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Teacher's Guide

To See or Not to See? Hydrophobic and Hydrophilic Surfaces

Grade Level: Middle & high school

Subject area(s): Physical science & Chemistry

Time required: (2) 50 minutes classes

Learning objectives: Through observation and experimentation, students will understand how the surface of a material can be chemically altered.

Summary: This activity can be completed as a separate one or in conjunction with the lesson *Superhydrophobicexpialidocious: Learning about hydrophobic surfaces found at: https://www.nnci.net/node/5895*. The activity is a visual demonstration of the difference between hydrophobic and hydrophilic surfaces. Using a polystyrene surface (petri dish) and a modified Tesla coil, you can chemically alter the non-masked surface to become hydrophilic. Students will learn that we can chemically change the surface of a material on the nano level from a hydrophobic to hydrophilic surface. The activity helps students learn that how a material behaves on the macroscale is affected by its structure on the nanoscale. The activity is adapted from Kim et. al's 2012 article in the *Journal of Chemical Education* (see references).

Background Information: Teacher Background: Commercial products have frequently taken their inspiration from nature. For example, Velcro® resulted from a Swiss engineer, George Mestral, walking in the woods and wondering why burdock seeds stuck to his dog and his coat. Other bio-inspired products include adhesives, waterproof materials, and solar cells among many others. Scientists often look at nature to get ideas and designs for products that can help us. We call this study of nature biomimetics (see Resource section for further information). Scientists have found a way to mimic the hydrophobic properties of many organisms such as the Lotus Leaf and the Namib beetle. In this activity, students will discover how to chemically create a hydrophobic surface. Students will be introduced to the concept that how a material behaves on the macroscale is affected by its structure on the nanoscale.

In this demonstration the instructor will corona treat a clear polystyrene petri dish using a modified Tesla coil. Corona treatment is a high frequency discharge that is used by industry to increase the adhesion of plastic surfaces. As stated in Kim et. al (2012)[1] " *Corona treatment is a widely adopted inexpensive process in the polymer film manufacturing industry for modifying the surface properties to improve adhesion and printability of plastic sheets or laminated films. During the corona treatment process, the electrical energy is converted to light (purple glowing arcs), sound (zapping noise), and heat-accelerated electrons break up the polymer chains and gas molecules in the air (e.g., oxygen), are ionized (cold plasma), and react with the surface of*

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nonpolar material to create more polar, higher surface energy, oxygenated material."[1] The Corona Treatment was invented in 1951 by Dutch engineer Verner Eisby. Eisby created the company Vetaphone at that time and obtained patent rights for the corona treatment system.

The chemistry involved in this process begins with the chemical structure of plastic (polymer) which consists of long chains of molecules (monomers). The monomers are joined end to end which leaves few open chains that can be bonded to a surface. This results in a surface that has poor wettability or low adhesion (Figure 1). To change a plastic's surface, such as that of polystyrene petri dish, the corona treatment uses electrons that cause the long bonds at the surface to break apart and thereby produce numerous open points for interaction at the surface. The corona treatment modifies the surface properties changing the surface energy of the material. All of this is occurring at the nanoscale and as noted by Vetaphone[2] this change occurs at the top of the molecular chains or at .01µ or 10nm.

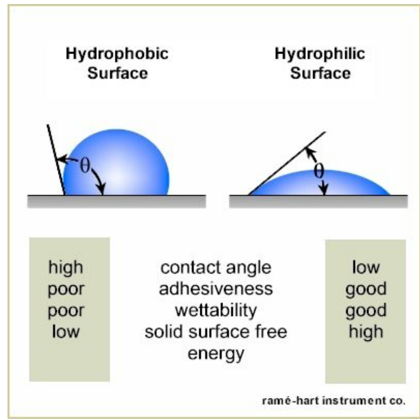

Figure 1. Properties of hydrophobic and hydrophilic. Image courtesy of Ramé-Hart Instrument Co.[3]

Corona treating a Petri dish that has areas covered with thick foam stickers (e.g., letters, numbers, or shapes) or tape converts hydrophobic surfaces to hydrophilic only on the surface surrounding the stickers. The Petri dishes originally have a plastic structure that repels water (hydrophobic). When treated with the Tesla coil, the air becomes conductive (plasma) and oxygen combines with the plastic, making the Petri dish surface attracted to water (hydrophilic). The area under the sticker is protected from the air, so it still repels water. Water in the dish sticks to the hydrophilic regions, keeping the message area dry.[4]

