Experiment 2

Intermolecular Forces

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PURPOSE

The purpose of this experiment is to explore the relationships between molecular size, composition, and intermolecular forces.

INTERMOLECULAR FORCES

Species with strong intermolecular forces are more difficult to convert from liquids into gases. It will be slower and less will vaporize. Further, as it requires energy to vaporize a liquid, faster vaporization implies a larger amount of evaporative cooling.

You should recall from lecture that the total strength of the intermolecular forces present depends upon both the types of forces present and the magnitude of those forces. For example, polar molecules will experience both dispersion and dipolar forces and thus have stronger intermolecular forces than similar nonpolar molecules. However, if the nonpolar molecules are significantly larger, they may experience stronger forces since the strength of dispersion forces increases with molar mass.

IN THIS EXPERIMENT

In this experiment, you will study a series of organic liquids. In particular, you will (1) monitor the rate at which they evaporate (reflected by the temperature drop due to evaporative cooling); and (2) measure their vapor pressure. Based upon the results, you will draw conclusions about the intermolecular forces present.

PRE-LABORATORY PREPARATION

1. Read the procedure and data analysis sections of the experiment.
2. Complete the PRELAB assignment in Canvas.

EXPERIMENTAL SECTION

REAGENTS PROVIDED

methanol, $CH_3OH(l)$
ethanol, $C_2H_5OH(l)$
n-propanol, $C_3H_7OH(l)$
n-pentane, $C_5H_{12}(l)$
n-hexane, $C_6H_{14}(l)$

HAZARDOUS CHEMICALS

All of the liquids are flammable – no open flames in the lab. Methanol is toxic. Pentane can be narcotic in high concentrations. Hexane can be irritating in the respiratory tract.

WASTE DISPOSAL

Pentane and hexane should be disposed of in waste containers in the hood. The remaining liquids can go down the drain.

PROCEDURE

This experiment will be done with a partner.

SETUP

1. Turn on the LabQuest2 by pressing the red power button on the top.

2. Attach temperature probes to both CH 1 and CH 2 on the left end of the LabQuest2.

There should be two large boxes with the two temperature readings. On the right side, it should show that the *Mode:* is *Time Based*.

3. Tap on *Duration* and then change it from *180* to *600* seconds. Tap on *Done* and *OK* to return to the meter screen.

4. Clean 6 test tubes and fill the bottom 2 cm (approximately) of each tube with one of the following liquids: distilled water, methanol, ethanol, n-propanol, pentane, hexane.

Either label your tubes, or be very careful to keep them in order in your test tube rack.

EVAPORATIVE STUDY

5. Wrap the lower part of each temperature probe with a square piece of filter paper. (It is not necessary to cover the very end.) Secure them with rubber bands.

As much as possible, avoid handling the metal part of the temperature probe.

6. Place one probe into the test tube of water and the other into the test tube of methanol such that the filter paper is immersed.

7. After 45 seconds (to allow the temperature to stabilize), record the initial (maximum) temperatures and tap on the Start button (in the lower left corner of the screen).

8. After 5 seconds, remove the probes from the liquids and hold them, or drape them over a buret stand, so they are suspended in air.

9. Monitor the temperatures. After both temperatures have reached minimums and started to increase, tap on stop.

If the minimum has not been reached after 600 seconds, stop anyway, it will be close enough.

You can move back-and-forth between the meter, graph, and data table screens by tapping on the appropriate icons at the top of the screen.

10. Record the minimum temperature for each liquid.

You do not need to save or print out the data. We collected it simply so it was easier to monitor when the minimum was reached.

11. Remove the filter paper from each probe (and discard in the wastebasket). Wipe off the probe with a paper towel.

12. Repeat steps 5-11 for the four remaining liquids (two-at-a-time).

Wipe off the temperature probes between trials and use fresh filter paper each time.

13. Dispose of the pentane and hexane in waste containers in the hood. The remaining liquids can go down the drain.

VAPOR PRESSURE STUDY

14. Remove the temperature probe from CH 1 of the LabQuest2. Connect a gas pressure sensor to CH 1. Leave the other temperature probe connected to CH 2.

The LabQuest2 should automatically recognize the pressure sensor. It will then ask what to do with the unsaved data. Tap ***Discard***.

