NANOYOU Teachers Training Kit in Nanotechnologies

Experiment D – Superhydrophobic Materials

Experiment Module

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MATERIAL INCLUDED IN THIS EXPERIMENT PACKAGE:

For teachers:

TEACHER RESOURCES FOR EXPERIMENT D

APPENDIX I EXPERIMENT D

For students:

EXPERIMENT D-STUDENT BACKGROUND READING

EXPERIMENT D-STUDENT LABORATORY WORKSHEET

Supporting videos:

NANOYOU VIDEO 3- LOTUS EFFECT® (PART 1)

NANOYOU VIDEO 4- LOTUS EFFECT® (PART 2)

LEVEL OF EXPERIMENT: Medium

DISCLAIMER: The experiments described in the following training kit use chemicals which need to be used accordingly to MSDS specifications. Follow school lab safety guidelines. Personal protection must be taken as indicated. As with all chemicals, use precautions. Solids should not be inhaled and contact with skin, eyes, or clothing should be avoided. Wash hands thoroughly after handling. Dispose as indicated. All experiments must be conducted in the presence of an educator trained for science teaching. 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.

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 233433

TEACHER RESOURCES FOR EXPERIMENT D: SUPERHYDROPHOBIC MATERIALS

AIM: The aim of this experiment is to show students some innovative materials that are **highly water repellent, stainless and require less cleaning thanks to their surface nano-engineering**. These materials have been developed using Nature as an inspiration, since some plant leaves (like the lotus leaf or the nasturtium (Tropeaolum)) leaf have the exceptional property of being superhydrophobic due to nanostructures that are present in their surface composition. Water simply rolls off these leaves! The effect is due to the interplay of surface chemistry and surface topography at the micro- and nano-level. The students will 1. Analyse different materials, including leaves, polymers, glass, etc. and analyse their wetting properties; 2. See and test functional nanomaterials that have been engineered at the nanoscale to be superhydrophobic: a porous silicon wafer fabricated at iNANO (analysis is done by watching a video); and a fabric (from Nano-Tex, Inc.).

FIELD OF NANOTECHNOLOGY APPLICATION: Energy & Environment: Environmentally friendly materials.

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”.

REQUIRED STUDENT PRE-KNOWLEDGE:
- Surface properties (hydrophilic, hydrophobic)
- Contact angle (use Appendix I if needed)

STUDENT READING:
- NANOYOU Students’ background document for Experiment D

EXPECTED OUTCOME:
- The effect of surface topography on contact angle, and the insurgence of super-hydrophobicity
- Novel advanced materials that have been engineered at the nanoscale to be superhydrophobic and their applications
- Analysis of a functional nanomaterial under research at iNANO, Aarhus University (through a video)
- Analysis and hands-on test of a superhydrophobic textile

STUDENT ASSESSMENT:
-NANOYOU Student laboratory worksheet Experiment D

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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**.). 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 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**).

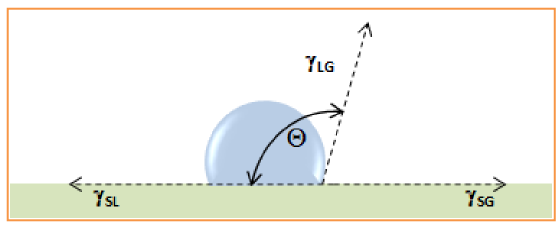

Figure 1. Static contact angle measurement of a droplet of water sitting on a flat solid surface. (Image credit: iNANO, Aarhus University, Creative Commons Attribution ShareAlike 3.0)

The contact angle 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.

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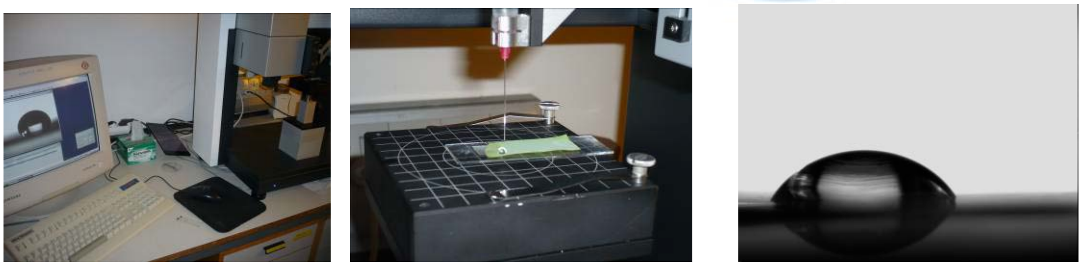

Figure 2. A contact angle goniometer with digital measurement capabilities. (Images credit: iNANO, Aarhus University, Creative Commons Attribution ShareAlike 3.0)

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 is defined as hydrophilic, if it is towards 90 is defined 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 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 super-hydrophobic 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

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fraction, the closer we get to this "ideal" situation (for a mathematical description of this relationship, see Appendix I).

