Vapor Pressure and Colligative Properties

Strand Phases of Matter and Kinetic Molecular Theory

Topic Investigating kinetic theory

Primary SOL CH.4 The student will investigate and understand that chemical quantities are based on molar relationships. Key concepts include

a) Avogadro's principle and molar volume;
b) stoichiometric relationships;
c) solution concentrations;
d) acid/base theory; strong electrolytes, weak electrolytes, and nonelectrolytes; dissociation and ionization; pH and pOH; and the titration process.

CH.5 The student will investigate and understand that the phases of matter are explained by kinetic theory and forces of attraction between particles. Key concepts include

a) pressure, temperature, and volume;
b) partial pressure and gas laws;
c) vapor pressure;
d) phase changes;
e) molar heats of fusion and vaporization;
f) specific heat capacity;
g) colligative properties.

Related SOL CH.1 The student will investigate and understand that experiments in which variables are measured, analyzed, and evaluated produce observations and verifiable data. Key concepts include

a) designated laboratory techniques;
b) safe use of chemicals and equipment;
c) proper response to emergency situations;
e) accurate recording, organization, and analysis of data through repeated trials;
g) mathematical manipulations including SI units, scientific notation, linear equations, graphing, ratio and proportion, significant digits, and dimensional analysis;
h) use of appropriate technology including computers, graphing calculators, and probeware for gathering data, communicating results, and using simulations to model concepts.

Background Information

Before undertaking this activity, students should have a basic understanding of ionic versus covalent bonding, molarity, basic kinetics, and solubility. This lesson will focus on the conceptual understanding of the influence of intermolecular forces on the magnitude of the vapor pressure of a liquid, the determination of the normal boiling point of a substance, and the effect of solute particles on the vapor pressure of a solution and the colligative properties that occur as a result of their presence.

Reviewing the concepts of polarity, dissociation, and "like dissolves like" is recommended. Students should be familiar with the units of temperature and pressure and the conversions between them.

Most of the activities are fairly straightforward; however, the evaporation-rate investigation is somewhat open-ended. For classes that need more structure, you might want to decide which procedure they should do, while for stronger classes, you may want to give them some choices. Classes that need less structure might design their own procedures within given parameters of the materials available. If temperature probes are available, students will find it extremely interesting to see the evaporation-rate effect graphically as evaporative cooling versus time. *CAUTION! Keep procedures as much on a microscale as possible to reduce fumes.*

Some options for measuring evaporation rate are the following:

- If you have electronic balances, measure loss of mass versus time directly.
- With timers, measure the time it takes for a drop to evaporate, doing repeated trials and averaging the results.
- With temperature probes, dip them in the liquid and then remove them, graphing temperature versus time. This allows the measurement of the time needed to evaporate (return to room temperature), and it allows students to see that more volatile liquids have a greater cooling effect when evaporating.

The molecular mass of hexane is too high to be used in this comparison. Pentane is fairly inexpensive and as safe as hexane to use, but you should still exercise caution. Butane (lighter fluid) could be used in place of pentane, but it is a greater fire risk and evaporates so quickly that only spot testing is an option.

Materials

Note: Materials will depend on the method(s) chosen for determining evaporation rate.

- Liquids: water, ethanol, acetone, pentane
- Solids: NaCl, sugar, wax (paraffin)
- NaCl solution (350 g/L)
- Sugar solution (350 g/L)
- Spotting plates or watch glasses
- Hot plates
- Beakers
- Erlenmeyer flask with stopper
- Thermometers or temperature probes
- Balances
- Timers
- Vacuum pump
- Toothpicks
- Attached worksheets Vapor Pressure Versus Temperature, and Vapor Pressure and Intermolecular Forces

Student/Teacher Actions (what students and teachers should be doing to facilitate learning)

