

Surface Tension: Liquids Stick Together

Teacher Advanced Version

In this lab you will learn about properties of liquids, specifically cohesion, adhesion, and surface tension. These principles will be demonstrated by adding drops of different liquids onto pennies to determine the strength of molecular attraction.

California Science Content Standards:

- 2. Chemical Bonds: Biological, chemical, and physical properties of matter result from the ability of atoms to form bonds from electrostatic forces between electrons and protons and between atoms and molecules.
- 2a. Students know atoms combine to form molecules by sharing electrons to form covalent or metallic bonds or by exchanging electrons to form ionic bonds.
- 2d. Students know the atoms and molecules in liquids move in a random pattern relative to one another because the intermolecular forces are too weak to hold the atoms or molecules in a solid form.
- **2h. Students know how to identify solids and liquids held together by van der Waals forces or hydrogen bonding and relate these forces to volatility and boiling/melting point temperatures.

Prerequisites:

- Students will be asked to create mixtures, place droplets of liquid onto a penny, count droplets, and write numbers and basic observations.
- Advanced students will follow the same procedure, but their mathematical calculations will focus on statistical methods and will be more complex; a calculator is required for advanced students.
- There are no mobility limitations with this lab nor are any particularly special materials required.

Key Concepts:

- **Cohesion** is the attraction between molecules of the same kind; i.e. between two water molecules. Because of cohesion holding the molecules together, water and other liquids form thin films and drops. This is why water bugs can walk on water, and why a carefully placed paper clip will float.
- **Adhesion** is the attraction between different substances; i.e. between a water molecule and a copper molecule. For example, adhesion allows water molecules to move upward through a narrow tube. The attraction of water to the walls of a tube sucks the water up more strongly than gravity pulls it down (i.e. water moving up a plant's roots and stem).
- **Surface tension** is a property of a liquid that allows them to resist external forces when placed on a different material. It combines the concepts of cohesion and adhesion. The strong attraction between molecules (cohesion) causes them to link together and remain uniform when placed on different surfaces (adhesion). When the molecules of the same kind possess weak attractive interactions, as is the case with rubbing alcohol, surface tension will be small compared to other liquids.

- **Hydrophobic** or “water-fearing” molecules are molecules that do not like to be near water. Water molecules have a **dipole**, meaning that one side of the molecule has a slightly positive charge and one part has a slightly negative charge.

Introductory Mini-Lecture

Have you ever wondered why small, bubble-like droplets appear on the table when you spill your water, or when rain falls against a window? Have you noticed the little spots of oil amongst water on the street after a rainy day? The explanation for these observations lies in the liquid principles of cohesion, adhesion, and surface tension.

The smallest unit that all matter is made up of is called an **atom**. Atoms are made of three types of small particles: neutral **neutrons**, positively charged **protons**, and negatively charged **electrons**. These electrons are always moving around, and sometimes they can end up on the same side of an atom or molecule (a group of atoms), making one side more positive and one side more negative. You can think of these like magnets, where opposite charges tend to attract. This attraction is a type of **intermolecular force** and can be very strong.

Take, for example, a water droplet on a desk. Molecules of the same substance, in this case water, can be attracted to each other, which is called **cohesion**. (*Can you think of other words that begin with co-?*) Molecules of different substances, in this case water and the desk, can also be attracted to each other, which is called **adhesion**. (*Where have you heard the word adhesion or adhesive before?*) **Surface tension** is the force that holds atoms or molecules of the same substance together when they are in contact with another substance. Here, the water molecules in the droplet are held together by surface tension while they are in contact with the desk. Other examples of surface tension include water striders, dew drops, raindrops on a window, and soap bubbles!

Today, we will examine surface tension by placing drops of different mixtures onto pennies. As we add more drops of each liquid, we will start to see cohesion taking place. The more drops we can add to a penny, the stronger the interaction between molecules and, hence, the greater the surface tension.

Additional considerations:

- To demonstrate cohesion, it is useful to show attraction using magnets.
- To demonstrate adhesion, it is useful to place droplets of liquids on a surface (i.e. desk).
- During the lab, the measurements (number of drops on a penny before spilling) may be affected by the cleanliness of the penny. You can either clean all pennies (make sure all soap is gone too!) before beginning *or* pose this question to students to have them contemplate results that may not have been what they predicted.

