Teacher's Guide

Superhydrophobicexpialidocious: Learning about hydrophobic surfaces

Grade Level: Middle

Subject area(s): Physcial science; general science

Time required: Part 1: (2) 50 minute classes; Part 2: (3) 50 minute classes

Learning Objectives: 1. Learn about hydrophobic surfaces; 2. Learn that a material can be chemically or physically changed to alter its surface properties.

Summary: This is a two-part lesson. In Part 1, the teacher will choose one of two lessons on hydrophobic materials. These lessons let students experiment with materials that have used chemicals to create hydrophobic materials. In Part 2, students will use pieces of Teflon to physically create a super-hydrophobic surface. They will use a protractor to measure the contact angle of a bead of water and compare grit size of sandpaper to contact angle. This activity can be completed as a separate one or in conjunction with the lesson *To See or not to See: Hydrophobic and Hydrophilic Surfaces* (https://www.nnci.net/node/6025).

Lesson Background: Commercial products have frequently taken their inspiration from nature. Scientists often look at nature to get ideas and designs for products that can help us. We call this study of nature biomimetics. Scientists have found a way to mimic the hydrophobic properties of many organisms. In these activities, students will discover two different ways of rendering a hydrophobic surface. One method uses a chemical change and the other method a physical change. They also introduce students to the concept that how a material behaves on the macroscale is affected by its structure on the nanoscale.

Part 1: The teacher may want to use one of two online lessons: *Nano Waterproofing from Try Engineering* or *How Dry am I? Exploring Biomimicry and Nanotechnology*. Both lessons (listed in resources) use chemicals to alter a material to become hydrophobic. In the *Try Engineering* lesson, students use common items such as crayons, wax, lanolin, etc. to waterproof a material. In the *NNCI* lesson, the teacher has treated materials with Rust-Oleum's NeverWet® to alter the surface chemistry. You may do all or part of the lesson to introduce students to hydrophobic materials before proceeding to Part 2.

Part 2: This inquiry activity will demonstrate that by simply sanding a piece of Teflon you can produce superhydrophobic surfaces with contact angles of 150°. Teflon is DuPont's trademarked brand name for PTFE – polytetrafluoroethylene, a polymer. It is a solid fluorocarbon, and is hydrophobic. The activity is based on the publication by Nilsson et al, 2010: *A novel and inexpensive technique for creating superhydrophobic surfaces using Teflon and sandpaper*.[3]

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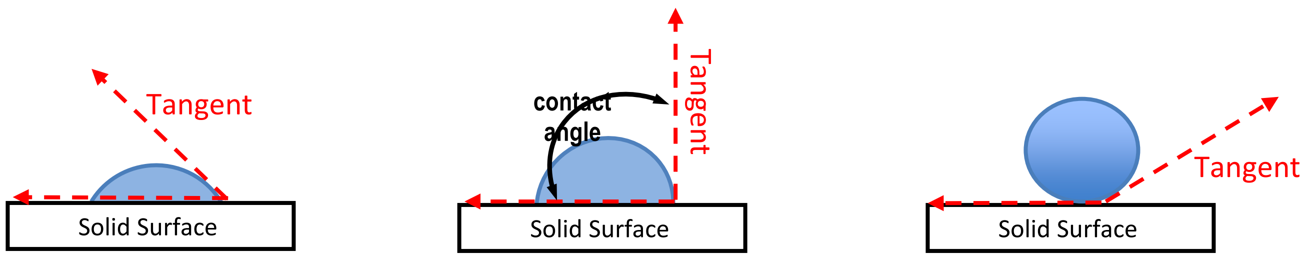
A surface is considered hydrophilic if it has an advancing contact angle less than 90°; hydrophobic if it has an advancing contact angle greater than 90°; and superhydrophobic if it has an advancing contact angle of greater than 150°. The advancing contact angle is the angle where a liquid/vapor interface meets a solid surface. It is simply measured by drawing a horizontal line along the surface and drawing a tangent line where the liquid drop meets the solid surface.



Hydrophilic $< 90^{\circ}$ Hydrophobic $\geq 90^{\circ}$ Superhydrophobic $> 150^{\circ}$

Students will be hypothesizing about how to make the surface more hydrophobic and then experimenting with different grits of sandpaper to see how the grit and roughness effects the surface angle of the water drop.

