Evaporation and Intermolecular Attractions

In this experiment, Temperature Probes are placed in various liquids. Evaporation occurs when the probe is removed from the liquid's container. This evaporation is an endothermic process that results in a temperature decrease. The magnitude of a temperature decrease is, like viscosity and boiling temperature, related to the strength of intermolecular forces of attraction. In this experiment, you will study temperature changes caused by the evaporation of several liquids and relate the temperature changes to the strength of intermolecular forces of attraction. You will use the results to predict, and then measure, the temperature change for several other liquids.

You will encounter two types of organic compounds in this experiment—alkanes and alcohols. The two alkanes are pentane, C_5H_{12}, and hexane, C_6H_{14}. In addition to carbon and hydrogen atoms, alcohols also contain the -OH functional group. Methanol, CH_3OH, and ethanol, C_2H_5OH, are two of the alcohols that we will use in this experiment. You will examine the molecular structure of alkanes and alcohols for the presence and relative strength of two intermolecular forces—hydrogen bonding and dispersion forces.

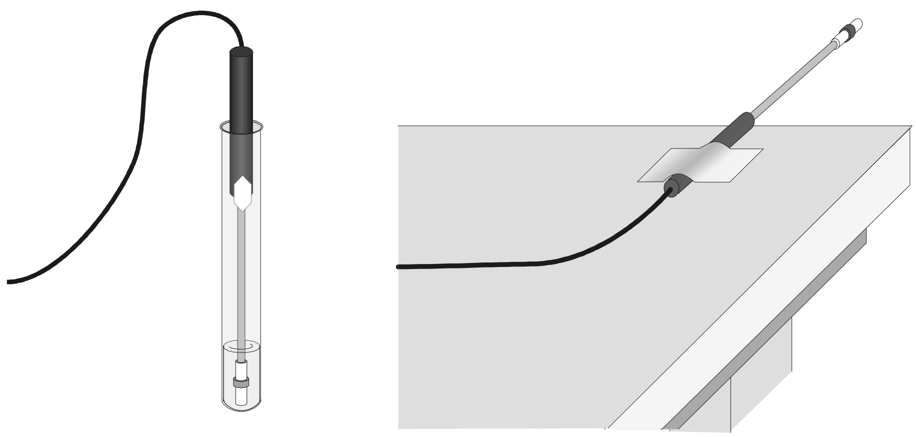


Figure 1

MATERIALS

TI-83 Plus or TI-84 Plus graphing calculator	methanol (methyl alcohol)
EasyData application	ethanol (ethyl alcohol)
data-collection interface	1-propanol
2 Temperature Probes	1-butanol
6 pieces of filter paper (2.5 cm x 2.5 cm)	n-pentane
2 small rubber bands	n-hexane
masking tape	

PRE-LAB EXERCISE

Prior to doing the experiment, complete the Pre-Lab table. The name and formula are given for each compound. Draw a structural formula for a molecule of each compound. Then determine the molecular weight of each of the molecules. Dispersion forces exist between any two molecules, and generally increase as the molecular weight of the molecule increases. Next, examine each molecule for the presence of hydrogen bonding. Before hydrogen bonding can occur, a hydrogen atom must be bonded directly to an N, O, or F atom within the molecule. Tell whether or not each molecule has hydrogen-bonding capability.

PROCEDURE

1. Obtain and wear goggles! **CAUTION:** *The compounds used in this experiment are flammable and poisonous. Avoid inhaling their vapors. Avoid contacting them with your skin or clothing. Be sure there are no open flames in the lab during this experiment. Notify your teacher immediately if an accident occurs.*

2. Turn on the calculator and connect it to the data-collection interface. Plug Temperature Probe 1 into Channel 1 and Temperature Probe 2 into Channel 2 of the interface.

