

# Vapor Pressure of Liquids

In this experiment, you will investigate the relationship between the vapor pressure of a liquid and its temperature. When a liquid is added to the Erlenmeyer flask shown in Figure 1, it will evaporate into the air above it in the flask. Eventually, equilibrium is reached between the rate of evaporation and the rate of condensation. At this point, the vapor pressure of the liquid is equal to the partial pressure of its vapor in the flask. Pressure and temperature data will be collected using a Pressure Sensor and a Temperature Probe. The flask will be placed in water baths of different temperatures to determine the effect of temperature on vapor pressure. You will also compare the vapor pressure of two different liquids, ethanol and methanol, at the same temperature.

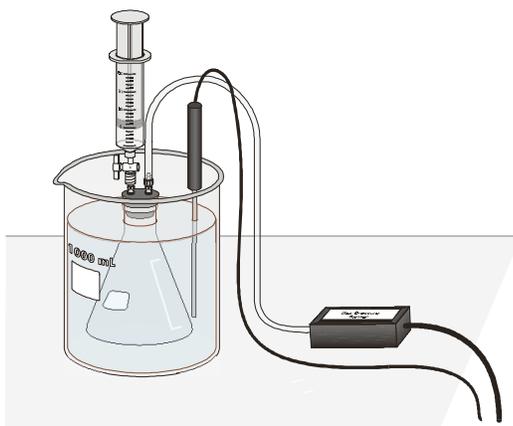


Figure 1

## MATERIALS

LabPro or CBL 2 interface	rubber-stopper assembly
TI Graphing Calculator	plastic tubing with two connectors
Vernier Gas Pressure Sensor or Pressure Sensor	two 125-mL Erlenmeyer flasks
Vernier Temperature Probe	methanol
four 1-liter beakers	ethanol
20-mL syringe	ice

## PROCEDURE

1. Obtain and wear goggles! **CAUTION:** The alcohols used in this experiment are flammable and poisonous. Avoid inhaling their vapors. Avoid contacting them with your skin or clothing. Be sure there are no open flames in the lab during this experiment. Notify your teacher immediately if an accident occurs.
2. Use 1-liter beakers to prepare four water baths, one in each of the following temperature ranges: 0 to 5°C, 10 to 15°C, 20 to 25°C (use room temperature water), and 30 to 35°C. For each water bath, mix varying amounts of warm water, cool water, and ice to obtain a volume of 800 mL in a 1-L beaker. To save time and beakers, several lab groups can use the same set of water baths.

## Experiment 10

3. Prepare the Temperature Probe and Pressure Sensor for data collection.
  - a. Plug the Temperature Probe into Channel 1 of the LabPro or CBL 2 interface.
  - b. Plug the Pressure Sensor into Channel 2 of the interface.
  - c. Identify which type of Vernier Pressure Sensor you are using:
    - Newer Vernier Gas Pressure Sensors have a white stem protruding from the end of the sensor box.
    - Older Vernier Pressure Sensors have a 3-way valve at the end of a plastic tube leading from the sensor box. Before proceeding with the next step, align the blue handle with the stem of the 3-way valve that will *not* be used, as shown in Figure 2—this will close this stem.
  - d. Obtain a rubber-stopper assembly with a piece of heavy-wall plastic tubing connected to one of its two valves. Attach the connector at the free end of the plastic tubing to the open stem of the Pressure Sensor with a clockwise turn. Leave its two-way valve on the rubber stopper open (lined up with the valve stem as shown in Figure 3) until Step 9.
  - e. Insert the rubber-stopper assembly into a 125-mL Erlenmeyer flask. **Important:** Twist the stopper into the neck of the flask to ensure a tight fit.



Figure 2

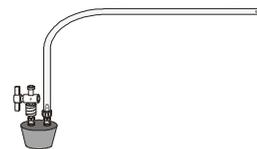


Figure 3

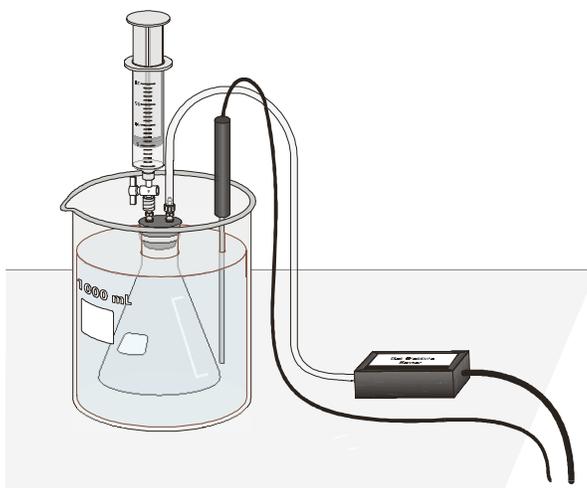
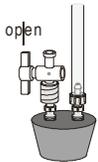
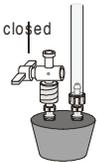