When the stickers are removed, the Petri dish still appears clear. However, due to the increased contrast in the hydrophobic masked areas, and hydrophilic unmasked areas, the invisible message can be seen by simply applying water.[4]

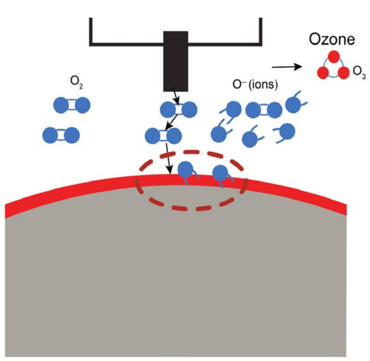

Fig. 2 Corona treatment affecting surface of plastic forming oxygen ions and ozone. Image courtesy of Vetaphone.

During corona treatment, high voltage is used to accelerate electrons into the surface of the plastic. The corona plasma causes the long polymer chains to break apart at the surface to create several open ends and free valences (at the end of the chains). The high voltage electrical discharge creates ozone. This oxygenation forms new carbonyl groups that have a higher surface energy. With higher surface energy, wettability increases (Fig. 1). The result is an improvement of the chemical connection between the molecules in the plastic and the applied liquid.

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Sources:

1. Philosek, K, "Hydroglyphics: Demonstration of Selective Wetting on Hydrophilic and Hydrophobic Surfaces." *Journal of Chemical Education* # 90 (2013): #625–628.
2. Vetaphone. "Corona Treatment". Accessed at (September 2020): https://www.vetaphone.com/our-offering/corona-treatment/
3. Rame-hart. "Contact angle". July 2013) http://www.ramehart.com/contactangle.htm
4. Tech News Daily. "Writing Messages with Water." Accessed at (July, 2013): http://www.technewsdaily.com

Materials: (based on 12 groups of 2)

- Modified Tesla coil (0.35 A, 110 V)8 see below
- A wire mesh head,
- Copper wire (16 gauge; ~20cm)
- Duct tape or aluminum tape. Duct tape works the best.
- Large stand and clamp (to hold the modified Tesla coil)
- 12 Petri dishes (unsterilized), 60 x 15 mm: 1 per student/group. These can be re-used.
- (24) or 1 per student 60mm petri dish.
- (24) or 1 per student/group: "Thicker™" stickers, (available at Michaels or Amazon) or foam sticker sheets
- 1 Stopwatch
- 6 Spray bottles or wash bottle 1/lab table
- Paper towel sheets for collecting waste water
- Aluminum foil to cover Petri dish
- 12 Tweezers or 2/lab table
- Food coloring – dark colors work best
- Plastic tray; 1 per student group
- Small fan to blow ozone (optional)
- Colored pencils (same color as the colored water)
- Safety goggles and protective gloves (teacher)

Advanced Preparation: (Modified from Kim et al 2013)

Part 1. Modify the Tesla Coil (**make sure power is off**)

a. Cut a 15-20 cm piece of copper wire.
b. Bend a loop in the middle of the wire that is 1-1.5cm in diameter. You can use a test tube or your finger to help with this.
c. Cut a mesh screen into a circle with a diameter of the petri dish. This needs to have no protruding pieces (edges) and should be able to snugly fit inside the petri dish.
d. Attach the mesh screen to the copper wire with duct or Al tape. The wire mesh should cover the inside area of the petri dish. Make sure the mesh does not have any sharp edges on it that may focus the arc. Wear safety goggles while cutting the wire, it's possible that bits of metal may fly up.(Fig.a)
e. Insert the copper wire into the Tesla coil or secure it to the coil with tape.
f. Mount the Tesla coil vertically using a stand clamp.(Fig. b)

