Nature’s raincoats

Mimicking the water-repellency of plants and insects

Keywords
Superhydrophobic surfaces • Micropatterning
Self-cleaning • Nanotechnology

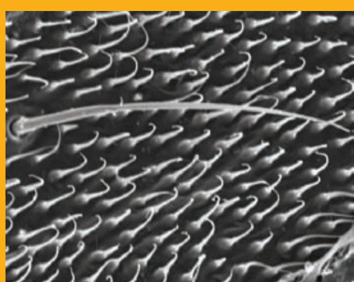
“Oh come on, I bet people thought Scuba gear looked silly when it was first invented!”

(Image ©Nottingham Evening Post, www.thisisnottingham.co.uk)

SELECTED 2009

THE ROYAL SOCIETY SUMMER SCIENCE EXHIBITION

If a water-repellent (hydrophobic) surface is roughened by patterning on a tiny length scale, it can become superhydrophobic. Small water drops balanced on these surfaces remain almost spherical, and slide across the surface with very little friction. There is a distinguished history of research studying drops on smooth surfaces – one of the most famous equations is due to Thomas Young who was appointed Foreign Secretary of the Royal Society in 1802 – but until very recently roughness has been regarded as a nuisance. Now advances in fabricating small surface features mean that it is possible to construct surfaces with well-defined patterns of tiny needles, posts or hairs and perform experiments backed up by theory and powerful simulations. Our work aims to explain the interplay between the surface structure, the extent to which it attracts or repels water, and the shape and dynamics of liquid drops moving across it.



Electron micrograph of the body of a diving beetle: the hairs trap air to allow the insect to breathe underwater

Much of the inspiration for the research has come from observing how plants and insects exploit surface patterning to deal with the water in their environment. Several plants have strategies to make their leaves superhydrophobic. Lotus leaves have bumpy, waxed surfaces. Lady’s Mantle and Euphorbia, both common garden plants, have hairy leaves; the hairs hold water drops away from the surface of the plant. It is not known why plants have adapted in this way. One suggestion is that as raindrops roll off the superhydrophobic leaves they take dust with them, helping clean the leaves. Another possibility is that the plants keep their leaves dry to aid respiration.

Exhibitors:
Professor Glen McHale, Dr Michael Newton and Dr Neil Shirtcliffe,
Nottingham Trent University
Professor Julia Yeomans, Dr Bortolo Mognetti, Dr Jorn Dunkel, Mr Matthew Blow, Mr Richard Matthews, Mr Victor Putz, Mr Ioannis Zacharoudiou and Mr Irwin Zaid,
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Imagine being hit by a ball of water a metre in diameter. Spare a thought then for butterflies, which face an equivalent problem whenever it rains. Butterflies have highly structured wings, often covered by triangular ridges. These act as ratchets, directing drops of water away from the body. The Namib desert beetle does not need to worry about such bombardments, but instead requires ingenuity to collect water. As early morning mists sweep over the desert the beetle lifts its tail into the wind so that water condenses on the hydrophilic (water attracting) bumps that cover its back. As the drops become larger, they roll down the insect’s back and into its mouth.

Two research groups are involved in presenting the ‘Nature’s raincoats’ exhibit. At Nottingham Trent University we are designing and building novel superhydrophobic substrates. These range from surfaces that are relatively easy to prepare, such as rusty metal or layers of sand covered in a hydrophobic compound, to tiny cylindrical posts in a regular array, which require sophisticated and time-consuming microfabrication techniques, similar to those used to make microchips. Although the ordered surfaces are harder to make, they are needed to provide a well-characterised testing ground for theories. However, we have found that complex, multiscale, roughness is far more effective than simple patterning in promoting superhydrophobicity. A potential use of micropatterned surfaces is to control the flow of fluids, and we are performing experiments to discover whether superhydrophobic coatings can enhance the rate at which water flows through a channel.

Water on knautia scabiosa: the surface is superhydrophobic and the drops are almost spherical

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At the University of Oxford we are using state-of-the-art computers to model fluids on micropatterned surfaces. The length scales where superhydrophobic behaviour occurs are between about 100 nanometres and 100 microns (one thousandth to one tenth of a mm). Conventional computational fluid dynamics algorithms, such as those widely used to design engines or ships, are suited to larger length scales. Microscopic algorithms, that describe the drops in terms of their constituent molecules, are also unsuitable because computers are not powerful enough to keep track of the motion of the billions of molecules that make up even a tiny liquid drop. We are developing novel mesoscale algorithms which bridge the length scale gap by keeping enough of the small-scale physics to correctly predict the drop behaviour, but not so much that the calculation becomes impossibly long.

Motivated by the patterning on butterfly wings, we set up simulations of drops moving across triangular posts, which we expected to act like ratchets. We found that the drops do indeed move more easily in one direction than the other but, to our surprise, in the wrong direction, towards the butterfly's body. This led us to predict, and find, a new superhydrophobic state that can exist on the ratcheted surfaces. Patterned surfaces where the shape of the posts can be used to control the direction of movement of drops or streams of liquids have potential as fluidic valves in microfluidic devices.

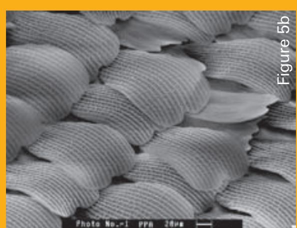
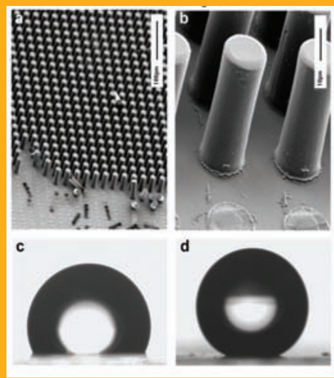


Figure 5: (a) Morpho absoloni and (b) the scales on its wings which help to direct raindrops away from the body. *(Images ©Professor Serge Berthier)*



(a) and (b) a superhydrophobic surface at different magnifications. (d) shows a water drop on the patterned surface, and (c) compares a drop on a flat surface of the same material. *(Image ©Institute of Physics)*

Another problem that interests us at present is why hairy surfaces can be hydrophobic overall, even though the surfaces of the hairs themselves attract water. We think that drops remain suspended on the hairs because of an energy balance. The energy of the liquid surface decreases as the hairs wrap around a drop, but this is offset by the increase in the elastic energy of the hairs as they bend. Similar technologies are used by water insects. For example, the diving beetle's body is covered by microscopic hairs which trap air, acting as a miniature aqualung that allows it to breathe underwater, and the structured hairs on the legs of the water strider may contribute to its ability to skip across the water surface.

When superhydrophobic surfaces were first made there was speculation about their widespread use as self-cleaning, stay-dry materials for windows and windscreens. However, it was soon realised that the superhydrophobic patterning is fragile, and easily damaged or clogged up. (Plants are not troubled by this as they continually renew the surfaces of their leaves.) Niche applications are slowly appearing – self-cleaning solar panels, stay-dry materials for swimsuits, no-drip decanters, showers for astronauts – and our ability to control the surface materials and patterning, and their interaction with liquids, is increasing. Look out for the novel uses of superhydrophobic surfaces that will appear in the next decade.

Further information

Exhibit website: **http://www.naturesraincoats.org.uk**

Professor Julia Yeomans' group website:
http://www-thphys.physics.ox.ac.uk/people/JuliaYeomans

Professor Glen McHale's group website:
http://www.ntu.ac.uk/research/groups_centres/sat/81255.html

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