Figure 4

4. Turn on the calculator and start the DATAMATE program. Press  to reset the program.
5. Set up the calculator and interface for a Temperature Probe in CH 1 and a Pressure Sensor in CH2.
  - a. Select SETUP from the main screen.
  - b. If the calculator displays a Temperature Probe in CH 1 and a Pressure Sensor in CH2, proceed directly to Step 6. If it does not, continue with this step to set up your sensor manually.
  - c. Press  to select CH 1.
  - d. Select TEMPERATURE from the SELECT SENSOR menu.
  - e. Select the Temperature Probe you are using (in °C) from the TEMPERATURE menu.
  - f. Press  once, then press  to select CH2.

- g. Select PRESSURE from the SELECT SENSOR menu.
  - h. Select the correct pressure sensor (GAS PRESSURE SENSOR or PRESSURE SENSOR) from the PRESSURE menu.
  - i. Select the calibration listing for units of kPa.
6. Set up the data-collection mode.
    - a. Advance the cursor to MODE using the  key, then press  to select it.
    - b. Select SELECTED EVENTS from the SELECT MODE menu.
    - c. Select OK to return to the main screen.
  7. The temperature and pressure readings should now be displayed on the calculator screen. While the two-way valve above the rubber stopper is still open, record the value for atmospheric pressure in your data table (round to the nearest 0.1 kPa).
  8. Finish setting up the apparatus shown in Figure 4:
    - a. Obtain a room-temperature water bath (20-25°C).
    - b. Place the Temperature Probe in the water bath.
    - c. Hold the flask in the water bath, with the entire flask covered as shown in Figure 4.
    - d. After 30 seconds, close the 2-way valve *above the rubber stopper* as shown in Figure 5—do this by turning the white valve handle so it is perpendicular with the valve stem itself.
- 

open



closed
- Figure 5
9. Obtain the methanol container and the syringe. Draw 3 mL of the methanol up into the syringe. With the two-way valve still closed, screw the syringe onto the two-way valve, as shown in Figure 4.
  10. Introduce the methanol into the Erlenmeyer flask.
    - a. Open the 2-way valve above the rubber stopper—do this by turning the white valve handle so it is aligned with the valve stem (see Figure 5).
    - b. Squirt the methanol into the flask by pushing in the plunger of the syringe.
    - c. *Quickly* return the plunger of the syringe back to the 3-mL mark of the syringe, then close the 2-way valve by turning the white valve handle so it is perpendicular with the valve stem.
    - d. Remove the syringe from the 2-way valve with a counter-clockwise turn.
  11. To monitor and collect temperature and pressure data:
    - a. Select START to begin data collection.
    - b. The flask should still be submerged in the water bath.
    - c. When the temperature and pressure readings displayed on the calculator screen have both stabilized, equilibrium between methanol liquid and vapor has been established. Select ENTER on the calculator to store the first temperature-pressure data pair.

## Experiment 10

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12. To collect another data pair using the 30-35°C water bath:
  - a. Place the Erlenmeyer flask assembly and the Temperature Probe into the 30-35°C water bath. Make sure the entire flask is covered.
  - b. When the temperature and pressure readings displayed on the calculator screen have both stabilized, select ENTER on the calculator to store the second data pair.
13. For Trial 3, repeat the Step-12 procedure, using the 10-15°C water bath. Then repeat the Step-12 procedure for Trial 4, using the 0-5°C water bath. After you have collected the fourth and last data pair, press  $\boxed{\text{STO}} \blacktriangleright$  to stop data collection. Remove the flask and the Temperature Probe from the last water bath.
14. Open the side valve of the Pressure Sensor so the Erlenmeyer flask is open to the atmosphere. Remove the stopper assembly from the flask and dispose of the methanol as directed by your teacher.
15. Press  $\boxed{\blacktriangledown}$  twice, then press  $\boxed{\text{ENTER}}$  to choose CH2 VS. CH1. Examine the data points along the displayed graph of pressure vs. temperature (°C). As you move the cursor right or left, the temperature (X) and pressure (Y) values of each data point are displayed below the graph. Record the data pairs in your data table. Round pressure to the nearest 0.1 kPa and temperature to the nearest 0.1°C.
16. Obtain another clean, dry 125-mL Erlenmeyer flask. Draw air in and out of the syringe enough times that you are certain that all of the methanol has evaporated from it.
17. Collect temperature-pressure data for ethanol at room temperature. To do this:
  - a. Press  $\boxed{\text{ENTER}}$ , then return to the main screen.
  - b. Repeat Steps 8-11 to do *one* trial only for ethanol in the room temperature water bath. When the pressure reading in Channel 2 stabilizes, record its value in the data table.
18. Open the 2-way valve of the Pressure Sensor. Remove the stopper assembly from the flask and dispose of the ethanol as directed by your instructor.