When talking about sandpaper "grit" is a reference to the number of abrasive particles per inch of sandpaper. The lower the grit the rougher the sandpaper and conversely, the higher the grit number the smoother the sandpaper. This makes sense if you imagine how small the particles on an 800-grit sandpaper would need to be to fit into a 1" square. Sandpaper is referred to by the size of its grit (i.e. 150-grit sandpaper).[2]

Sources

1. Wisegeek. "Teflon." (July, 2013). http://www.wisegeek.org/what-is-teflon.htm
2. Woodsource. "Sandpaper." (July. 2013). http://www.woodzone.com/Merchant2/articles/sandpaper/
3. Nilsson, M., *A Novel and Inexpensive Technique for Creating Superhydrophobic surfaces using Teflon and Sandpaper.* Journal of Physics D: Applied Physics, 2010.

Pre-requisite Knowledge: Students should know how to use a protractor and determine the tangent angle. They should also know something about surface tension.

Materials Per Class: (I have 9 groups with 4 students each)

- 9 Teflon pieces, 1 per group, (approx. 3cm x3cm x 1mm)
- 9 Different grits of Sandpaper ranging from 40-600, 1 per group, (approx. 3cm x cm)
- Safety goggles-1 per student
- 9 Sharpies
- Acetone
- Distilled water (1 Gal.)
- 18 Wash bottles : 9 for acetone, 9 for distilled water
- 18 Glass beakers (250-500ml)

- 9 Air cans
- 9 Tweezers
- Paper towels (1 per group)
- Lab tray (optional) 1 per group, to catch water
- 9 Small beakers of colored water, or dropper bottles of colored water
- 9 Disposable pipettes or syringes
- 1 Large beaker- to collect waste acetone
- Digital camera or use of a cell phone with a good camera.
- 9 protractors
- Dark piece of construction paper, to use as a background when taking pictures.
- Resealable baggies to store Teflon pieces
- Unbent paper clips to scratch the Teflon

Sources for PTFE sheets (0.04” thickness)

- McMaster-Carr: http://www.mcmaster.com
- ePlastics: https://www.eplastics.com/sheets/ptfe

Advance Preparation:

1. Cut Teflon into ~1”x1” pieces. You will need 1 piece for each group. You should be able to cut up the Teflon sheets with a sharp paper cutter, dissecting blade, or knife. **Make sure the Teflon pieces are flat.**
2. Cut sandpaper into ~1”x1” pieces I used a variety of grits, a different one for each group, ranging from 40-600.
3. Fill wash bottles with acetone and distilled water
4. Optional: Set up a tray. I have one tray for two groups:

Bottle of acetone	Protractor
Bottle of distilled water	Paper towel or sponge
Air can	Small beaker with clear or colored water
Pipette or syringe	2 empty waste beakers for acetone and water rinses
Sharpie/baggie	
Tweezers	

Safety Information:

Students should wear safety glasses, since they are working with acetone. Use in a well-ventilated room. Caution students to close the acetone container immediately after using and empty waste beak after acetone rinse. Use your school’s disposal guidelines for acetone.

Vocabulary and Definitions:

1. *Hydrophobic:* A substance that is water “fearing” or repels water.

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2. *Superhydrophobic:* A substance that is “highly afraid of water”.
3. *Contact angle:* The contact angle is the angle where a liquid/vapor interface meets a solid surface.
4. *Surface tension*: a physical property equal to the amount of force per unit area necessary to expand the surface of a liquid. It is the tendency of a fluid surface to occupy the smallest possible surface area.
5. *Chemical Change:* the process in which one or more substances are altered into one or more new and different substances.
6. *Physical Change:* a physical change does not produce a new substance.
7. *Grit*: refers to the number of abrasive particles per inch of sandpaper. The lower the grit the rougher the sandpaper and the higher the grit number the smoother the sandpaper.
8. *Nanoscale*: measured in nanometers; typically referring to materials between 1 and 100 nm but others use up to several hundred nanometers.
9. *Nanometer*: $1x10^{-9}$ or one billionth of a meter.
10. *Nanotechnology*: Nanotechnology is science, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometers. It is the study and application of extremely small things and can be used across all the other science fields, such as chemistry, biology, physics, materials science, and engineering.

Troubleshooting Tips:
Make sure they sand all over the surface
Remind students not to touch the surface of the Teflon. The oils from their fingers may ruin the properties.
Make sure students know how to measure the angles with the protractor.

An optional component of Part 2 would be to have students measure the contact angle to the materials they used in Part 1. This could be included if there is sufficient time – particularly at day 2. They could also graph their Part 1 materials to compare to the physically altered Teflon results.

Part 2 Procedure for the Activity:
Day 1:
1. Introduce lab with guided dialog.
2. Pass out all materials and lab sheet.
3. Have students come up with their hypothesis, and choose grit of sandpaper. Print out the grit sheet and put it under document camera, and explain what the size of grit means.
4. Quickly go over the procedure with them. If you have time, you could have them come up with a procedure as a class, and have them write it down, instead of having it already written out for them.
5. Have them put on their safety glasses before they start the actual lab:
6. Lab Procedure:
    a. With an unfolded paper clip on the top right corner, have them scratch in an “X”. This is the control side.