Introduction

1. Start this lesson by having students diagram the molecules of the target liquids and identify their dominant intermolecular force.
2. Have students predict the relative magnitude of the intermolecular forces from weakest to strongest by having them complete the attached "Vapor Pressure and Intermolecular Forces" worksheet.
3. Define *vapor pressure,* and discuss its relationship to intermolecular forces. Along with this discussion, either demonstrate vapor pressure or use a computer simulation of it (see Resources, if you do not have one), showing how it is affected by temperature. For example, if you have a temperature probe, insert it into a one-hole stopper that fits an Erlenmeyer flask containing a small amount of water. Seal the flask, and start recording temperature versus time as you gently warm the flask so students can see the pressure increase as the temperature increases.
4. Ask students at what temperature water boils. Then ask them whether all substances that are liquid at room temperature boil at this temperature. Ask them whether water always boils at this temperature. Have them explain their reasoning.
5. Demonstrate water boiling at different temperatures. Place 100 mL of water into each of three small beakers, and label them "50°C," "65°C," and "80°C." Raise the temperature of the water in each beaker to the labeled temperature. Have a student check the temperatures, which do not need to be exactly the labeled temperatures, and record the measured values. Place all three beakers on the plate of the vacuum pump, seat the lid, and turn on the pump. Ask students to watch and record the order in which they boil as the pressure decreases.
6. Release the vacuum, and discuss the relationship between air pressure and boiling point. Ask students if they think it is possible to make ice water boil. If you have a good vacuum pump, you should be able to demonstrate this; if not, you may wish to show a video clip of it. As an alternative, under Resources there is a demo listed that shows water boiling by using ice.
7. Hand out the "Vapor Pressure versus Temperature" worksheet, and have students focus on curve A. Have them explain where the liquid and gas phases for substance A would be located and how many boiling points liquid A would have. *(Many)* Ask them where they would find the normal boiling point. Have them identify the normal boiling point of each of the four substances.

Procedure

Part 1: Determining Relative Vapor Pressures by Measuring Evaporation Rates

1. Ask students to explain the relationship between vapor pressure and evaporation rate. Encourage them to use their knowledge of intermolecular forces in this discussion.
2. Have students brainstorm some ways to measure evaporation rates with available lab equipment.
3. Divide the class into groups, and have each group choose a method of measuring evaporation rates.

4. Have each group design an experiment by writing a research question and hypothesis and identifying variables and constants. (Students are not always good at predicting all of the constants needed.) Check and approve the written questions and hypotheses before giving students the go-ahead to write detailed procedures.
5. Have the groups do multiple trials of their experiments and adjust their procedures as needed.
6. Have the groups organize their data into a table and graph their average values.

Part 2: Comparing Vapor Pressures

1. Hand out the "Vapor Pressure and Intermolecular Forces" worksheet.
2. Have students complete the worksheet.
3. Check the completed worksheets for accuracy.

Part 3: Effect of Solutes on the Vapor Pressure of Solutions

1. Have each student group find the boiling point of water at the prevailing pressure by heating the water on a hot plate and using a temperature probe.
2. Have the groups write a research question and hypothesis concerning the effect of sodium chloride (NaCl) on the boiling point of water and identify variables and constants.
3. Give each group 100 mL of NaCl solution (350 g/L), and have them find its boiling point. Make sure they understand that they need to record the temperature when it levels off. Have them graph the result.
4. Have each group repeat steps 2 and 3, using a sugar solution (also 350 g/L).

Part 4: Effect of Bond Type on Solubility

1. Give student groups the four liquids—water, ethanol, acetone, and pentane. *CAUTION! Exercise care when using pentane.* Also, give them the three solids—sodium chloride (NaCl), sugar, and wax (paraffin).
2. Have the groups determine the solubility of each liquid in each of the other liquids, and the solubility of each solid in each liquid.
3. Have the groups design an appropriate data table before they start their experimentation.
4. Have the groups carry out each test by placing a small amount of each substance in the same well, stirring with a clean toothpick, and recording whether the substances are miscible or not.

Observations and Conclusions

Hold a class discussion, or give an assessment, in which students do the following:

1. Define *vapor pressure,* and explain how it is measured.
2. Explain the relationship between intermolecular forces and vapor pressure.
3. Explain why water, with its low molar mass, has a much higher vapor pressure than carbon dioxide (CO_2), which has a much higher molar mass.
4. Read about colligative properties in the text, and explain how and why the addition of a solute affects the vapor pressure of the solvent.

5. Using the masses dissolved per liter of solution in Part 3 above, determine the molarity of the salt and sugar solutions. Did you have an equal number of particles in each solution? If not, which solution had a higher particle concentration?
6. Explain whether the number of particles in solution causes elevation of boiling point. Should it?
7. Tell which would have a higher particle concentration—a 1.0 *M* solution of salt or a 1.0 *M* solution of sugar? Why? Which solute would have greater effect on the vapor pressure of water? Why?
8. Explain why $CaCl_2$ melts ice on sidewalks more efficiently than does NaCl.
9. Explain why we cannot use wax particles to de-ice our sidewalks. What solubility rules determine this? How does your data from Part 4 support these rules? Give examples.
10. What is the normal boiling point of each liquid used in this lab?
11. Complete the questions on the "Vapor Pressure versus Temperature" worksheet.

Assessment

- **Questions**
  - Why does it take longer to boil an egg in Denver than in Richmond?
- **Journal/Writing Prompts**
  - Explain the function of antifreeze in a car and the danger of adding plain water when the antifreeze gets low. Your explanation should include both boiling point elevation and freezing point depression.

