TEACHER GUIDE –

EXPERIMENT D : SUPERHYDROPHOBIC MATERIALS

Aims:

- Understanding the concept of hydrophobic and hydrophilic materials.
- Examining natural superhydrophobic surfaces versus common surfaces.
- Testing novel advanced material that have been engineered to be superhydrophobic,

BACKGROUND INFORMATION

1) Fundamentals of surface properties

The surface properties of a material are largely related to chemical species that are present at the surface. A very important surface property is its wetting behaviour, that is, how water interacts with the surface. This property is related to the terminal groups of the molecules at the surface interface, which can be either hydrophilic ("water-loving") or hydrophobic ("water-hating").

TIP TO TEACHER:

A very simple example to show in class is a drop of oil in water: oil is made of unsaturated fatty acids which have a chemical structure that makes them extremely water-repellent, so when oil is dropped in water, the oil molecules minimise their contact with water, forming a compact droplet. The instructor can start this part of the experiment by asking students to mention surfaces that are hydrophobic (plastic) or hydrophilic (glass).

One of the methods to quantify the wetting behaviour of a surface is to measure its contact angle (CA). The contact angle is the angle at which a liquid/vapour interface meets the solid surface as illustrated in **Figure 1**.).

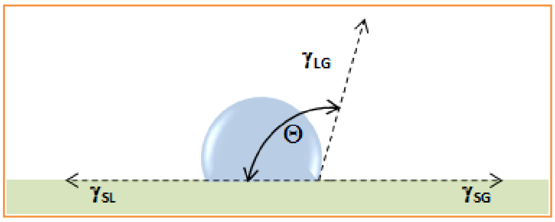

Figure 1. Static contact angle measurement of a droplet of water sitting on a flat solid surface. (Image credit: iNANO, Aarhus University, Creative Commons Attribution ShareAlike 3.0)

The contact angle is the angle formed by the liquid and the three phase boundaries. The shape of the droplet is controlled by the three forces of interfacial tension, as

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shown in **Figure 1**. The contact angle provides **information on the interaction energy between the surface and the liquid** (advanced description of the contact angle and its mathematical formulation are provided in **Appendix I for Experiment D**).

The contact angle θ can be measured using an instrument called a contact angle **goniometer**. This gives a static measurement of contact angles. A droplet of water is deposited over the surface under investigation and the angle θ measured either manually or, in modern instruments, digitally, by capturing a digital image and using dedicated software.

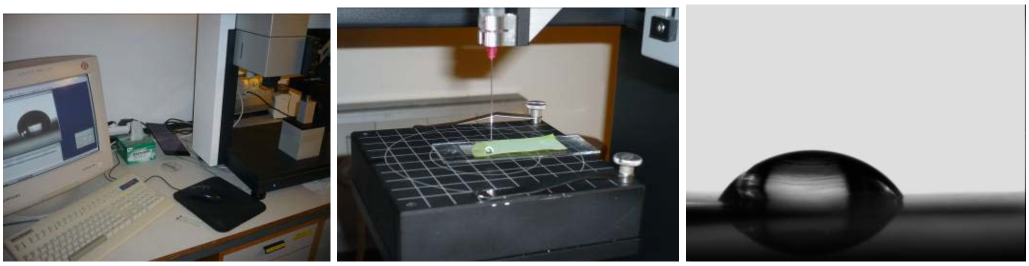

Figure 2. A contact angle goniometer with digital measurement capabilities. (Images credit: iNANO, Aarhus University, Creative Commons Attribution ShareAlike 3.0)

Surfaces can be classified depending on their contact angle as illustrated in the Table below.

Contact angle value	Type of surface	Example
~0	Super-hydrophilic	UV irradiated TiO_2
<30	Hydrophilic	Glass
30-90	Intermediate*	Aluminium
90-140	Hydrophobic	Plastic
>140	Superhydrophobic	Lotus leaf

* If the value is towards 30 it is defined as hydrophilic, if it is towards 90 it is defined as hydrophobic.

The larger the contact angle, the more hydrophobic a surface is. Think of what happens if you put water on a piece of glass: the water droplet will completely spread out on the glass and the contact angle will be close to 0°. The water droplet will be so flat that the measurement of the CA is actually difficult. On most hydrophilic surfaces, water droplets will exhibit contact angles between 0° and 30°.If

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the droplet is placed on less strongly hydrophilic solids, such as a piece of metal, it will have a contact angle up to 90° or larger depending on the material. Highly hydrophobic surfaces have water contact angles as high as 150° or even nearly 180°. These surfaces are called superhydrophobic. On these surfaces, water droplets simply rest on the surface, without actually wetting to any significant extent.