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b. Turn Teflon piece over. Sand the side w/o the X in a random pattern for 20 seconds. (make sure they sand all over the surface)
c. With a tweezer, pick up a corner of the Teflon and wash the sanded side with acetone. Wash over the acetone waste beaker.
d. Wash it with distilled water (catching water in waste beaker), and dry with air can. (both sides)
e. Using the colored water, give them about 5 min. to play with the piece*. Have them compare how the water behaves on each side. Compare 1 drop first and them have them look at a stream of water.
***REMIND STUDENTS NOT TO TOUCH THE SURFACE-IT MAY RUIN THE PROPERTIES**!
f. Read and answer the contact angle questions**.
****You may have to do a quick lesson on how to read a protractor. Some of my students were not reading the angle the correct way!**
g. Have them write with the sharpie their names and period number on a baggie. Have them place the dry Teflon piece in the bag to use tomorrow.
h. Cleanup: All groups should pour their rinse acetone into the large beaker, to be put outside and evaporated by the teacher later. Or, follow school disposal procedures.

If they will use their cell phones tomorrow for pictures, remind them to bring their cords to upload the photos!

Day 2:

1. Pass out their bags with the Teflon pieces.
2. Have them place piece on the edge of the table and place **one** drop on the edge of the Teflon.
3. Have them take a picture with the digital camera or their cell phone. They will need a dark piece of paper to prop behind the piece of Teflon to see the drop more clearly.
   - My students all have computers. I am going to have them upload them into their computers to get the contact angle. You could also print them out for them to take the angle on paper. Make sure you have them label the background, so you know whose picture it is.
4. Have them find the contact angle by drawing a horizontal line and a tangent line on their drop of water. Use the protractor to find the angle.
5. They will present their results to the class in a PowerPoint slide.

Day 3

1. Have all students collect class data in table. If more than one group did the same grit #, have them take the average, and graph only the average.
2. Graph angle vs. grit size.
3. Analyze class data, and show SEM pictures of the different grits to see if they can discover why a certain grit will make the surface superhydrophobic.

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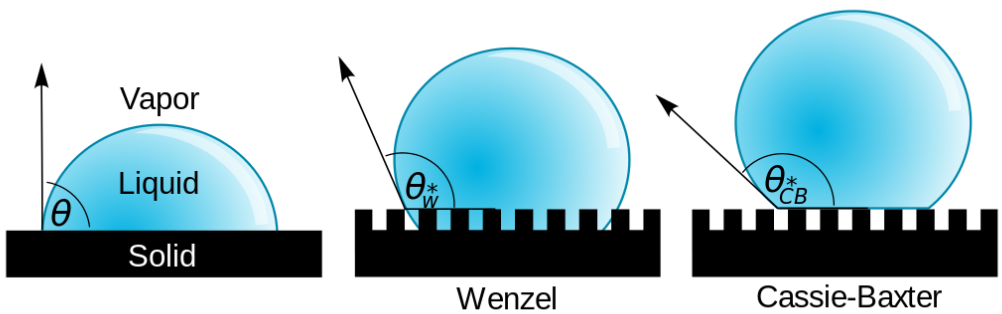
Expected Results:

- Surface roughness can effect a water droplets contact angle, effectively making a hydrophobic surface superhydrophobic
- The 320 grit had the highest contact angle of those tested and was the most hydrophobic. The 220 grit produced the next highest angle at 137º.
- With 60 grit, the valleys are probably not deep enough to maintain a water-air interface. This will give lower contact angles because the water is 'pinned' to the surface. The size of the peaks and valleys increases as you get to the 200-300 size grit sandpaper. These deeper features allow for more formation of water/air interfaces, Cassie state. As you increase the roughness even more with the 60 grit, the valleys probably become too large making it transition back to the Wenzel state, and more pinning of the water droplet.

Cassie-Baxter state: the water droplet sits on top of tiny air bubbles.
Wenzel state: no air bubbles are underneath the droplet, it is in complete contact with the surface.



Wikipedia Image: Creative Commons Attribution-Share Alike 3.0
https://commons.wikimedia.org/wiki/File:Contact_angle_microstates.svglicensed

Follow these links to read more about the Cassie and Wenzel states.