Complete List of Materials

- Pennies (*at least 3 per student/group, need to be very clean and free of soap*)
- Water (*sink water is fine*)
- Soap (*dishwashing detergent works best; use 1 tsp per ½ cup water*)
- Rubbing Alcohol
- Dropper
- Paper towels
- Calculator (*1 per student/group, required for advanced lab only*)
- Milk (*non-fat milk works best*)

- Food coloring (*non-gel food coloring works better*)
- Toothpick
- Bowl

Part I: Drops of Water on a Penny

(Adapted from [www. middleschoolscience.com](http://www.middleschoolscience.com))

In this portion of the lab, you will determine which liquid has the highest surface tension: water, soapy water, or rubbing alcohol. To do this, you will count the number of droplets that can fit onto a penny without spilling over for each liquid. The liquid that can fit the most droplets onto the penny has the highest surface tension, because it can hold onto itself the tightest!

Q1. Using your own words, define surface tension.

Surface tension is a property of a liquid that holds molecules of the same type together when they contact a different substance.

Q2. List two examples of surface tension in everyday life:

There are many different examples of surface tension in everyday life, but here are a few examples:



www.boards.na.leagueoflegends.com

Water Striders



<http://marketismic.files.wordpress.com/2011/02/drop.jpg>

Dew Drops



<http://thedishonscience.stanford.edu/posts/phase-separation/>

Vinegar forms spheres when added to oil due to surface tension!



www.catholiclane.com

Bubbles! Soap must be added to water to create bubbles, because it lowers the surface tension of the liquid.

Q3. Make a prediction: The penny will hold the greatest number of drops when I use...

- (a) clean water
- (b) soapy water
- (c) rubbing alcohol

ANSWERS WILL VARY.

Q4. Approximately how many drops of clean water do you think the penny will hold? Soapy water? Rubbing alcohol?

These are predictions... there are no right or wrong answers! Ideally, the student may be able to predict that the number of droplets will be highest for regular water.

Q5. Explain the reasoning behind your prediction

Advanced students would ideally be able to support their prediction by stating that more water droplets will fit on the penny because it has the highest surface tension as compared to soapy water and rubbing alcohol. For soapy water it depends on the soap concentration.

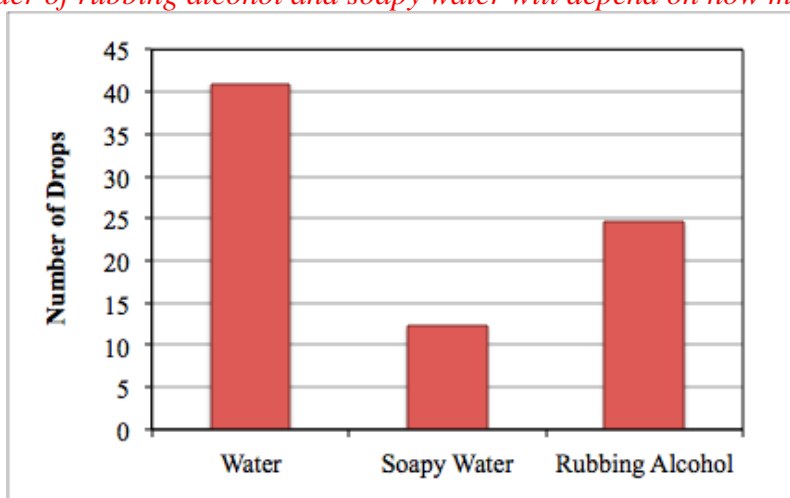
Procedure:

1. **Fill a dropper** with water.
2. **Place the penny**, *heads up*, on top of a paper towel. Make sure it is on heads--using tails will give different results!
3. **Hold your dropper** about ½ inch above the penny at a steep angle and slowly **add drops of water** to the surface of the penny until it overflows--count this as *any time the water goes off of the edge*.
4. *Record the number of drops of water the surface of the penny can hold in the table on the next page under the column labeled "Run 1."*
5. **Repeat** steps 2-4 two more times and record your results for "Run 2" and "Run 3."
6. **Repeat** the experiment (steps 2-6) for rubbing alcohol and then soapy water. Be sure to rinse and dry the penny thoroughly between experiments if reusing! You should also clean the droppers if you are reusing them.
7. *Add the number of droplets of water the penny held for Run 1, Run 2, and Run 3 and write this total in the column labeled "Sum of Runs."*
8. *Divide this number by three, the number of runs performed, and record this number in the column labeled "Average."* This is the average number of drops the penny held for your three runs.
9. **Repeat** this process with the results from soapy water and rubbing alcohol.
10. *Plot the average number of droplets for each liquid using the bar graph provided on the next page.*