Surfaces with nanostructures tend to have very high contact angles, which can reach the superhydrophobic level. This can be understood by imagining that a surface with nano-roughness is formed of a series of very small pillars. When a droplet rests on this "mat of pillars" it is in contact with a large fraction of air. If we think of the ideal case of a single droplet of water in air, it will have a totally spherical shape (θ= 180). For a droplet of water on a surface with a large air fraction, the larger this fraction, the closer we get to this "ideal" situation (for a mathematical description of this relationship, see Appendix I).

2) Learning from nature: the Lotus Effect®

Material scientists have long used different chemicals to change the surface properties of a certain surface; for instance silanes are routinely used to render glass hydrophobic.

TIP TO TEACHER: A simple example to bring into class is metal kitchen utensils such as cooking pans: a layer of Teflon, which is a type of plastic, is added to the metal surface of the pan to make it non-stick. Surface chemistry can, however, only be used to make hydrophobic surfaces. To reach the superhydrophobic condition, it is necessary to insert topography into the surface, such as a micropattern (details are explained in the Appendix I).

Superhydrophobicity is a surface property found in nature, for instance in some leaves, such as the lotus leaf, and in some animals, as in the leg of water striders.

Figure 3. Two examples of natural materials that exhibit the lotus-effect: (left) a water strider (Image: Izabela Raszkova, Wiki commons, Creative Commons Attribution ShareAlike 3.0); (right): a Lotus leaf (Image credit: iNANO, Aarhus University, Creative Commons Attribution ShareAlike 3.0).

The Lotus effect® is described in detail in Chapter 2 of Module 1 "Natural nanomaterials".

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The **superhydrophobic effect found in lotus leaves** has been extensively researched. The lotus plant (*Nelumbo Nucifera*) is a native Asian plant which has the distinctive property of having its leaves particularly clean even if its natural habitat is muddy. The leaves of the lotus plant have the outstanding characteristic of totally repelling water because they are superhydrophobic. The same effect is found in other leaves such as those of Nasturtium-Tropeaolum and some Canas.

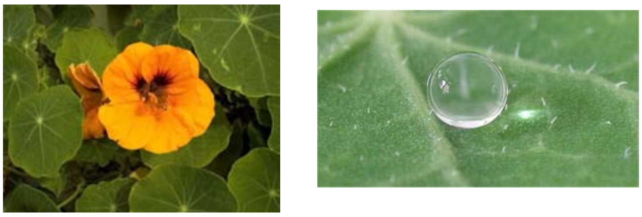

Figure 4. (Left) A nasturtium plant (Image credit: Wiki commons, Creative Commons Attribution ShareAlike 3.0) and (right) a water droplet resting on the surface of a nasturtium leaf. (Image credit: A. Otten and S. Herminghaus, Göttingen, Germany, NISE Network, reprinted under NISE network terms and conditions.)

HOW IS THIS "NANO"?

Detailed SEM analysis of leaves that display the Lotus effect® has revealed the presence of wax nanocrystals on the leaf surface. **These crystals provide a water-repellent layer, which is enhanced by the roughness of the surface, making it a superhydrophobic surface, with a contact angle of about 150**. The result is that water droplets interfacing with such a leaf are in contact with a large fraction of air. This forces the water to bead and roll off. The images below show the progressive magnification of a nasturtium leaf. In the last image on the right, **nanocrystals a few tens of nanometres** in size are shown.

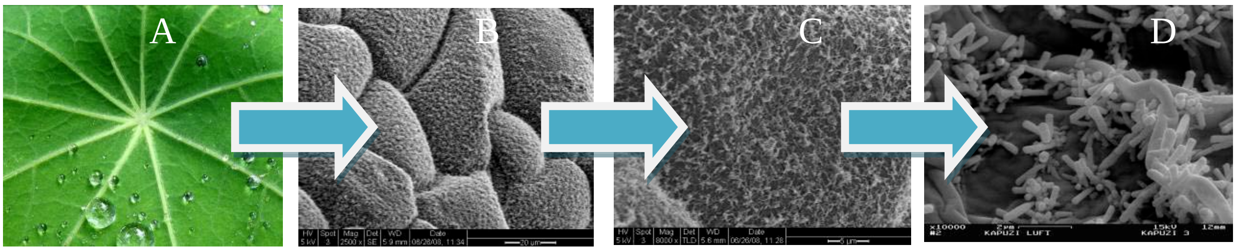

Figure 5. Close-up views at progressive magnification of a nasturtium leaf revealing the presence of surface nanocrystals (image on the far right). (Image credit (A): A. Snyder, Exploratorium; (B, C): A. Marshall, Stanford University, (D): A. Otten and S. Herminghaus, Göttingen, Germany, all images are material of the NISE Network, www.nisenet.org, reprinted under NISE network terms and conditions.)

