Experiment 3: Vapor Pressure of Water

Purpose

To measure the vapor pressure of water as a function of temperature, and to determine the value of ΔH_{vap} for water.

Equipment Needed

10 mL graduated cylinder, test tube tongs, tall form 1000 mL beaker, thermometer, hot plate or Bunsen burner

Discussion

Although the average kinetic energy of the molecules of a liquid is a function of temperature, the exact amount of energy of a specific molecu1e is random. At a given temperature, the energies of the molecules of a liquid are distributed about a mean value, with both very slow molecules and very fast molecules present. Even at low temperatures, there will be some molecules with a high amount of kinetic energy, and these fast molecules will be able to escape the attractive forces that tend to bind liquid molecules together. Because the number of fast molecules is a function of temperature, the rate at which liquid molecules escape into the vapor phase will be a function of temperature.

Within the gas phase, molecules are moving randomly and are constantly entering into collisions with the each other and with the liquid phase. Interactions involving these slow moving gas molecules will usually result in one or more molecules loosing sufficient energy to cause it to condense back into a liquid. The rate at which this occurs depends strictly on the number of collisions which occur, which is directly proportional to the partial pressure of the vapor.

Thus, there are two competing processes occurring. If evaporation occurs faster than condensation at a given temperature, the vapor pressure will increase, which will cause an increase in the rate of condensation. If condensation occurs faster than vaporization at a given temperature, the vapor pressure and the rate of collisions will drop. Either way, an equilibrium state will be reached in which evaporation and condensation occur at equal but opposite rates. If the temperature rises, more vapor will form, and the rate of condensation will increase until equilibrium is reestablished. If the temperature drops, evaporation will slow, and condensation will cause a decrease in vapor pressure which will cause a subsequent decrease in the rate of condensation. When equilibrium is reestablished, the vapor pressure will be a function of temperature.

For the reaction

$$\text{liquid} \rightleftharpoons \text{vapor} \qquad\qquad K_{eq} = P_{vapor}$$

the relationship between P and T is given by equation 1

$$\ln P = -\frac{\Delta H_{vap}}{RT} + \frac{\Delta S}{R} \qquad \text{(eq. 1)}$$

where P is the vapor pressure in atm
ΔH_{vap} is the enthalpy of vaporization of the liquid
R is the gas law constant (8.314 J/mol K)
T is the temperature in degrees K
ΔS is the entropy change for the reaction.

In this experiment, we will measure vapor pressure as a function of temperature and plot the natural log of P (lnP) versus $\frac{1}{T}$. This should yield a straight line with slope = $-\frac{\Delta H}{R}$ and a y-intercept of $\frac{\Delta S}{R}$.

Procedure

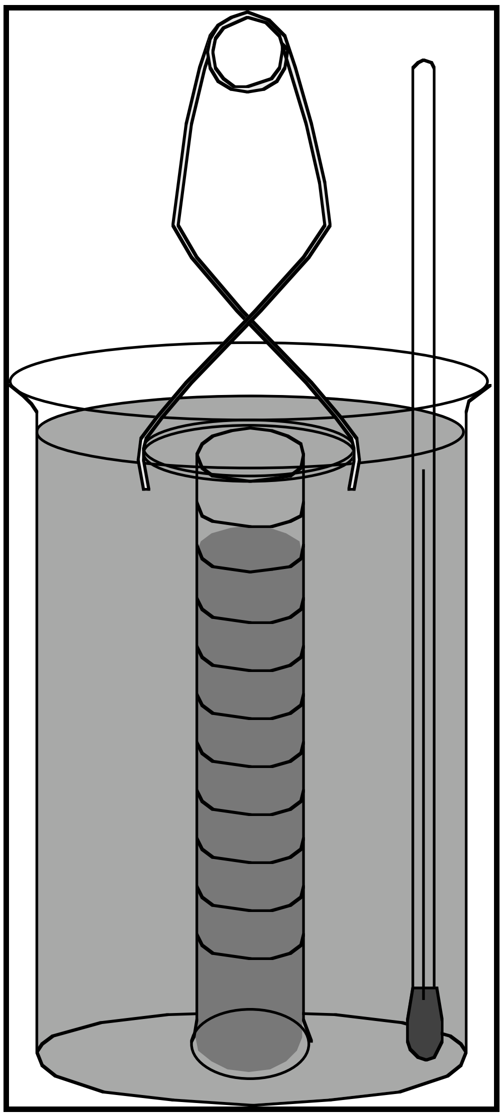

figure 1

Obtain a barometric pressure reading from your instructor and record it on the data sheet. Fill a tall form 1000 mL beaker nearly full with water. Fill a 10 mL graduated cylinder to within 1 inch of the top with water. With a finger placed over the opening, rapidly invert the graduated cylinder and place it in the beaker of water. An air bubble should remain trapped at the top of the inverted cylinder, and the water level within the cylinder should be within the marked region. Add water to the beaker until the cylinder is completely covered. Place the thermometer in the beaker

Heat the water on a hot plate or over a Bunsen burner to a temperature of 80° C. Remove the beaker from the heat and begin gathering data as follows:

1. Read and record the temperature.
2. Read and record the water level in the cylinder.

Continue taking readings at 5° intervals. When the temperature has dropped to below 50°, add ice to the beaker to speed the cooling process and to obtain data below room temperature. Do not collect additonal data until the temperature has fallen to 5° C. Empty the beaker and cylinder, return the beaker and thermometer to the side shelf, and clean up your area.

Calculations

Complete the data table on the data sheet. Convert temperature to degrees Kelvin ($K = °C + 273$) and calculate $1/T$.

To calculate P_{air}, assume that the vapor pressure of water at 5° is negligible, so that the volume measured in the cylinder is all air. Then, by the ideal gas law,

$$P_{air}(\text{at temp T}) = \frac{P_{air}(\text{at }5°)V_{air}(\text{at }5°)T_{air}(\text{at temp T (in K)})}{V_{air}(\text{at temp T})T_{air}(\text{at }5°(\text{in K}))}$$

P_{water} at each T is calculated from Dalton's Law of Partial Pressures:

$$P_{total} = P_{air} + P_{water}$$

where P_{total} is the recorded barometric pressure. P must be in atm. Calculate $\ln P_{water}$ at each T.

Prepare a graph of $\ln P_{water}$ vs. $1/T$ (attach graph to your data sheet). Scale your y-axis so that your graph can be extrapolated to a y value of zero. The graph should be a straight line, with a slope equal to $\frac{-\Delta H_{vap}}{R}$ and a Y-intercept of $\frac{\Delta S}{R}$. Measure and record the slope and intercept. Calculate ΔH_{vap} (use $R = 8.314$ J/mol K) and ΔS_{vap}.

To determine the normal boiling point of water, extend the line on graph 2 and find the point where $\ln P = \ln(1.0 \text{ atm})$. Find the corresponding value of $1/T$, and calculate and record T.

Lab Report
Experiment 3
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Name ______________________________

Date ______________________________

Lab Partner ______________________________

1. Barometric Pressure (torr) ____________________

2.

Temperature (° C)	V (mL)

3.

T (° C)	T (K)	1/T (K^{-1})	P_{air} (atm)	P_{water} (atm)	ln P_{water}

4. Slope of ln P vs. 1/T from graph ____________________

5. ΔH_{vap} for water ____________________

6. ΔS_{vap} for water ____________________

7. Normal boiling point of water ____________________

Question:

1. The vapor pressure of acetone is 100 torr at 7.7° C and 400 torr at 39.5° C. Calculate ΔH_{vap} for acetone.