Extensions and Connections (for all students)

- Have students research how refrigerators and heat pumps work. Ask them to include an explanation of how vapor pressure must be considered when finding replacements for chlorofluorocarbons (CFCs).
- Have students explain why sweating cools the body and why rubbing alcohol and acetone feel cold on the skin. Make clear they need to demonstrate an understanding of vapor pressure in their answers.
- Have students explain how a pressure cooker works.

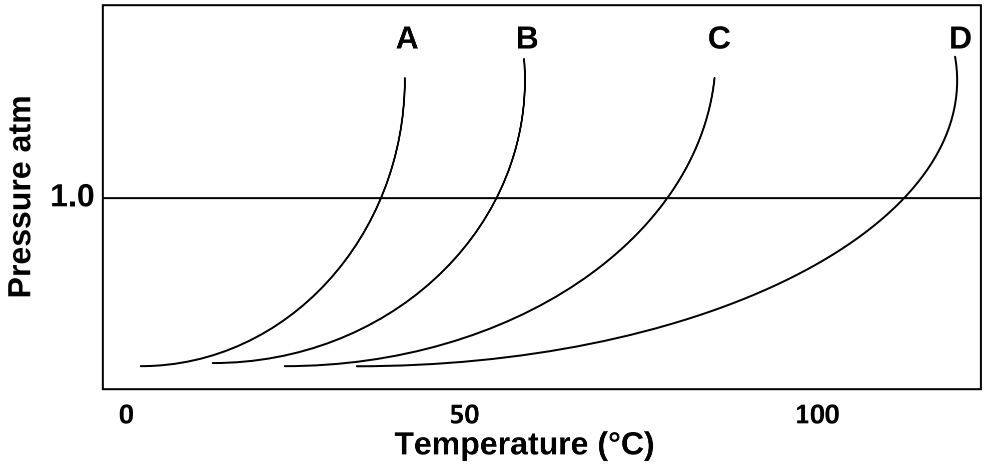
Strategies for Differentiation

- Prepare the data table prior to completing the moles activities so students can record information in an organized manner.
- Have students input information collected on a data chart template (computer). Data entry areas should be locked so students cannot add information or edit anything but the areas required by the activity.
- Record the steps in the activities on tape so students can repeat the directions multiple times throughout the activity.
- Have students highlight the lab procedures in one color and the questions in another to assist in preparing for the activity.
- Have an air conditioning installer speak to the class on the pros and cons of the alternatives to CFCs.

- Have students draw conclusions from student-created experiments that incorporate rubbing alcohol or acetone comparisons to water evaporation (incorporating fans or other methods to increase the rate of evaporation).
- Have students document their knowledge of colligative properties and their effects on vapor pressure.

Vapor Pressure Versus Temperature

Name: ____ **Date:** ______________________________



1. Every point on each line is a boiling point for that substance. At what temperature does substance B boil at 0.5 atm? ________________
2. Normal boiling point occurs at 1.0 atm. What is the normal boiling point for substance C? ______________________
3. Which substances would be liquids at room temperature and 1.0 atm? ________________
4. Which substances would be gases at room temperature and 1.0 atm? ________________
5. What would be the physical state of substance D at 120°C and 0.50 atm? ________
6. Which substance has the strongest intermolecular forces? Why?
7. Which substance has the weakest intermolecular forces? Why?
8. If you have a mixture of A and C, which substance would boil first? Why?
9. If all of these substances were nonpolar, which would have the lowest molecular mass? Why?
10. If all of these substances were polar, which one is most likely to have hydrogen bonding? Why?
11. The substances on the graph above are the four liquids used in this lab. Identify each liquid.

A ________________________ B ___________________________

C ________________________ D ___________________________

Vapor Pressure and Intermolecular Forces

Name: ____ **Date:** __________________________

Part 1: Complete the table.

Substance	Lewis Dot Diagram	Structural Diagram	Bond Type	Polarity
Water				
Ethanol				
Acetone				
Pentane				
NaCl				N/A
Sugar				
Wax				

Part 2: Answer the following questions.

1. Which liquids should be able to dissolve wax? Why?

2. Which liquids should be able to dissolve salt? Why?

3. Which liquids should be able to dissolve sugar? Why?

4. Which type of IMF is predominant in water? Why?

5. Which type of IMF is predominant in pentane? Why?

6. Which type of IMF is predominant in acetone? Why?

7. Place the solvents (liquids) in order of increasing IMF. Explain your reasoning.

8. Both salt and sugar dissolve in water. Which one also dissociates? Why?

9. Write an equation to show how each substance (salt and sugar) dissolves, and then explain the difference in the number of particles produced per mole of compound.