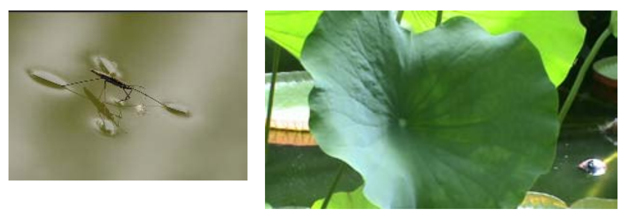
2) Learning from nature: the Lotus Effect®

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, be used only 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 in the lotus leaf, and in some animals, such as in the leg of water striders.



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

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 **superhydrophobic effect found in lotus leaves** has been extensively researched. The lotus plant (*Nelumbo Nucifera*) is a native Asian plant which has the distinct 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.)

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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.

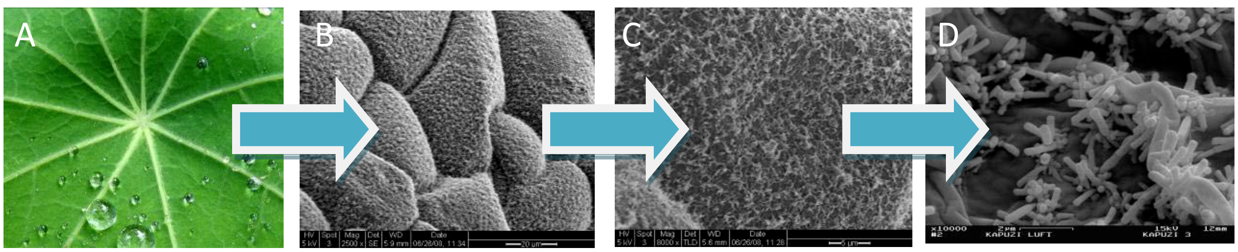

Figure 5. Close-up views at progressive magnification of a nasturtium leaf revealing the presence of surface nanocrystals (image on the far right). (Image credit (A): A. Snyder, Exploratorium; (B, C): A. Marshall, Stanford University, (D): A. Otten and S. Herminghaus, Göttingen, Germany, all images are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

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.

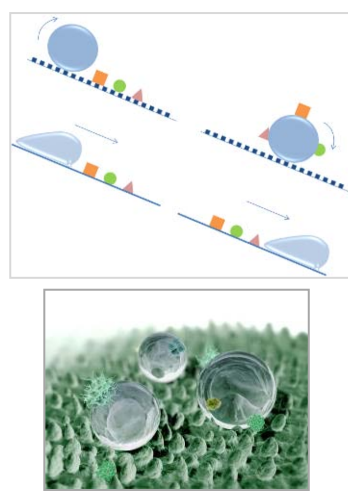

Figure 6. (Top) Diagram summarising the connection between roughening and self-cleaning: in the top image a droplet of water removes dirt from a surface thanks to the Lotus effect (bottom): Graphical representation of contaminants and water droplets on a lotus leaf (Image credit: by William Thielike,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

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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 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) 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

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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

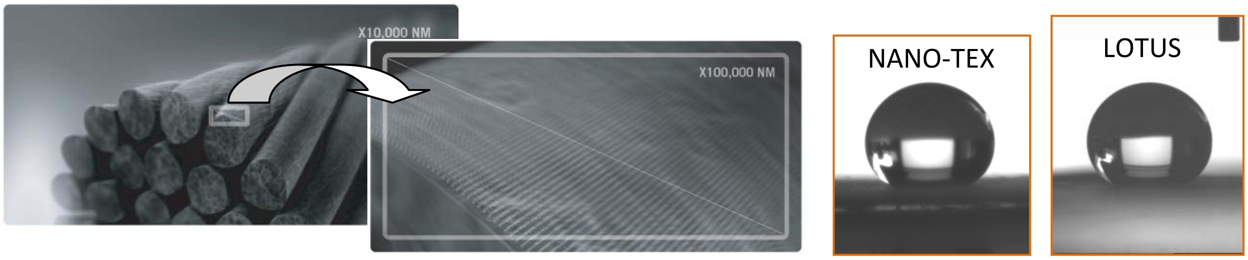

Figure 8. High resolution images of the Nano-Tex® fabric (Images courtesy of Nano-Tex, Inc., Copyright Nano-Tex. Inc). (Right): contact angle images of water droplets on Nano-Tex fabric and Lotus leaf (Images: iNANO; Aarhus University, Creative Commons Attribution ShareAlike 3.0).

