Superhydrophobicity:
A balance between forces

Center for Nanotechnology Education

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Superhydrophobicity

Abstract

This module demonstrates and gives students an understanding of the forces behind hydrophobic and hydrophilic interactions. The balance between cohesive and adhesive forces results in an almost spherical drop of water standing on a surface, such as a lotus leaf. This effect is called superhydrophobicity. Many factors such as liquid type, surface, and temperature will determine whether a surface/liquid combination results in a hydrophobic effect. Students are encouraged to evaluate all the forces acting on the surface/liquid system and write inequalities that support the observations.

Outcomes

- Understanding cohesive and adhesive forces
- Comprehension of hydrophilic and hydrophobic surfaces
- Dependence of interaction and observed effect on liquid and surface characteristics.

Prerequisites

- Atomic and molecular structure
- Electron density concepts

Correlation

Science Concepts:

- Molecular bonds, specifically hydrogen bonds between water molecules
- Temperature dependence or influence on the strength of molecular bonds
- Electron density concepts and molecular modeling
- Relative strengths of different types of bonds (hydrogen, covalent, ionic etc.)

Nanoscience Concepts:

- Atomic and molecular structures
- Priorities of forces and interactions
- Size matters

Background Information

Interactions with water on a surface can be characterized in several ways. The exact type of interaction is dependent upon surface characteristics and environmental constraints such as temperature. In general, surfaces are defined with respect to the response to water (hydro) and characterized by the contact angle between the surface and the drop of water.

Hydrophilic: tending to be dissolved in, mixed with, or wetted by water. Hydro (water) philic (loving).

Figure 2: Hydrophilic

Figure 2: Hydrophobic

Hydrophobic: tending not to dissolve in, mix with, or be wetted by water. Hydro (water) phobic (fearing).

The interaction which drives these observed results is the relationship between cohesive and adhesive forces. The cohesive force is the overall category for intermolecular forces between like (the same) molecules, which in this case are the water molecules. Adhesive forces are the overall category for forces between unlike molecules. In this case, adhesive forces act between the water and the surface it is resting upon. There is also an adhesive force between the water and air molecules. Note that cohesive and/or adhesive forces between molecules can be either repulsive or attractive in nature, depending on the charge distribution within the contributing molecules.

A surface is said to be hydrophobic when the cohesive forces between the molecules of the water are much greater than the adhesive forces between the water and the surface. In this case the water assumes the energy efficient shape of a sphere.

The degree of hydrophobicity is determined by the contact angle, which is the angle formed where the liquid interface meets the surface. If the contact angle between the water and the surface is 90° or more, the surface is hydrophobic; if it is below 90°, the surface is said to be hydrophilic; if the contact angle exceeds 150°, the surface is considered superhydrophobic.

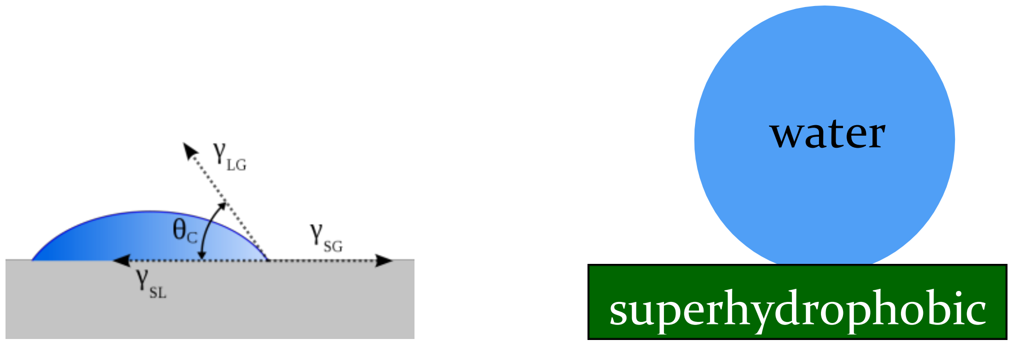


Figure 3: Contact angle and the superhydrophobic response.