Data Table 1: Drops of liquid on a penny. (see next page for standard deviation calculation)

Name of Liquid	Number of Droplets until overflow			Sum of Runs (total # of droplets)	Average = $\frac{\text{Sum of Runs}}{\text{Number of Runs}}$	Standard Deviation
	Run 1	Run 2	Run 3			
Water	37	42	44	123	41.0	3.6
Soapy Water	11	14	12	37	12.3	1.5
Rubbing Alcohol	29	22	23	74	24.7	3.8

Values provided in the table were obtained from a “test run” of the experiment and are provided to indicate the range of values you might expect to see during the experiment. Student results will vary. The order of rubbing alcohol and soapy water will depend on how much soap you add.



Standard Deviation: Mini-Lecture

Standard deviation is a term you might have heard a lot, but what does it actually mean? Standard deviation (SD) is a **statistical measure** of how spread out numbers are. The higher the SD for a set of numbers, the more spread apart the values are. The smaller the SD, the less variable our results are. The reference point we use here is the **mean**, or the average.

Additionally, the SD can also tell us the expected **range** for your values: 68% of our values should fall within 1 SD of the average (average +/- 1 SD) and 95% of our values should fall within 2 SD's of the average (average +/- 2 SD). For example, if the average of our sample is 20 and our calculated SD is 5, roughly 2/3 of our values should fall between 15 and 25, and 95% of our values should fall between 10 and 30.

Ranges calculated using standard deviations could also tell us about the **significance** of our data – whether the difference we see meaningful or not. For example if the range we calculate for water droplets and alcohol droplets do not overlap, then they are **distinct** and we can conclude that the difference we observe between the two liquids is important and not just a fluke.

Instructions for calculating standard deviation:

Note: The formula to calculate standard deviation is the following: $\sigma = \sqrt{\frac{\sum(x-\bar{x})^2}{N}}$

- σ Standard deviation
- \sum Summation symbol; take the sum of whatever follows the symbol - in this case $(x - \bar{x})^2$.
- \bar{x} Mean average
- x Value of interest, in this case the number of drops
- N Number of trials

- Write down the # of droplets of **clean water** that fit onto the penny in **Column A** of **Table 2** for the indicated trial.
- Write down the average # of droplets of clean water that fit onto the penny (calculated in Question 1) in **Column B** of **Table 2**.
- Subtract column B from column A (A-B) and write this value in **Column C**. It is okay if the value is a negative number.
- Square the values in Column C and record these values in **Column D**.
- Add all the values in Column D together and record this number in **Column E**.
- Divide the value in Column E by 3 (the number of trials you performed). Record this value in **Column F**.
- You're almost there! Take the square root of the value in Column F and record the solution in **Column G**. You have now calculated the standard deviation! Write this value in Data Table 1.
- If time allows, repeat the process for Soapy Water (Table 3) and Rubbing Alcohol (Table 4).

Table 2: Calculating Standard Deviation for Water Measurements

Water							
	A	B	C	D	E	F	G
Trial #	x	\bar{x}	$(x - \bar{x})$	$(x - \bar{x})^2$	$\sum (x - \bar{x})^2$	$\frac{\sum(x - \bar{x})^2}{N}$	$\sigma = \sqrt{\frac{\sum(x - \bar{x})^2}{N}}$
1	37	41	-4	16	26	8.7	2.9
2	42	41	1	1			
3	44	41	3	9			

Table 3: Calculating Standard Deviation for Soapy Water Measurements

Soapy Water							
	A	B	C	D	E	F	G
Trial #	x	\bar{x}	$(x - \bar{x})$	$(x - \bar{x})^2$	$\sum (x - \bar{x})^2$	$\frac{\sum(x - \bar{x})^2}{N}$	$\sigma = \sqrt{\frac{\sum(x - \bar{x})^2}{N}}$
1	31	33.3	-2.3	5.3	8.7	2.9	1.7
2	34	33.3	0.7	0.5			
3	35	33.3	1.7	2.9			