NOTE: 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.

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.

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How does it work?

Surfaces engineered to be superhydrophobic are made of very small "pins" inspired from the microstructure of the Lotus leaf. The porosity and spacing of this fine structure determines the wetting properties of the material. To do so, scientist modify the surface of normal silicon (which is normally hydrophilic) with specialized methods. For instance, electrochemical dissolution of crystalline silicon with HF[1]. Surfaces engineered to be superhydrophobic have many applications (solar panel coatings, protein array surfaces etc.). In this experiment, inside **Video 4- Lotus Effect® (Part 2)** students will see a piece of porous silicon prepared by Dr. Anton Ressine during his research at the Lund Institute of Technology (Sweden) and now under research at iNANO.

Figure d10 shows some samples of **porous silicon**, which can be engineered to be superhydrophobic. In Figure d10, sample A is normal silicon (untreated) and samples B, C and D are porous silicon samples obtained with different fabrication conditions. **Table 2** summarizes the contact angle of each sample.

Sample	Contact Angle (°)
A	64
B	110
C	155
D	167

Table 2

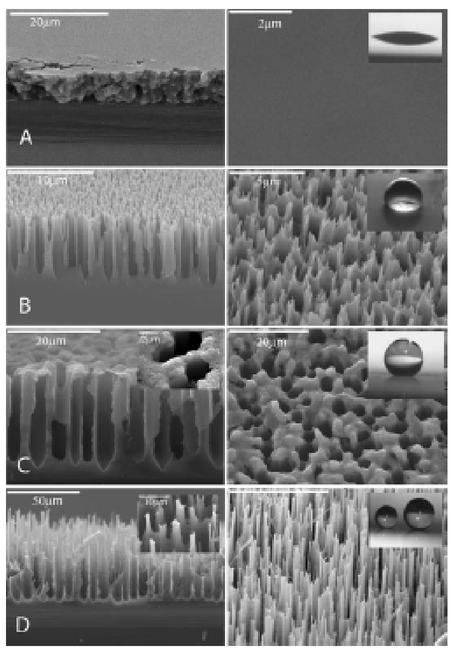

Figure d10. SEM Images of four different samples showing a change in contact angle from hydrophilic (A) to hydrophobic and superhydrophobic. Samples B-D are made of porous silicon, sample D is the one with the higher contact angle (Image reprinted with permission from: A. Ressine, "Development of protein microarray chip technology", PhD thesis 2005)

The sample of porous silicon shown **in the video is sample D**. As seen from Figure d10 and Table 2 it is the most superhydrophobic with a contact angle of 167. What is interesting to note is that in sample B the distance between the "pillars" is smaller than in sample D, so the porosity (percentage of voids in

[1] The interested reader can find more information in numerous reviewed papers, such as: Ressine et al., Anal. Chem. 2003, 75, 6968-6974.

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the material) is lower. Therefore in sample D there is a larger "fraction of air" to which the droplet is exposed, and the contact angle is larger. This examples shows that to engineer superhydrophobic surfaces scientists need to find the right fabrication conditions to obtain the right balance of "nano-pillars" and porosity within the silicon surface. It is this balance of micro and nanotexturing that leads to superhydrophobic materials.

The surface of the superhydrophobic porous silicon remarkably resembles that of a water strider, which also displays a micro-/nanotextured surface. Notably, the contact angle of the water strider leg is also 167 C.

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THIS EXERCISE IN CLASS

Depending on time and the level of the class this experiment module can be used in different ways. The authors suggest:

1. Starting with a general discussion on surface properties:

- What property can be used to compare them?
- How does water interact with different surfaces?

