Teacher's Preparatory Guide

How Dry Am I?Exploring Biomimicry and Nanotechnology

Purpose:
Through a series of activities, students will explore superhydrophobic properties of materials. This inquiry based lesson leads them through activities that has them compare and contrast physical properties of superhydrophobic coated materials with uncoated materials. In the process they will learn what constitutes "superhydropobic" and surface tension.

Time required:
Two 50-minute class periods

Level:
Middle grades: 6-8 Physical Science and Biology

Big Idea: Structure of Matter; Forces and Interactions

Teacher Background:

Lotus Effect:
The lotus flower (Nelumbo Nucifera) is a symbol of purity in several Asian religions because the leaves are self-cleansing. Barthlott and Neinhuis, two botanists from the University of Bonn, discovered by using a scanning electron microscope (SEM) that the surface of the Lotus leaf is anything but smooth. The surface is actually quite rough at the nano and micro scale levels. The lotus leaf is known for its superhydrophobic surface which is the result of structures at the nanoscale level. The leaf consists of very tiny bumps (approximately 100nm) which are covered in a waxy substance. These bumps cover the surface of larger structures (10µm) which cover the surface of the leaf. A combination of the physical structure and the chemical (waxy) coating results in water beading up and barely touching the surface of the leaf. A layer of air is captured between the rough ridges so that water, dirt, debris almost never touch the surface but rest mostly on the bed of air. The water bead rolls off taking dirt and debris with it. Because the surface of the leaf never gets wet, it repels virtually all germs and bacteria from its surface. Engineers have mimicked this effect by creating man-made products that use superhydrophobic surfaces to repel water, dirt, oils and bacteria; protect equipment from corrosion; keep surfaces and equipment clean; and manufacture stain resistant textiles. To learn more about the Lotus Effect, see the resource section.

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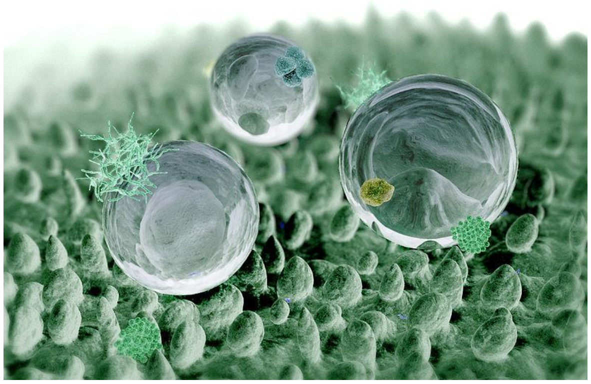

Figure 1A. Image from William Thielicke http://en.wikipedia.org/wiki/File:Lotus3.jpg GNU Free Documentation License and Creative Commons Attribution ShareAlike license

Figure 1B. Image Ralf Pfiefer http://en.wikipedia.org wiki/ File: LotusEffekt1.jpg GNU Free Documentation License

Nanoscale surface coatings:

Surface coatings mimicking the lotus leaf have been engineered as nanomaterials. Scientists and engineers have developed nanoscale surface coatings to provide further functionalities. These coatings are mixtures of film-forming materials (thin films) plus additives. Surfaces are nanopatterned or nanostructured that result in the superhydrophobic properties of the material. Nanomaterials are not as small as atoms but have dimensions in the range of the largest molecules found in the natural world. Applications of nanoscale surface coatings are seen in areas of biocides and altering physical properties of a material's surface which can include making materials biocompatible for use in medical applications. A new coating developed at the University of Michigan is 95 percent air and repels almost all liquids including hydrochloric acid and sulfuric acid. This type of coating can produce super stain-resistant clothes and breathable garments to protect soldiers. You may be familiar with the coating on windshields that allows the water to bead up and roll off to improve visibility during rain.

Why do small textures cause super hydrophobicity? Why not large ones?

Water sits on top of the textures, and surface tension acts at the perimeter of the tops. More length at the perimeter gives more surface tension force. Surface tension is force per unit length. Small textures packed closely together have more total top texture length than larger textures do. A classic example of this is a floating paper clip. A paper clip is denser than water and will sink if you push it down. But, if you gently place it on top of the water, surface tension will allow it float. This is because surface tension is force/length, and the paper clip has a lot of length. This is similar to how a water strider walks over water. You can show students this demonstration.