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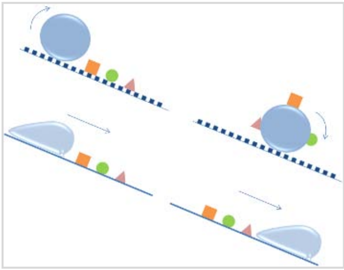
The consequence is that water droplets roll off the leaf surface and in doing so they drag dirt away from it, as in the illustration in **Figure 6**. This effect, called "self-cleaning", renders the Lotus leaf clean and resistant to dirt.

Contaminants on the surface (generally larger than the cellular structure of the leaves) rest on the tips of the rough surface. When a water droplet rolls over the contaminant, the droplet removes the particle from the surface of the leaf.



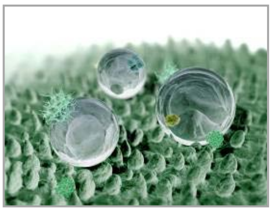


Figure 6. (Top) Diagram summarising the connection between roughening and self-cleaning: in the top image a droplet of water removes dirt from a surface thanks to the Lotus effect (bottom): Graphical representation of contaminants and water droplets on a lotus leaf (Image credit: by William Thielike, Wiki commons, Creative Commons ShareAlike 3.0.)

3) Lotus-inspired innovative materials

The Lotus Effect® has been an **inspiration for several innovative materials**, such as paints, coatings and textiles. The realisation that certain surface properties can induce water repellence is important in numerous applications. Material scientists are now engineering numerous types of materials to render them superhydrophobic. The main areas of applications are:

- **Environmentally friendly coatings** and textiles that are dirt repellent and **require less cleaning**. This includes materials such as façade paints, textiles (including personal clothing) and sanitary coatings. In all these materials the added advantage is that less cleaning is needed (therefore less detergent and waste water), with a consequent benefit for the environment.

- **Improving the performance of solar cells (energy application)**. One of the problems with this technology is that these cells are kept outdoors and therefore prone to become very dirty. This layer of dirt "masks" the catalytic areas of the solar cells and therefore reduces their efficiency and life-time. Coating the solar panel with a superhydrophobic coating keeps the panel considerably cleaner. Because

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of the nano-surface roughness, the coating is transparent to UV light, a necessity for these types of devices. The superhydrophobic coating is also durable, which further improves the solar panel life-time.

Products examined in this exercise:

1. NANO-TEX®

There are many instances where avoiding the wetting of a surface is an advantage, for instance in **textiles**, which are routinely stained by liquids (juices, coffee, etc) and solids (mustard, ketchup etc). Some companies such as Nano-Tex, Inc. are now commercialising textiles that are engineered to confer superhydrophobic properties on their textiles **(Figure 7**). This effect is obtained by the presence of "nano-sized whiskers" on the surface of the fibres that compose the fabric.

Figure 7. Liquid staining on a Nano-Tex® fabric. (Image credit: image courtesy of Nano-Tex, Inc., Copyright Nano-Tex. Inc.)

In this experimental module the students will analyse and test a superhydrophobic textile from Nano-Tex, Inc. (Nano-Tex® Resist Spills fabric)[1] and compare it with a real Lotus leaf.

How does it work? Nano-Tex® Resist Spills fabric is engineered to mimic the Lotus effect®. This is achieved though a large number of very small "pins", or "whiskers" on the surface of the fibres. Therefore the fabric does not contain a surface coating (which could be removed by washing or sweating), but rather the fibres are nano-engineered. The result is a material which is super-hydrophobic, as illustrated by the contact angle measured and shown in **Figure 8**. A picture of the contact angle of a lotus leaf is shown for comparison

[1] Nano-Tex® Resist Spills fabric is used in a number of commercial products. See www.nano-tex.com for more information on the fabric and a list of brands that use this fabric in their products. Other companies are developing fabrics nano-engineered to resist spills and stains or with other improved properties. See the product inventory at http://www.nanotechproject.org/inventories/consumer/ for details.

