Doerr (Swansea), Dr Stuart Brewer (Dstl),
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Demonstrations/Organization

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