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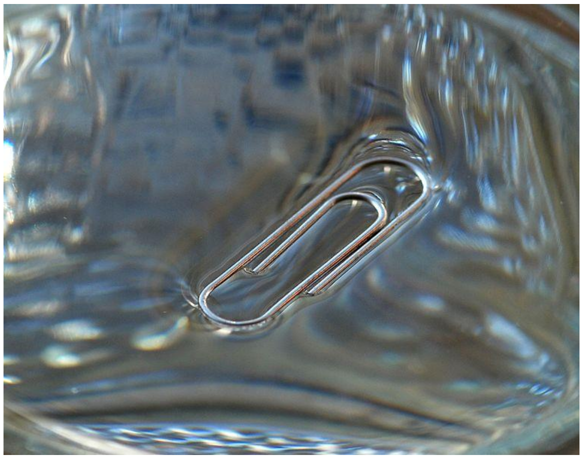


Figure 2. Surface tension suspends long paper clip
http://en.wikipedia.org/wiki/File:Surface_tension_March_2009-3.jpg

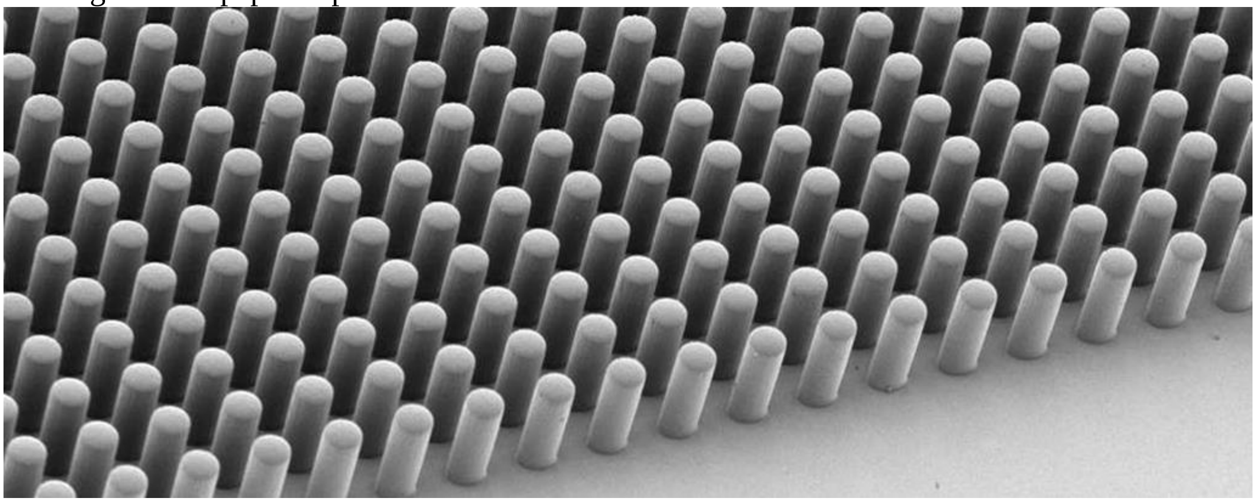
Ask the students: "How long does the paper clip need to be for surface tension to hold it up?"

- Surface tension of water = 0.07 grams/cm
- Weight of paper clip = 0.5 gram

Answer
Weight of paper clip = Force due to Surface tension
Weight = Length*Surface tension
0.5 gram = Length*0.07 gram/cm
Length = 0.5 gram/(0.07 gram/cm)
Length = 7 cm

Next, with the paper clip floating, add a drop of dish soap to the water. The paper clip immediately sinks because the soap is a surfactant that decreases the surface tension of the water.

This concept has been used to develop a superhydrophobic material – Nano Water Guard. As can be seen in Figure 3, it mimics the "bumps" of the lotus leaf. The images below show the nano textures of Nano Water Guard. Note that millions of these textures create a lot of length (shown in blue) to support the water. The total length of all the blue circles added together is similar to the length of the paper clip.