The cohesive force between the water molecules has the specific name of “hydrogen bonds”. These hydrogen bonds and hence the cohesive force within a water droplet is due to the polar nature of the water molecule.

Within the water molecule the electrons from the two hydrogen atoms are more highly attracted to the positive nucleus of the oxygen atom (containing 8 protons) than they are attracted to the single proton that resides in the nucleus of the hydrogen atom. This shifting of the electrons toward the oxygen atom results in “exposure: of the positive protons in the hydrogen atoms. This means that the portion of the water molecule where the oxygen atom is located will have a negative charge most of the time, and that the portion of the water molecule where the hydrogen atoms are located will have a positive charge most of the time. When drawing a water molecule, this non-uniform charge distribution is designated by the Greek letter (small) sigma, δ, with either a positive or negative symbol as a superscript. Hence a water molecule is defined as a polar molecule where there is an unequal distribution of charges within the molecule.

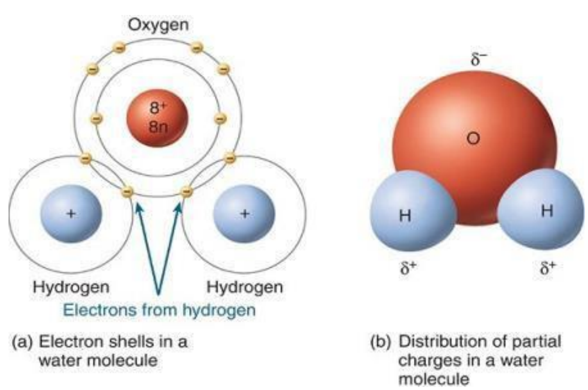


Figure 4: Water molecule (polar)

Ref: alevelnotes.com

Superhydrophobic surfaces are the result of a combination of the physical structure and the chemistry of the surface. A superhydrophobic surface uses nano-scale structures as well as the non-polar properties of the coating to create a surface that is unable to be wetted by water. Magic sand uses the nano-structures on the sand in combination with a polymer coating that is applied to the sand to create a superhydrophobic surface.