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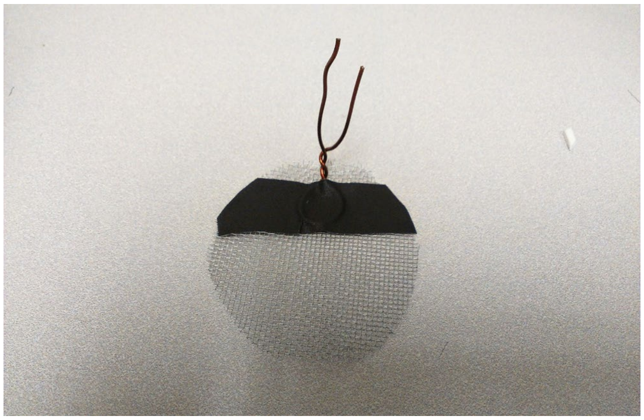
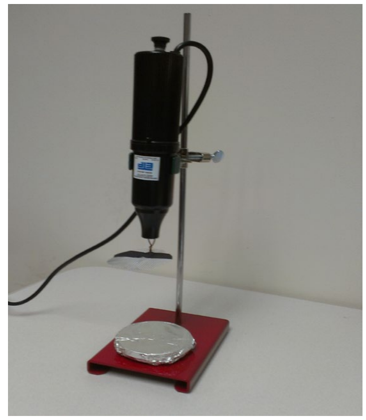
g. Cover a petri dish with aluminum foil, and place it on the base of the ring stand (Fig. b).

a.



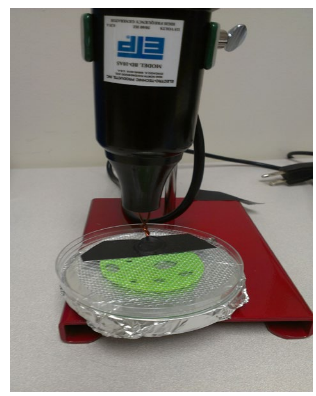
b.



Part 2. Make Demo petri dishes:

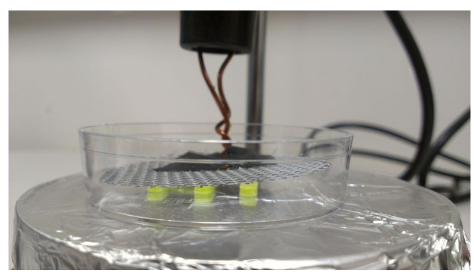
Prepare several petri dishes that have been corona treated. The number will depend on how many you want per student. I made one dish per 2 students for students to observe and compare with an untreated petri dish during the observation activity. This should be done at least one day before the demonstration. This involves trial and error and several practice runs. Allow time for trial and error.

c.



a. Take a petri dish and place sticker image or message on the bottom of the dish to produce a mask (Any flat, smooth, soft rubber like material can be used). The mask will block the air plasma from reacting with the masked area. [1]
b. Check the back of the dish to make sure there are no air gaps between the dish and the masking material (stickers).
c. Place the petri dish on top of the aluminum-covered petri dish. This will create a uniform corona treatment over the dish. Make sure the ring stand is then placed on a non-conductive surface to ground. (Fig. c)
d. Bring down the Tesla coil until it is just above the sticker or mask. Make sure the wire is <u>NOT</u> touching the sides of the petri dish. Also, if there are any sharp edges on the screen, it will focus the arc and melt the petri dish. Make sure the wire screen is flat, to get an even treatment of the dish.(Fig. d)

d.



e. Turn on the Tesla coil and treat for approximately 15 seconds. Turn off the Tesla coil, turn the dish 180^0 and treat again for approx. another 15 seconds. (Treatment can vary depending on the size of the dish and the Tesla coil). The Tesla coil used in this demo, had a button, that had to be held down for it to be on. I occasionally would get a shock. I recommend wearing protective gloves to avoid shock.
f. Using the tweezers, carefully peel off the sticker. Avoid touching the dish with your hands as oils from your fingers will contaminate the surface. Some types of stickers leave

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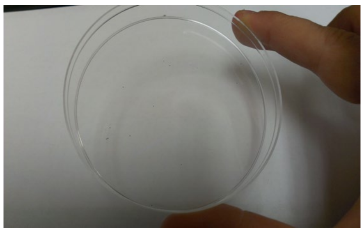
a residue. I found that the Thicker™ brand left little or no residue. If treated too long the stickers can also leave more residue.

g. Breathe onto the dish (like you are trying to fog up a window). The image will appear.
h. You can also use a wash bottle or a pipette to place a small amount of water to just cover the dish and the water will stick to the areas that were not masked. Colored water will make a better contrast.
i. If too much water is applied the message cannot be seen. Pour off the excess water and let it dry. Do not use a towel to dry the surface, it will ruin the treated surface.
j. If kept covered and free from dust or smudges, the message can last for over a month. [1]