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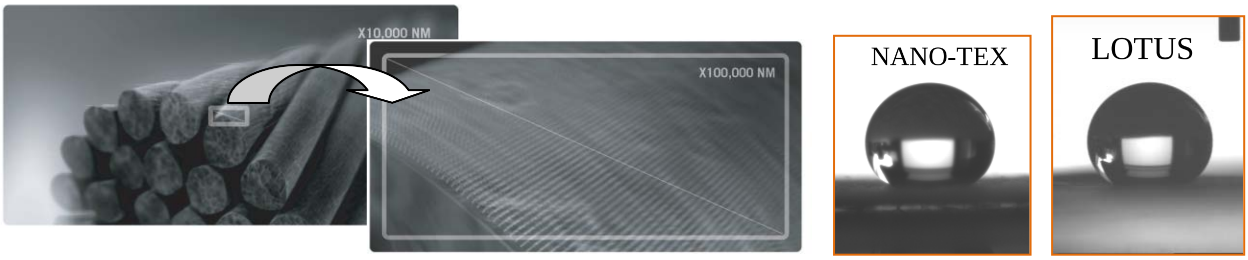

Figure 8. High resolution images of the Nano-Tex® fabric (Images courtesy of Nano-Tex, Inc., Copyright Nano-Tex. Inc). (Right): contact angle images of water droplets on Nano-Tex fabric and Lotus leaf (Images: iNANO; Aarhus University, Creative Commons Attribution ShareAlike 3.0).

2. POROUS SILICON

The second material analysed in this experiment is a material under research at iNANO which is made of **porous silicon.**

In this exercise students cannot use a real piece of porous silicon. A video is provided to show in class (NANOYOU Video 4- Lotus Effect® part 2).

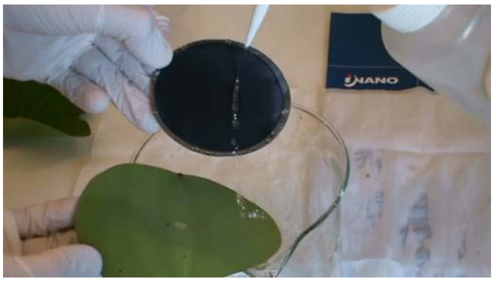

Figure d9. A still from the NANOYOU Video 4- Lotus Effect®-Part 2 where a piece of porous silicon is compared to a real Lotus leaf. (Image credit: L. Filipponi, iNANO, Aarhus University, Creative Commons Attribution ShareAlike 3.0)

As mentioned above, surfaces (or textiles) engineered to be superhydrophobic are made of very small "pins", or "whiskers" inspired from the microstructure of the Lotus leaf. The **porosity and spacing of this fine structure determines the wetting properties of the material**. The material shown in the video has a contact angle of 167.

The superhydrophobic effect results from the peculiar micro/nanotexture of this surface.

EXTRA TEACHER READING: Chapter 2 "Natural nanomaterials" and Chapter 5 "Overview of nanomaterials" in Module 1; Chapter 2 "Applications of Nanotechnologies: Environment" and Chapter 3 "Applications of Nanotechnologies: Energy" in Module 2 of the "NANOYOU Teachers Training Kit in Nanotechnologies".

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ABOUT THIS EXERCISE:

Part 1 - Understanding surface properties: from hydrophilic to superhydrophobic

To visualize the concept of hydrophobic and hydrophilic materials students will deal with:

1.a The shape of the droplets

Observe and compare shapes (profile) of the water droplets on the different materials.

1.b The concept of "From 'water lovers' to 'water haters'"

Sort the materials: from hydrophilic to superhydrophobic

1.c The sliding of droplets

Observe how water slides or rolls on hydrophobic and superhydrophobic surfaces

Part - Analysis of functional nanomaterial

To learn the properties of advanced material that have been engineered to be superhydrophobic, students will:

2.a: Interaction with water

Test and compare shapes of the *water droplets* on Nano-Tex® and a piece of normal cotton fabric.

2.b: Interaction with different liquids

Step 1: Test and compare the "stain effect" of *different liquids* on different fabrics.

Step 2: Test and compare the "dirt effect" (resistance to *organic soil*) on different fabrics.

Step 3: Test and compare the "cleaning level" (cold water and soap) on different fabrics.