15. Change the pressure units to mm Hg by first tapping on the Pressure reading (when you are viewing the meter screen). Then tap on *Change Units* and select *mm Hg*.

We choose mm Hg simply because it is the unit most commonly used for vapor pressure.

If the sensor is operating correctly, the pressure should be close to 760 mm Hg (although most days it is closer to 740-750). If it is not, your instructor needs to check your setup.

16. Prepare a water bath containing hot tap water and put the temperature probe into it.

Take a 600 mL beaker and fill it with about 400 to 450 mL of hot tap water.

17. Obtain a utility clamp and loosely attach it to a buret stand (below the buret clamp).

18. Take the two-hole (or three-hole) rubber-stopper (with two plastic fittings) from the Gas Pressure sensor box and insert it firmly into a 125 mL-Erlenmeyer flask.

Important: To ensure a tight fit, twist the stopper slightly as you are inserting it into the neck of the flask. Note that the necks on some flasks are too large for the stoppers. Exchange for one with a smaller neck, if needed.

19. Connect the stopper to the gas-pressure sensor with the plastic hose provided.

The stopper has two fittings on the top. The hose can be connected to either of the fittings.

20. Securely fasten the 125-mL Erlenmeyer flask in the utility clamp. Raise the clamp so that the flask can be lowered into the water bath. Then lower the flask into the bath as far as possible and tighten the clamp.

Allow at least two minutes for the air temperature in the flask to equilibrate with the water bath before attaching the syringe (step 22). However, you can proceed with step 21 and get the syringe ready, while waiting.

21. Prepare a 10-mL syringe with 1 mL of ethanol.

There will be a covered beaker of ethanol on the front bench.

a. Push the syringe's plunger all the way in.
b. Place the end of the syringe in the ethanol.
c. Pull back on the plunger to draw ethanol into the syringe until it reads 1 (±0.2) mL.
d. Re-cover the beaker of ethanol.

22. Attach the plastic syringe to the other fitting on the stopper, but do NOT inject the sample yet.

The syringe can be attached by gently turning clockwise about half a turn. Check that the connections are tight as leaks will affect your results.

23. Tap on the Start button, allow about 10-15 seconds for the reading to stabilize, and then record the air pressure and temperature inside the flask as P_1 and T_1.

We are assuming the air temperature inside the flask is equal to the water bath temperature.

If you wait too long, ethanol from the syringe will start vaporizing and the pressure will begin systematically drifting upward.

24. Squirt the ethanol into the flask by pushing the plunger in all of the way.

Do NOT remove the syringe. Drawing the plunger back to where it started would eliminate any bogus pressure variation due to the volume of the flask changing when the ethanol is added. However, given the crudeness of our apparatus, the relative error introduced is negligible.

This injection may cause a spike in your pressure-temperature plot. If so, ignore this spike when looking for the peak pressure later.

25. Monitor the pressure reading. After the pressure has reached its peak value and starts to go back down, tap on stop and record the peak pressure and the corresponding temperature as T_2 and P_{final}.

P_{final} is the pressure due to both the air and the vapor pressure of the injected ethanol.

The pressure in the container should not be large enough to force the syringe plunger out. But, make sure it remains pushed in.

It should reach its peak within a few minutes. The peak reading should be at least 70 mmHg greater than the initial reading. If not, you probably have a leak (probably the rubber stopper) and should try again. If you repeat, either use a different flask or clean yours thoroughly to remove the alcohol.

While you are waiting, you could answer the questions for the Evaporative Study (and occasionally monitor the pressure). A good, efficient lab worker can multi-task.

26. In a second 600-mL beaker, prepare a water bath with 400-450 mL of cold tap water.

Often, the cold water is about room temperature.

27. Remove the temperature probe from the hot water bath and move it into the cold bath.

28. Disassemble your apparatus. Dump out the excess ethanol (in the sink), rinse and dry the Erlenmeyer flask.

When you open the flask, a little ethanol may spray out.

29. Repeat steps 18-25 using ethanol and the cold water bath.

30. Disassemble your apparatus. Dump out the excess ethanol (in the sink), rinse and dry the Erlenmeyer flask. Over a sink, pump the syringe several times to eject any residual ethanol out the end.

