Flash Freezing Ice Cream Spheres for a Lesson on Surface Tension

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1 Lesson Overview

We present a lesson on the fundamentals of surface tension to be presented to high school biology and earth science students at Superior High School. The students will complete the inquiry based lesson over three days by performing experiments, actively engaging in lectures, and observing demonstrations. We hope every student will gain a better understanding of the scientific principals of surface tension while recognizing the importance of surface tension in scientific advancements from the past and in the future.

1.1 Purpose

BioMEMS (biological microelectromechanical systems) and Lab-on-a-chip devices are becoming prominent systems for medical diagnostics as well as excellent platforms for biological testing. It is important to understand the effects surface tension has on these devices as they become smaller and surface tension forces dominate. Work towards the Grand Challenge of Engineering the Tools of Scientific Discovery using BioMEMS and Lab-on-a-chip devices requires an understanding of surface tension.

1.2 Keywords

Surface tension, biology, earth science, ice cream, engineering history, liquid nitrogen.

1.3 Target Audience

This lesson was designed for high school earth science and biology classes.

2 Standards Met

The Arizona High School Science Standards which are met through this lesson are:

- Strand 1 - The inquiry process. This includes forming observations, questions, and hypotheses, testing and analyzing, as well as communicating results.
- Strand 2, Concept 1 - The history of science as a human endeavor.
- Strand 4, Concept 1, PO3 - The importance of water to cells.
- Strand 4, Concept 3, PO2 - Analyzing how organisms are influenced by their environment by a combination of biotic and abiotic factors.
- Strand 5, Concept 1 - The structure and properties of matter.

3 Materials

- pennies - one per person
- dropper - one per person
- penny sized discs without an edge - one per person

- bell jar for lung breathing demonstration
- needles - one per group (earth science)
- magnet - one per group (earth science)
- PDMS (polydimethylsiloxane) - a few solid pieces for the whole class (possibly get from a local university)
- tesla coil
- mixture of 1 gallon of milk, 1 quart of heavy whipping cream, 1 1/2 cups of sugar, and 3 tablespoons of vanilla - this recipe can be scaled to make desired amount of ice cream
- plastic cups
- large metal bowls
- mixing bowls
- large metal spoons
- metal strainer or colander
- whisk
- serving bowls and spoons
- liquid nitrogen (approx. 10 L per 1 gallon of milk used)
- styrofoam cups
- plastic dropper pipettes

4 Day 1 Activities

The lesson begins with an inquiry based lab. Students are asked to predict how many drops of water they can put on a penny. Students should record the shape of water that is formed and perform the experiment multiple times to get an average result. Additionally students should wipe the penny off before each trial to remove oil from touching the penny as well as remaining water. Students will also be provided metal discs the size of a penny that don't have a rim on them. This will allow the students to observe that the rim isn't responsible for holding the water on the penny. This inquiry based activity will spark interest and get the students to start asking questions. Additionally ideas of variable control and the scientific method should be discussed.

An introductory lecture will expand on previous topics of charge and bonding to discuss hydrogen bonding in water. Additionally the topics of cohesion and adhesion will be addressed. To further introduce the concept a large number of naturally occurring phenomena can be introduced to the students. Some examples include water striders, basilisk lizards, and droplets of water. Furthermore some examples of how humans have used surface tension should be discussed such as in lava lamps and testing for jaundice. The large variety of examples will stimulate interest in the subject of surface tension as well as encourage students to notice surface tension in their own environment.

Finally students will repeat the initial experiment using a soapy solution. Students should predict how this will change the results and note any visual differences. The topic should be left open to allow the students to think about what changed from the addition of soaps until discussion on day two.

5 Day 2 Activities

Day two will begin with a brief discussion to review the concepts that were covered the first day. The review will easily change into a discussion on how we can alter surface tension properties and common applications of these changes such as with soaps and hot water. The students should be able to discuss what they do to clean their own clothes and dishes to make this more interactive. A graph of temperature versus surface tension of water should be discussed as well as typical values and the units of surface tension (fig 1). Additionally a graph of concentration of solutes versus surface tension such as figure 2 should be discussed.

