Name ___________________________

Lab 1: Evaporation & Intermolecular Attraction:Water As An Evaporative Coolant

Objectives

- To establish the relationship between the rate of evaporative cooling and the strength of intermolecular forces of attraction.
- To examine the effects of hydrogen bonding and London Dispersion Forces (LDF) on the rate of evaporation of a liquid.

Introduction

Endothermic animals maintain homeostasis in their body temperatures by sweating to release excess heat. The evaporation of liquid from the skin surface requires thermal energy, which is supplied by the organism's body.

In this experiment, temperature probes are placed in various liquids. Evaporation occurs when the probe is removed from the liquid's container. Again, this endothermic process results in a temperature decrease. **The magnitude of a temperature decrease is directly 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, specifically hydorgen bonding and London dispersion forces.

In this procedure, you will encounter six liquids: water (H_2O), four different alcohols, and pentane (C_5H_{12}), an alkane. An alkane is a hydrocarbon containing only single carbon-carbon bonds. Alcohols, you will remember, contain the -OH functional group bonded to one of the carbon atoms found in the molecule. For naming and identification purposes, the carbon atom to which this -OH group is attached is numbered, when appropriate. The alcohols used in this experiment are methanol (CH_3OH), ethanol (C_2H_5OH), 1-propanol (C_3H_7OH), and 1-butanol (C_4H_9OH). An alkane is an organic hydrocarbon molecule whose atoms are linked by single bonds.

You will examine the molecular structure of water, pentane, and alcohols for the presence and the relative strengths of two intermolecular forces - **hydrogen bonds and dispersion forces** - *as measured by the rate of temperature decrease during evaporation.* A temperature probe, graphing calculator, and LabPro interface will be used to obtain your data on evaporation rates.

Consider the following information when you make hypotheses and interpretations during this lab: **London dispersion forces exist between any two molecules, and generally increase as the molecular weight of the molecule increases. Before hydrogen bonding can occur, a hydrogen atom must be bonded directly to an N, O, or F atom within the molecule.**

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Background Information Summary:

- Intermolecular forces of attraction (IMFs) must be overcome in order for the molecule to evaporate
- IMFs include **hydrogen bonds** – which can consistently form when the molecule is held together with *polar covalent bonds* – and LDFs – which can form intermittently whenever electrons in adjacent molecules intermittently cluster

Pre-Lab Questions

Prior to doing the experiment, complete **Table 1** on page 5. The name and formula are given for each compound.

- Determine the Molar Mass of each molecule.

Sample Calculation for Molar Mass for **Ethanol (C_2H_5OH):**

atomic weight Hydrogen = 1.008 u
atomic weight Carbon = 12.011 u
atomic weight Oxygen = 15.999 u

Molar Mass =
(# Carbon Atoms * weight C) + (# Hydrogen Atoms * weight H) + (# Oxygen Atoms * weight O)
(2*12.001) + (6*1.008) + (1*15.999)
46.069 g/mol

- Draw the Lewis Structure for one molecule of each compound.
- Indicate if the molecue is Polar or Nonpolar
- Examine each molecule for the presence of hydrogen bonding. Circle all hydrogen atoms that can participate in hydrogen bonding. Tell whether or not each molecule has hydrogen-bonding capability, noting **the number of hydrogen atoms available for H-bonding.**

PRE-LAB CONSEPTUAL QUESTIONS

1. As evaporation occurs, the temperature reading on the temperature probe will ~~*increase*~~ **/ *decrease***. *(circle one)*

2. In order for compounds to have a hydrogen bond, the molecule must be ***polar* /** ~~*nonpolar*~~ and the molecule must contain hydrogen.

3. If the intermolecular forces are strong, the substance does not readily evaporate. Therefore, a ***lot* /** ~~*little*~~ energy is required to change the substance from liquid to vapor.

4. If the intermolecular forces are strong, the substance does not readily evaporate. Therefore, the absolute value of temperature change will be ***small* /** ~~*large*~~.

Materials

Computer
Vernier computer interface
Logger*Pro*
one temperature probe

methanol (methyl alcohol)
ethanol (ethyl alcohol)
1-propanol (propyl alcohol)
1-butanol (butyl alcohol)

Experimental Procedure:

- Open the file “09 Evaporation” from the *Chemistry with Vernier* folder.

