Evaporation and Intermolecular Attractions

1. In the Electronic Resources you will find multiple versions of each student experiment—one for each supported data-collection software or app (Logger *Pro*, Graphical Analysis 4, Spectral Analysis, LabQuest App, and EasyData). Deliver to your students the version that supports the software and hardware they will use. Sign in to your account at **vernier.com/account** to access the Electronic Resources. See Appendix A for more information. **Note**: The printed version of the book and the PDF of the entire book (found in the Electronic Resources) include only the Logger *Pro* versions of the experiments.

2. This activity is ideally performed with two Temperature Probes. It is possible to perform this activity with one Temperature Probe, but it will take additional time. If you use only one Temperature Probe, you can do the entire experiment in one class period; alternately, do four of the liquids in one class period and the remaining two liquids the next day. This provides students with additional time to consider their predictions. Time can also be saved by wrapping the Temperature Probes in advance.

3. 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.

4. One teacher found that fabric piping cord, which can be purchased at a yard goods or sewing store, serves as an appropriate sleeve for the temperature probe. You have to cut it in short pieces and remove the "rope," but then it works well and gives a nice, consistent fit.

5. 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.

6. 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.

7. Sets of the liquids can be supplied in 13 × 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.

8. 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.

9. Other properties, besides Δt 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.

10. In the Procedure, students are asked to predict the Δt values for the other solutions they will test after completing the first round of data collection. You can also encourage them to use the Add Prediction tool in Logger *Pro*, LabQuest App, or Graphical Analysis to draw one of their predictions on the graph before measuring the temperature change.

11. In the Processing the Data section, students are instructed to create a graph of change in temperature (Δt) *vs*. molecular mass. They can do this outside of the data-collection software, or they can use the "Add Manual Column" option in the software to create a column for the molecular mass. After creating the manual column and populating it with the mass values, they can change the graph axes to create a graph of change in temperature *vs*. molecular mass.

12. The stored calibration for our Temperature Probes works well for this experiment.

13. For additional information about the Vernier probeware used in this experiment, including tips and product specifications, visit **www.vernier.com/manuals** and download the appropriate user manual.

14. If you are using Go Direct sensors, see **www.vernier.com/start/go-direct** for information about how to connect your sensor.

HAZARD ALERTS

The chemical safety signal words used in this experiment (DANGER, WARNING, and N/A) are part of the Globally Harmonized System of Classification and labeling of Chemicals (GHS). Refer to the Safety Data Sheet (SDS) that came with the chemical for proper handling, storage, and disposal information. These can also be found online from the manufacturer.
See Appendix C for more information.

1-Butanol, C_4H_9OH: **DANGER**: Keep away from heat, sparks, open flames, and hot surfaces—highly flammable liquid and vapor. Toxic if swallowed, in contact with skin, or if inhaled. Do not eat or drink when using this product. Do not breath mist, vapors, or spray. Causes skin and serious eye irritation. Causes damage to organs.

Ethanol, 95%, denatured, CH_3CH_2OH: **DANGER**: Highly flammable liquid and vapor. Keep away from heat, sparks, open flames, and hot surfaces. Do not eat or drink when using this product—harmful if swallowed. Causes skin and serious eye irritation. May cause respiratory irritation. Avoid breathing mist, vapors, or spray. Causes damage to organs. Addition of denaturant makes the product poisonous. Cannot be made nonpoisonous.

n-Hexanes, C_6H_{14}: **DANGER**: Keep away from heat, sparks, open flames, and hot surfaces—highly flammable liquid and vapor. Do not eat or drink when using this product. Avoid breathing mist, vapors, or spray. May be fatal if swallowed and enters airways. May cause damage to organs. Causes skin and eye irritation. May cause drowsiness or dizziness. Suspected of damaging fertility or the unborn child. Do not handle until all safety precautions have been understood. Use personal protective equipment as required.

Methanol, CH_3OH: **DANGER**: Keep away from heat, sparks, open flames, and hot surfaces—highly flammable liquid and vapor. Toxic if swallowed, in contact with skin, or if inhaled. Do not eat or drink when using this product. Do not breath mist, vapors, or spray. Causes skin and serious eye irritation. Causes damage to organs.

n-Pentane, $CH_3(CH_2)_3CH_3$: **DANGER**: Keep away from heat, sparks, open flames, and hot surfaces—highly flammable liquid and vapor. Do not eat or drink when using this product—harmful if swallowed or in contact with skin. Avoid breathing mist, vapors or spray. May cause drowsiness or dizziness.

1-Propanol: **DANGER**: Keep away from heat, sparks, open flames, and hot surfaces—highly flammable liquid and vapor. Do not eat or drink when using this product—harmful if swallowed. Causes mild skin irritation and serious eye damage. May be harmful if inhaled. May cause drowsiness or dizziness.

