Evaporation and Intermolecular Attractions

Intermolecular Forces

FLINN SCIENTIFIC CHEM FAX!

Introduction

It's a hot and sunny summer day, and you step out of the pool, cool and refreshed. Soon, however, your teeth start chattering and your lips turn blue. Water evaporating from the skin draws heat from the body, leaving you feeling cold. The "cooling effect of evaporation" is nature's most important way of cooling not only our bodies but also the earth! How cool is evaporation?

Concepts

- Evaporation
- Kinetic-molecular theory
- London forces
- Polar vs. nonpolar compounds

Materials

Acetone, $(CH_3)_2CO$, 2 mL
Ethyl alcohol, CH_3CH_2OH, 2 mL
n-Heptane, C_7H_{16}, 2 mL
Hexanes, C_6H_{14}, 2 mL
Isopropyl alcohol, $(CH_3)_2CHOH$, 2 mL
Methyl alcohol, CH_3OH, 2 mL
Corks or stoppers to fit test tubes, 6
Data collection software and technology interface (LabQuest™, LoggerPro™ with LabPro™)
Filter paper, 11-cm, 2
Pipets, disposable graduated, 6
Rubber bands, small (orthodontic-type), 6
Scissors
Temperature probes or sensors, 2
Test tube rack
Test tubes, small, 6

Safety Precautions

Acetone, methyl alcohol, ethyl alcohol, hexanes, heptane, and isopropyl alcohol are flammable liquids and a dangerous fire risk. Avoid contact of all liquids with heat, flames or other sources of ignition. Methyl alcohol is toxic by ingestion. Acetone, ethyl alcohol, and heptane are slightly toxic by ingestion or inhalation. Addition of denaturant makes ethyl alcohol poisonous—it cannot be made non-poisonous. Do not allow chemicals to come into contact with eyes and skin. Perform this experiment in a well-ventilated lab only. Wear chemical-splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

1. Cut ten identical pieces of filter paper approximately 3 cm square each.
2. Label six test tubes #1–6 and place them in a test tube rack. Obtain 2–3 mL of the appropriate solvent in each test tube, according to the following scheme. Stopper the test tubes with corks or rubber stoppers until needed.

Test tube	1	2	3	4	5	6
Solvent	Hexanes	Heptane	Methyl alcohol	Ethyl alcohol	Acetone	Isopropyl alcohol

3. Wrap one filter paper square around each temperature probe and secure the filter paper with a small rubber band.
4. Set up temperature probes or sensors to take two readings every second for a total of 2–3 minutes.
5. Place the first temperature probe into test tube #1 (hexanes) and the second temperature probe into test tube #2 (n-heptane). The liquid level in the test tubes should be above the filter paper to ensure that the paper is thoroughly

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soaked with liquid. Allow the temperature probes to soak in the liquid for about 30 seconds.

6. Remove the temperature probes from the test tubes and carefully extend the probes over the test tube rack or edge of the lab table. Avoid jostling the temperature probes (air drafts may change the rate at which the liquids evaporate).
7. Collect the data for the full time.
8. Remove the filter paper squares from the temperature probes and carefully dry the probes with a paper towel.
9. Repeat steps 3–8 using methyl alcohol (test tube #3) and ethyl alcohol (test tube #4).
10. Repeat steps 3–8 using acetone (test tube #5) and isopropyl alcohol (test tube #6).

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. Ethyl alcohol may be rinsed down the drain with plenty of water according to Flinn Suggested Disposal Method #26b. Acetone, n-heptane, hexanes, isopropyl alcohol and methyl alcohol may be evaporated in a chemical fume hood according to Flinn Suggested Disposal Method #18a.