After removing the sticker

Breathing warm air

Applying colored
water

Safety Information: This demonstration should be done in a well-ventilated area because the corona treatment creates ozone. It is recommended to use a ventilation hood but if one is not available, any large room should be ok. You can place a small fan near the Tesla coil to disperse the gas. Prolonged exposure to a high dose can cause light headaches. The electric arc from the Tesla coil will find a conductive path toward an electrical ground. Do not touch conductive objects nearby when using the coil to avoid being shocked. The amount of current from the coil is actually rather small and should not cause harm. Other safety information is noted throughout the Advanced Preparation section.

Possible sources for Tesla Coil:

- Tesla Coil ($250) https://www.teachersource.com/product/oudin-coil-tesla-coil-wsafety-switch. This is the one I used.
- Mini Tesla Coils (may work also but contact company before purchasing) https://www.amazing1.com/categories/tesla-coils/small-coils-science-projects.html
- Electro-Technic Products: https://www.electrotechnicproducts.com/bd-10a-high-frequency-generator/?gclid=CjwKCAjw74b7BRA_EiwAF8yHFASvX2GxLyCARhjTpQ4jBFx6N3KmYMAUa0z-Y8A3D0ahShAw5XQluBoCGx0QAvD_BwE

Vocabulary and Definitions

1. *Hydrophobic*: repels water; does not mix with water; "fears" water
2. *Hydrophilic*: can be wetted with water; mixes with water; "likes" water
3. *Tesla coil*: a form of induction coil (also called electrical resonant transformer circuit) which was created in 1891 by inventor Nikola Tesla. It is used to produce high-frequency alternating currents.

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4. *Corona treatment*: is a surface modification technique that uses a low temperature corona discharge plasma to impart changes in the properties of a surface. The corona plasma is generated by the application of high voltage to an electrode that has a sharp tip. The plasma forms at the tip. (Wikipedia: https://en.wikipedia.org/wiki/Corona_treatment)
5. *Plasma*: Plasma is one of the four fundamental states of matter, along with solids, liquids, and gases. Plasma is a state of matter where the gas phase is energized until atomic electrons are no longer associated with any particular atomic nucleus. Plasmas are made up of positively charged ions and unbound electrons. Plasma may be produced by either heating a gas until it is ionized or by subjecting it to a strong electromagnetic field. (Thought Company - Plasma Definition in Chemistry and Physics https://www.thoughtco.com/definition-of-plasma-605524)
6. *Polymer*: materials made of long, repeating chains of molecules. Polymers are created when monomers (small molecules) react in a chemical reaction to form polymer chains sometimes referred to as macromolecules. The term polymer is often used to describe plastics, which are synthetic polymers.
7. *Monomer*: a small molecule than can react with other monomers to form polymer chains
8. *Ozone*: highly reactive gas composed of three oxygen atoms (O3) and can be natural or man made.
9. *Contact angle*: angle that a liquid creates with a solid surface when both materials come in contact together. Contact angle is one of the common ways to measure the wettability of a surface or material.
10. *Wettability*: the ability of a liquid to maintain contact with a solid surface, resulting from intermolecular interactions when the two are brought together. The degree of wetting (wettability) is determined by a force balance between adhesive and cohesive forces (Wikipedia: https://en.wikipedia.org/wiki/Wetting).
11. *Nanoscale*: measured in nanometers; typically referring to materials between 1 and 100 nm but others use up to several hundred nanometers.
12. *Nanometer*: $1x10^{-9}$ or one billionth of a meter.
13. *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.

Suggested Teaching Strategies or Troubleshooting Tips:

Day/Time	Activity
Day 1	
5 min	Introduce students to the topic by showing them 2 petri dishes, one treated and one untreated. Make observations.
10 min.	Have students breathe on both and make observations. Have them place small amount of water on each and make observations.