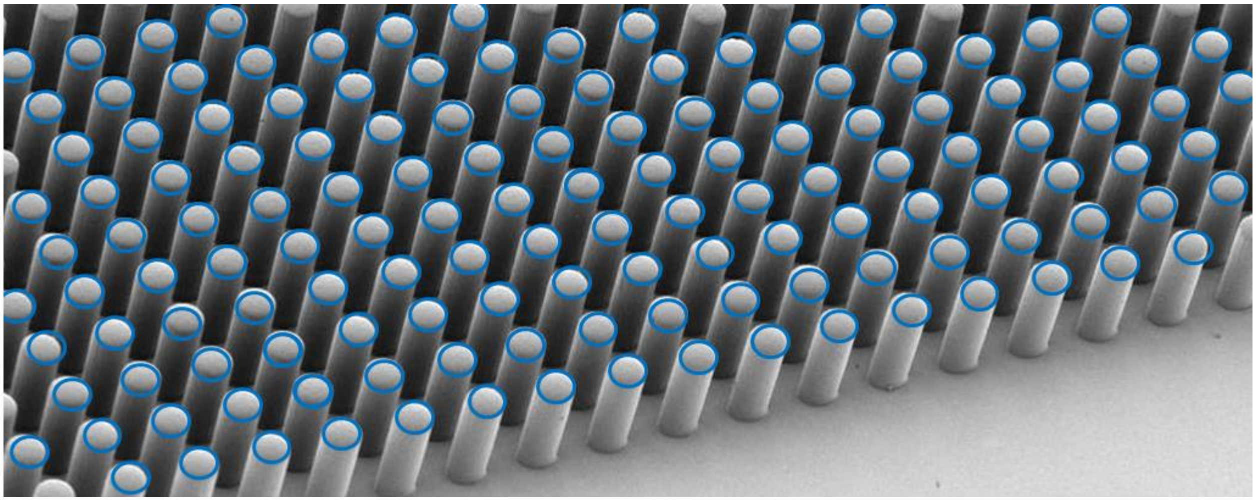


Figure 3. Microscope image of Nano Water Guard showing in blue the long total length of small textures packed closely together.
Images courtesy of Andrew Cannon of 1900 Engineering, Nano Water Guard.

You can also show students a short video of NanoWater Guard in action -- https://www.youtube.com/watch?v=z4EFycryEU4

Contact Angle and Wetting Capability

Whether a material is considered hydrophobic, superhydrophobic, or hydrophilic is based on the contact angle. As noted above, whether a liquid beads or sheets when it meets a solid surface is determined by both the properties of the surface and the liquid. Students learn the terms hydrophilic as water loving and hydrophobic as water hating.

The contact angle is the angle where a liquid meets a solid surface. This angle will determine the wettability of a substance by the liquid. Figure 2 below shows the different forms of wetting that a material can have. To be superhydrophobic, the contact angle must be 150^o while hydrophobic materials have a contact angle of greater than 90^o (see Figure 4).

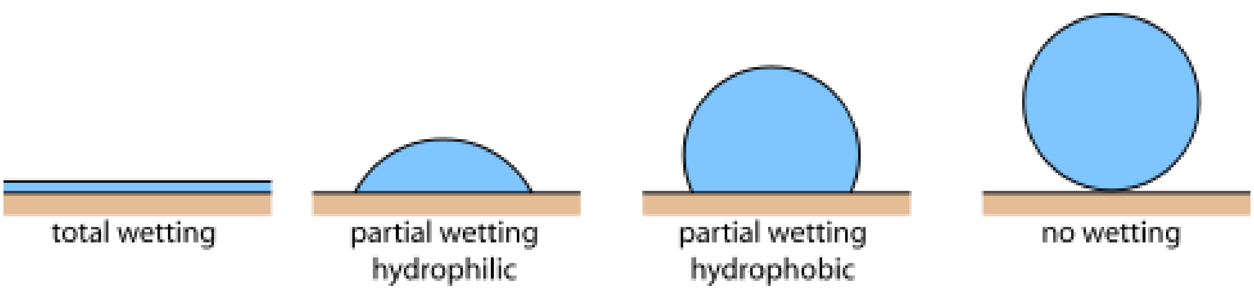


Figure 4. Image source: http://commons.wikimedia.org/wiki/File:Wetting.svg PMarmottant GNU Free Documentation License