- http://www.teachengineering.org/view_lesson.php?url=collection/duk_/lessons/duk_surfacetensionunit_lessons/duk_surfacetensionunit_less4.xml
- http://www.youtube.com/watch?v=PPJ0Khs7uWs

Enhancing Understanding: Cover this section after the activity.
Review the findings with students: Analyze the class data/graphs. Discover which grit of sandpaper produced the greatest contact angle and have them explain why.

Khan Academy Enrichment. You can show them the following video which really explains surface roughness and energy well:
http://www.youtube.com/watch?v=PPJ0Khs7uWs

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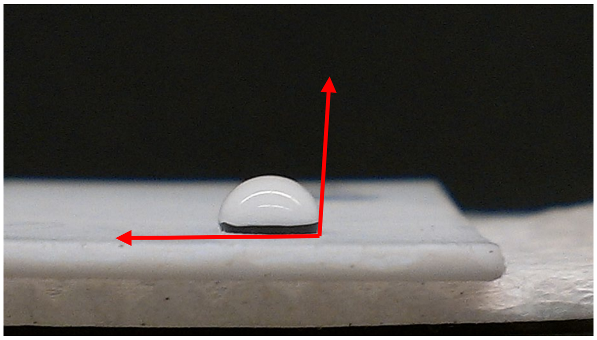
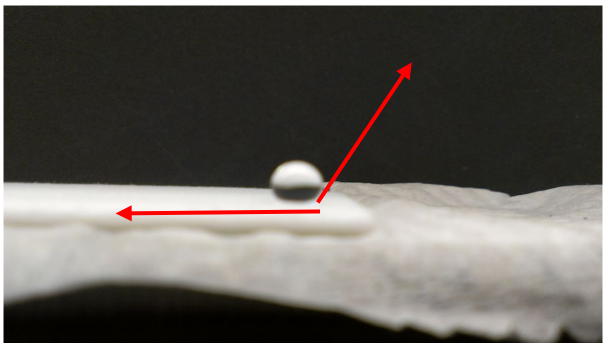
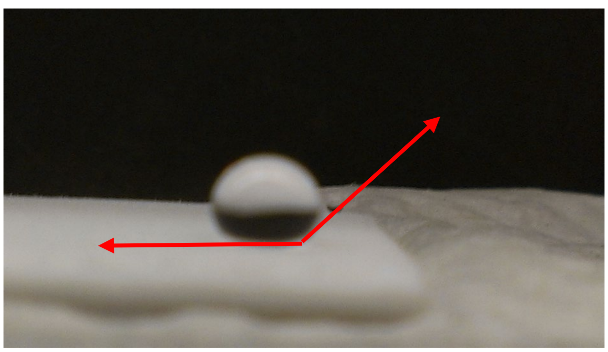
All pictures were taken with a cell phone camera, the tangent lines drawn in and angle measured with a protractor on the computer screen.
Control-smooth Teflon. Contact angle = **93^o -hydrophobic**



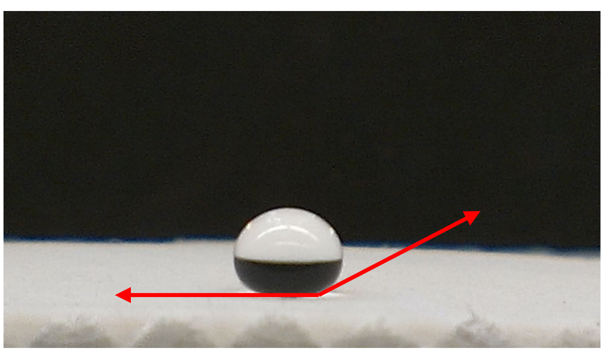
60 grit sanded Teflon. Contact angle = **123^o-hydrophobic**



