13. Intermolecular Forces

Driving Questions

- If chemical bonds hold atoms together to form molecules, what holds the molecules together to form solids and liquids?
- Which type of alcohol hold its molecules together the strongest? Why?
- How does the length of a molecule and the shape of a molecule affect the strength with which molecules are held together?

Background

Evaporation is the process of changing from a liquid to a gas. The rate at which a substance evaporates depends on several variables including temperature, surface area, and the chemical structure of the substance. Different liquids evaporate at different rates because the molecules are held together by varying strengths of attraction. The attractions between molecules are called intermolecular forces. The different types of intermolecular attractions are: dispersion (London) forces, dipole-induced dipole interactions, ion-induced dipole interactions, dipole-dipole interactions, and hydrogen bonding.

Materials and Equipment

For each student or group:

- Data collection system
- Stainless steel temperature sensor
- Graduated cylinder, 10-mL
- Test tube (7), 15-mm x 100-mm
- Test tube rack
- Stopper (7), to fit the test tubes
- Wash bottle and waste container
- Masking tape (2), 6 cm strips
- Methanol (CH_3OH), 5 mL
- Ethanol (C_2H_5OH), 5 mL
- Propanol (C_3H_7OH), 5 mL
- Butanol (C_4H_9OH), 5 mL
- Pentanol ($C_5H_{11}OH$), 5 mL
- 2-Propanol (C_3H_7OH), 5 mL
- 2-Butanol (C_4H_9OH), 5 mL

Safety

Add these important safety precautions to your normal laboratory procedures:

- Use a wafting motion when smelling chemicals.
- Alcohols are flammable. Smother pentanol and 2-butanol fires with sand or a Type B fire extinguisher.
- Ensure that there is good ventilation in the room. Butanol and pentanol have strong odors.

Sequencing Challenge

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

○	○	○	○	○
Place the temperature sensor in the test tube containing methanol.	Measure 5 mL of each alcohol into separately labeled test tubes.	Repeat the process for each of the other alcohols.	Start recording data, and then remove the temperature sensor from the methanol.	Stop data recording when the temperature begins to increase.

Procedure

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Note: When you see the symbol "[1]" with a superscripted number following a step, refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There you will find detailed technical instructions for performing that step. Your teacher will provide you with a copy of the instructions for these operations.

Set Up

1. ☐ Prepare test tubes with methanol, ethanol, propanol, butanol, pentanol, 2-propanol, and 2-butanol using the following procedure:
   a. Use a graduated cylinder to measure approximately 5 mL of an alcohol.
   b. Transfer the alcohol into a test tube, seal it with a stopper, and label the test tube.
   c. Clean the graduated cylinder by rinsing it several times with water.

2. ☐ Why is it necessary to stopper a test tube containing alcohol?

_____

3. ☐ Predict what will happen to the temperature as each alcohol evaporates from the temperature sensor.

_____

4. ☐ Predict how the temperature changes will compare among the five different alcohols of the homologous series (methanol, ethanol, propanol, butanol, and pentanol). Explain your prediction.

_____

_____

_____

5. ☐ Predict how the temperature changes will compare between the isomeric forms of the alcohols (2-propanol versus propanol, and 2-butanol versus butanol). Explain your prediction.

_____

_____

_____

6. ☐ Start a new experiment on the data collection system. ◆(1.2)

7. ☐ Connect a stainless steel temperature sensor to the data collection system. ◆(2.1)

8. ☐ Display Temperature (°C) versus Time (s) in a graph. ◆(7.1.1)

Collect Data

9. ☐ Remove the stopper from the test tube containing methanol, and place the temperature sensor in the methanol.

10. ☐ While viewing the graph display, start recording data. ◆(6.2)

11. ☐ Remove the temperature sensor from the methanol and tape it such that the metal section is hanging over the edge of the lab table. Replace the stopper on the test tube of methanol.

12. ☐ Adjust the scale of the axes as necessary to see the temperature change. ◆(7.1.2)

13. ☐ What is happening to the liquid on the temperature sensor? How is the temperature affected?

_____

14. ☐ How can the evaporation rate be determined from the graph?

_____

_____

15. ☐ Stop recording data when the temperature begins to increase. ◆(6.2)

16. ☐ Name the data run “methanol”. ◆(8.2)

17. ☐ Rinse the temperature sensor several times with clean water, and then dry it completely.