3. Set up EasyData for data collection.
   a. Start EasyData if it is not already running.
   b. Select (File) from the Main screen, and then select **New** to reset the application.
   c. Select (Setup) from the Main screen, and then select **Time Graph…**
   d. Select (Edit) on the Time Graph Settings screen.
   e. Enter **3** as the time between samples in seconds and select (Next).
   f. Enter **80** as the number of samples and select (Next) (data will be collected for 4 minutes).
   g. Select (OK) to return to the Main screen.

4. Wrap Probe 1 and Probe 2 with square pieces of filter paper secured by small rubber bands as shown in Figure 1. Roll the filter paper around the probe tip in the shape of a cylinder. **Hint:** First slip the rubber band up on the probe, wrap the paper around the probe, and then finally slip the rubber band over the wrapped paper. The paper should be even with the probe end.

5. Stand Probe 1 in the ethanol container and Probe 2 in the 1-propanol container. Make sure the containers do not tip over.

6. Prepare 2 pieces of masking tape, each about 10 cm long, to be used to tape the probes in position during Step 7.

7. After the probes have been in the liquids for at least 30 seconds, select (Start) to begin collecting temperature data. A live graph of temperature *vs.* time for both Probe 1 and Probe 2 is being plotted on the calculator screen. The live readings are displayed in the upper-right corner of the graph, Probe 1 first, Probe 2 below. Monitor the temperature for 15 seconds to establish the initial temperature of each liquid. Then simultaneously remove the probes from the liquids and tape them so the probe tips extend 5 cm over the edge of the table top as shown in Figure 1.

8. Data collection will stop after 4 minutes (or select (Stop) to stop *before* 4 minutes has elapsed). On the displayed graph of temperature *vs.* time, each point for Probe 1 is plotted without a marker, and each point for Probe 2 with a square. As you move the cursor right or left, the time (X) and temperature (Y) values of each Probe 1 data point are displayed above the graph. Based on your data, determine the maximum temperature, t_1, and minimum temperature, t_2. Record t_1 and t_2 for Probe 1.

Press ▽ to switch the cursor to the curve of temperature *vs.* time for Probe 2. Examine the data points along the curve. Record t_1 and t_2 for Probe 2.

9. For each liquid, subtract the minimum temperature from the maximum temperature to determine Δ*t*, the temperature change during evaporation.

10. Roll the rubber band up the probe shaft and dispose of the filter paper as directed by your instructor

11. Based on the Δ*t* values you obtained for these two substances, plus information in the Pre-Lab exercise, *predict* the size of the Δ*t* value for 1-butanol. Compare its hydrogen-bonding capability and molecular weight to those of ethanol and 1-propanol. Record your predicted Δ*t*, then explain how you arrived at this answer in the space provided. Do the same for n-pentane. It is not important that you predict the exact Δ*t* value; simply estimate a logical value that is higher, lower, or between the previous Δ*t* values.

12. Select Main to return to the Main screen. Test your prediction in Step 11 by repeating Steps 4–10 using 1-butanol with Probe 1 and n-pentane with Probe 2. **Note:** After selecting Start to begin data collection, select OK to overwrite the latest run and start data collection.

13. Based on the Δ*t* values you have obtained for all four substances, plus information in the Pre-Lab exercise, predict the Δ*t* values for methanol and n-hexane. Compare the hydrogen-bonding capability and molecular weight of methanol and n-hexane to those of the previous four liquids. Record your predicted Δ*t*, then explain how you arrived at this answer in the space provided.

14. Select Main to return to the Main screen. Test your prediction in Step 13 by repeating Steps 4–10, using methanol with Probe 1 and n-hexane with Probe 2. **Note:** After selecting Start, select OK to overwrite the latest run and start data collection.

PROCESSING THE DATA

1. Two of the liquids, n-pentane and 1-butanol, had nearly the same molecular weights, but significantly different Δ*t* values. Explain the difference in Δ*t* values of these substances, based on their intermolecular forces.

2. Which of the alcohols studied has the strongest intermolecular forces of attraction? The weakest intermolecular forces? Explain using the results of this experiment.