2. Introducing the concepts of hydrophobicity and hydrophilicity

- Give definition and some examples.
- How can one make a hydrophilic surface (such as glass) hydrophobic? Students/teacher should discuss coatings and their effect on surfaces.
- Define the contact angle as a surface characterisation method (depending on the level of the class, this can be less or more advanced; for an advanced class, refer to Appendix I)

3. Test different surfaces. Different materials should be tested for their wetting behaviour. The details are given in the next section. Materials that can be tested (from more hydrophilic to more hydrophobic) are: glass, coated wood, aluminium, plastic, parafilm.

- Ask the students to draw up a scale of hydrophobicity based on what they can see. Use the images provided in this kit (at the end of the **Students Laboratory Worksheet for Experiment D**).

4. Test of a superhydrophobic surface: the lotus leaf. If available a lotus leaf should be obtained from a botanical garden. If not available, alternative plants can be used, such as nasturtium.

- Discuss the Lotus Effect® and how this is inspirational for new materials.
- Watch the NANOYOU **Video 4 Lotus Effect®- Part 2** showing the Lotus Effect® on a real lotus plant and the same effect on an artificially made surface (porous silicon, iNANO research labs)
- Let the students observe the effect on a real leaf and compare with other leaves

5. Test a superhydrophobic textile

- Test the Nano-Tex® textile for spills of liquids, solids, soil, etc.

6. Discuss applications and implications

- Nano-Tex® is an example of a practical application of nanotechnologies. Ask the students to think of other applications where the super-hydrophobic effect might be useful.

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MATERIAL NEEDED

The material below is indicated assuming students will work in pairs.

Materials for the entire class (to be shared)

- Different stain agents to test (**amounts indicated are for the entire class**):

  * Water
  * Juice (1 L) or coke (1L)
  * Balsamic vinegar or wine (1 glass)
  * Cooking oil (1 glass)
  * Ketchup (1 small container)
  * Mustard (1 small container)
  * Mayonnaise (1 small container)
  * Organic soil (a couple of handfuls)

Materials for each student pair:

- Different surfaces to test:

  * 1 microscope glass slide
  * 1 flat piece of plastic 10x10 cm (e.g., cut a piece out of a plastic sheet such as a plastic folder)
  * 1 flat piece of aluminium foil 10x10 cm
  * 1 piece of cloth 10x10 cm (ask students to bring from home or get remnants from fabric store)
  * 2 pieces of filter paper
  * pieces of textiles to compare (each about 10x10 cm): 4 Nano-Tex® Resist Spills fabric[2] and two other types (3 samples of 100% cotton and 3 sample of fabric made with synthetic fibre such as polyester or cotton/poly blend; in this protocol we used a fabric with 70% polyester, 30% cotton)

- 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

[2] We suggest purchasing from a local department store or on-line a pair of trousers or a shirt made from the Nano-Tex® fabric (about 40 Euros) and cutting it into pieces. See www.nano-tex.com for more information on the fabric and a list of brands that use this fabric in their products. A list of commercial products made of Nano-Tex® fabric can also be found using: http://www.google.co.uk/products?q=nano+tex&hl=en. Some products will be made of Nano-Tex® Resist Spills, or Nano-Tex® Resist Spills and Releases Stains. Both are fine for this experiment but might give slightly different results in terms of resistance to solids. See www.nano-tex.com for details on the technical difference between these two types of fabric.

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- 5 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 (this can be shared by the entire class)
- A 10x10 cm piece of sandpaper (a large sheet can be cut up)
- 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 does not 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 eye protection. Collect all liquids and washing water in glass/plastic containers and dispose of in sink. 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

It is assumed that most schools will not have access to an instrument to measure contact angles, so this is not suggested and images are provided throughout the text on actual contact angle measurements conducted at iNANO. Images of contact angles on different surfaces are given in the Student Laboratory Worksheet for Experiment D. However, if a teacher has access to this instrument this experimental activity can include a session dedicated to contact angle measurements.

1. Understanding surface properties: hydrophilic and hydrophobic

Give students the different surfaces to test (as detailed in the “Material Needed” section): glass slide, plastic, aluminium foil, wood, filter paper. Ask the students to place a couple of droplets of water on each material, recording their observations. Filter paper will absorb water very quickly.

Ask the students to put the material in a scale, starting from the most hydrophilic to the most hydrophobic based on their visual observation. Then ask the students to use the photos of water droplets provided in the Student Laboratory Worksheet for Experiment D and match them to the scale they have just made.

Students should complete questions Q1 to Q4 in the Student Worksheet.

