Properties of Liquids
Surface Tension and Capillary Action

Introduction

Have you ever seen an insect or spider appear to "walk" on water? The ability of water bugs to stay on top of the water is due to its very high surface tension, which acts like an invisible film that prevents the bug from breaking the surface. Surface tension and other properties of liquids depend on the nature and the strength of attractive forces between molecules.

Concepts

- Properties of liquids
- Surface tension
- Capillary action
- Intermolecular forces

Background

The properties of liquids are due to the motion of molecules in the liquid phase and the existence of attractive forces between molecules. According to the kinetic-molecular theory, the molecules in a liquid are in constant, random motion. The molecules are close enough together, however, that attractive forces between neighboring molecules influence their motion and give liquids their characteristic properties. Comparing the properties of different liquids allows us to compare the strength of attractive forces between different types of molecules. The boiling point of a liquid, for example, reflects the ability of molecules in the liquid phase to break the attractive forces between them and "escape" into the vapor phase. Liquids with low boiling points are considered volatile—they will evaporate readily from an open container. The boiling point of a liquid depends on the strength of attractive forces between the molecules. Liquids with strong intermolecular attractive forces have higher boiling points than liquids with weaker attractive forces.

Surface tension is a result of uneven attractive forces experienced by molecules at the surface versus those in the rest of the liquid (Figure 1). Molecules in the liquid are bound to neighboring molecules all around them. Molecules at the surface, however, have no neighboring molecules above them. Because the forces acting on the surface molecules are not balanced in all directions, the surface molecules are drawn inward toward the rest of the liquid. The result is *surface tension*—a net attractive force that tends to pull adjacent surface molecules inward, thus decreasing the surface area to the smallest possible size. Surface tension acts as an invisible film that makes it more difficult to move an object through the surface than through the bulk of a liquid.

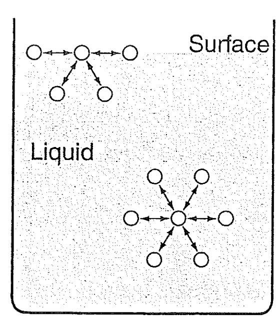


Figure 1. Attractive Forces Between Molecules and the Origin of Surface Tension.

The cause of surface tension (uneven attractive forces) explains why water has a very high surface tension compared to that of other liquids. The greater the forces of attraction between molecules in the liquid phase, the higher the surface tension will be. There are three fundamental types of intermolecular attractive forces—London dispersion forces, dipole-dipole interactions, and hydrogen bonding. Nonpolar molecules are attracted to each other by relatively weak and fleeting London dispersion forces. Polar molecules that contain permanent dipoles are bound by stronger electrostatic forces, called dipole-dipole interactions. Molecules containing highly polar O–H or N–H groups form hydrogen-bonded networks with adjacent molecules. Water's high surface tension is a consequence of its strong hydrogen bonds and explains such phenomena as how water striders walk on water and why water beads up into large droplets on a waxy leaf surface.

Capillary action, the rise of liquid in a narrow tube or fiber, is another natural phenomenon that may be explained in terms of surface tension. Examples of capillary action include the transport of water from the roots of a plant to its leaves and the migration of solvent in paper chromatography. A liquid will rise quite high in a narrow tube if there are strong attractive forces (adhesion) between the liquid molecules and the molecules that make up the surface of the tube. Adhesion tends to pull the liquid molecules upward along the surface of the tube, against the force of gravity. The surface tension acts to hold the surface together, so instead of just the edges moving upward, the whole liquid surface is dragged upward. The height to which capillary action will lift a liquid depends on the weight of the liquid which the surface tension will support—narrow tubes and high surface tension result in tall columns of liquid. The overall rise of a liquid in a capillary tube is proportional to the surface tension and inversely proportional to the density of the liquid.

Experiment Overview

The purpose of this experiment is to observe the effect of surface tension in water and then to compare the surface tension and capillary action of different liquids.

Pre-Lab Questions

1. Draw the structure of a water molecule and show by means of a diagram the hydrogen bonds between water molecules. How many hydrogen bonds does each water molecule form?

2. Hydrocarbons are nonpolar compounds containing carbon and hydrogen atoms. The properties of three hydrocarbons are summarized below. (a) How do the attractive forces between molecules change in the transition from the gas to the liquid to the solid state? (b) Based on its properties, which compound has the strongest attractive forces? The weakest attractive forces? (c) Write a general statement describing how the size of a molecule influences the strength of London dispersion forces between molecules.

