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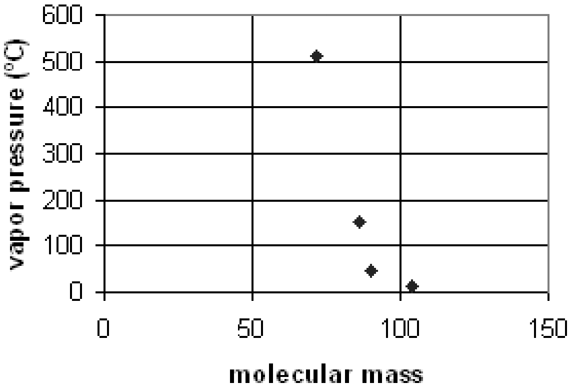
Teacher Activity
Vapor Pressure and the Case of the Burning Apartments
Companion Web pages: http://www.chemheritage.org/classroom/chemach/environment/index.html

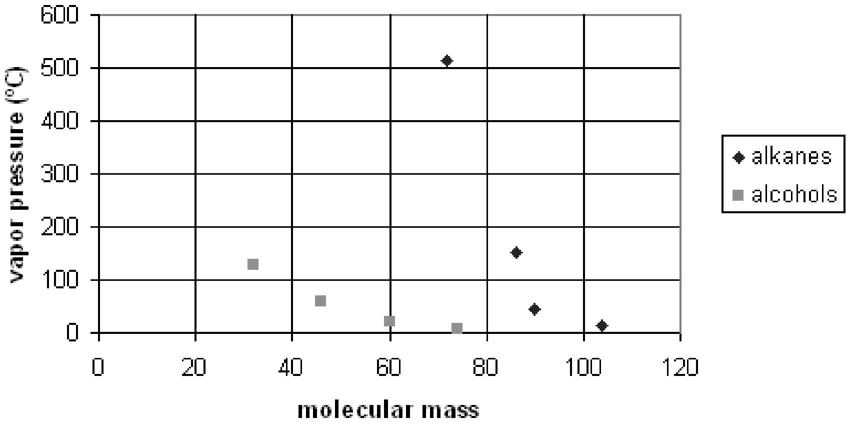
Procedure

The activity should be carried out in teams of three or four students. Each team will design its own method of determining the relationship between molecular mass and vapor pressure for a series of liquid *n*-alkanes. The student teams should bring you their proposed methods for approval before carrying them out. A good method should involve measuring the vapor pressure of several liquid *n*-alkanes and plotting their vapor pressures vs. molecular mass. For this part of the experiment make *n*-pentane, *n*-hexane, *n*-heptane, and *n*-octane available to the students. At the conclusion of Part 1, the students should be able to conclude that there is an inverse relationship between molecular mass and vapor pressure for a series of *n*-alkanes. A typical plot will look something like this:



The procedure for measuring the vapor pressure is a simple technique making use of calculator-based lab technology, as described in Vernier Software and Technology's *Chemistry with Calculators*.[1] It requires a graphing calculator equipped with a data interface and a pressure probe.

In Part 2 of the activity you will provide each team with one of four *n*-alcohols: methanol, ethanol, 1-propanol, or 1-butanol. Each team will test their alcohol, whose vapor pressure will fall well above the curve generated earlier for vapor pressure vs. molecular mass in a series of *n*-alkanes. The student procedure asks them to speculate about why they observe this deviation. The procedure then asks the teams to bring their data to you to compile. Plot their data on a graph that also shows a typical curve for the *n*-alkanes. Make your plot on an overhead slide or some other medium that will allow you to show the plot to the class as a whole. Your plot should look something like this:



This plot shows that among the *n*-alcohols, there is a relationship between vapor pressure and molecular mass similar to that shown by *n*-alkanes. The students may have already speculated that the greater polarity and stronger intermolecular forces of the alcohols are the causes of the difference between the two curves. If the students have not made that connection, the fact that all alcohols, not just the one they tested, show lower vapor pressures than their analogous alkanes may drive the point home.