ANSWERS TO QUESTIONS

1. Even though n-pentane and 1-butanol have molecular weights of 72 and 74, respectively, 1-butanol has a much smaller Δt due to the presence of hydrogen bonding between its molecules. This results in a stronger attraction, and a slower rate of evaporation.

2. The 1-butanol has the strongest attractions between its molecules. Methanol has the weakest attractions. The 1-butanol has the largest molecules and resulting strongest dispersion forces. This gives it the lowest evaporation rate and the smallest Δt.

3. The n-hexane has the stronger attractions between its molecules. The n-pentane has the weaker attractions. The n-hexane has the larger molecules and the resulting stronger dispersion forces. This gives it a lower evaporation rate and the smallest Δt.

4. See Figure 4.

PRE-LAB RESULTS

Substance	Formula	Structural formulas	Molecular weight	Hydrogen bond (Yes or No)
ethanol	C_2H_5OH	H H | | H–C–C–O–H | | H H	46	yes
1-propanol	C_3H_7OH	H H H | | | H–C–C–C–O–H | | | H H H	60	yes
1-butanol	C_4H_9OH	H H H H | | | | H–C–C–C–C–O–H | | | | H H H H	74	yes
n-pentane	C_5H_{12}	H H H H H | | | | | H–C–C–C–C–C–O–H | | | | | H H H H H	72	no
methanol	CH_3OH	H | H–C–O–H | H	32	yes
n-hexane	C_6H_{14}	H H H H H H | | | | | | H–C–C–C–C–C–C–H | | | | | | H H H H H H	86	no

DATA TABLE

Substance	t_1 (°C)	t_2 (°C)	Δt ($t_1 - t_2$) (°C)
ethanol	23.5	15.2	8.3
1-propanol	23.0	18.1	4.9
1-butanol	23.2	21.5	1.7
n-pentane	23.0	6.9	16.1
methanol	22.9	9.8	13.1
n-hexane	23.2	11.2	12.0

Substance	Predicted Δt (°C)	Explanation
1-butanol	varies (< 4.9°C)	It has a higher molecular wt. than 1-propanol (both have H-bonds).
n-pentane	varies (> 8.3°C)	It has a higher molecular wt. than either, but no H-bonding.
methanol	varies (> 8.3°C)	It has a lower molecular wt. than ethanol (both have H-bonds).
n-hexane	varies (< 16.1°C)	It has a higher molecular wt. than n-pentane; also no H-bonding.

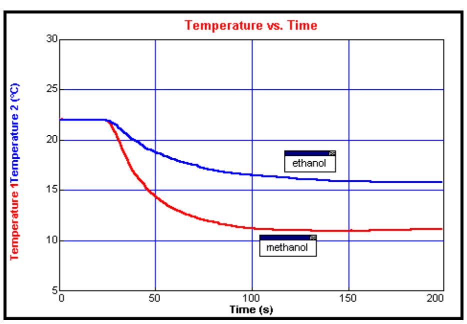

Figure 1
Evaporation of methanol and ethanol

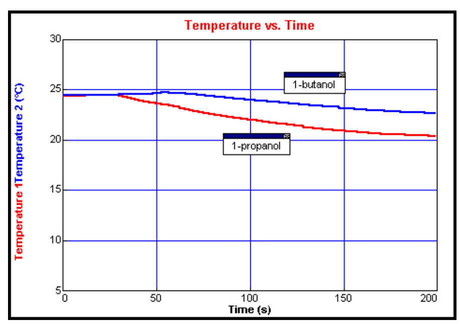

Figure 2
Evaporation of 1-propanol and 1-butanol

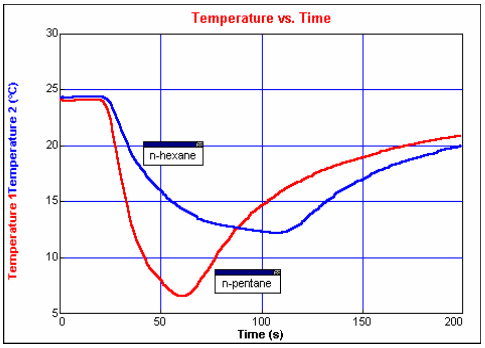

Figure 3
Evaporation of n-pentane and n-hexane

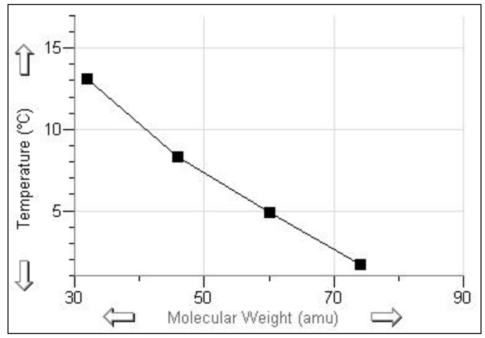

Figure 4
Temperature change vs. *alcohol molecular wt.*