Tips

- "Hexanes," a mixture of n-hexane and other isomers, may be used as the source of hexane for Part A. The boiling point of the mixture (68–70 °C) is close enough to that of n-hexane (69 °C) that its use should not be a problem. In general, branched-chain alkanes have lower boiling points than their straight-chain isomers—the boiling points of n-hexane, 3-methylpentane (1 branch) and 2,3-dimethylbutane (2 branches) are 69 °C, 63 °C, and 58 °C, respectively. (This is attributed to the lower surface area of spherical, branched-chain compounds compared to their rod-like, straight-chain isomers.)
- Isopropyl alcohol is recommended rather than n-propyl alcohol (1-propanol) because it is more readily available in high school chemistry labs and because it is less toxic by inhalation (the TLV is 983 mg/m^3 for isopropyl alcohol compared to 492 mg/m^3 for n-propyl alcohol).
- Temperature measurements may be made using bare temperature probes that have been dipped into the liquid. The liquid will evaporate very quickly, however, so the temperature will bottom out after about 30 seconds and will then start to increase.
- Many different solvent pairs may be tested in this experiment. We tried to balance availability and relative toxicity of different solvents against the desire for good pair-wise comparisons (e.g., effect of molar mass in alkanes, polar versus nonpolar, presence or absence of hydrogen bonding). Mindful of the inhalation hazard for both students and the teacher in this "evaporation lab," we decided to limit the total number of solvents to no more than six (three trials). Hexane was selected rather than pentane for the alkane series, for example, because pentane has a very low flash point and is narcotic in high concentrations. *n*-Butyl alcohol was not included in the alcohol series because of its strong odor and low TLV. Teachers who want to further limit the number of solvents used in the lab may want to restrict the solvents to only one category or variable, such as the series of methyl, ethyl, propyl, and butyl alcohol.

Discussion

Vaporization is the process by which a substance changes from a liquid to a gas or vapor. When vaporization occurs gradually from the surface of a liquid, it is called *evaporation*. Evaporation is an endothermic process—energy is required for molecules to leave the liquid phase and enter the gas phase.

Evaporation and the cooling effect of evaporation may be explained using the *kinetic-molecular theory*. According to this model, molecules in the liquid state are in constant motion, and interactions among neighboring molecules influence the motion of the molecules and the properties of the liquid. The temperature of a substance is proportional to the *average kinetic energy*, and thus the average speed, of the molecules. Evaporation occurs when fast-moving molecules near the surface of a liquid have enough energy to break free of their interactions with neighboring molecules and "escape" into the gas phase. Molecules with the highest kinetic energy evaporate and become gas molecules. The average kinetic energy, and thus the temperature, of the remaining molecules decreases—a liquid cools as it evaporates. This phenomenon is known as "evaporative cooling." The rate of evaporation of a liquid increases at higher temperatures, because more molecules have enough energy to break free of the liquid's surface.

The rate of evaporation of a liquid depends on the nature of the liquid and the type of attractive forces between molecules. Strong intermolecular attractions hold the molecules in a liquid more tightly. Liquids with weak intermolecular attractive forces have low heats of vaporization and are volatile—they evaporate easily. Liquids with strong intermolecular attractive forces evaporate more slowly, because a greater amount of energy is needed to overcome the attractive forces between molecules.

Nonpolar compounds generally have very weak attractive forces, called London dispersion forces, between molecules. The strength of London dispersion forces increases in a regular manner as the size of the molecules increases. Dipole interactions occur when polar molecules are attracted to one another. Because dipole interactions are stronger than dispersion forces, polar compounds generally have higher heats of vaporization and evaporate more slowly than nonpolar compounds. Hydrogen bonding represents a special case of dipole interactions, in which O–H and N–H groups in molecules associate very strongly with electronegative atoms in adjacent molecules. Hydrogen bonds are the strongest type of intermolecular attractive forces. Hydrogen bonding in water, for example, leads to a high degree of association among water molecules in the liquid and solid state. As a result, water is a very unusual liquid in many ways. It has an unusually high heat of vaporization and a very high boiling point compared to other compounds of similar molecular weight or similar structure.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Systems, order, and organization
Evidence, models, and explanation
Constancy, change, and measurement

Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter

Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Evaporation and Intermolecular Attractions* activity, presented by Penney Sconzo, is available in *Intermolecular Forces* and in *Vapor Pressure of Liquids*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Intermolecular Forces and Vapor Pressure of Liquids* are available from Flinn Scientific, Inc.

Catalog No.	Description
A0009	Acetone, 500 mL
E0009	Ethyl Alcohol, 500 mL
H0051	Heptane, 100 mL
H0046	Hexanes, 100 mL
I0019	Isopropyl Alcohol, 500 mL
M0054	Methyl Alcohol, 500 mL
TC1500	LabPro™
TC1421	LoggerPro™ Software
TC1157	LabQuest™
TC1502	Temperature Probes, 2

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.