- Prepare the temperature probe by inserting a rubber band on the probe, and wrapping a square of filter paper so it is flush with the tip of the probe.

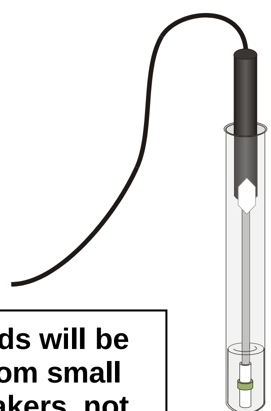
- Apply safety goggles to yo’ face. Maintain them especially when bottles are open.

- **One Igor is responsible for holding the bottles upright during this procedure. Until the bottles are safely closed, Igor has no other responsibility!**

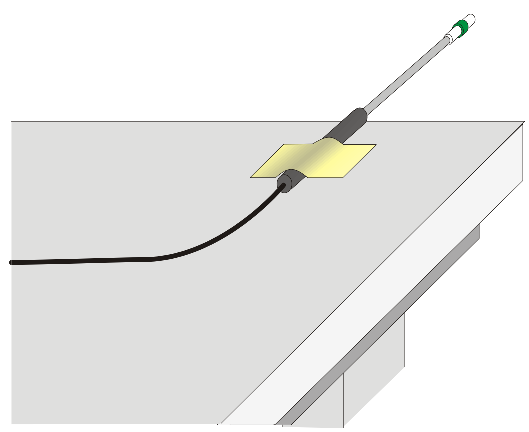
- Gently dip the filter paper-covered probe into the ethanol for ~30 seconds. Maintain ~ constant dip times for each liquid.

- Tape or hold the probe off the edge of the lab bench. Then click START to begin data collection. Collect until the sample has reached a temperature minimum (and has begun to increase). Then click STOP.

- For each liquid, subtract the minimum temperature from the maximum temperature to determine **Δ*T*,** the temperature change during evaporation. This will be a negative #, since temperature declined during evaporation.



***Note:* Liquids will be obtained from small bottles / beakers, not from test tubes.**

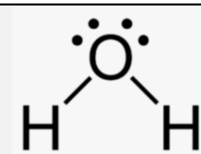
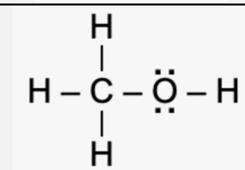
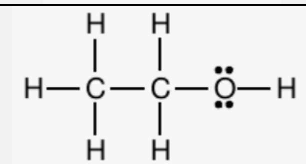
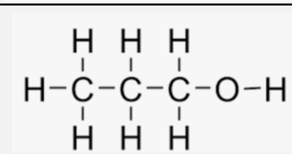
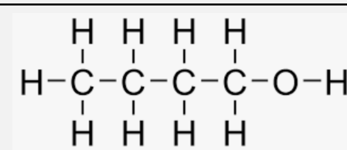
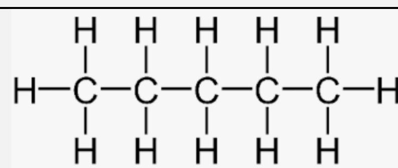
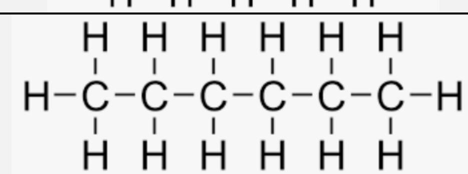


- Use a paper towel to avoid skin contact with the filter paper. Place used papers on a paper towel for easy non-epidermal disposal. Repeat for 1-propanol.

- Record your data.

For each piece of data, consider the influence of both hydrogen bonding and LDF attractions between each molecule.