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Property	Distribution of surface tension	Contact angle	Wetting
Super-hydrophobic	$\gamma_{LV} \gg \gamma_{SV}$	$\theta > 150°$	Very low
Hydrophobic	$\gamma_{LV} > \gamma_{SV}$	$\theta > 90°$	Poor
Hydrophilic	$\gamma_{LV} < \gamma_{SV}$	$\theta < 90°$	Good
Pinning	$\gamma_{LV} \approx \gamma_{SV}$	$\theta \approx 90°$	Neutral

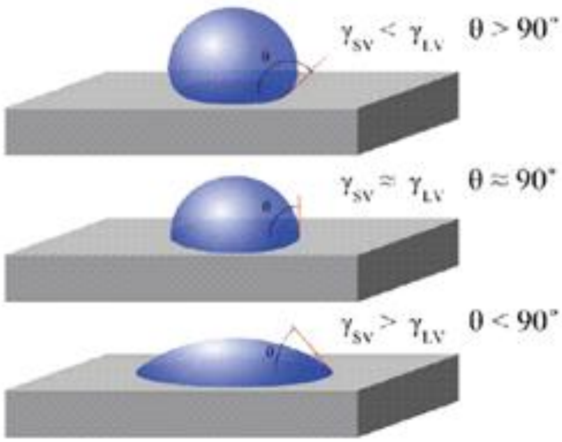

Figure 5. Image source: http://www.tcnano.com/presse.asp?news_id=171&print=news&page=1

Materials: Per groups of 4 students

- SEM pictures of lotus leaf and magnolia leaf structure (included)
- 3 droppers or pipettes
- 4 small paper/plastic cups (6-8 oz.)
- 4 pairs of disposable gloves
- 4 safety glasses
- Oil (Vegetable)
- Water (50mL)
- Tomato Sauce or Ketchup (50mL)
- Optional: potting soil (fill a plastic cup))
- Index cards 3 X 5; one coated with Rustoleum® NeverWet™ and one uncoated
- Coated and Uncoated Samples (using Rustoleum® NeverWet™ to coat): pieces of wood, plastic vinyl, tile, linoleum, siding, whit poaster board, etc.
- * Rustoleum® NeverWet™ (or a similar product)

(*Note: Rustoleum® NeverWet™ can be bought and ordered online at Home Depot ~$16.50)

- Nanoscale Science Activities for Grades 6-12 by Jones et. al.
- LCD projector and computer with Internet

Advance Preparation: Day 2

For Part B: Prepare the superhydrophobic coated samples by following the instructions on the product, Rustoleum® NeverWet™ (or a comparable superhydrophobic spray coating). This preparation should be done in a hood or preferably outside using gloves and goggles. The process is two step and will take about one day to complete (60 minute application time and possible overnight curing). Do not have students prepare the materials as the fumes are very strong. Label each C and U (coated and uncoated).

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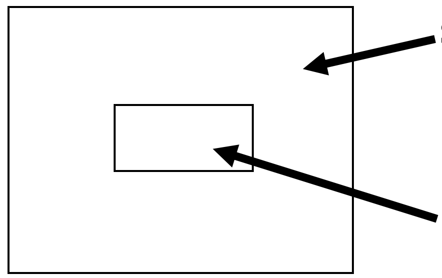
For Part C: Take a piece of heavy plastic or linoleum and place an index card in the center/ Spray the plastic/linoleum with Rustoleum® NeverWet™ according to the directions. This will create a "frame of coating. Once dried, remove the index card.



Safety Information:
Students should wear gloves, especially while handling coated products and plants.