Table 4: Calculating Standard Deviation for Rubbing Alcohol Measurements

Rubbing Alcohol							
	A	B	C	D	E	F	G
Trial #	x	\bar{x}	$(x - \bar{x})$	$(x - \bar{x})^2$	$\sum (x - \bar{x})^2$	$\frac{\sum (x - \bar{x})^2}{N}$	$\sigma = \sqrt{\frac{\sum (x - \bar{x})^2}{N}}$
1	29	24.7	4.3	18.5	28.7	9.6	3.1
2	22	24.7	-2.7	7.3			
3	23	24.7	-1.7	2.9			

Q6. Which liquid do you think has the highest surface tension? Why?

Water has the highest surface tension, because the number of drops of water that stayed on the penny was highest.

Q7. What is the surface tension of water? Of rubbing alcohol? (Hint: If you have access to a computer you can find these values online, or you can ask your teacher). Were your predictions correct?

Surface Tension of Water (at 20 °C) = 72.8 mN/m

Surface Tension of Isopropyl Alcohol (at 20 °C) = 23.0 mN/m (Note that the actual surface tension of rubbing alcohol will be slightly higher than the value for pure isopropyl alcohol, because rubbing alcohol is 70% isopropyl alcohol and 30% water.)

Q8. What are the units of surface tension? Hint: surface tension is measured in force per unit length.

N/m (Newton per meter) OR dyne/cm (dyne per centimeter).

Note: surface tension can also be thought of as energy per unit area and is sometimes referred to as "surface energy." Regardless, the units work out to be the same ☺

Q9. What variables might affect surface tension values?

Temperature, the liquid itself (e.g. alcohol vs. water), contamination, solutes, addition of soaps.

Q10. What does your calculated standard deviation tell you about the reproducibility of your results?

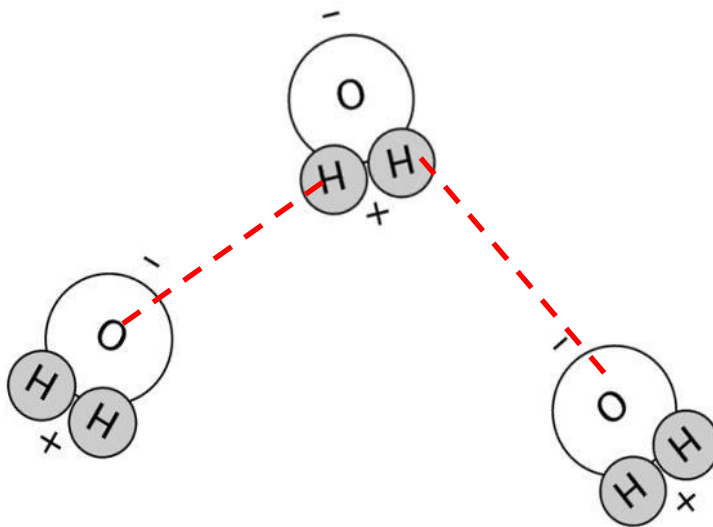
The standard deviation tells the researcher what range they should expect their values to fall in with respect to the mean average. For example, if the average number of water drops that a penny can hold is 41 and the standard deviation for that measurement is 4, then I would expect that if I repeated the experiment the majority of my results would fall between 37 and 45. More specifically, approximately 68% of the results should fall within one standard deviation of the mean and 95% should fall within 2 standard deviations of the mean (in the example above, two standard deviations would range between 33 and 49 droplets. The smaller the standard deviation, the closer the results are to the mean average and the more reproducible they are.

Q11. How do you think calculating the standard deviation might help a researcher to determine if, for example, the number of drops of soapy water is significantly different from the number of drops of clean water that fit onto the penny?