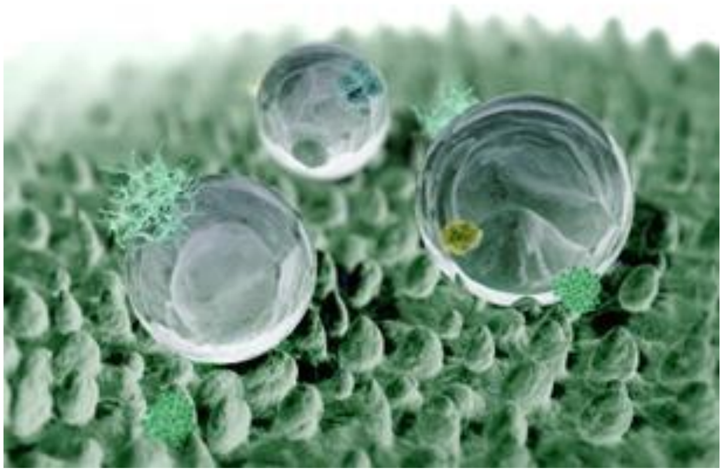
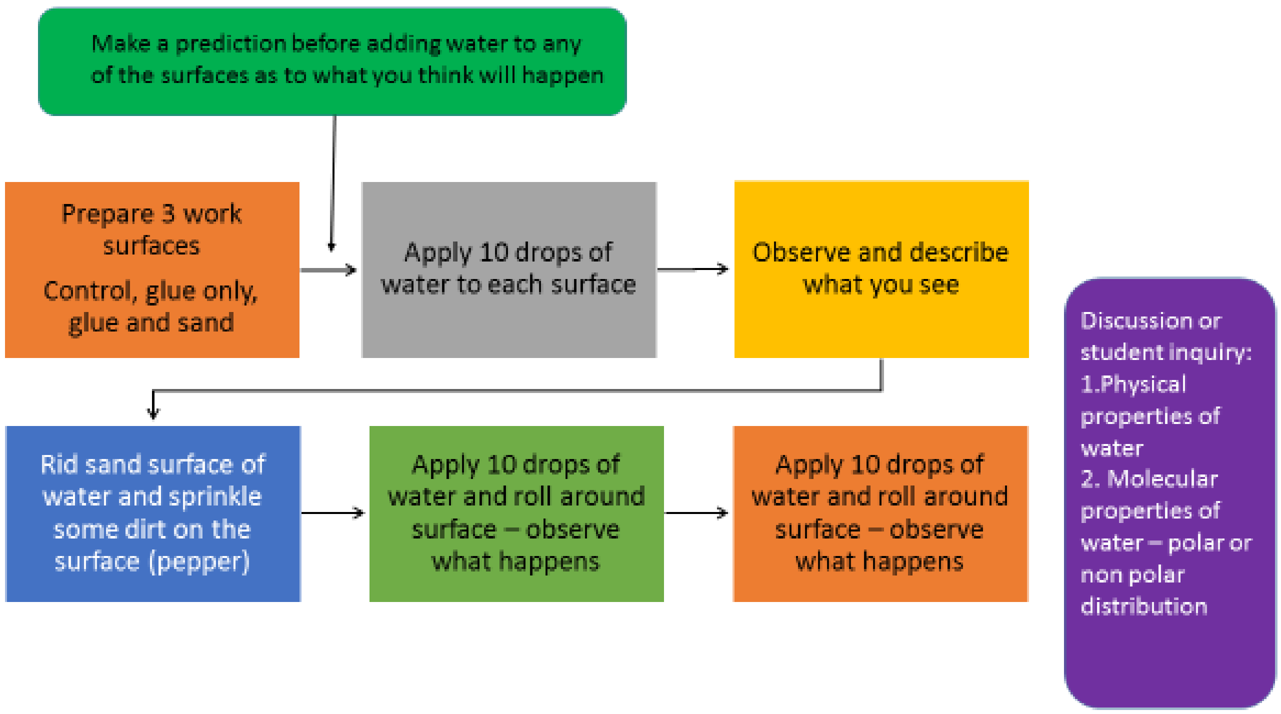


Figure 5. The nanoscale structure of a lotus leaf.

Learning Activity

Activity Flow Chart



Video of Activity

Exploring the Properties of Hydrophobic and Hydrophilic Interactions

Materials:

- Magic Sand
- Three individual pieces of paper
- Pipette or dropper
- Glue-sticks (make sure glue is water resistant)
- Various liquids: water, oil, soap, salt water, sugar water, isopropanol, acetone

Procedure: Activity 1

1. Each of the three pieces of paper will serve as test sites. The first piece of paper requires no preparation. The second piece of paper requires a layer of glue to be applied to it. On the third piece of paper, first apply the glue, then coat the surface with Magic Sand. Make sure that you have a uniform covering of the sand. There should be no paper showing through, nor should there be a large pile of loose sand on the surface.
2. While the test sites dry, make a prediction of the results for the three tests. Predict what will occur when several drops of water are applied to each of the three surfaces.
3. Use a pipette to place several drops of water onto the surface for each site, record your observations on the data sheet.
4. Repeat procedure using other liquids (oil, alcohol, salt water)

Procedure: Activity 2

1. Remove any water drops from the sand covered surface.
2. Sprinkle a small amount of pepper flakes over the surface of the sand.
3. Using the transfer pipette place a drop of water on the pepper sprinkled sand coated surface.
4. Roll the water droplet over the pepper flakes and observe the interaction of the pepper and water.
5. Roll the water droplet off of the sand covered surface and observe the response.

Current and Future Applications

There are many applications of hydrophobicity currently on the market. Products such as Rain-X, NeverWet, and Oakley Hydrophobic are coatings that can be applied to a surface to create a superhydrophobic layer that repels water, oils, and even dirt. Future applications include self-cleaning vehicles which will use a special superhydrophobic paint that will prevent water, oils, dust, and other particles from accumulating on the surface of the car. Nissan is already experimenting with self-cleaning cars by applying Ultra-Ever Dry paint finish on a Nissan Note Supermini. Another future application is the *vapor harvest system* which would use a superhydrophobic/phillic surface to collect water from rain and the surrounding air. This device will be ideal in places that have very little rainfall.