3. Which of the alkanes studied has the stronger intermolecular forces of attraction? The weaker intermolecular forces? Explain using the results of this experiment.

4. Plot a graph of Δ*t* values of the four alcohols versus their respective molecular weights. Plot molecular weight on the horizontal axis and Δ*t* on the vertical axis.

PRE-LAB

Substance	Formula	Structural Formulas	Molecular Weight	Hydrogen Bond (Yes or No)
ethanol	C_2H_5OH			
1-propanol	C_3H_7OH			
1-butanol	C_4H_9OH			
n-pentane	C_5H_{12}			
methanol	CH_3OH			
n-hexane	C_6H_{14}			

DATA TABLE

Substance	t_1 (°C)	t_2 (°C)	Δt ($t_1 - t_2$) (°C)
ethanol			
1-propanol			
1-butanol			
n-pentane			
methanol			
n-hexane			

Predicted Δt (°C)	Explanation

TEACHER INFORMATION

Evaporation and Intermolecular Attractions

1. This activity is ideally performed with a LabPro or CBL 2 and two Stainless Steel Temperature Probes.

   It is possible to perform this activity with the following set ups, however, it will take additional time:

   - 1 Stainless Steel Temperature Probe per LabPro or CBL 2
   - 1 Stainless Steel Temperature Probe with an EasyLink connected directly to the USB port on a TI-84 Plus calculator
   - 1 EasyTemp connected directly to the USB port on a TI-84 Plus calculator

   If you use only one Temperature Probe per calculator, this experiment can still be completed in one class period. It is also possible to do four of the liquids during one class period, and the remaining two liquids the next day. This provides students with additional time to consider their predictions.

   Note: We do not recommend that you use the TI Temperature Probe that was shipped with the original CBL; our tests show that pentane liquid sometimes penetrates the seal on the tip of the TI-Temperature Probe.

2. We recommend wrapping the probes with paper as described in the procedure. Wrapped probes provide more uniform liquid amounts, and generally greater Δt values, than bare probes. Chromatography paper, filter paper, and various other paper types work well.

3. Snug-fitting rubber bands can be made by cutting short sections from a small rubber hose. Surgical tubing works well. Orthodontist's rubber bands are also a good size.

4. Other liquids can be substituted. Although it has a somewhat larger Δt, 2-propanol can be substituted for 1-propanol. Some petroleum ethers have a high percentage of hexane and can be used in its place. Other alkanes of relatively high purity, such as n-heptane or n-octane can be used. Water, with a Δt value of about 5°C, emphasizes the effect of hydrogen bonding on a low-molecular weight liquid. However, students might have difficulty comparing its hydrogen bonding capability with that of the alcohols used.

5. Sets of the liquids can be supplied in 13 x 100 mm test tubes stationed in stable test-tube racks. This method uses very small amounts of the liquids. Alternatively, the liquids can be supplied in sets of small bottles kept for future use. Adjust the level of the liquids in the containers so it will be above the top edge of the filter paper.

6. Because several of these liquids are highly volatile, keep the room well-ventilated. Cap the test tubes or bottles at times when the experiment is not being performed. The experiment should not be performed near any open flames.

7. Other properties, besides Δ*t* values, vary with molecular size and consequent size of intermolecular forces of attraction. Viscosity increases noticeably from methanol through 1-butanol. The boiling temperatures of methanol, ethanol, 1-propanol, and 1-butanol are 65°C, 78°C, 97°C, and 117°C, respectively.

8. **HAZARD ALERTS:**

   n-Hexane: Flammable liquid: dangerous fire risk; may be irritating to respiratory tract. Hazard Code: B—Hazardous.

   Methanol: Flammable; dangerous fire risk; toxic by ingestion (ingestion may cause blindness). Hazard Code: B—Hazardous.