Data Table 1: Summary of Physical Properties

Substance	Formula	Molar Mass (g/mol)	Lewis Structure	Molecular Polarity	# H atoms available to H-bond	Type(s) of IMF
water	H_2O	**18.02**		**Polar**	**2**	**Hydrogen bond LDF**
methanol	CH_3OH	**32.04**		**Polar**	**1**	**Hydrogen bond LDF**
ethanol	C_2H_5OH	**46.07**		**Polar**	**1**	**Hydrogen bond LDF**
1-propanol	C_3H_7OH	**60.10**		**Polar**	**1**	**Hydrogen bond LDF**
1-butanol	C_4H_9OH	**74.12**		**Polar**	**1**	**LDF**
n-pentane	C_5H_{12}	**72.15**		**Non-Polar**	**0**	**LDF**
n-hexane	C_6H_{14}	**86.18**		**Non-Polar**	**0**	**LDF**

Data Table 2: ***Evaporation Rates Of Water vs. 4 Alcohols, and 2 Alkanes***

Substance	Formula	T_1 (°C)	T_2 (°C)	|ΔT| (T_2-T_1) (°C)	Molar Mass (g/mol)
water	H_2O	24.7	22.0	2.7	18.02
methanol	CH_3OH	22.9	9.8	13.1	32.04
ethanol	C_2H_5OH	23.5	15.2	8.3	46.07
1-propanol	C_3H_7OH	23.0	18.1	4.9	60.10
1-butanol	C_4H_9OH	23.2	21.5	1.7	74.12
n-pentane	C_5H_{12}	23.0	6.9	16.1	72.15
n-hexane	C_6H_{14}	23.2	11.2	12.0	86.18

Processing the Data: Use your understanding of our lab to answer the following questions

GRAPH: Using Google Sheets: Construct a graph to show how the *Absolute Value of the ΔT for water, the four alcohols and the 2 hexanes vs. their respective molecular weights*.

- Include a title
- Put the independent variable (mass) on the x-axis and the dependent variable (change in temperature) on the y-axis
- Label axes with **label & unit**
- Plot the data as a scatter plot
    - **Note: Graphing ALL of the data on a single graph may not be the most appropriate way to present this data. You may need to make several graphs to get your point across to the reader**

DATA ANALYSIS QUESTIONS:

1. a) Which of the alcohols studied has the *strongest intermolecular forces of attraction*?
   Butanol

   b) The *weakest intermolecular forces of attraction*?

   Methane

   c) Support your claim using evidence from the data.

- **Butanol has the strongest IMF and methanol has the weakest. All the alcohols have hydrogen bonding capability, so the difference in their Δ*t* is the result of their differing LDF.**
- **Butanol has the greatest number of electrons, and therefore has the most polarizable electron cloud, resulting in the strongest LDF of the group. With the least number of electrons, methanol has the weakest LDF of the group, and thus evaporates most readily.**
- **This comparison shows us that it is not simply the presence or absence of hydrogen bonding that determines the evaporation of the molecules. The ability to evaporate is affected by considering all the IMF and their strengths within the molecule.**

2. a) Which of the alkanes studied has the *strongest intermolecular forces of attraction*?

   Hexane

   b) Support your claim using evidence from the data.

- **The stronger IMF result in a decreased tendency to evaporate, and thus give hexane a smaller Δ than pentane.**
- **Hexane has stronger IMF than pentane. With more electrons in hexane (50 versus 42), the electron cloud is more polarizable, and therefore forms stronger LDF between hexane molecules.**

3. What relationship exists between the rate of evaporation of the liqiuid and the change in temperature

- **The more quickly a liquid evaporates, the greater the change in temperature.**

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

Because pentane and butanol have the same number of electrons, we expect their LDF to be approximately equal. The difference in evaporation rates arises from the hydrogen bonding that occurs between butanol molecules. Pentane molecules do not exhibit hydrogen bonding. The hydrogen bond between neighboring butanol molecules requires more energy to overcome and separate the molecules than the LDF in pentane. As a result, not as many molecules are able to escape into the vapor phase, and the Δ*t* is not as large.

CONCEPTUAL QUESTIONS:

1. Describe what is occurring at the molecular level when a liquid evaporates.

When a liquid evaporates, the molecules gain energy from collisions. When enough energy is gained, the molecules are able to overcome the IMF and escape into the gas phase.

2. a) What accounts for water's slow evaporation rate, given its relatively low molecular weight?

Water has 2 hydrogen bonds. Yeah it does.

b) Explain using the results of this experiment why *water is an efficient, long term evaporative coolant for endothermic organisms*.

Water evaporates consistently but slowly, providing a long term coolant for warm-blooded (endothermic) organisms.