220 grit sanded Teflon. Contact angle = **137^o-hydrophobic**



320 grit sanded Teflon. Contact angle = **152^o-superhydrophobic**



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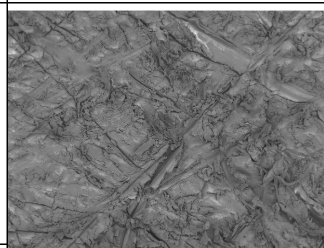
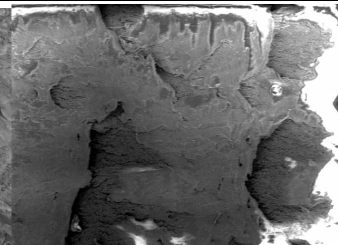
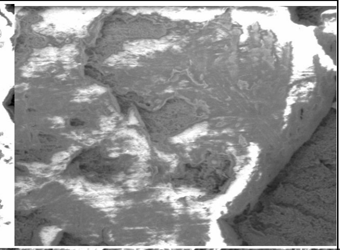
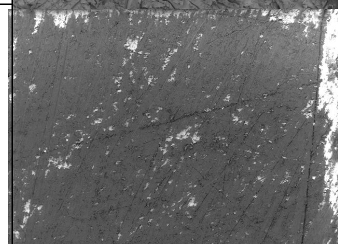
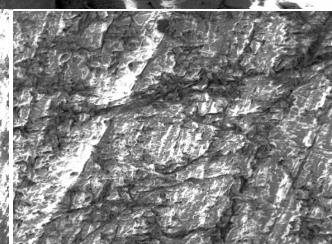
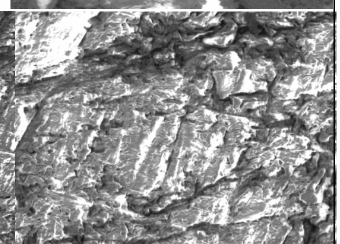
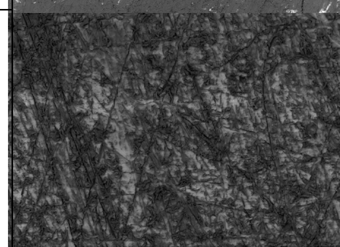
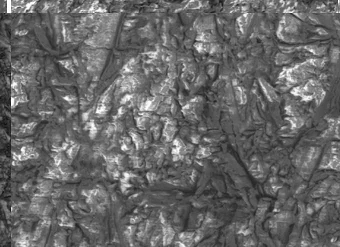
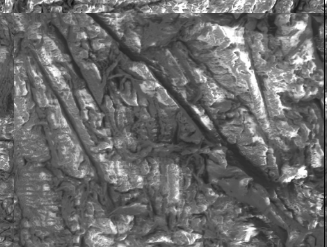
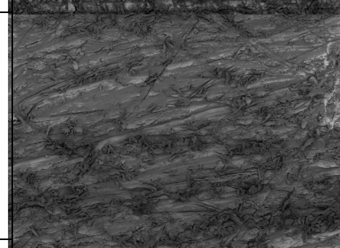
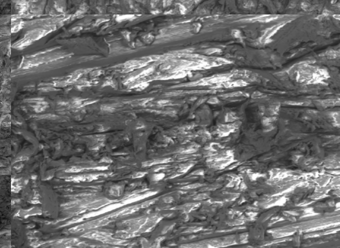
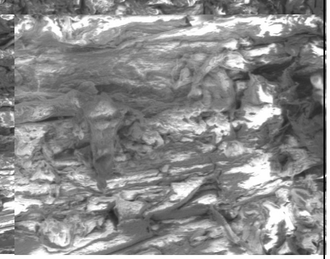
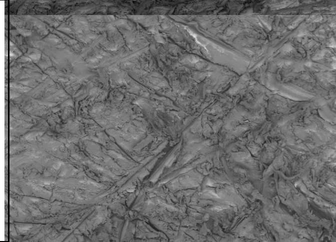
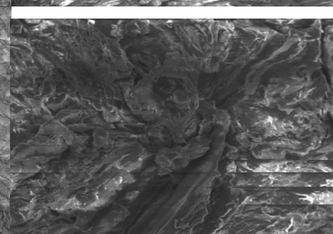
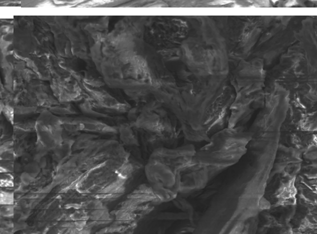
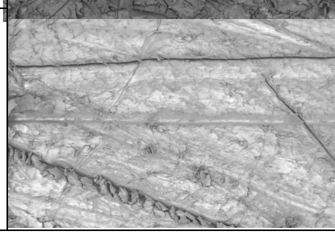
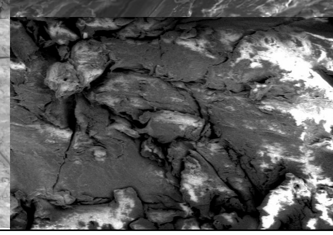
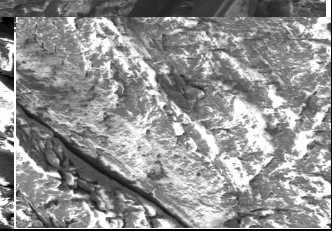
Scanning Electron Microscope (SEM) pictures of Teflon with different sandpaper grit:

Sandpaper grit	**Magnification**		
	100x	**500x**	**1000x**
None (smooth)			
600			
320			
220			
120			
60			

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Assessment:

- Presentation of a PowerPoint slide that states the following: whether their hypothesis was correct; includes a picture and gives the contact angle of their water drop; if the surface is hydrophobic or superhydrophobic and why; analyze their surface compared with other grits of sandpaper.
- Lab analysis questions in student guide.

