Vapor Pressure and Heat of Vaporization

When a liquid is placed in a container, and the container is sealed tightly, a portion of the liquid will evaporate. The newly formed gas molecules exert pressure in the container, while some of the gas condenses back into the liquid state. If the temperature inside the container is held constant, then at some point equilibrium will be reached. At equilibrium, the rate of condensation is equal to the rate of evaporation. The pressure at equilibrium is called *vapor pressure*, and will remain constant as long as the temperature in the container does not change.

In mathematical terms, the relationship between the vapor pressure of a liquid and temperature is described in the Clausius-Clayperon equation,

$$\ln P = \frac{-\Delta H_{vap}}{R}\left(\frac{1}{T}\right) + C$$

where ln P is the natural logarithm of the vapor pressure, ΔH_{vap} is the heat of vaporization, R is the universal gas constant (8.31 J/mol·K), T is the absolute, or Kelvin, temperature, and C is a constant not related to heat capacity. Thus, the Clausius-Clayperon equation not only describes how vapor pressure is affected by temperature, but it relates these factors to the heat of vaporization of a liquid. ΔH_{vap} is the amount of energy required to cause the evaporation of one mole of liquid at constant pressure.

In this experiment, you will introduce a specific volume of a volatile liquid into a closed vessel, and measure the pressure in the vessel at several different temperatures. By analyzing your measurements, you will be able to calculate the ΔH_{vap} of the liquid.

OBJECTIVES

In this experiment, you will

* Measure the pressure inside a sealed vessel containing a volatile liquid over a range of temperatures.
* Determine the relationship between pressure and temperature of the volatile liquid.
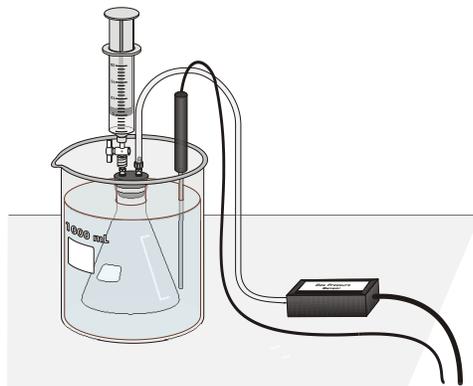* Calculate the heat of vaporization of the liquid.

Figure 1

MATERIALS

Vernier computer interface	20 mL syringe
computer	two 125 mL Erlenmeyer flasks
Vernier Gas Pressure Sensor	ethanol, CH_3CH_2OH
Temperature Probe	400 mL beaker
rubber stopper assembly	1 liter beaker
plastic tubing with two connectors	hot plate

PROCEDURE

1. Obtain and wear goggles. **CAUTION:** The alcohol used in this experiment is flammable and poisonous. Avoid inhaling the vapors. Avoid contact with your skin or clothing. Be sure that there are no open flames in the room during the experiment. Notify your teacher immediately if an accident occurs.

2. Use a hot plate to heat ~200 mL of water in a 400 mL beaker.

3. Prepare a room temperature water bath in a 1 liter beaker. The bath should be deep enough to completely cover the gas level in the 125 mL Erlenmeyer flask.

4. Connect a Gas Pressure Sensor to Channel 1 of the Vernier computer interface. Connect a Temperature Probe to Channel 2 of the interface. Connect the interface to the computer with the proper cable.

5. Start the Logger *Pro* program on your computer. Open the file "34 Vapor" from the *Advanced Chemistry with Vernier* folder.

6. Use the clear tubing to connect the white rubber stopper to the Gas Pressure Sensor. (About one-half turn of the fittings will secure the tubing tightly.) Twist the white stopper snugly into the neck of the Erlenmeyer flask to avoid losing any of the gas that will be produced as the liquid evaporates (see Figure 1). **Important**: Open the valve on the white stopper.

7. Your first measurement will be of the pressure of the air in the flask and the room temperature. Place the Temperature Probe near the flask. When the pressure and temperature readings stabilize, record these values in the first column (Initial) of your data table.

8. Condition the Erlenmeyer flask and the sensors to the water bath.

   a. Place the Temperature Probe in the room temperature water bath.
   b. Place the Erlenmeyer flask in the water bath. Hold the flask down into the water bath to the bottom of the white stopper.
   c. After 30 seconds, close the valve on the white stopper.