Calculating standard deviation provides a basis for comparison. For example, if you do the penny experiment with water and get 38 droplets and then repeat the experiment with rubbing alcohol and get 37 droplets, how do you know if there is a significant difference between the surface tension of water and rubbing alcohol? If we repeat the experiments four more times, we may get the sample data listed in Table 1 with an average of 40.6 for water and an average of 33.0 for rubbing alcohol. Then we can calculate a standard deviation of 4.1 for water and 2.9 for rubbing alcohol. Thus, we can expect more than 2/3 of the results to fall between 37 and 45 drops for water and between 30 and 36. If the difference between the two liquids is not significant, then there will be a large overlap in these ranges. In this case, the ranges are distinct enough to determine that a significant difference does exist despite the lack of sensitivity of the experimental set-up.

Q12. Below is a cartoon depicting three water molecules. Please do the following:

- Label each atom of the molecule "H" or "O" (for hydrogen and oxygen, respectively).
- Indicate the partial charge of each atom positive (+) or negative (-).
- Draw lines to indicate how you think the molecules "bond" or interact with one another.

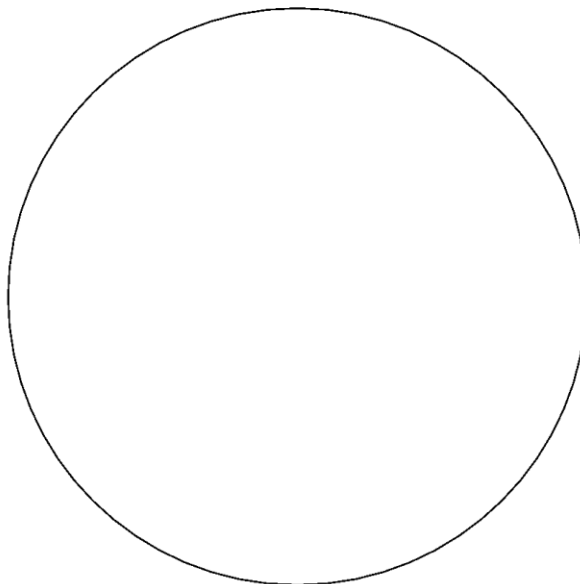


Part 2 - Tie Dye Milk

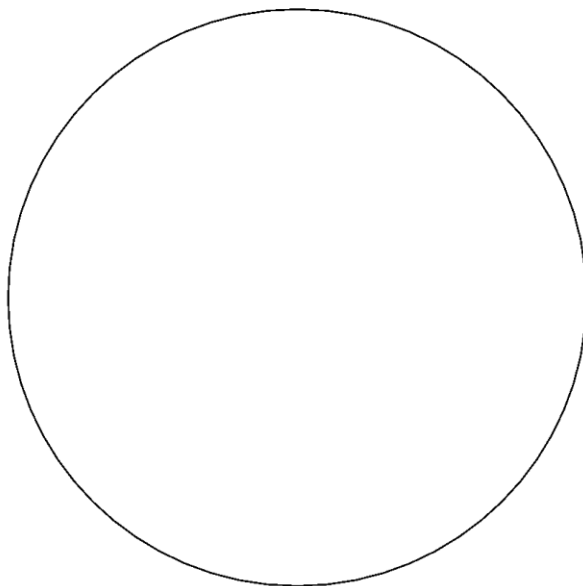
In this portion of the lab you will alter the *surface tension* of milk by adding a very small amount of dishwashing liquid to it. Milk produced by cows is mostly water (87.7%), but it also contains protein (3.4%), fat (3.6%), sugar (4.6%), and minerals (0.7%). When you add dishwashing liquid to the milk, the soap molecules move to the surface of the milk. They prefer the surface of the milk because they are *hydrophobic* or “water-fearing” and they can interact with air molecules at the surface versus being surrounded by water molecules in the bulk liquid. The soap molecules have to squeeze between the water molecules to gain access to the surface of the liquid. When the soap molecules get in between two water molecules, they decrease the water’s ability to hold onto itself. This in turn causes the *surface tension* of the milk to decrease. To visualize the change in surface tension you will first add food coloring to the milk to create a design of your choosing. Then watch what happens you add soap using a toothpick!

Procedure:

1. **Fill** bowl $\frac{3}{4}$ full with milk.
2. **Place** a few droplets of food coloring into the milk (have fun making your design!).
3. *Draw a picture* of the design you made below in the space provided below.