Student Skills Required

Students should already have a conceptual understanding of the phenomena of vapor pressure and gas pressure and of evaporation and condensation. They should be familiar with the units in which pressure is measured (e.g., mm Hg, atm, etc.), have a conceptual and mathematical understanding of Dalton’s law of partial pressures, and be familiar with the concept of molecular mass.

Student Misconceptions

A proper conceptual understanding of the phenomenon of vapor pressure is essential for carrying out this activity in a meaningful way. A number of common misconceptions related to vapor pressure were reported by Canpolat.[2] Among them are the erroneous notions that the vapor pressure of a liquid varies with the volume of air above the liquid, the amount of liquid in the container, or the air pressure in the container. In addition, some students were found to think that evaporation (and hence vapor pressure) is a phenomenon that only occurs when the liquid is at its boiling temperature. Careful use of diagnostic questions can be helpful in rooting out such misconceptions and replacing them with a proper understanding of vapor pressure. For this reason you may choose to use the following set of diagnostic questions, which are similar to those used by Canpolat. These questions are written to be used as diagnostic assessment rather than as a graded activity.

1. Write a definition for *vapor pressure*. Be as careful as possible when writing your definition.

   Answer: Vapor pressure is the partial pressure of the vapor of a liquid in a closed container at equilibrium. Not all students grasp the equilibrium nature of vapor pressure, so a mention of equilibrium is a central part of a correct answer. This activity is designed to reinforce the equilibrium nature of vapor pressure.

2. Write a definition for *vaporization*. Be as careful as possible when writing your definition.

   Answer: Vaporization is the transition of a liquid into a gas. Vaporization can happen at any temperature. Not all students recognize that vaporization can happen below the boiling point of a liquid. Hence, such students may conclude that vaporization and vapor pressure are only observed when a liquid boils.

3. Consider a jar with a piston, like the one shown below. The air in the jar is at normal atmospheric pressure, and the temperature of the system is 25ºC. The vapor pressure in the jar is allowed to reach equilibrium.

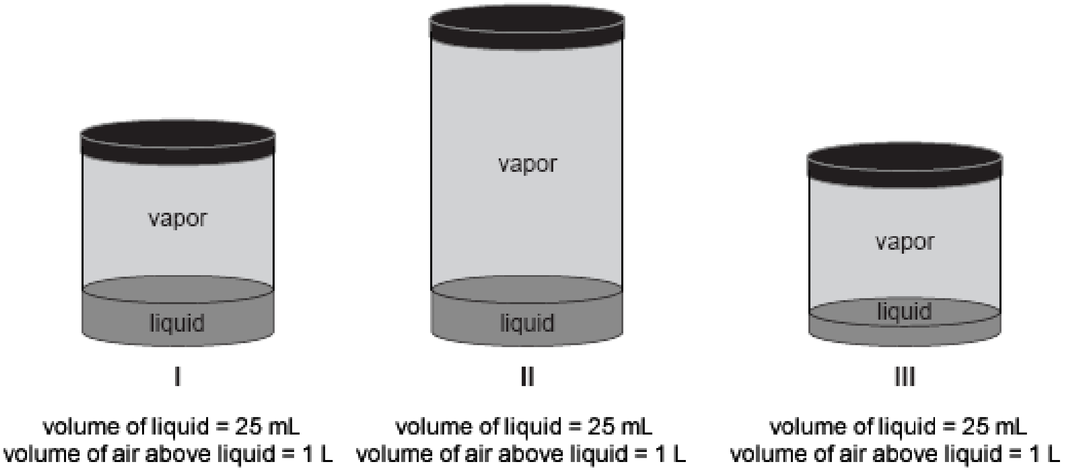
   a. If the piston is pushed down far enough that the volume of the air over the water is reduced by half, and the system is allowed to reach equilibrium, how will this affect the vapor pressure of the water? Why? Explain your answer as carefully as you can.