18. ☐ Why is it necessary to clean and dry the temperature sensor after each trial?

_____

_____

_____

19. ☐ Repeat the "Collect Data" steps for each of the remaining alcohols. Name each data run according to the alcohol being tested. ◆(8.2)

20. ☐ Save your experiment and clean up the lab station according to the teacher’s instructions, especially those concerning your excess alcohols. ◆(11.1)

Data Analysis

1. ☐ Determine the initial temperature, final lowest temperature, and change in temperature for each alcohol in the homologous series. Record the values in Table 1 below. ◆(9.2)

Table 1: Temperature changes in the homologous series of alcohols

Alcohol	Initial Temperature (°C)	Final Lowest Temperature (°C)	Change in Temperature (°C)
Methanol			
Ethanol			
Propanol			
Butanol			
Pentanol			

2. ☐ Determine the initial temperature, final lowest temperature, and change in temperature for each isomeric alcohol pair. Record the values in Table 2 below. ◆(9.2)

Table 2: Temperature changes for isomeric pairs of alcohols

Alcohol	Initial Temperature (°C)	Final Lowest Temperature (°C)	Change in Temperature (°C)
Propanol			
2-Propanol			
Butanol			
2-Butanol			

3. ☐ Determine the evaporation rate for the first 20 seconds of each trial in the homologous series and record the values in Table 3 below.

   a. Display the run of data you want to analyze. (7.1.7)

   b. Select the first 20 seconds of decreasing temperature data. (7.1.4)

   c. Apply a linear fit and determine the slope of the linear fit line. (9.6)

Table 3: Evaporation rate for alcohols in a homologous series

Alcohol	Equation of Linear Fit For the First 20 Seconds	Evaporation Rate (°C/s)
Methanol		
Ethanol		
Propanol		
Butanol		
Pentanol		

4. ☐ Determine the evaporation rate for the first 20 seconds of each trial for the isomeric alcohol pairs. Record the values in Table 4 below.

   a. Display the run of data you want to analyze. (7.1.7)

   b. Select the first 20 seconds of decreasing temperature data. (7.1.4)

   c. Apply a linear fit and determine the slope of the linear fit line. (9.6)

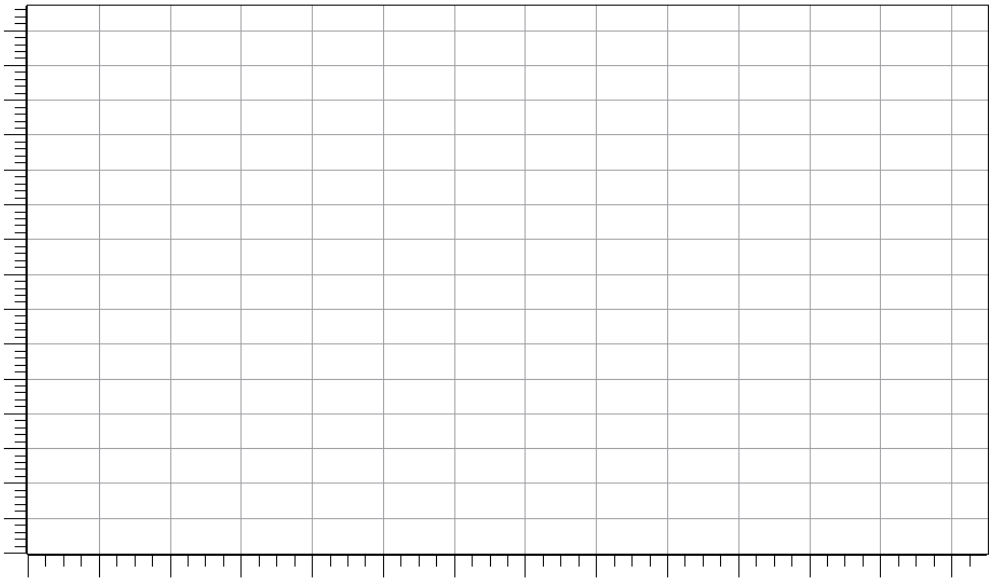
Table 4: Evaporation rates for isomeric pairs of alcohols

Alcohol	Equation of Linear Fit For the First 20 Seconds	Evaporation Rate (°C/s)
Propanol		
2-Propanol		
Butanol		
2-Butanol		

5. ☐ Create a graph with all seven runs of data displayed on your data collection system. (7.1.3)

Note: Not all data collection systems will display all seven runs of data on one set of axes. If this is not possible, you may decide to display all the homologous alcohols on one set of axes and the isomeric pairs on a different set.