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10 min.	Discuss what is happening in the dish. Why does it look different, what is happening to the liquid? Why is one "sticking" to one part and not to the other?
10 min.	Discuss hydrophobic and hydrophilic. Include contact angle and wettability. Ask how they think this is happening? Why is one different that the other?
15 min.	Demonstrate how to corona treat the dish. Briefly explain what a Tesla coil is and how it works. Discuss why this is a chemical reaction.
Day 2	**The day of the student lab**
5 min	Review with the students that they will be making their own hidden messages.
40 min	Distribute *Student Worksheets* to students. Students follow procedures to make message.
5 min	Clean up

Teaching Strategies: For the demonstration activity, I gave an untreated petri dish and a treated petri dish to 2 students. I did a variety of masks, so each group had a different image.
I had a tray on each table with colored pencils and a wash/spray bottle.
****If you have more than one class, you may want to do more petri dishes. One problem I ran into was trying to get the petri dishes rinsed and dry before the next class period. I had the students lightly rinse them and then I dried them with an air can (remember if you wipe the surface, it will ruin it).**

For the lab activity I gave each student their own petri dish and let them take them home. I used the 60 mm dishes to save on cost.
I tried to use the lids of the petri dishes to also save on cost, but for some reason they did not treat as well. Maybe they are sterilized differently, and therefore I did not get good results. It is better for the students to have the lids anyway, so they can protect their messages/image.

** For the research questions on the student lab sheet, they need to watch a video. My students have individual laptops, but you could have them also watch it as a class. Since it is on you tube- and most school systems can't get to that, the students need to load it on their computer. FAQ #10 at www.nisenet.org/faq it gives directions on how to download videos from the NISEnet catalog to save on your desktop/computer.

Guided Dialog for Demonstration:

1. Distribute a treated and untreated petri dish to students. (I had 2 per group)
2. Ask them to make observations on each dish. *They are clear, circular, about 1 cm high 10 cm in diameter etc.*
3. How are they the same? How are they different? *Both are clear, same shape, same size, don't appear to be much different. Some may make note of scratches and pre-printed numbers.*
4. Direct students to breathe warm air into each dish, show them how it should be done.
5. Now have them compare/contrast the 2 dishes. **ASK THEM NOT TO TOUCH THE INSIDE OF THE DISH!** This allows you to reuse them with the next class. REMEMBER to rinse and dry them but not with a towel.

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6. Ask them how they are different. *In one you can see an image appear, the other you cannot.*
7. Have the student squirt a very small amount of colored water into the each dish, and observe what happens. Where is the liquid sticking? *The water doesn't stick to the image but seems to stick to the area around it.*
8. Have them draw what they see in the petri dish. Give them a crayon/colored pencil to color on their paper where the water goes.
9. Discuss what it means to fear something; that the water seems to 'fear' the image. Ask: What is it called when someone is afraid of something, like spiders? *Phobic*
10. Say: So we can say part of the dish is water phobic. What is another name for water? Give them hints to come up with the word hydro. Say: So the image is afraid of water, what do we call that? *Hydrophobic*
11. Ask, What about the place where the water likes or sticks to? See if any students might know the suffix *philic*, if not you will have to tell them.
12. Say: so what is the word for something that likes water? *Hydrophilic*
13. Ask: What caused this change in the surface? *Chemical change, since the properties are different.*
14. Show the students how you made the petri dish. Are there any signs that a chemical reaction is taking place? *Odor is given off (ozone)*
15. Briefly explain what a tesla coil is and how it works. See Resources section for information on Tesla Coils.
16. Ask: What happens when electricity is passed through a gas? *Plasma is formed*
17. Explain that we changed the chemical properties of the surface. Note that the change only occurs along the top of the polystyrene or at the nanoscale. When treated with the Tesla coil, the air becomes conductive (plasma) and oxygen combines with the plastic, making the Petri dish surface attracted to water (hydrophilic). The area under the sticker was protected from the air, so it still repels water. Water in the dish sticks to the hydrophilic regions, keeping the message area dry
18. Tell students that they will be able to make their hidden message tomorrow.

Enhancing Understanding : Review the findings with students:

Corona (plasma) treating the dish, chemically changed the surface of the petri dish on the nano level. This is why we cannot visibly see the change until water is added. The areas that were masked by the sticker, remained hydrophobic and the unmasked areas were converted to a hydrophilic(or wettable) surface.

Going Further: Students who have a good grasp of the content of the lab can be further challenged with these questions:

1. Will the type of liquid make a difference? *Answers will vary and will depend on the viscosity, acidity etc.*
2. Does the type of material make a difference? *They should find that it needs to be a plastic polystyrene material to react to the corona treatment..*

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Assessment
Students should be able to correctly answer the lab analysis questions.