   Ethanol: Dangerous fire risk; flammable; addition of denaturant makes the product poisonous—it cannot be made non-poisonous; store in a dedicated flammables cabinet or safety cans. If a flammables cabinet or safety cans are not available, store in a Flinn *Saf-Stor*® Can. Hazard Code: C—Somewhat hazardous.

   n-Pentane: Flammable liquid; narcotic in high concentrations. Hazard Code: B—Hazardous.

   1-Propanol: Flammable liquid; dangerous fire risk; harmful to eyes and respiratory tract. Hazard Code: B—Hazardous.

   1-Butanol: Moderate fire risk; toxic on prolonged inhalation; eye irritant; absorbed by skin. Substance may develop explosive hydroperoxides. Use fresh materials only. All Flinn chemicals are date labeled. Hazard Code: B—Hazardous.

   The hazard information reference is: Flinn Scientific, Inc., *Chemical & Biological Catalog Reference Manual, 2000*, P.O. Box 219, Batavia, IL 60510. See *Appendix F* of this book, *Chemistry with Calculators*, for more information.

ANSWERS TO QUESTIONS

Answers have been removed from the online versions of Vernier curriculum material in order to prevent inappropriate student use. Graphs and data tables have also been obscured. Full answers and sample data are available in the print versions of these labs.

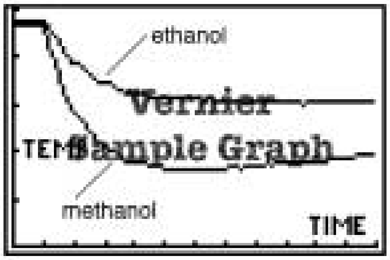
DATA TABLE

Substance	t_1 (°C)	t_2 (°C)	Δt ($t_1 – t_2$) (°C)
ethanol	xxxx	xxxx	xxxx
1-propanol	xxxx	xxxx	xxxx
1-butanol	xxxx	xxxx	xxxx
n-pentane	xxxx	xxxx	xxxx
Methanol	xxxx	xxxx	xxxx
n-hexane	xxxx	xxxx	xxxx

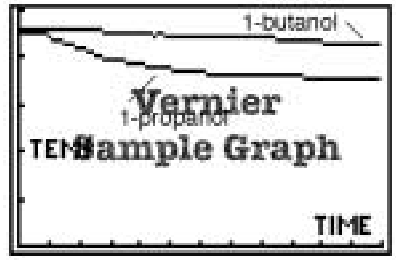
Predicted Δt (°C)	Explanation
varies (< 4.9°C)	xxxx
varies (> 8.3°C)	xxxx
varies (> 8.3°C)	xxxx
varies (< 16.1°C)	xxxx

PRE-LAB RESULTS

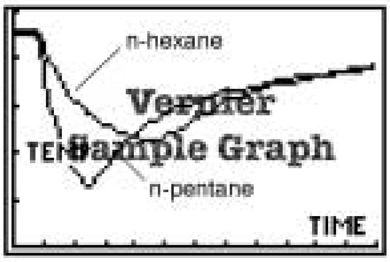
Substance	Formula	Structural Formulas	Molecular Weight	Hydrogen Bond (Yes or No)
ethanol	xxxx	XXXXX	xxxx	xxxx
1-propanol	xxxx	XXXXX	xxxx	xxxx
1-butanol	xxxx	XXXXX	xxxx	xxxx
n-pentane	xxxx	XXXXX	xxxx	xxxx
methanol	xxxx	XXXXX	xxxx	xxxx
n-hexane	xxxx	XXXXX	xxxx	xxxx



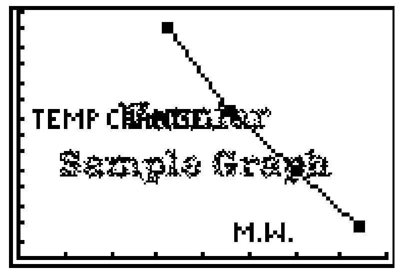
Evaporation of methanol and ethanol



Evaporation of 1-propanol and 1-butanol



Evaporation of n-pentane and n-hexane



Temperature change vs. alcohol molecular wt.