      Answer: The vapor pressure remains the same. While the water vapor will initially undergo an increase in partial pressure, this increase will cause a proportionate increase in the rate of condensation. This increased condensation means that when the system again reaches equilibrium, the vapor pressure will be the same as before the piston was pushed down. Some students may reason, based on the gas laws, that decreasing the volume of the air above the liquid will increase the vapor pressure, without considering that vapor pressure is an equilibrium phenomenon and that the system will adjust to restore equilibrium after the piston is pushed down.

b. If the piston is pulled up far enough that the volume of the air over the water is double, and the system is allowed to reach equilibrium, how will this affect the vapor pressure of the water? Why? Explain your answer as carefully as you can.

Answer: The vapor pressure remains the same. While the water vapor will initially undergo a decrease in partial pressure, this decrease will cause a proportionate increase in the rate of vaporization. This increased vaporization means that when the system again reaches equilibrium, the vapor pressure will be the same as before the piston was pushed down. Some students may reason, based on the gas laws, that increasing the volume of the air above the liquid will decrease the vapor pressure, without considering that vapor pressure is an equilibrium phenomenon and that the system will adjust to restore equilibrium after the piston is pulled up.

4. The three jars in the picture below contain the same liquid—water—at the same temperature—25ºC. Write a few sentences comparing the vapor pressures of the water in each of the jars.



Answer: The vapor pressure is the same in all three jars. While the jars with greater volumes of air above the water will see more water vaporize, because the water vapor will be occupying a proportionately larger volume, the partial pressure of the water vapor in each jar will be the same. The amount of liquid water in the jar does not affect the rate of vaporization. Some students may reason that a greater amount of liquid in the jar will lead to an increased rate of vaporization.

5. Consider a beaker filled with water, a beaker filled with 15% solution of NaCl in water, and a beaker filled with ethanol. Each system is at normal atmospheric pressure. All three beakers are heated by a Bunsen burner flame until the liquids in them boil. Write a few sentences comparing the vapor pressures in each beaker.

Answer: The vapor pressure for all three systems is equal to atmospheric pressure. This must be so because vapor pressure increases with temperature, and boiling occurs when the vapor pressure rises to the point where it is equal to atmospheric pressure. Some students may confuse room-temperature vapor pressure with the vapor pressure at the boiling temperature.

Reasoning that since liquids with lower boiling points have higher vapor pressures at room temperature, students may incorrectly answer that boiling ethanol has the highest vapor pressure, then water, then the 15% NaCl solution. While this ranking holds when the liquids are all at room temperature, it does not hold when each liquid is at its respective boiling point.

Answers to Pre-Lab Questions

1. Benzene has a vapor pressure of 100.84 mm Hg at 25ºC, while toluene has a vapor pressure of 28.47 mm Hg at 25ºC. Which compound would you expect to evaporate faster at room temperature?

   Answer: Benzene evaporates faster at room temperature.

2. In a sealed jar half-filled with water at equilibrium, which happens faster: the evaporation of water or the condensation of water vapor?

   Answer: At equilibrium, evaporation and condensation take place at the same rate.

3. Why do we work in fume hoods when handling liquids with high vapor pressures?

   Answer: We work in fume hoods when handling liquids with high vapor pressures to prevent toxic, flammable, or smelly vapors from filling the air in the laboratory.

Answers to Post-Lab Questions

1. How did the pressure you measured for each liquid vary with time?

   Answer: Students should observe the pressure initially increase with time until leveling off at a constant value.

2. Which compound showed the highest vapor pressure?

   Answer: *n*-Pentane should show the highest vapor pressure

3. Which compound showed the lowest vapor pressure?

   Answer: *n*-Octane should show the lowest vapor pressure

4. For the following pairs of compounds, indicate which one you think has the higher vapor pressure at room temperature.

   a. Benzene or toluene? **Answer:** toluene
   b. Toluene or phenol? **Answer:** phenol
   c. Acetone or methyl ethyl ketone? **Answer:** methyl ethyl ketone

5. How do you think the vapor pressure of a liquid should vary with temperature?

   Answer: Vapor pressure should increase as temperature increases.