Resources

1. How a Tesla Coil Works at Real Clear Science: https://www.realclearscience.com/articles/2014/01/29/how_tesla_coils_work_108474.html
2. How Tesla Coil Works at HV Tesla: http://www.hvtesla.com/
3. The Biomimicry Institute: https://biomimicry.org/
4. How Biomimicry is Inspiring Human Innovation; Smithsonian Magazine: https://www.smithsonianmag.com/science-nature/how-biomimicry-is-inspiring-human-innovation-17924040/
5. Lotus leaf video: http://nisenet.org/catalog/media/zoom_lotus_leaf_video
6. Biomimicry: 9 Ways Engineers Have Been 'Inspired' by Nature accessed at: https://interestingengineering.com/biomimicry-9-ways-engineers-have-been-inspired-by-nature
7. Nano101: National Nanotechnology Initiative: https://www.nano.gov/nanotech-101

Next Generation Science Standards
Middle School

8. MS.PS1A: Structure and properties of matter
9. MS.PS1.B: Chemical reactions
10. Crosscutting Concepts
    - Cause and effect
    - Structure and function
    - Influence of science, engineering, and technology on society and the natural world

High School

11. HS.PS1A: Structure and properties of matter
12. HS.PS1.B: Chemical reactions
13. Crosscutting Concepts
    - Structure and function
    - Influence of science, engineering, and technology on society and the natural world

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

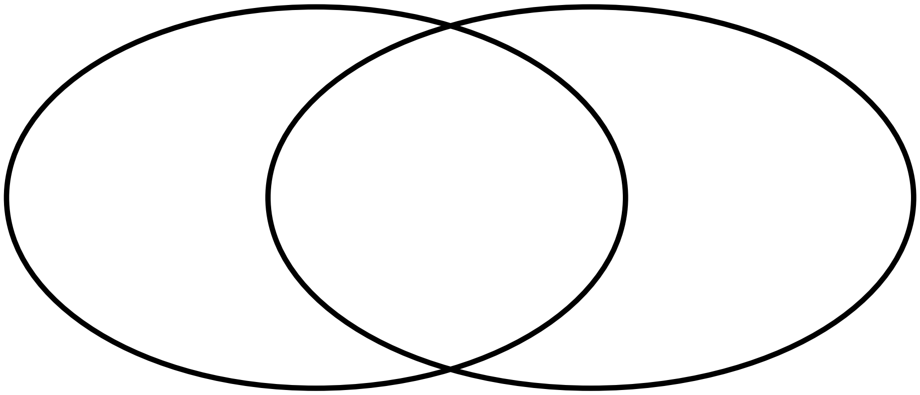
Student Worksheet (with answers in red)

To See or Not to See? Demonstration Activity

***N**ame:_______________________________Date:_______________Class:________________*

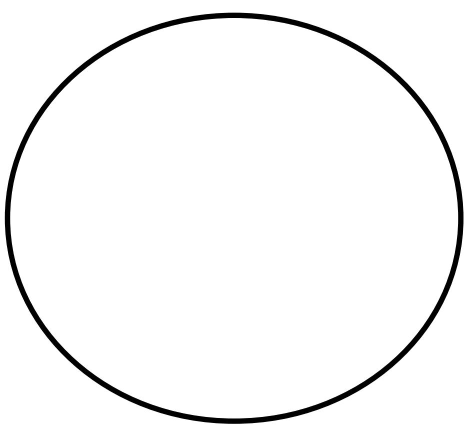
Think/Pair/Share: (answers are in the Guided Dialog)

1. **<u>Without touching the inside of the petri dish</u>**, carefully observe them. How are they the same? How are they different? Show your answers below:



2. The teacher will now ask you to do something. What changed?

3. Draw what you see: with the colored pencil, **shade in** the areas where the water goes (sticks).



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4. Prefix for water: hydro Suffix for "fearing" phobic Suffix for "liking" philic

water "fearing"=__hydrophobic_ water "loving"=_hydrophilic_

5. What do you think caused the change in the petri dish? Why?

Answers will vary but should include a chemical change caused by the tesla coil.

6. Can you think of some products that use this technology (hydrophobic)?

Waterproof clothing, waterproof sprays/treatments, umbrellas, car windshields, shoes. Students could be given computer time to research the answer.