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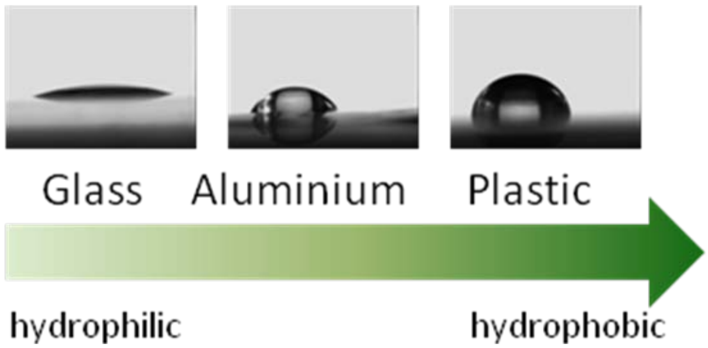
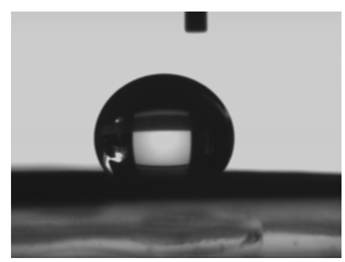


2. Analysis of natural nanomaterials: the lotus leaf

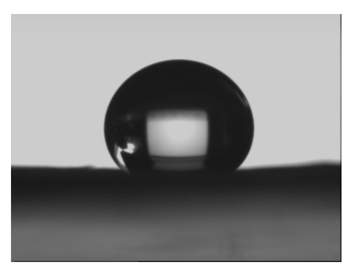
- Collect some plant leaves with the students from the school garden, or ask them to bring a few from home (e.g. ivy).

TIP TO TEACHER: The collection of the leaves could be combined with a school visit to a botanical garden for a more general lesson on plants, their surface properties, etc. This would allow an interdisciplinary lesson that bridges natural sciences with chemistry.

- If possible, collect a LOTUS leaf from a botanic garden in your town.
- If this is problematic, there are some alternative plants that can be used such as Nasturtium-Tropeaolum.



TIP TO TEACHER: Nasturtium can be bought in the Spring time as seeds and planted in a medium size pot. This way a school can have its "lotus-like plant" to be used and tested as required at minimal cost! The entire plant can easily be bought at garden shops (in summer).



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STEP 1.

- Ask the students to test the "common" leaves they have collected (or brought from home) for their wetting behaviour. Let them pour some water over the leaf and observe how it rolls off the surface. A bucket or other container should be used to collect the water. Paper towel should be on hand.

Students should complete questions Q5 and Q6 in the Student Worksheet.

STEP 2.

- **Now ask the students to test a lotus or nasturtium leaf**. Cut leaf into several pieces if you don't have enough for all the class.

Students should complete questions Q7 and Q13 in the Student Worksheet.

STEP 3.

- After observing the Lotus effect® on a real plant, show the class the NANOYOU Video 4 Lotus Effect®-Part 2 provided in this training kit, which shows a surface engineered at iNANO (Aarhus University), with surface properties comparable to the Lotus leaf (superhydrophobic).

ALTERNATIVE: If collection of leaves is problematic, this part of the experiment can be shown entirely through the video in the appendix (**Video3 Lotus Effect®- Part 1**: natural plants showing the lotus effect; **Video3 Lotus Effect®- Part 2**: the wetting properties of lotus leaves compared with conventional leaves, with the wetting behaviour of an advanced material investigated at iNANO, and with a piece of Nano-Tex® fabric. A direct comparison between a lotus leaf and these advanced materials is shown). The questions listed in the Student Laboratory Worksheet for Experiment D should be used while watching these videos to encourage class discussion.

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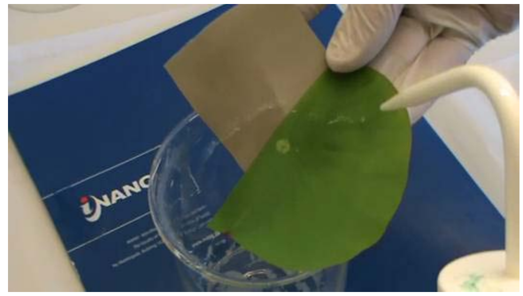
3. Analysis of a functional nanomaterial. In this part of the experiment students analyse a textile that has been engineered to replicate the Lotus effect® and has self-cleaning properties

STEP 1.