SUGGESTED STRATEGIES FOR TEACHING

Warm up activity: demonstration and discussion:

Demonstration

- Pour some water on the teacher's desk and ask the students:

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Q: How does water interact with the desk? (Describe what you see)

Would it be different if we poured half a cup of water on a towel? In what way? (Demonstrate it)

Discussion:

- Does it follow your assumption/expectation? What kind of property can be used to compare the two demonstrations ?

Write the various answers (don't respond orally)

Divide the class into groups for the following experiment (part 1)

MATERIAL NEEDED:

- Different surfaces to test:
    * 1 microscope glass slide
    * 1 flat piece of plastic 10x10 cm (e.g., cut a piece out of a smooth plastic sheet such as a plastic folder, or use a CD.)
    * 1 flat piece of aluminium foil 10x10 cm
    * 1 piece of filter paper
    * Pieces of textiles to compare (about 10x10 cm):
        - 3 pieces of Nano-Tex® Resist Spills fabric
        - 3 samples of 100% cotton
        - 2 samples of fabric made with synthetic fibre such as polyester or cotton/poly blend; in this protocol we used a fabric with 70% polyester, and 30% cotton)

- Different stain agents to choose from
    * 1 glass of water,
    * 1 glass of juice and/or 1 glass of coke
    * Balsamic vinegar or wine (1 glass)
    * cooking oil (1 glass)
    * Ketchup (1 spoon)
    * Mustard (1 spoon)
    * Mayonnaise (1 spoon)

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* Organic soil (a couple of handfuls)

- Different plant leaves (collect from school garden or bring from home)

* One common plant leaf such as ivy

* One piece of Lotus leaf or Nasturtium

- Laboratory bottle filled with water
- Eyedroppers (or Pasteur pipettes) to apply the liquid stain agents - Plastic knives or spoons for applying the other stain agents
- A bucket with laundry detergent and water (you might need to share this with the entire class)
- 1 permanent marker
- Several plastic cups to hold water and stain agents
- Several plastic plates to put materials in when conducting the material testing
- Paper glue and scissors

SAFETY NOTE: This experiment doesn't use chemicals but only common liquids and solids. Nevertheless staining is possible so wash hands and surfaces thoroughly after handling. Use appropriate clothing protection, gloves and eyes protection. Collect all liquids and washing water is glass/plastic containers and dispose in water basin. All experiments will be carried out at your own risk. Aarhus University (iNANO) and the entire NANOYOU consortium assume no liability for damage or consequential losses sustained as a result of the carrying out of the experiments described.

PROCEDURE

You will now test a series of materials, starting from common ones and moving towards more advanced ones. When you test the materials with water or other liquids, do so by placing the material inside a plastic plate in order to collect the water neatly. **Dispose of the collected water in between stages of the tests**.

Part 1 - Understanding surface properties: from hydrophilic to super hydrophobic

1.a: The shape of the droplets

Observe and compare shapes of the water droplets on the different materials.

Place in plastic plates the six surfaces that are to be tested: **a glass slide, a piece of plastic, a square of aluminium foil, a square of filter paper, and one leaf of Nasturtium or Lotus. Place a couple of droplets of water on each material.**

Q1: What are the shapes of the water droplets on the different surfaces? Fill the table.

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Material	Profile of the drop
Aluminium	
Plastic	
Filter paper	
Glass	
Common Leaf	** Depends on the type of leaf*
Nasturtium/ lotus leaf	

Q2: Describe in your own words the differences in the droplets' shapes.

On some materials the droplet's shape is flatter while on the Nasturtium/lotus leaf the droplet's shape is spherical. The filter paper is exceptional since the water is completely absorbed.

* In your opinion, what is the reason for these differences?

Note: *it is important to motivate student by asking challenging questions.*

It is <u>not expected</u> that the students will know exactly the right answer. Do they relate the different shapes to physical /chemical properties? or to the surface roughness?

- If possible, collect a Lotus leaf from a botanic garden in your town. If this is not possible, there are some alternatives plants that can be used, such as Nasturtium. Nasturtium can be bought in springtime at a garden shop as a plant or as seeds that can be planted in a medium size pot.