Directions for the Activity:

PRE-LAB ACTIVITY Day 1
Biomimicry: The Mystery of the Lotus Leaf This activity can be found in Nanoscale Science: Activities for Grades 6-12 pages 71-76. (see resource section)

LAB ACTIVITY Day 2
Part A
Observe structure of lotus leaves and magnolia leaves using SEM microscope or images. What do you observe? What structures in each leaf creates or prevents hydrophobicity?
The magnolia leaf has a fairly smooth surface compared to the bumpy surface of the lotus leaf.
Draw a Venn diagram to compare and contrast the structure of the leaves.
View: 24-Second Lotus Leaf video-clip http://www.youtube.com/watch?v=MFHcSrNRU5E

Part B
Note: Students should handle samples with gloves.
1. Place 5 drops of water on sample 1, C (coated) and U (uncoated). Hold samples over cup of water and let drip into the cup. Record observations in chart.
2. Repeat step 1 for each sample, C and U (coated and uncoated). Record observations in chart.
3. Now place 5 drops of oil on each sample, coated and uncoated. Drip excess oil into another cup. Record observation in chart.
4. Do the same for tomato sauce. Record observation.
5. Optional: dry soil on samples and then wet the soil. Shake off.
6. Compare the data in your chart to your data from the *Mystery of the Lotus Leaf* activity on day 1. What comparisons can be made?
7. What do you think the C and U labels on the samples mean?

Have a class discussion of the data.

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Part C
Mystery of the Pooled Water
Teacher Demo or Group activity (if group activity then make more squares of the material)

1. Show students piece of plastic/linoleum but do not tell them how it was treated. With student help, begin placing drops of water in the middle of the linoleum until they pool up in a rectangle.
2. The water will remain in the middle of the linoleum and will pool up and will not cross over into the frame-treated part of the linoleum. Water will pool up in the shape of the index card.
3. Challenge students to solve the mystery of the pooled water from the information learned from the past two activities. Ask them, "How would you replicate this demonstration?" Draw an illustration showing why the water pooled up and did not fall off the plastic. (see image above)

Once the students have completed the activities, there should be a class discussion about why they think the materials behaved the way that they did. At this time, you should explain what C and U mean and how the samples were prepared.

View Home Depot NeverWet Video-clip
http://www.homedepot.com/p/t/204216476?storeId=10051&langId=-1&catalogId=10053&productId=204216476&R=204216476#.UdsCh-jD9jo

Part D (Extension Activity)
Access *the Creating Colors by Changing Scale* activity in the NNIN Demonstration Guide http://www.nnin.org/sites/default/files/files/NNIN_Outreach_Demo_Guide-11_10.pdf. This activity can help students understand how thin films can be created. You can then relate the thin films to surface coatings used make hydrophobic materials.

Poster Project: Have students create a poster showing 10 ways superhydrophobic coatings could be used in their household.

Cleanup:

- If repeating activity within a couple of days, refrigerate left-over plant leaves in plastic bag wrapped in wet paper towel. If not, discard.
- Throw away uncoated products.
- Carefully wipe off coated products to use again.

Resources:

- Lotus Effect:
    - http://en.wikipedia.org/wiki/Lotus_effect
    - http://www.mecheng.osu.edu/nlbb/files/nlbb/Lotus_Effect.pdf
    - http://www.nanowerk.com/spotlight/spotid=19644.php
    - http://www.p2i.com/blogs/articles/magic_lotus_leaf_natures_nanotechnology
- *The Gecko's Foot Bio-inspiration: Engineering New Materials from Nature* by Peter Forbes, W.W. Norton & Company 2005.

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- Gizmag article on University of Michigan "Superomniphobic" nanoscale coating repels almost any liquid" accessed at: http://www.gizmag.com/superomniphobic-liquid-repelling-coating/25836/
- Nanoscale Science: Activities for Grades 6-12 by Jones et al, 2007. NSTA Press. (http://www.nsta.org/store/product_detail.aspx?id=10.2505/9781933531052)

Videos:
Lotus effect: http://www.youtube.com/watch?v=MFHcSrNRU5E
Never Wet: http://www.homedepot.com/p/t/204216476?storeId=10051&langId=-1&catalogId=10053&productId=204216476&R=204216476#.UdsCh-jD9jo
Nanoscale Coatings: http://www.sciencedaily.com/releases/2013/01/130116123523.htm
Paper clip floating on water demonstration and explanation:
http://en.wikipedia.org/wiki/Surface_tension

Next Generation Science Standards:
Middle School
PS 1. Matter and its Interactions
    PS1 A. Structure and properties of matter
PS 2. Forces and Interactions
    PS2 A. Forces and motions
    PS2 B. Types of interactions

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