Additional Resources:

- NanoWaterproofing; Try Engineering: http://teachers.egfi-k12.org/wp-content/uploads/2009/11/nanowaterproofing.pdf
- How Dry am I? Exploring Biomimicry and Nanotechnology;NNCI.net: https://www.nnci.net/node/5298
- Exploring Properties of Magic Sand: Hydrophobic Materials; NNCI.net: https://www.nnci.net/node/5372
- Naturally Hydrophobic; University of Akron: https://uakron.edu/cpspe/agpa-k12outreach/lesson-plans/naturally-hydrophobic
- Engineering Self-Cleaning Hydrophobic Surfaces: Teach Engineering: https://www.teachengineering.org/makerchallenges/view/rice-2389-hydrophobic-surfaces-engineering-challenge
- Super Hydrophobicity – The Lotus Effect; Teach Engineering: https://www.teachengineering.org/lessons/view/duk_surfacetensionunit_less4
- Exploring the Lotus Effect; Teach Engineering: https://www.teachengineering.org/activities/view/duk_surfacetensionunit_act4
- Wetting and Contact Angle; Teach Engineering: https://www.teachengineering.org/lessons/view/duk_surfacetensionunit_less3
- Investigating what is behind water repellent surfaces; My ScopeTeacher Resources: http://myscope-explore.org/lessonPlans/MyScope%20Teaching%20resources%20-%20hydrophobic%20surfaces.pdf
- Nature's Non-Stick Solutions by Rachel Brazil; Chemistry World: https://www.chemistryworld.com/features/superhydrophobic-materials-from-nature/3010321.article
- Nilsson, M., *A Novel and Inexpensive Technique for Creating Superhydrophobic surfaces using Teflon and Sandpaper.* Journal of Physics D: Applied Physics, 2010.
- You tube video from Khan Academy: http://www.youtube.com/watch?v=PPJ0Khs7uWs

Next Generation Science Standards:

- MS-PS1.A Structure and Properties of Matter
- MS-ETS1-3 Analyze data from tests to determine similarities and differences
- **Crosscutting:**
  - MS-PS1-2 Patterns
  - MS-PS1-3 Structure and function
  - MS-PS2-3 and MS-PS2-5 Cause and effect
  - MS-LS1-1 Cause and effect

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Optional: Activity extension

Design an experiment to test other materials that you would like to examine their movement across the Teflon or items you treated in Part 1 (chemical). What other variables would you test? Would you want to use other liquids such as an oil? Maybe a more viscous or acidic material? What other materials would you add to the surface to examine hydrophobicity? Dirt, dust, grease pen? Design your experiment and have the instructor approve your design before testing. Follow the experimental procedures of above. Write up your results and then share as a short presentation to the class.

Contributor: Jenny Willis, RET at University of California Santa Barbara

Supporting Programs: NNIN RET program at University of California Santa Barbara NSF EEC 1200925 and National Nanotechnology Coordinated Infrastructure NSF ECCS 1626153

Student Guide

(with Answers)

Name:_______________________________Date:_______________Class:________________

Superhydrophobicexpialidocious

Safety

Wear goggles; do not squirt anyone or anything with the liquids or the compressed air.

Introduction: You have been amazed by the difference between hydrophilic and hydrophobic surfaces! Now it's time to try to go even further and try to make a material "superhydrophobic" or really afraid of water! In this activity, you will be using sandpaper and pieces of Teflon to determine if you can make the Teflon superhydrophobic. To determine if superhydrophobic, you will be measuring contact angles of drops of water.

Pre-lab questions: (answer in your lab notebook)

Which grit of sandpaper will change the surface of the Teflon to be the most hydrophobic?
I think that the more rough the surface, the more hydrophobic the surface will be and give it a larger contact angle. So the 60 grit sandpaper will be the most hydrophobic

What is the independent variable? *Sandpaper grit*

What is the dependent variable? *The contact angle of the water drop.*

Materials:

- Teflon piece
- Sandpaper
- Safety goggles, 1 per student
- Sharpie
- Acetone
- Distilled water
- 2 wash bottles: 1 for acetone, 1 for distilled water
- 2 glass beakers (250-500ml)
- Air can
- Tweezers
- Paper towels
- 1 small beakers of colored water or dropper bottles of colored water
- 1 disposable pipette or syringe
- Digital camera or a cell phone with a good camera
- Protractor
- Dark piece of construction paper, to use as a background when taking pictures.
- Resealable baggie to store Teflon pieces
- Paper clip to scratch the Teflon

