DETERMINATION OF VAPOR PRESSURE OF WATER

Students work in pairs

Educational Objectives

The student will experimentally measure the vapor pressure of water as a function of temperature change, prepare a graph of ln(P) as a function of $\frac{1}{T(K)}$ **and calculate the enthalpy of Vaporization (ΔH_{vap}) of water.**

Safety

Goggles must be worn. Dispose of the water down the drain.

Pre-Lab Notebook Content:

Title, date, purpose, procedure, data tables;

E-Lab

None

Additional Materials

Digital thermometer, ring stand, three pronged clamps or thermometer clamps, vapor pressure apparatus, 1000 mL tall form beaker, DI water, hot plate, magnetic stir bar, siphon bottles, ice.

Sample Exercises

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Pre-Lab Questions

Determine the heat of vaporization of liquid nitric acid. (See the sample exercises section.)

T (°C)	P_{vap} (mm Hg)
0	14.4
20	47.9
40	133

Introduction

Vaporization is an endothermic process in which energy, in the form of heat, is absorbed from the surroundings to overcome the intermolecular forces in a liquid. The stronger the forces, the more energy that will be required to drive the molecules into the gas phase. The energy required to vaporize 1 mole of a liquid at 1 atm (760 mmHg) pressure is the **enthalpy of vaporization ΔH_{vap}.**

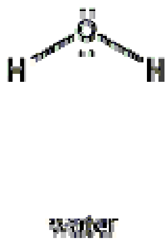
The reverse process, by which a vapor returns to the liquid phase, is condensation. In a closed container, the system is at equilibrium when the rate of evaporation equals the rate of condensation. The pressure exerted by the vapor on the walls of the container at equilibrium is the **equilibrium vapor pressure, P_{vap}.**

In a closed container, pressure inside the system, must equal the pressure outside the system, thus:

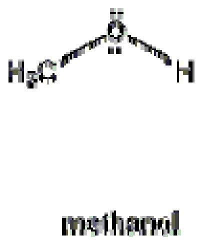
1. $P_{atm} = P_{air} + P_{vap}$

Boiling occurs when the vapor pressure equals the atmospheric pressure. The **normal boiling point** of a liquid is defined as the temperature at which the vapor pressure of the liquid is 1 atm.

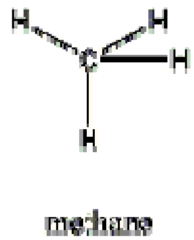
In the liquid state, water, a polar molecule (MM =18 g/mol) has strong hydrogen bonding between its molecules and a much higher boiling point than methane, a non polar, organic molecule (MM =16 g/mol) of comparable molar mass. Methane molecules do not form hydrogen bonds and exhibit only weak London dispersion interactions. Intermediate in boiling point between these two, is methanol, a polar organic molecule (MM = 32 g/mol) which does form extensive hydrogen bonds resulting in a relatively high boiling point. A generalization can be made then, that strong interactions between the molecules in liquid result in both a higher boiling point and a higher enthalpy of vaporization.



B.P.$_{(1atm)}$ = 100 °C



B.P.$_{(1atm)}$ = 64.7°C



B.P.$_{(1atm)}$ -161.6°C

Vapor pressure increases with increasing temperature as the number of molecules having sufficient kinetic energy to escape the liquid phase also increases. In the case of water, the vapor pressure approaches 0 torr at temperatures below 5°C but rapidly increases with increasing temperature.

Figure 1: The Vapor Pressure of Water as a Function of Temperature

A plot of the natural logarithm of P_{vap} as a function of the inverse temperature (in Kelvin) is linear and the slope of the line is $\frac{-\Delta Hvap}{R}$.

Figure 2: Plot of ln(P_{vap}) versus 1/T

Summarizing:
The equation of this line has the form: $y = m x + C$

or

$$\textbf{2.}\quad \ln P_{vap} = \frac{-\Delta Hvap}{R} \frac{1}{T(K)} + C$$

Where the slope of the line is $\frac{-\Delta Hvap}{R}$,

If one chooses two temperatures T_1 and T_2, then:

$$\textbf{3.}\quad \ln (P_{vap,\ T1}) = \frac{-\Delta Hvap}{R} \frac{1}{T_1(K)} + C \quad \text{and}$$

$$\textbf{4.}\quad \ln (P_{vap,\ T2}) = \frac{-\Delta Hvap}{R} \frac{1}{T_2(K)} + C$$

Subtracting equation 3 from equation 4 and rearranging terms gives the Clasius-Clapeyron equation:

$$5.\ \ln P_2 - \ln P_1 = \frac{-\Delta Hvap}{R} \quad \frac{\frac{1}{T_2}-\frac{1}{T_1}}{}$$

Where

ln P denotes the natural logarithm of the vapor pressure

$-\Delta H_{vap\ is}$ the enthalpy of vaporization

R is the ideal gas constant, $\frac{8.314 \text{ joule}}{\text{K} \cdot \text{mole}}$

T is the temperature of the water in Kelvin

The objective of this lab is to experimentally determine the enthalpy of vaporization of water. The student will determine the volume of a gas bubble containing air and water vapor as a function of temperature. At temperatures below 5 °C the vapor pressure due to water is negligible and the volume of the gas can be assumed to be due to the air alone. This volume $V_{(air)}$ is used to find the number of moles of air in the vessel.

6. $n_{(air)} = \frac{P_{(atm)}V_{(air)}}{RT}$ T<278 K

At temperatures above 5 °C the air is saturated with water vapor and the partial pressure of air $P_{(air)}$ is :

7. $P_{(air)} = \frac{n_{(air)}RT}{V_{(bubble)}}$

Procedure

The barometric pressure is supplied in lab.

Fill a1000 mL tall form beaker with ~500 mL of DI water. Into the vapor pressure apparatus (a graduated syringe attached to a perforated rubber stopper.) add 6.5 mL of DI water. Cap your thumb over the opening of the syringe and invert it into the beaker of water. An air bubble, 4 to 5 mL in volume must remain in the syringe. Clamp the apparatus in place as demonstrated by your instructor. The bottom flange of the syringe should be level with the 100 ml mark of the beaker. Insert the digital thermometer through the hole in the stopper and add DI water to completely cover the syringe.

Heat with slow stirring until the air bubble in the syringe expands beyond the 10 cc mark and the water temperature is 78 ± 3 °C. Turn off the heat but continue to stir the water. When the meniscus of the air bubble is within the calibrated area of the syringe, record the volume of the air bubble and the water temperature. Take readings every 4°C until the water temperature cools to 50 °C, while insuring that the tip of the digital thermometer stays at the level of the air meniscus.

Siphon off DI water if necessary and add ice to the beaker.

Record the volume of the air bubble at 5 °C.

turn this page in STUDENT NAME: DATE:

Daily Grading Metric:

	Possible points	Points Earned
Notebook	20	
Completing preparatory calculations		
Pre-Lab Quiz	**15**	
Clean up, check out	**5**	
TOTAL	**100**	

Barometric pressure ______

Temperature (°C) of water	Volume

Tabulate the following data for each measurement in your notebook. (Best done on an MS EXCEL spreadsheet.)

T (°C of water) T (K) of water $\frac{1}{T(K)}$ Volume (mL) P_{air} (torr) P_{H2O} (torr) ln P turn this page in STUDENT NAME: DATE:

Make a graph of ln P as a function of 1/ T (K). Use the least squares regression to find the best straight line through the data and the slope of the line.

Calculate ΔH_{vap} the enthalpy of vaporization of water. _________

Use the graph to predict the normal boiling point of water. __________

Use the graph to predict the boiling point of water at 380 torr. __________