Some ethanol will definitely be ejected when the syringe is pumped, so be sure the syringe is not pointing at anybody.

31. Repeat steps 18-25 using methanol and the cold water bath.

We are only collecting data for methanol using the cold water temperature water bath. Similar to the ethanol, it will take a few minutes for the methanol to totally saturate the vapor phase. You should see an increase of at least 20 mmHg in the pressure. If not, you have a leak.

32. Disassemble your apparatus. Dump the excess methanol in the sink; rinse and dry the Erlenmeyer flask. Over a sink, pump the syringe several times to eject any residual methanol.

When you open the flask, a little methanol may spray out. Some methanol will definitely be ejected when the syringe is pumped, so be sure the syringe is not pointing at anybody.

33. Shutdown the LabQuest2.

This can be done by first tapping ***File**, then* ***Quit***. If asked, choose to ***Discard*** the data. Next, tap on the ***System*** folder and then ***Shut Down*** and, finally, ***OK***.

RETURN EVERYTHING TO WHERE IT WAS AT THE START OF LAB. HAVE AN INSTRUCTOR CHECK YOUR STATION BEFORE LEAVING.

It's always a good idea to wash your hands before leaving the laboratory.

Name ______________________ Station Used __________ Instructor/Day/Time ______________________

Partner ______________________ Station Checked & Approved ______________________

DATA SHEET AND DATA ANALYSIS

EVAPORATIVE STUDY

Substance	Maximum Temperature (°C)	Minimum Temperature (°C)	ΔT $T_{max} - T_{min}$ (°C)
Water, H_2O			
Methanol, CH_3OH			
Ethanol, C_2H_5OH			
n-Propanol, C_3H_7OH			
Pentane, C_5H_{12}			
Hexane, C_6H_{14}			

1. In the hypothetical case of a liquid that had such strong intermolecular forces it would never evaporate, what temperature change would you expect to see?

2. Which one of the three alcohols had the strongest intermolecular forces? Explain why this result makes sense (assuming it does) based upon the structure of the three molecules.

3. Would you expect the value of ΔT for n-butanol, $C_4H_9OH(l)$, to be larger or smaller than the value for n-propanol, $C_3H_7OH(l)$?

4. Given that the molar mass of n-butanol is very similar to that of pentane, $C_5H_{12}(l)$, which would have a larger value for ΔT? Explain why, based upon the intermolecular forces present.

VAPOR PRESSURE STUDY

Substance	Ethanol		Methanol
Trial	**Hot Water**	**Cold Water**	**Cold Water**
T_1, Initial Air Temperature (°C)			
P_1, Initial Air Pressure at T_1 (mmHg)			
T_2, Final Temperature (°C)			
P_{final}, Final Pressure (mmHg)			
P_2, Air Pressure at T_2 (mmHg)			
P_{vap}, Vapor Pressure (mmHg)			

5. Calculate P_2 for each sample using Amonton's Law and record it in the above table: $\frac{P_1}{T_1} = \frac{P_2}{T_2}$

Show a sample calculation for the ethanol hot water bath. Be sure to convert T into *kelvin (273 + °C)*.

6. Determine P_{vap} for each sample by subtracting P_2 from the measured final pressure, P_{final}.

7. According to the Clausius-Clapeyron equation, where R is the gas constant (8.31 J/mol·K):

$$\ln\left(\frac{P_{vap,c}}{P_{vap,h}}\right) = \left(\frac{-\Delta H_{vap}}{R}\right)\left(\frac{1}{T_{2,c}} - \frac{1}{T_{2,h}}\right)$$

T_2 is in kelvin, P_{vap} is the vapor pressure, and c is for cold water and h is for hot water. Rearrange and solve for the enthalpy of vaporization, ΔH_{vap}, of ethanol in kJ/mol. (If either of your P_{vap} values were negative, insert them as positive numbers to do this calculation.) Show your calculation:

ΔH_{vap} = ____________________________

8. Based upon the cold-water-bath-temperature vapor pressures, which liquid had the stronger intermolecular forces? Briefly explain why this result makes sense (assuming it does) based upon the structure of the two molecules.