## PROCESSING THE DATA

1. Convert each of the Celsius temperatures to Kelvin (K). Record the answers.
2. To obtain the vapor pressure of methanol and ethanol, the air pressure must be subtracted from each of the measured pressure values. However, for Trials 2-4, even if *no* methanol was present, the pressure in the flask would have increased due to a higher temperature, or decreased due to a lower temperature (remember those gas laws?). Therefore, you must convert the atmospheric pressure at the temperature of the *first* water bath to a *corrected* air pressure at the temperature of the water bath in Trial 2, 3, or 4. To do this, use the gas-law equation (use the Kelvin temperatures):

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

where  $P_1$  and  $T_1$  are the atmospheric pressure and the temperature of the Trial 1 (room temperature) water bath.  $T_2$  is the temperature of the water bath in Trial 2, 3, or 4. Solve for  $P_2$ , and record this value as the *corrected* air pressure for Trials 2, 3, and 4. For Trial 1 of

methanol and Trial 1 of ethanol, it is not necessary to make a correction; for these two trials, simply record the atmospheric pressure value in the blank designated for air pressure.

3. Obtain the vapor pressure by subtracting the corrected air pressure from the measured pressure in Trials 2-4. Subtract the uncorrected air pressure in Trial 1 of methanol (and Trial 1 of ethanol) from the measured pressure.
4. Plot a graph of vapor pressure vs. temperature ( $^{\circ}\text{C}$ ) for the four data pairs you collected for methanol. Temperature is the independent variable and vapor pressure the dependent variable. As directed by your instructor, plot the graph manually or use Graphical Analysis software.
5. How would you describe the relationship between vapor pressure and temperature, as represented in the graph you made in the previous step? Explain this relationship using the concept of kinetic energy of molecules.
6. Which liquid, methanol or ethanol, had the larger vapor pressure value at room temperature? Explain your answer. Take into account various intermolecular forces in these two liquids.

## DATA AND CALCULATIONS

Atmospheric pressure _____ kPa
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Substance	Methanol				Ethanol
Trial	1	2	3	4	1
Temperature ( $^{\circ}\text{C}$ )	$^{\circ}\text{C}$	$^{\circ}\text{C}$	$^{\circ}\text{C}$	$^{\circ}\text{C}$	$^{\circ}\text{C}$
Temperature (K)	K	K	K	K	K
Measured pressure	kPa	kPa	kPa	kPa	kPa
Air pressure	no correction	corrected	corrected	corrected	no correction
	kPa	kPa	kPa	kPa	kPa
Vapor pressure					
	kPa	kPa	kPa	kPa	kPa

## EXTENSION

The Clausius-Clapeyron equation describes the relationship between vapor pressure and absolute temperature:

$$\ln P = \Delta H_{\text{vap}}/RT + B$$

where  $\ln P$  is the natural logarithm of the vapor pressure,  $\Delta H_{\text{vap}}$  is the heat of vaporization,  $T$  is the absolute temperature, and  $B$  is a positive constant. If this equation is rearranged in slope-intercept form ( $y = mx + b$ ):

$$\ln P = \Delta H_{\text{vap}}/R \cdot \frac{1}{T} + B$$

the slope,  $m$ , should be equal to  $-\Delta H_{\text{vap}}/R$ . If a plot of  $\ln P$  vs.  $1/T$  is made, the heat of vaporization can be determined from the slope of the curve. Plot the graph on the TI calculator:

1. Enter the temperature ( $^{\circ}\text{C}$ ) and vapor pressure values into your calculator:

## TI-73 Calculators

- a. To view the data lists, press  $\boxed{\text{LIST}}$ .
- b. Clear L1 and L2 by moving the cursor to the L1 or L2 headings and pressing  $\boxed{\text{CLEAR}} \boxed{\text{ENTER}}$ .
- c. Enter the four Celsius temperature values in L1 and the four corresponding *vapor pressure* values in L2. **Important:** Enter the values in order of increasing temperature.
- d. To create a list of reciprocal of Kelvin temperature values (in L3), move the cursor until the L3 column heading is highlighted, then press  $\boxed{(\ )} \boxed{2\text{nd}} \boxed{\text{STAT}} \boxed{[\text{L1}] + 273} \boxed{(\ )} \boxed{2\text{nd}} \boxed{[X^{-1}]} \boxed{\text{ENTER}}$ .
- e. To create a list of natural log (ln) of vapor pressure values (in L2), move the cursor until the L2 column heading is highlighted, press  $\boxed{\text{MATH}} \boxed{\blacktriangleright} \boxed{\blacktriangleright} \boxed{\blacktriangleright}$  and select  $[\ln(\ )]$  from the log menu. Then press  $\boxed{2\text{nd}} \boxed{\text{STAT}} \boxed{[\text{L2}]} \boxed{\text{ENTER}}$ . Proceed to Step 2.

## TI-83 and TI-83 Plus Calculators

- a. To view the data lists, press  $\boxed{\text{STAT}}$  to display the EDIT menu, and select Edit.
- b. Clear L1 and L2 by moving the cursor to the L1 or L2 headings and pressing  $\boxed{\text{CLEAR}} \boxed{\text{ENTER}}$ .
- c. Enter the four Celsius temperature values in L1 and the four corresponding *vapor pressure* values in L2. **Important:** Enter the values in order of increasing temperature.
- d. To create a list of reciprocal of Kelvin temperature values (in L3), move the cursor to the L3 column heading, then press  $\boxed{(\ )} \boxed{2\text{nd}} \boxed{[\text{L1}] + 273} \boxed{(\ )} \boxed{[x^{-1}]} \boxed{\text{ENTER}}$ .
- e. To create a list of natural log (ln) of vapor pressure values (in L2), move the cursor to the L2 column heading, then press  $\boxed{\text{LN}} \boxed{2\text{nd}} \boxed{[\text{L2}]} \boxed{\text{ENTER}}$ . Proceed to Step 2.

## TI-86 Calculators

- a. To view the data lists, press  $\boxed{2\text{nd}} \boxed{[\text{STAT}]}$ , then select <EDIT>.
- b. Clear any previous data from lists L1 and L2 — move the cursor to the L1 heading and press  $\boxed{\text{CLEAR}}$ , then  $\boxed{\text{ENTER}}$ . Do the same for the L2 list.
- c. Enter the four temperature values in L1 and the four corresponding *vapor pressure* values in L2. **Important:** Enter the values in order of increasing temperature.
- d. To create a list of reciprocal of Kelvin temperature values (in L3), move the cursor until the L3 column heading is highlighted, then select <NAMES>. Press  $\boxed{(\ )} \boxed{<\text{L1}> + 273} \boxed{(\ )} \boxed{2\text{nd}} \boxed{[X^{-1}]} \boxed{\text{ENTER}}$ .
- e. To create a list of natural log (ln) of vapor pressure values (in L2), move the cursor until the L2 column heading is highlighted, then press  $\boxed{\text{LN}} \boxed{<\text{L2}>} \boxed{\text{ENTER}}$ . Press  $\boxed{2\text{nd}} \boxed{[\text{QUIT}]}$ . Proceed to Step 2.

## TI-89 Calculators

- Press **APPS**, then select Home.
- Enter the four Celsius temperature values in L1 and the four corresponding *vapor pressure* values in L2. **Important:** Enter the values in order of increasing temperature. First, enter the temperature values (shown here as t1, t2, ...) into L1. To do this, press **CLEAR** **2nd** **{}** t1 **,** t2 **,** t3 **,** t4 **2nd** **}** **STO▶** **ALPHA** **[L]** **1** **ENTER**.
- Now enter the four corresponding vapor pressure values (shown here as p1, p2, ...) into L2. To do this, press **CLEAR** **2nd** **{}** p1 **,** p2 **,** p3 **,** p4 **2nd** **}** **STO▶** **ALPHA** **[L]** **2** **ENTER**.
- To create a list of reciprocal of Kelvin temperature values (in L3), press **CLEAR** **1** **÷** **(** **ALPHA** **[L]** **1** **+** **273** **)** **STO▶** **ALPHA** **[L]** **3** **ENTER**.
- To create a list of natural log (ln) of vapor pressure values (in L2), press **CLEAR** **LN** **ALPHA** **[L]** **2** **)** **STO▶** **ALPHA** **[L]** **2** **ENTER**. Proceed to Step 2.