- Give each student **1 piece of Nano-Tex® and 1 piece of a normal cotton fabric**. Place both in a plastic plate and let them pour water over it. If possible, have a lotus or nasturtium leaf available in class for comparison (the leaf can be cut into pieces if necessary and shared in class). **NB** If lotus or nasturtium leaves are not available, use the **Video 3 Lotus Effect® - Part 2 provided in this teachers kit**).



Students should complete question Q15 in the Student Worksheet.

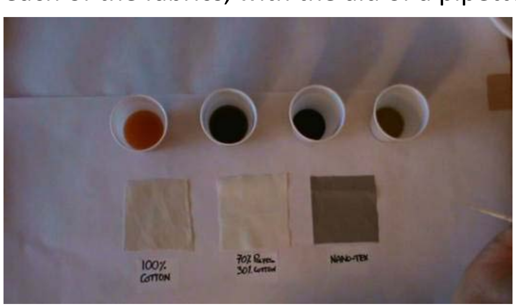
STEP 2.

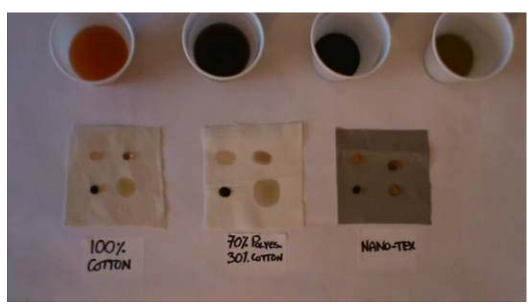
Now students should test the Nano-Tex® fabric and compare it with normal cotton and with a semi-synthetic fabric. In this step liquid stains should be used (coke, vinegar, oil, etc.)

- Each student should have 1 piece of cotton fabric, 1 piece of a semi-synthetic fabric, and 1 piece of Nano-Tex®.

- Give each student 4 plastic cups, each containing one of the liquids to be tested (juice, coke, vinegar, oil, etc.)

- Let the students place a droplet of each liquid to be tested (juice, coke, vinegar or wine, and oil) on each of the fabrics, with the aid of a pipette.





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- Students should let the solutions stay on the **three types of fabrics at the same time for a fixed duration**.

TIP FOR THE TEACHER: A good idea would be to assign different "testing times" to different students or small group of students. This way students could test the effect of liquid staining on the fabric (in particular the Nano-Tex®) for 5 minutes, 10 minutes, 20 minutes and so on. Otherwise each student could do so, but then more pieces of fabrics should be given accordingly.

- After the set time, ask the students to remove each liquid gently from the fabric using a piece of kitchen paper.

Students should complete questions Q16 and Q17 in the Student Worksheet.

STEP 3

Now students should test the Nano-Tex® fabric and compare it with normal cotton and with a semi-synthetic fabric. In this step semi-solid stains should be used (mayonnaise, mustard, etc.)

- Each student should have 1 piece of cotton fabric, 1 piece of a semi-synthetic fabric, and 1 piece of Nano-Tex®.

- Give each pair of students a plastic plate with some of the semi-solids to test (mayonnaise, ketchup, mustard, etc). Also give them a permanent marker. **Students should have kitchen paper or a damp cloth on hand.**

- Now let the students test the three types of fabrics with the "solids" chosen, ketchup, mustard, mayonnaise. On the fourth area available let them mark it with a permanent marker or a pen.

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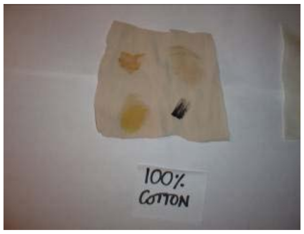
- After a set time (e.g., 5 minutes), let the students try to remove the solids from the fabrics, using a damp cloth or kitchen paper. Students should be careful not to mix the different solids. Observations on how the fabrics stain should be recorded.



Students should complete questions Q18 and Q19 in the Student Worksheet.

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

- The same piece of Nano-Tex® can be re-used so students can be encouraged to test it to the limit, by vigorously rubbing the solids to the fabric and see what happens!

STEP 4

Now students should test the Nano-Tex fabric and compare it with normal cotton and with a semi-synthetic fabric. In this step organic soil is used.

- Each student should have 1 piece of cotton fabric, 1 piece of a semi-synthetic fabric, and 1 piece of Nano-Tex®. Give each pair of students some organic soil in a plastic plate.