- If the collection of leaves is problematic, this part of the experiment can be shown through the ***NANOYOU Video 3: Lotus Effect® - Part 1***

** The video can be downloaded from the NANOYOU portal* http://www.nanoyou.eu/

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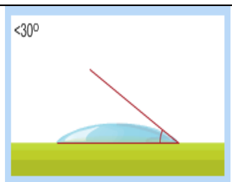
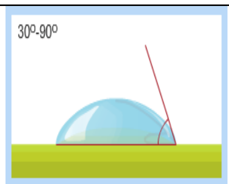
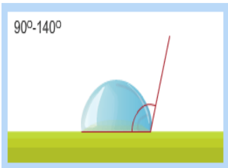
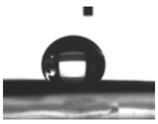
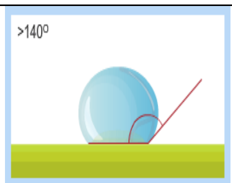
1.b: From "water lovers" to "water haters"

Sort the materials: from hydrophilic to superhydrophobic

Q3: Now use the information from question 1 to fill in the missing data in the following table:

Shape (profile)	Contact angle value	Type of surface	materials
		*Hydrophilic*	*Glass*
		*Intermediate**	*Aluminium*
		*Hydrophobic*	*Plastic*
		*Superhydrophobic*	*Nasturtium leaf*

Q4. The filter paper behaved unlike the other materials; in what way?

Unlike the other materials, the filter paper absorbs the water droplets

Q5. How do you think we can decide if the filter paper is hydrophobic or hydrophilic?

Usually it is decided by the shape (contact angle) of the water drop.

In the case of filter paper the water is absorbed so there is no contact angle. The absorbance by itself makes it clear that it is ***hydrophilic ("water lover").***

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1.c: The movement of droplets

Observe how water rolls on hydrophobic surfaces.

Choose the two most hydrophobic surfaces (hint: the Nasturtium leaf should be one of them). Use a spoon or a Pasteur pipette to pour some water over each surface, and observe how water rolls off the surface.

(A container should be used to collect the water, and a paper towel should be on hand.)

Q : Do the water droplets wet the surfaces (i.e., is water left over the surfaces once you stop pouring it)? Give an answer for each type of surface you have tested.

Water wets all the surfaces including the common leaves except the Nasturtium/lotus leaf.

Q : Do the water droplets roll or slide over the surfaces?

Water droplets slide all over all the surfaces including the common leaves except the Nasturtium/lotus leaf; water droplets roll like beads over it.

Q8: Can you get a droplet to rest still over the surface? Is it easy or difficult?

Unlike the other materials, it is very hard to get a water droplet to rest on the Nasturtium/lotus leaf . It behaves like a bead, and is very unstable. This means that the surface is extremely hydrophobic.

Q9: Based on all the above observations and information, which is the more hydrophobic surface of the two? Explain. Is this consistent with the drop shapes that were used to assess these types of surfaces?

The Nasturtium/lotus leaf has the most hydrophobic surface, since the droplet behaved like a bead on it. Yes, it was consistent with the spherical drop shape

Q10: Write your conclusions for Part 1 of this experiment:

Possible conclusions:

- Droplets of water on different material surfaces create different types of drop profiles *(from a flat droplet that is spread on a glass surface to a completely spherical droplet that rests on the Nasturtium leaf/lotus leaf)*.

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- The drop profile is defined by the contact angle between the drop and the material surface *(contact angle is the angle at which the droplet meets the solid surface)*.
- Materials can be classified on a scale (from Hydrophilic to Intermediate, Hydrophobic and Superhydrophobic) according to the contact angle – the larger the contact angle, the more superhydrophobic ("water hater") a surface is.
- Superhydrophobic surfaces are found in nature, for instance in some leaves, such as the Nasturtium leaf or lotus leaf.

Summary and wrap up

- *Relate to the warm up activity:*

  What kind of property did you suggest to compare between the two demonstrations? Is it different from the property tested through the experiment?

- *Show the video: NANOYOU Video 3: Lotus Effect® - Part 1*

  * can be downloaded from the NANOYOU portal http://www.nanoyou.eu/

Discussion:

- Ask students to think of applications where a hydrophobic material (such as the lotus) might be useful.

- *Use the summary as a test (summative assessment)*

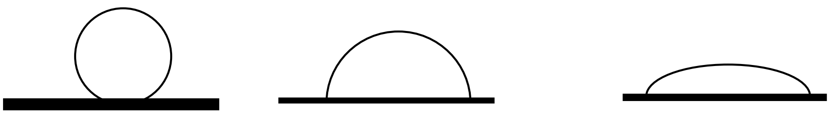
Examples:

1. Droplets of water on different material surface create different types of drop profile.

   Draw three different types of droplet profiles

2. The drop profile is defined by the contact angle between the drop and the material surface *(contact angle is the angle at which the droplet meets the solid surface)*.