7. How is the corona treatment related to nanotechnology?

The corona treatment changes only the surface properties and this happens at the nanoscale because the changes occur at the top 10nm of the plastic. They should also mention that the dishes look the same at the macroscale but are different at the nanoscale.

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Name:________________________________Date:_______________Class:________________

Student Worksheet

To See or Not to See? Lab Activity

Safety
Be careful when around the Tesla coil. Do not touch the coil or any part of the base while it is on.

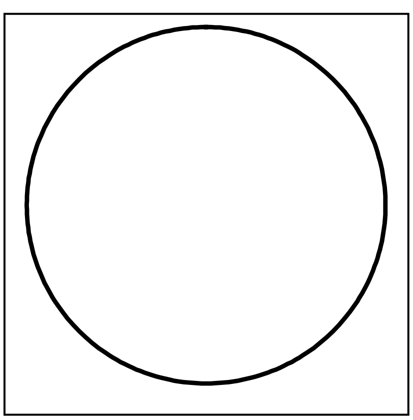
Introduction: Yesterday you saw how we could chemically change the surface of a plastic dish to make it both hydrophobic and hydrophilic. Today you will get a chance to repeat that by creating your own "hidden message!"

Materials:
Petri dish
Stickers/sticker sheet
Stopwatch or timer
Water bottle
Tweezers

Procedure I:

1. Decide what shape/design you want for your mask using the materials provided.
2. On the bottom of the dish place the sticker down. Press it down gently, you don't want any air bubbles between the sticker and the dish. Turn the dish over to make sure tere are no air bubbles.
3. Wait until the teacher calls you up to treat your dish.

While waiting answer the questions.



Procedure II: After your dish is treated.

1. When your dish is treated, slowly peel the sticker off with a tweezers. **DO NOT TOUCH** the inside of the dish, or you will ruin it with the oils from your fingers.
2. Breathe on the dish to see your image. Then you may add a **little** water to the dish. If you add too much you will not see the image.
3. Draw your image in the circle to the left.
4. Cover your dish with the lid to take it with you.

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Review Question:

1. What is the difference between hydrophobic and hydrophilic?
Hydrophobic means “water fearing” and water will not stick or wet a surface that is hydrophobic. Hydrophilic means “water loving” and water will be attracted and stick to a hydrophilic surface.

Research questions:

In this lab, we took inspiration from nature and reproduced it in the lab chemically! Scientists do this all the time. We call this Biomimetics or Biomimicry.

Read and answer the following questions:

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.** Almost all living organisms are uniquely adapted to the environment in which they live, some so well that scientists study them in hopes of replicating their natural designs in products and technologies for humans. For example, when humans were trying to decide how to fly, they examined the flying organisms, birds and insects, and realized that wings were a fundamental idea. Burrs on a dog's coat led to the invention of Velcro. After looking at the burr closely, engineer George de Mestral noticed there were special hooks and loops that gave the burr its “stickiness.” That's an example of biomimetics—the science of adapting designs from nature to solve modern problems. Hydrophobic and hydrophilic properties were also first noticed in nature. Learn more about what scientists call the Lotus effect.
Go to http://nisenet.org/catalog/media/zoom_lotus_leaf_video Watch the video, and answer the following questions:

1. What is unusual about the Lotus leaf and where it lives?

   It lives in dirty, muddy ponds but its leaves do not get dirty.

2. As you zoom in, what is the surface of the leaf actually like?

   It has a rough surface

3. The superhydrophobicity happens because of ?

   The chemistry and the shape of the surface on the micro and nanoscale

4. As you zoom in what is the texture of the leaf actually like?

   Bumpy or rough texture

5. What is on the bumps-what makes the Lotus leaf so effective at repelling water?

   Tiny hairs on the waxy bumps

6. Research and briefly explain about another organism in nature that scientists are trying to mimic. To start, go to: How Biomimicry is Inspiring Human Innovation; Smithsonian Magazine: https://www.smithsonianmag.com/science-nature/how-biomimicry-is-inspiring-human-innovation-17924040/ or Biomimicry: 9 Ways Engineers Have Been 'Inspired' by Nature accessed at: https://interestingengineering.com/biomimicry-9-ways-engineers-have-been-inspired-by-nature

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