6. How do you think your curve of pressure vs. time might be different if the container were not closed, but instead was open to the atmosphere?

Answer: The pressure would not increase appreciably because all the vapor that evaporates would escape into the atmosphere. While a few milliliters of pentane evaporating might make a difference in the pressure inside the small volume of a 125-mL Erlenmeyer flask, it will not noticeably affect the pressure of the entire atmosphere.

Assessment

1. As an authentic assessment you can ask students how they might decrease the vapor pressure of a liquid in a closed container without altering the chemical nature of the substance and then allow them to test their methods. Since vapor pressure is independent of the amount of liquid in the jar, the volume of the air above the jar, and the area of the liquid-surface interface, the only way to cause a decrease in the vapor pressure will be by lowering the temperature of the liquid. Students might do this using an ice bath, for example. (Note: Do not ask students how they might *increase* the vapor pressure, since vapor pressures are necessarily measured in closed containers and to increase the vapor pressure students would have to heat the closed container.)
2. You can use the post-lab questions as an assessment tool.

Answers to Extension Questions

1. How might the earth's climate be different if water had a much lower vapor pressure?

   Answer: A lower vapor pressure for water would mean that water would evaporate more slowly from oceans, lakes, and rivers. This effect would mean less rainfall and a drier climate.

2. Why is gasoline used as fuel for cars instead of kerosene?

   Answer: Gasoline or any other fuel must be vaporized before it can burn in an automobile engine. Kerosene has a relatively high vapor pressure, but it would still be too difficult to vaporize in an automobile engine. Gasoline, however, has a higher vapor pressure than kerosene and therefore is easy to vaporize inside an automobile engine.

3. When swimmers get water in their ears, they often use ear drops that contain rubbing alcohol, also called isopropanol. How does isopropanol help remove water from swimmers' ears?

   Answer: According to Raoult's law, the vapor pressure of a solvent in a solution will be lower than that of a pure solvent. Adding isopropanol to the water in a swimmer's ears will produce a solution of water and isopropanol. This mixture will lower the vapor pressure of the water in the swimmer's ears, making it evaporate faster.

4. What is a refrigerant? Should a compound used as a refrigerant have a high vapor pressure or a low vapor pressure? Why?

   Answer: A refrigerant is a substance used as a coolant in a refrigerator or an air conditioner. Refrigerants have to evaporate and condense quickly over and over again at or near room temperature, so they should have high vapor pressures.

5. What are ionic liquids, and why might they be more environmentally friendly than regular solvents?

   Answer: Ionic liquids are salts whose melting temperatures are low enough that they exist as liquids at room temperature. Because they contain ionic bonds, they do not evaporate and show negligible vapor pressures. Further, because they do not evaporate, they do not become airborne, so they contribute little to air pollution. For this reason they are being considered for use as “green solvents” for industrial chemical processes. In addition to being environmentally friendly, the lack of evaporation also means ionic liquids can be recycled for repeated use. Finally, their ionic composition creates unique chemical environments in which chemical reactions not feasible in other solvents may be carried out.

Additional Teacher Resources

Vapor Pressure of a Mixture: Raoult’s Law — Demonstrations and video illustrating Raoult’s law, which describes the vapor pressure behavior of solutions. Part of *Chemistry Comes Alive!* from the Journal of Chemical Education Online.
http://jchemed.chem.wisc.edu/JCEsoft/CCA/CCA2/MAIN/VAPORES6/CD2R1.HTM

References

1. Procedure adapted from Dan Holmquist and Donald Volz, “Vapor Pressure of Liquids,” in *Chemistry with Calculators* (Beaverton, OR: Vernier Software and Technology, 2006).

2. Nurtaç Canpolat et al., “Prospective Teachers’ Misconceptions of Vaporization and Vapor Pressure,” *Journal of Chemical Education*, 83:8 (2006), 1,237.