- Place some organic soil in the middle of each fabric, fold the fabric and let the student rub it. Then open each piece of fabric, remove the soil in each, and observe. Did all the fabrics get dirty? In the same way? Some soil will be visible also on the Nano-Tex® fabric.

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- Now ask the students to try to **clean the fabrics with their hands**: while the cotton and semi-synthetic fabric will remain somewhat dirty (the soil seems to have got inside the fibres of the fabric), the Nano-Tex® fabric will appear considerably cleaner. In the images below the Nano-Tex® fabric is shown after it has been rubbed with some soil (left), and how it appears after the dirt has been wiped off just by using the fingers (right).

Students should complete question Q20 to Q26 in the Student Worksheet.

STEP 5

Test the Nano-Tex® with sand paper.

- Each student should have 1 new piece of Nano-Tex® and a piece of sandpaper.

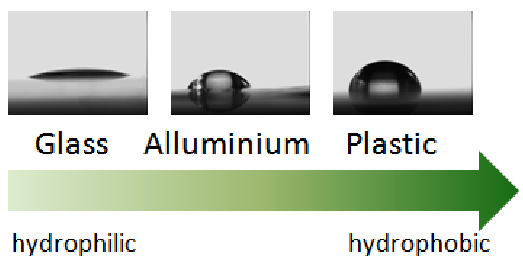
- This can be tested to see **how durable the fabric is**. Let the students observe how water rolls off this fabric first. Then give them a piece of sandpaper, and let them rub it over the fabric. Does this affect the fabric? Test the fabric to its limit! **NB** the use of heat is not recommended.

Students should complete question Q27 in the Student Worksheet.

ANSWERS TO QUESTIONS

Q1. Filter paper absorbs water, so it is very hard to estimate the contact angle. Also, because water is absorbed by this material, contact angle would not be the right tool to assess its surface properties.

Q2. It should be glass, aluminium, plastic. Glass should be on the side of "very hydrophilic" but plastic should not be classed as "very hydrophobic".



Q3. None of the material is very hydrophobic, as shown by the shape of the droplet.

Q4. The photos should be as in the image here displayed.

Q5. Water will wet common leaves.

Q6. Water droplets slide over the leaf but don't roll.

Q7. Water doesn't wet the surface of the leaf.

Q8. Water droplets roll off the leaf, they look like beads.

Q9. Water droplets bounce off the leaf like beads.

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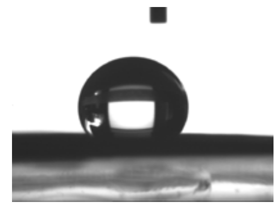
Q10. It is very hard to get a water droplet to rest on the leaf, it behaves like a bead, and is very unstable. This means the surface is extremely hydrophobic.

Q11. No, even if the leaf is kept under running water, when you stop the water it is completely dry.

Q12. it is much more hydrophobic than plastic.

Q13. The picture should be placed on the far right of the scale. The correct picture is displayed here.



Q14. The porous silicon material behaves very similarly to the Lotus leaf.

Q15. Yes, it does.

Q16. Yes, there is. All liquids seem to rest on the surface of Nano-Tex® and form little beads, whereas in the other fabrics liquids quickly spread.

Q17. Liquid stains are easily removed from the fabric simply by absorbing them with kitchen paper. Almost no trace is left. Cleaning is very simple.

Q18. When solids are placed on Nano-Tex® the effect is not so clearly visible as with liquid stains.

Q19. Removal of solid stains is easy but a little bit of stain remains. This can be easily taken away by simply brushing the fabric with the hands.

Q20. All solids can be removed using a wet cloth. The only one that cannot be removed with this method is the permanent marker stain.

Q21. All fabrics *except* Nano-Tex® seem to "absorb" the dirt, in the sense that it clearly penetrates the fabric. In the case of Nano-Tex® dirt seems to remain on the surface, and overall this fabric is stained less.

Q22. No, even Nano-Tex® shows a little bit of stain, although much less than the other fabrics.

Q23. Nano-Tex®.

Q24. The only fabric that becomes clean as new is the piece of Nano-Tex tested with dirt. All others show a little of stain, particularly from the permanent marker stain.

Q25. Nano-Tex®.

Q26. The stain that is hardest to remove from Nano-Tex® is the permanent marker. This has some chemicals that are deliberately made very hard to remove.

Q27. Even after sanding, the piece of Nano-Tex® retains its properties. The material is very durable. N.B: The answer here depends also on the degree of damage done by the students, how long they sand it, etc!

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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