4. **Dip** one end of the toothpick into dishwashing soap.
5. **Lightly touch** the soapy end of the toothpick to the milk surface.
6. *Draw a picture* of the design you made after you touched the surface of the milk with the soapy toothpick in the space provided on the next page.



Q13. Describe what happened when you touched the surface of the milk with the soapy end of the toothpick.

When students touch the soapy toothpick to the surface of the milk, they will see a very rapid movement of the milk outward. The food coloring helps students visualize this movement.

*Q14. What do you think is happening to the **surface tension** of the milk when you add the dishwashing soap?*

When the soap is added to the surface of the milk it will spread along the surface and cause a rapid decrease in surface tension, which is what causes the observed reaction. It is like popping a balloon, where you are “poking a hole” in the “skin” of the milk.

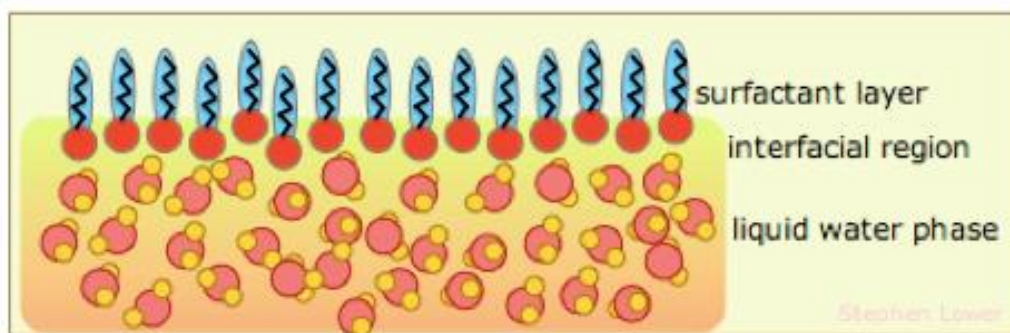
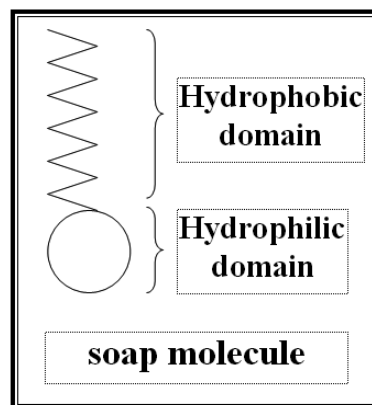
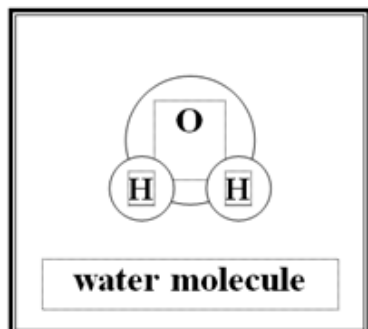
*Q15. Soap molecules are **amphipathic**, meaning they possess both a **hydrophobic** (“water fearing”) and a **hydrophilic** (“water-loving”) domain. How do you think this affects the surface tension of milk, which is primarily composed of water?*

Soap molecules are hydrophobic (“water-fearing”). This is important because the soap molecules do not want to be surrounded by the water molecules and therefore move to the air/water interface. When the soap molecules move to the interface, they displace water molecules at the surface. Basically, you can think of it as the soap molecules pushing the water molecules apart and weakening the bond between them. This causes a decrease in surface tension. The decrease in surface tension should be concentration-dependent until the soap molecules fill or saturate the water surface.

Q16. If you repeat the experiment do you get the same result? Why do you think this is?

You should get the same result if you repeat the experiment. However, the effect will be less dramatic with successive trials as the surface becomes saturated with soap molecules.

Q17. Using the illustrations below depicting a water molecule and a soap molecule, draw a cartoon image of how the soap and water molecules align themselves at the surface of the milk in the space provided below.



(chemwiki.ucdavis.edu/wikitexts)

Note that the soap molecules are primarily located at the surface and not in the bulk liquid. The soap or surfactant is composed of a hydrophilic head and a hydrophobic tail. The tails like to be in contact with the air and avoid contact with the water molecules as much as possible. The students' drawing does not need to be this detailed, but they should understand that the soap is near the surface because it possesses a hydrophobic entity that does not like to be near the water molecules.