To introduce biology concepts a biological surfactant example can be presented by giving a brief demonstration on the function of the lungs using a bell jar. This will allow the students to see how our lungs expand and contract as we breath and will lead into a discussion on the importance of surfactants to breathing. Discussion should include a look at the Law

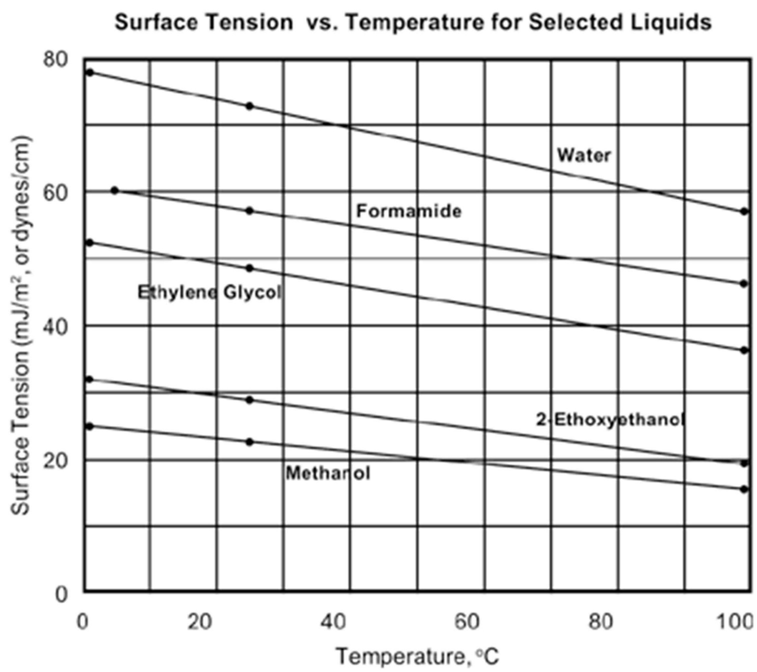

Figure 1: A graph to show the effects of temperature on surface tension.

of Laplace which is defined as $Pressure = \frac{2\gamma}{radius}$ where γ is the radius. Students should analyze the equation to see what happens to pressure in alveoli without changes in surface tension thanks to pulmonary surfactant.

An alternative activity to the pulmonary surfactant example for the earth science students is to discuss making their own compass as a survival technique. After discussions on the magnetic field of the earth a magnetized needle can be suspended on water by surface tension. (A simple way to do this is to place the magnetized needle on a paper towel and place this on the water allowing the paper towel to sink). The needle aligns with the magnetic field of the earth allowing us to find magnetic north. Students should observe that the surface tension forces hold up the needle to allow this to happen.

The ideas of surface tension being dependant on the material the fluid is in contact with will be demonstrated through an experiment on contact angle. An interactive activity to observe contact angle changes on a polydimethylsiloxane (PDMS) surface will allow students a hands-on example with Lab-on-a-chip materials. Students will place a drop of water on PDMS

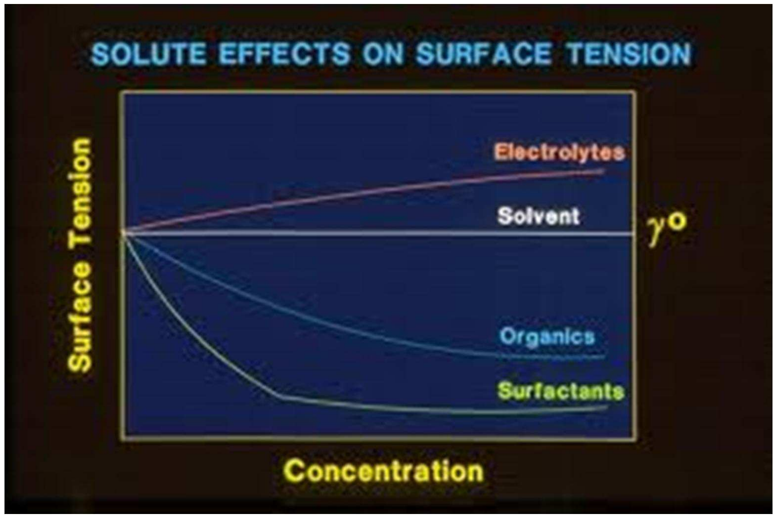

Figure 2: A graph to show the effects adding solutes to surface tension. Note that adding surfactants only decreases surface tension to a certain concentration.

then observe the contact angle. Students will then modify the surface using the Tesla coil and repeat the water drop and observe any changes. This activity will allow the students to observe differences in the behavior of water while encouraging them to relate the results to their own experiences. If PDMS is not available students can test out different surfaces such as glass, plastic, and rubber and observe differences in contact angle.

6 Day 3 Activities

The last day of the lesson will begin with a scientific history lesson on the use of shot towers. Shot towers were once used as the primary method of producing shot balls for ammunition. Molten lead was dropped through a copper sieve from the top of the tower and surface tension forces form the drops into spheres as they fell. Upon cooling the lead is solidified as perfect spheres appropriate for shot.