9. Obtain a small amount of ethanol. Draw 3 mL of ethanol into the 20 mL syringe that is part of the Gas Pressure Sensor accessories. Thread the syringe onto the valve on the white stopper (see Figure 1).

10. Add ethanol to the flask.

    a. Open the valve below the syringe containing the 3 mL of ethanol.
    b. Push down on the plunger of the syringe to inject the ethanol.
    c. Quickly pull the plunger back to the 3-mL mark. Close the valve below the syringe.
    d. Carefully remove the syringe from the stopper so that the stopper is not moved.

11. Gently rotate the flask in the water bath for a few seconds, using a motion similar to slowly stirring a cup of coffee or tea, to accelerate the evaporation of the ethanol.

12. Monitor and collect temperature and pressure data.

    a. Click ▶ Collect to begin data collection.
    b. Hold the flask steady once again.
    c. Monitor the pressure and temperature readings.
    d. When the readings stabilize, click ⊛ Keep.

13. Add a small amount of hot water, from the beaker on the hot plate, to warm the water bath by 3–5°C. Use a spoon or a dipper to transfer the hot water. Stir the water bath slowly with the Temperature Probe. Monitor the pressure and temperature readings. When the readings stabilize, click ⊛ Keep.

14. Repeat Step 13 until you have completed five total trials. Add enough hot water for each trial so that the temperature of the water bath increases by 3-5°C, but do not warm the water bath beyond 40°C because the pressure increase may pop the stopper out of the flask. If you must remove some of the water in the bath, do it carefully so as not to disturb the flask.

15. After you have recorded the fifth set of readings, open the valve to release the pressure in the flask. Remove the flask from the water bath and take the stopper off the flask. Dispose of the ethanol as directed.

16. Click ■ Stop to end the data collection. Record the pressure readings, as P_{total}, and the temperature readings in your data table.

17. Do not exit the Logger *Pro* program until you have completed 1–4 of the Data Analysis section.

DATA TABLE

	Initial	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
P_{total} (kPa)						
P_{air} (kPa)						
P_{vap} (kPa)						
Temperature (°C)						

DATA ANALYSIS

1. The P_{air} for Trials 2-5 must be calculated because the temperatures were increased. As you warmed the flask, the air in the flask exerted pressure that you must calculate. Use the gas law relationship shown below to complete the calculations. Remember that all gas law calculations require Kelvin temperature. Use the P_{air} from Trial 1 as P_1 and the Kelvin temperature of Trial 1 as T_1.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

2. Calculate and record the P_{vap} for each trial by subtracting P_{air} from P_{total}.

3. Prepare and print a graph of P_{vap} (y-axis) *vs.* Celsius temperature (x-axis).

    a. Disconnect your Gas Pressure Sensor and Temperature Probe from the interface.
    b. Choose New from the File menu. An empty graph and table will be created in Logger *Pro*.
    c. Double-click on the x-axis heading in the table, enter a name and unit, then enter the five values for temperature (°C) from your data table above.
    d. Double-click on the y-axis heading in the table, enter a name and unit, then enter the five values for vapor pressure from your data table above.
    e. Does the plot follow the expected trend of the effect of temperature on vapor pressure? Explain.

4. In order to determine the heat of vaporization, ΔH_{vap}, you will first need to plot the natural log of P_{vap} *vs.* the reciprocal of absolute temperature.

    a. Choose New Calculated Column from the Data menu.
    b. Create a column ln vapor pressure.
    c. Create a second column, reciprocal of absolute temperature, 1/(Temperature (°C) + 273).
    d. On the displayed graph, click on the respective axes, and then select ln vapor pressure to plot on the y-axis, and reciprocal of absolute temperature to plot on the x-axis. Autoscale the graph, if necessary.
    e. Calculate the linear regression (best-fit line) equation for this graph. Calculate ΔH_{vap} from the slope of the linear regression.
    f. Prepare and print a second graph.

5. The accepted value of the ΔH_{vap} of ethanol is 42.32 kJ/mol. Compare your experimentally determined value of ΔH_{vap} with the accepted value.