Add the contact angles to the following profiles:



3. Explain the relations betwe ophilic/Hydrophobic surfaces.

   Or, Classify the following materials according to the contact angle

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Materials: Glass, lotus leaf, aluminium

Part - Analysis of functional nanomaterial

This part of the experiment analyses Nano-Tex®, which has been engineered to replicate the Lotus Effect® and have self-cleaning properties

2.a: Interaction with water

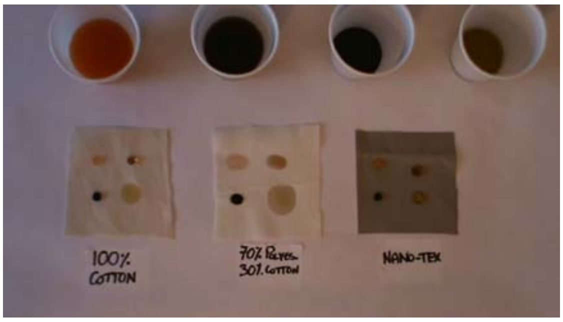
Place one piece of Nano-Tex® Resist Spills and one piece of a normal cotton fabric in a plastic plate and pour some water over them.

Q11: Which material from part 1.a does the Nano-Tex® fabric behave like? In what way? Which material does the cotton behave like?

The Nano-Tex® fabric behaves like the Nasturtium/lotus leaf in the way that the water beads on it. The cotton behaves like the filter paper in the way the water is absorbed .

Step 1: Test and compare the "stain effect" of *different liquids* on different fabrics.

Testing the effects of liquids (coke, vinegar, oil etc.) and emulsions (mayonnaise, mustard etc.).



Q12: Record your observations in the table provided. In each cell refer to two aspects, where there can be three levels within each aspect:

Absorbed: Not at all, a bit, a lot

Stained: Not at all, a bit, a lot

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A good idea would be to assign different "testing times" to different small groups of students. This way students could test the effect of staining materials on the fabrics for 5 minutes, 10 minutes and so on.

Time of liquid staining: …………seconds (*fill in*)					
	liquid 1 (for example juice)	**liquid 2** (for example oil)	**thick liquid 1** **(**for example mustard)	**thick liquid 2** (for example mayonnaise)	**Marker**
Cotton fabric	*Absorbed:* **a lot** *Stained:* **a lot**	*Absorbed:* **a lot** *Stained:* **a lot**	*Absorbed:* **a bit** *Stained:* **a lot**	*Absorbed:* **a bit** *Stained:* **a lot**	*Absorbed:* **a lot** *Stained:* **a lot**
Semi-synthetic fabric	*Absorbed:* **according to the type of the fabric** *Stained:* **according to the type of the fabric**	*Absorbed:* **according to the type of the fabric** *Stained:* **according to the type of the fabric**	*Absorbed:* **according to the type of the fabric** *Stained:* **according to the type of the fabric**	*Absorbed:* **according to the type of the fabric** *Stained:* **according to the type of the fabric**	*Absorbed:* **a lot** *Stained:* **a lot**
Nano-Tex®?	*Absorbed:* **Not at all** *Stained*: **Not at all**	*Absorbed:* **Not at all** *Stained*: **Not at all**	*Absorbed:* **Not at all** *Stained*: **a bit**	*Absorbed:* **Not at all** *Stained*: **a bit**	*Absorbed:* **a lot** *Stained:* **a lot**

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Q13: Were there differences between the fabrics? Describe.

Yes. There were. All liquids seem to rest on the surface of the ***Nano-Tex®*** *and form little beads, whereas in the other fabrics liquids spread quickly.*

Q14: Did all stains come off the **Nano-Tex®**?

Not all the stains come off the ***Nano-Tex®***

Nano-Tex® repels liquid stains of all kinds but does not completely repel stains caused by things that are not liquids (or thick liquids) such as mustard and mayonnaise. And the marker stained it a lot

The Nano-Tex® will appear considerably less stained than the other fabrics, but traces of thick liquids could be left (depending on what is used), which can be removed easily with the fingers. The permanent marker stain will not be removed with this method (it needs soap and water).

Step 2: Test and compare the "dirt effect" (resistance to *organic soil*) on different fabrics.