The culminating activity for the surface tension lesson will be the production and consumption of flash frozen spheres of ice cream, commonly known by their commercial name of Dippin Dots. Students will be able to help produce their own ice cream spheres in a fashion similar to the method used to produce lead shot. As drops of ice cream fall they will form into individual spheres as in figure 3. When the spheres fall into liquid nitrogen they will be flash frozen and retain their spherical shape. This activity will reinforce the lesson on surface tension by giving the students a fun interactive experience that they will remember.

Figure 3: General method of flash freezing ice cream spheres.

7 Procedure #1 for Freezing Ice Cream Spheres

This procedure for freezing ice cream spheres is more difficult than method #2. If time isn't an issue and ample LN2 is available then this would be the method to make a larger quantity of ice cream. This method was tested and a few difficulties were noted. The first was that a large quantity of LN2 has to be used at one time. This is because the container holding the LN2 has to be wide enough to catch lots of drops at the same time - so at least 12-18" in diamater. From testing it was found that the deeper the LN2 is in the container the better. Anything less than a few inches deep makes the drops clump up and form into one solid mass. An additional issue is creating individual droplets to fall into the LN2. Multiple strainers and colanders were used in testing but they all had holes that were spaced so closely that liquid ice cream would flow through and form into one stream eliminating the individual spheres. Nevertheless, thanks to Georgia Southern University SAACS for this procedure for ice cream spheres.

1. Take the solo cup and poke small holes throughout the bottom of it(a small metal knife works best for this'make about 20 holes total)
2. Combine all ingredients into the large plastic mixing bowl and whisk together. Be sure to allow sugar ample time to dissolve. (You can substitute sugar with simple syrup if desired)
3. Take one of the Large metal bowls and fill it $\frac{3}{4}$ of the way with N2(lq).
4. Have person 1 hold the strainer approximately 1ft above the bowl of N2(lq). Have person 2 take the solo cup and fill it with the dippin' dot solution made in Step 2. Take the solo cup and hold it approximately 1ft above the strainer and let it pour out of the holes in the bottom of the solo cup. Either person 1 or 2 takes metal spoon 1 and break up the frozen dippin' dots as they freeze in the N2(lq).
5. Make sure to notice when the N2(lq) becomes low. Once there is no N2(lq) in metal bowl 1 remove the dippin' dots by using the strainer and put the dippin' dots in metal bowl 2.
6. Take the dippin' dots in the metal bowl 2 and break them up using the metal spoon 2.
7. Divide out the dippin' dots into the individual bowls.
8. DO NOT SERVE UNTIL THEY HAVE STOPPED SMOKING! **Note step 8 is important: if they are eaten too soon they will stick to the inner parts of the mouth; so allow ample time to heat up.**
9. Repeat steps 1-8 until all dippin' dots solution is gone.

8 Procedure #2 for Freezing Ice Cream Spheres

A better method for this lesson scales down the operation making it more interactive for each student. Students are put into groups of 3-5 and each given safety goggles. Each student is also given a small bathroom cup with liquid ice cream mix (about 2 ounces) and a plastic pipette. Each group is then given a 12 ounce styrofoam cup that is about $\frac{3}{4}$ full of LN2. Students are then able to use the droppers to drop individual drops of liquid ice cream into the liquid nitrogen and observe the freezing. This also allows some experimentation on height and frequency needed for good results. Students will be able to continue putting in drops until they can no longer drop directly into the LN2. It is important to not continue putting liquid ice cream in at this point because it will cause a solid mass of ice cream to form which destroys the individual dots created before. The entire contents of the cup should be poured through a strainer to remove remaining LN2 and the drops can be placed onto a paper towels to warm. Some dots stick together and some are irregular - this is normal and happens in the commercial process too (they sort them out) - but this should make for a good topic of discussion with the students while the dots are warming. Once the liquid nitrogen has evaporated and the dots no longer stick to fingers or lips they are safe to eat. If one is eaten that sticks to a students tongue tell them to move the dot around in their mouth and it should warm and melt within seconds.

This method is superior to the bulk method because it allows for the LN2 to be deeper with a small container. The added depth allows dots to be made for a longer period of time. It also helps to use styrofoam cups instead of larger bowl because the cups will insulate the LN2. Using this method a full recipe (based on 1 gallon of milk) will make enough for about 50-60 students to each have a cup of liquid ice cream to make.