6. ☐ Sketch or print a graph of Temperature (°C) versus Time (s) for all seven alcohols on one set of axes. Be sure to label each alcohol. Also label the overall graph, the x-axis, the y-axis, and include units on the axes. (11.2)



Analysis Questions

1. **How does evaporation affect temperature? Explain.**

2. **Explain how the magnitude of the evaporation rate changed with the size of the molecules in the homologous series?**

3. **Explain how the magnitude of the evaporation rate changed with the shape of the molecules in the isomeric alcohol pairs?**

4. **Which evaporated liquid from the experiment has the strongest intermolecular forces? How does your data support your answer?**

5. **Which evaporated liquid from the experiment has the weakest intermolecular forces? How does your data support your answer?**

6. **Explain the effects of molecular size on the strength of intermolecular forces for different alcohols from the same homologous series.**

7. **Explain the effects of molecular shape on the strength of intermolecular forces for different isomeric alcohol pairs.**

Synthesis Questions

Use available resources to help you answer the following questions.

1. **Vigorous exercise causes people to sweat. How does perspiration regulate body temperature?**

2. **If you enclosed methanol in one container and butanol in a second container, how would the pressures in those containers compare? Why?**

3. **Which do you expect to have the higher boiling point, butanol or 2-butanol? Why?**

4. **Would you expect water (H_2O) or hydrogen sulfide (H_2S) to have stronger intermolecular attractions? Explain your reasoning.**

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. **Which alcohol will evaporate the fastest?**

   A. Methanol
   B. Ethanol
   C. Propanol
   D. Butanol

2. **Which of the following are the strongest intermolecular forces found in propanol?**

   A. Dipole-dipole
   B. Dispersion (London)
   C. Ionic bonding
   D. Hydrogen bonding

3. **How does the size of an alcohol affect the strength of its intermolecular forces?**

   A. As the size of the alcohol decreases, the strength of intermolecular forces increases
   B. As the size of the alcohol decreases, the strength of intermolecular forces decreases
   C. As the size of the alcohol increases, the strength of its intermolecular forces decreases
   D. The size of the alcohol does not have an effect on its intermolecular forces

4. **As a liquid evaporates, the temperature of the remaining liquid will**

   A. Decrease
   B. Increase
   C. Stay the same
   D. Increase or decrease depending on the liquid

5. **Which of the following substances has the weakest intermolecular forces of attraction?**

   A. H_2O
   B. Cl_2
   C. $C_4H_{10}O$
   D. NH_3

Key Term Challenge

Fill in the blanks from the list of words in the Key Term Challenge Word Bank.

1. Physical properties, such as the state of matter, evaporation rate, and boiling points, can all be explained by intermolecular forces. The attraction that holds molecules together in the liquid and solid states are called _____ forces. There are several types of intermolecular forces. _____ forces occur between non-polar molecules and are the _____ type of intermolecular forces. _____ interactions occur between polar molecules, because the positive end of one molecule is attracted to the negative end of another. _____ is the strongest type of intermolecular force and occurs between molecules that contain hydrogen and either fluorine, _____, or nitrogen. This attraction is strong because of the large difference in _____ between these atoms.

2. The process of changing from a liquid to a gas is called _____. The rate at which evaporation occurs depends on the _____ of the intermolecular attractions holding the particles together. Liquids with strong intermolecular attractions evaporate _____, while liquids with weak intermolecular attractions evaporate _____. In homologous series, such as primary alcohols, the evaporation rate _____ as the size of the molecule increases. _____ evaporates quickly, because it has weak intermolecular forces. _____, on the other hand, evaporates at a much slower rate, because the intermolecular forces are stronger. In all cases, evaporation causes a decrease in the _____ of the remaining liquid.

Key Term Challenge Word Bank

Paragraph 1	Paragraph 2
chlorine	condensation
covalent bonding	decreases
dipole-dipole	evaporation
dispersion (London)	increase
electronegativity	methanol
hydrogen bonding	propanol
intermolecular	quickly
intramolecular	slowly
ionic bonding	strength
oxygen	temperature
sulfur	weakness