Testing for resistance to dirt. In this step organic soil is used to compare Nano-Tex® fabric with normal cotton and with a semi-synthetic fabric.

Q15: Did all the fabrics get dirty in the same way? Describe.

All fabrics except Nano-Tex® seem to "absorb" the dirt, in the sense that it clearly penetrates the fabric fibres. In the case of Nano-Tex®, dirt seems to remain on the surface, and overall this fabric is stained less.

Now try to clean the fabrics with your hands.

Q16: Could you clean the fabrics? Is there a clear difference among them? If so, describe which type of fabric could be cleaned more easily.

Both the cotton and semi-synthetic fabrics are quite hard to get clean, the dirt seems "trapped inside" the fibres. In the case of Nano-Tex®, some cleaning is obtained just by using hands; the dirt does not seem to be so "trapped inside".

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Q17: Was there a fabric that could be totally cleaned and appear as new?

No, even Nano-Tex® shows a little bit of stain, although much less than the other fabrics.

Step 3: Test and compare the "cleaning level" (cold water and soap) on different fabrics.

Testing for ease of cleaning. Now try to clean the three fabrics used in ALL STEPS (the ones with the liquids as well) with cold water and soap.

Q18: Do all the fabrics become clean? If not, which one does?

The cotton and semi-synthetic fabrics showed stains after hand-washing (the result on the semi-synthetic fabric depends on what fabric is used). On Nano-Tex®, cleaning appears easier and more effective, although a "shadow of stain" is visible in some cases.

The only fabric that becomes as clean as new is the piece of Nano-Tex® tested with dirt. All others show a little staining, particularly from the permanent marker stain.

Q19: Which type of fabric could be cleaned most easily?

The Nano-Tex® fabric

Q20: Is there a type (or more) of stain that doesn't come off from the Nano-Tex® samples? Which one? Why do you think this is so?

The stain that is hardest to remove from **Nano-Tex®** *is the permanent marker. This has some chemicals that are very hard to remove.*

The Nano-Tex® might appear nearly perfectly clean, but not totally. Point this out to the students, as it is important to keep in mind that "nano is not magic", and even this fabric will need some cleaning but this will require much less effort and detergent.

Q21: Write your conclusions for Part 2 of this experiment:

Possible conclusions:

- The Lotus effect is an inspiration for new innovative materials like **Nano-Tex®**.

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- These innovative materials are highly water-repellent, stainless and require less cleaning thanks to their surface nano-engineering
- Super hydrophobic surfaces found in nature are nanostructure surfaces
- Nano-structure surfaces provides a water-repellent layer which forces the water droplet to be spherical and roll off.
-

Q22: What are possible applications of Nanomaterials?

(Compare and discuss with whole class)

Ask students to think of applications where Nano-Tex® or other superhydrophobic engineering material might be useful.

- *Show the video:* ***NANOYOU Video 4: Lotus Effect® - Part 2***

  *can be downloaded from the NANOYOU portal http://www.nanoyou.eu/

In this video students can see an engineered surface made of porous silicon that is under development in the laboratories of iNANO, Aarhus University, and that mimics the properties of the Lotus leaf. Discuss with students applications where they think such properties could be useful, such as:

- ***Environmentally friendly coating*** *and textiles that are dirt repellent and less cleaning. This includes materials such as façade paints, textiles (including personal clothing) and sanitary coatings. In all these materials the added advantage is that less cleaning is needed (therefore less detergent and water wasted), with a consequent benefit for the environment.*

- ***Improving the performance of solar cells*** *(energy application). One of the problems with this technology is that they are kept outdoors and therefore prone to become very dirty. This layer of dirt "masks" the catalytic areas of the solar cells and therefore reduces its efficiency and life time. Coating the solar panel with superhydrophobic coating keeps the panel considerably cleaner. The superhydrophobic coating is also durable, which further improves the solar panel life-time.*

Videos from YouTube

Nice Suit, Bob! Nano-Tex Suit Goes For a Swim

http://www.youtube.com/watch?v=0hb-G3IfERg

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Coffee vs. Nano-Tex Fabric

http://www.youtube.com/watch?v=SD8sFVf626g

Nano-Tex Resists Spills Shirt on Today Show. Nanotechnology

http://www.youtube.com/watch?v=g9UENE6JMLI

CREDIT NOTE:

This experiment is partly adapted from the Application activity: Nano-Tex, http://mrsec.wisc.edu/Edetc/IPSE/educators/nanoTex.html.

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