Discussion Questions

- How does surface area affect the interactions?

- What do different interactions tell us about the molecular structure of the materials involved? Consider the lotus leaf vs. human skin as examples.

- The study of hydrophobic surfaces involves science from several different fields. How does what you did today apply to biology, physics, and chemistry?

- What are some of the applications of this technology?

Contributors

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Multimedia Resources

Videos

- http://www.youtube.com/watch?v=VgrA5vNryQk Clear-n-Clean Side by Side(0:46)
- http://www.youtube.com/watch?v=berp-odsKFo&NR=1 Sandia National Laboratories 4:12 Superhydrophobic coating (2008 R&D 100 winner)
- Nanoprotect – This site describes a product available for purchase to add a nanotechnology application to glass. http://www.nanoprotect.co.uk/nano-for-household.html
- http://www.techtimes.com/articles/6076/20140427/nissan-develops-self-cleaning-car-goodbye-carwash-video.htm
- http://www.oakley.com/innovation/optical-superiority/hydrophobic

Articles

Scientific American – Self-Cleaning Materials: Lotus Leaf-Inspired Nanotechnology

http://insurftech.com/docs/links/Related-Papers/Article-1-Scientific-American-Self-Cleaning-Materals-Lotus-Effect.pdf

http://www.colettebazirgan.com/vhs.pdf

Alignment to the Next Generation Science Standards

Table 1 and 2 clarify the nature of the alignments by Scientific and Engineering Practice (Practice), Disciplinary Core Idea (DCI), and Crosscutting Concept as related to the Performance Expectation.

TABLE 1: ALIGNMENT TO SPECIFIC PERFORMANCE EXPECTATIONS	**ALIGNMENT RATING**
HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.	*Strong alignment*

TABLE 2. ALIGNED PRACTICES, DISCIPLINARY CORE IDEAS, AND CROSSCUTTING CONCEPTS		
PRACTICES	***DCI***	***CROSSCUTTING CONCEPT***
HS. Obtaining, evaluating, and communicating information Communicate scientific and technical information (e.g. about the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). *Strong in student materials*	*HS.PS2.B: Types of interactions:* Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects. *Strong in teacher and student materials*	*HS. Structure and Function:* Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem. *Partial in student materials*

Alignment to the Common Core State Standards for English Language Arts/Literacy and Mathematics

Alignments in Table 3 were made to the Anchor Standards, unless a more specific version of the standard was a closer fit to the skills in the module.

TABLE 3. ALIGNED COMMON CORE STANDARDS FOR ENGLISH LANGUAGE ARTS & LITERACY
CCR.L.6: Acquire and use accurately a range of general academic and domain-specific words and phrases sufficient for reading, writing, speaking, and listening at the college and career readiness level; demonstrate independence in gathering vocabulary knowledge when encountering an unknown term important to comprehension or expression. *Partial in teacher and student materials*
RST.11–12.3: Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text. *Strong in student materials*
RST.6–8.7: Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). *Strong in student materials*

For mathematics, Table 4 shows alignments to standards found in the 8th through 12th grade levels.

TABLE 4. ALIGNED COMMON CORE STANDARDS FOR MATHEMATICS
HS.N-VM.1 (+) Recognize vector quantities as having both magnitude and direction. Represent vector quantities by directed line segments, and use appropriate symbols for vectors and their magnitudes (e.g., **v**, |**v**|, ||**v**||, v). *Strong in student materials*
HS.N-VM.3 (+) Solve problems involving velocity and other quantities that can be represented by vectors. *Strong in student materials*
HS.A-CED.1 Create equations and inequalities in one variable and use them to solve problems. *Include equations arising from linear and quadratic functions, and simple rational and exponential functions.* *Strong in student materials*