Methane	Octane	Eicosane
CH_4	$CH_3CH_2CH_2CH_2CH_2CH_2CH_2CH_3$	$CH_3(CH_2)_{18}CH_3$
Natural gas	Gasoline	Lubricant (grease)
Gas, bp –161 °C	Liquid, bp 126 °C	Solid, mp 37 °C

Materials

Distilled water, 1 mL
Tap water
Isopropyl alcohol, $(CH_3)_2CHOH$, 1 mL
25% Isopropyl alcohol, 1 mL
70% Isopropyl alcohol, 1 mL
Soap solution (sodium lauryl sulfate), 1%, 1 mL
Glass jar or beaker, 125- or 250-mL
Beral-type pipets, 6
Capillary tubes, open-ended, 6
Metric ruler
Paper towels
Pennies, 30–40
Reaction strip, 8- or 12-well

Safety Precautions

Isopropyl alcohol is a flammable liquid and a dangerous fire risk—avoid contact with flames and heat. It is slightly toxic by ingestion and inhalation. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

Part A. Surface Tension Demonstration

1. Do this part in a group with four students. Place a small glass jar on a mat of paper towels and fill the jar with tap water all the way to the top until the water just begins to overflow.
2. Predict how many pennies can be added to the jar without causing the water to spill over the edge. Record your group's estimate in the data table and give a reason for the "guess."
3. Carefully add a penny to the jar without spilling any water. *Hint:* This may take some practice. Gently place the penny halfway through the water surface and then let it fall slowly to the bottom.
4. Continue adding pennies one at a time to the jar. What happens to the top of the water surface as more and more pennies are added? Describe your observations in the data table.
5. Record how many pennies were added to the jar before water began to spill over the edge in the data table.

Part B. Capillary Action

6. Obtain an 8- or 12-well reaction strip. Fill well #1 about two-thirds full with distilled water.
7. Place an open-ended capillary tube in the well and allow the water level in the tube to stabilize (about 15 seconds). Carefully remove the capillary tube from the well and measure the height in mm of the liquid in the tube. Record the liquid height in the data table.
8. Remove the capillary tube from the well and immediately blot the tube on a paper towel to drain the liquid. *Note:* Do not touch the bottom of the capillary tube with your hands. Even trace amounts of skin oils will change the surface tension of water.

9. Repeat steps 7 and 8 two more times using the same liquid to obtain a total of three measurements. Use a fresh capillary tube if air bubbles develop in the tube.

10. Fill well #2 about two-thirds full with isopropyl alcohol. Using a fresh capillary tube, repeat steps 7–9 to measure the rise in liquid level due to capillary action. Record all three measurements in the data table.

11. Fill well #3 about two-thirds full with 25% isopropyl alcohol. Using a fresh capillary tube, repeat steps 7–9 to measure the rise in liquid level due to capillary action.

12. Fill well #4 about two-thirds full with 70% isopropyl alcohol. Using a fresh capillary tube, repeat steps 7–9 to measure the rise in liquid level due to capillary action.

13. Fill well #5 about two-thirds full with tap water. Using a fresh capillary tube, repeat steps 7–9 to measure the rise in liquid level due to capillary action.

14. Fill well #6 about two-thirds full with 1% soap solution. Using a fresh capillary tube, repeat steps 7–9 to measure the rise in liquid level due to capillary action.

Name: ______________________________

Class/Lab Period: ______________________

Properties of Liquids

Data Table

Part A. Surface Tension Demonstration	
How many pennies may be added to the jar before the water overflows?	Prediction: Explain:
	Observations: Number of pennies added (step 5):

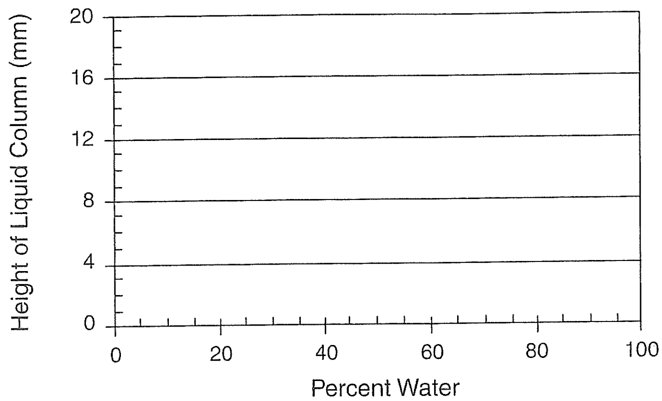
Part B. Capillary Action	Height of Liquid Column (mm)			
Liquid	Trial 1	Trial 2	Trial 3	Average
Distilled Water				
Isopropyl Alcohol				
25% Isopropyl Alcohol				
70% Isopropyl Alcohol				
Tap Water				
1% Soap Solution				

Post-Lab Questions

1. Explain why the water in an apparently full glass or jar does not overflow as pennies are added to the water. What force prevents the water from spilling over the edge?

2. Based on capillary action, which liquid has a higher surface tension, water or isopropyl alcohol? Explain in terms of the polarity of water versus isopropyl alcohol and the strength of their attractive forces.

3. Plot the data for pure water, pure isopropyl alcohol, and isopropyl alcohol–water solutions on the following graph. Note that the x-axis is *percent water* (not percent isopropyl alcohol).



4. Which statement better describes the observed trend? (a) The change in surface tension is proportional to the amount of isopropyl alcohol added to water; OR (b) Adding even a small amount of isopropyl alcohol produces a large change in the surface tension of water. Suggest a reason for the observed trend.

5. What effect does soap have on the surface tension of water? How is this related to how soaps work?

6. Tap water contains dissolved solids, in particular, magnesium and calcium salts. How do these salts change the surface tension of water?

7. *(Optional)* Soaps and detergents work better in hot water than in cold water. What effect should increasing the temperature have on the surface tension of water? Explain in terms of the kinetic-molecular theory and the attractive forces between molecules.