Procedure Day 1:

1. Put on goggles.
2. Using the paperclip, scratch an "X" on one corner of the Teflon piece. This will mark the back or the control side.
3. Turn the Teflon over. Using your sandpaper, sand the Teflon for 20 seconds.
4. You now want to **AVOID TOUCHING THE SURFACE!** Using the tweezers, grab a corner and wash it with acetone. Make sure you hold it over the **acetone waste beaker**.
5. Next, wash it with distilled water, over the **water waste beaker.**
6. Holding the piece with tweezers, carefully dry both sides with the compressed air. Not too close or it will blow the piece away!

Observations/Results: (in you lab notebook)

1. Place **ONE** drop of colored water on the rough or sanded side. What do you observe?

   A very round drop, that really beads up on the surface of the Teflon.

   a. Draw shape of drop here: Place **ONE** drop of colored water on the control side, what do you observe?

   This drop is not as round as the sanded side

   a. Draw shape of drop here:

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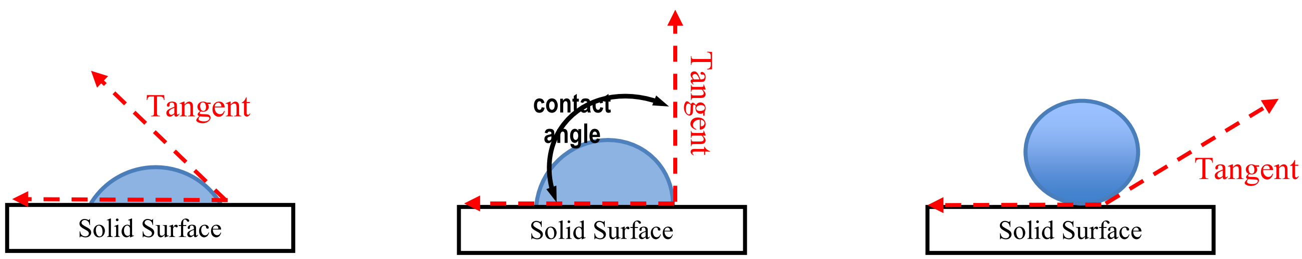
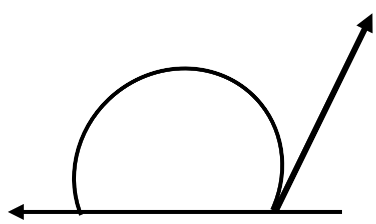
3. Using the tweezers, now tilt the piece and squirt a steady stream of water on the control side (**over the waste water beaker**), how does the water react? Now squirt a stream over the sanded side. Compare/contrast each side and write your observations.

<u>**READ:**</u> So how do we know how water resistant your Teflon is? Scientists measure the contact angle of a droplet to find out if it is hydrophilic, hydrophobic or superhydrophobic. The contact angle is the angle where a liquid meets a solid surface. It is simply measured by drawing a horizontal line along the surface and drawing a tangent line where the liquid drop meets the solid surface.



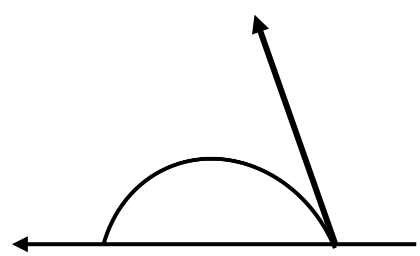
Hydrophilic < 90º **Hydrophobic $\geq$ 90º** **Superhydrophobic > 150º**

Practice finding the angle on these drops with the protractor and circle whether it is hydrophobic, hydrophilic or superhydrophobic:



Degree = *116º*

hydrophilic/**hydrophobic**/superhydrophobic



Degree = *72º*

hydrophilic/hydrophobic/superhydrophobic

Procedure Day 2:

You are now going to take a picture of a water droplet to find the contact angle and how hydrophobic it is!

1. Place the Teflon piece, sanded side up on the edge of your table, it must be flat!
2. Place one drop of colored water on the front edge of the Teflon.
3. Prop up a dark piece of construction paper behind the Teflon. (so you can see the drop better).

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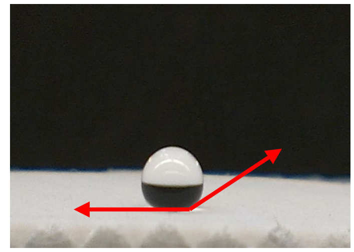
4. Using the digital camera, or your smart phone, take a picture of the drop. Try to get the clearest image possible.
5. Upload this image into your computer or send it to yourself from your phone so that it can be uploaded to your computer.
6. Bring up the picture on your computer. On the picture, using the drawing tools, draw a horizontal line across the solid surface under the drop and a tangent line where the drop touches the surface. **DO NOT resize the picture (unless you lock the aspect ratio first), or it will distort your angle!**



7. Place the protractor on the screen and fine the contact angle of the droplet.
8. Record the in the data table or create table in lab notebook.

Data Table:

Sandpaper grit #	Class Contact angles	Average Contact angle	Hydrophilic or Superhydrophilic?
60	*90, 123*	*106.5*	*hydrophobic*
80			
120			
220	*130, 140, 120*	*130*	*hydrophobic*
240			
320	*153*	*153*	*superhydrophobic*
400			
600			

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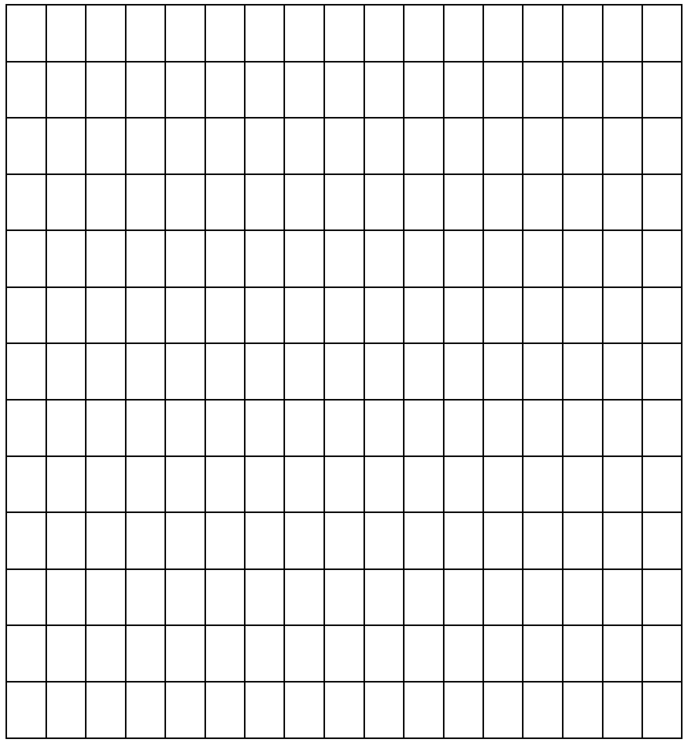
Analyze the Results: Graph the angle vs. grit size. **Angle on the x-axis, grit on the y-axis**

Effect of grit size on contact angle



Draw Conclusions:

1. Which grit is had the greatest contact angle? The least?

   The 30 grit is the most with a contact angle of 153^{o}, and the 60 grit is the least with a contact angle of 106.5

2. Was your hypothesis correct? Why or why not?

   My hypothesis was incorrect, I thought that the 60 grit paper would make it the most hydrophobic because it would produce the roughest surface, but the grit in the middle range of 320 had the highest contact angle, making it superhydrophobic.

3. Explain any sources of error.
   Our team accidentally touched the surface of the Teflon, after we dropped it on the floor.

4. Explain why you think a certain grit produced the greatest contact angle? Look at the teacher SEM images of the different sandpaper grits to help you explain it.
   I think that the coarsest grit gave the least contact angle because it made the surface too rough, so there weren't as many points for the water to stick to and spread out.

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5. How does this lab compare with the Part 1 lab? How are they different?
   In both labs we changed the surface of the material on the microscopic or nano level. In Part 1 we observed how you could chemically make a surface hydrwe made a hydrophilic surface hydrophobic, this was done by a chemical change. In this lab we changed a hydrophobic surface to a superhydrophobic surface. This was done by a physical change.

6. What does hydrophobicity and superhydrophobicity have to do with nanoscale science?
   Both of these are due to molecular forces at the liquid and solid interface. Surface tensions changes when there are more bumps on the surface of the solid. When we learned about the Lotus Effect, the leaf's bumps were on the nanoscale.

7. How is a superhydrophobic material useful? Create/Design a new commercial product that is superhydrophobic.

Optional: Activity extension

Design an experiment to test other materials that you would like to examine their movement across the Teflon or items you treated in Part 1 (chemical). What other variables would you test? Would you want to use other liquids such as an oil? Maybe a more viscous or acidic material? What other materials would you add to the surface to examine hydrophobicity? Dirt, dust, grease pen? Design your experiment and have the instructor approve your design before testing. Follow the experimental procedures of above. Write up your results and then share as a short presentation to the class.

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