## TI-92 and TI-92 Plus Calculators

- Press **APPS**, then select Home.
  - Enter the four Celsius temperature values in L1 and the four corresponding *vapor pressure* values in L2. **Important:** Enter the values in order of increasing temperature. First, enter the temperature values (shown here as t1, t2, ...) into L1. To do this, press **CLEAR** **2nd** **{}** t1 **,** t2 **,** t3 **,** t4 **2nd** **}** **STO▶** **L** **1** **ENTER**.
  - Now enter the four corresponding vapor pressure values (shown here as p1, p2, ...) into L2. To do this, press **CLEAR** **2nd** **{}** p1 **,** p2 **,** p3 **,** p4 **2nd** **}** **STO▶** **L** **2** **ENTER**.
  - To create a list of reciprocal of Kelvin temperature values (in L3), press **CLEAR** **1** **÷** **(** **L** **1** **+** **273** **)** **STO▶** **L** **3** **ENTER**.
  - To create a list of natural log (ln) of vapor pressure values (in L2), press **CLEAR** **LN** **L** **2** **)** **STO▶** **L** **2** **ENTER**. Proceed to Step 2.
- Follow this procedure to calculate regression statistics and to plot a best-fit regression line on your graph of ln pressure vs. reciprocal of Kelvin temperature:
    - Start the DATAMATE program.
    - Select ANALYZE from the main screen.
    - Select CURVE FIT from the ANALYZE OPTIONS menu.
    - Select LINEAR (CH1 VS CH2) from the CURVE FIT menu. (CH1, or L2, is ln vapor pressure and CH2, or L3, is 1/Kelvin temperature.) The linear-regression statistics for these two lists are displayed for the equation in the form:
 
$$y = ax + b$$
 where  $x$  is 1/Kelvin temperature,  $y$  is ln vapor pressure,  $a$  is the slope, and  $b$  is the y-intercept. Record the value of the slope,  $a$ , to use in calculating the heat of vaporization in Step 3.
    - To display the linear-regression curve on the graph of ln vapor pressure vs. 1/Kelvin temperature (K), press **ENTER**. Examine your graph to see if the relationship between ln pressure vs. 1/ Kelvin temperature is linear.
    - (optional) Print a copy of the graph.
  - Use the slope value you recorded in Step 2 to calculate the heat of vaporization for methanol ( $m = a = -\Delta H_{\text{vap}}/R$ ).



## TEACHER INFORMATION

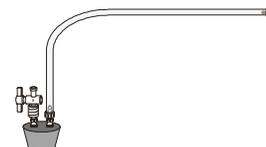
# Vapor Pressure of Liquids

1. Have a good supply of room-temperature tap water available for students to use for the Trial 1 water bath. Room-temperature water helps prevent the water-bath temperature from changing between Trial 1 of methanol and Trial 1 of ethanol. This improves the validity of comparing their vapor pressures.
2. Emphasize to your students the importance of providing an airtight fit with all plastic-tubing connections and when closing valves or twisting the stopper into the Erlenmeyer flask.
3. All of the pressure valves, tubing, and connectors used in this experiment are included with Vernier Pressure Sensors shipped after February 15, 1998. These accessories are also helpful when performing vapor pressure experiments such as Experiment 7 in this manual, *Pressure-Temperature Relationship in Gases*

If you purchased your pressure sensor at an earlier date, Vernier has a Pressure Sensor Accessories Kit (PS-ACC, \$7) that includes all of the parts shown here for doing pressure-temperature experiments (except the Erlenmeyer flask). Using this kit allows for easy assembly of a completely airtight system. The kit includes the following parts:

- two ribbed, tapered valve connectors inserted into a No. 5 rubber stopper
- one ribbed, tapered valve connectors inserted into a No. 1 rubber stopper
- two Luer-lock connectors connected to either end of a piece of plastic tubing
- one two-way valve
- one 20-mL syringe
- two tubing clamps for transpiration experiments

4. Connect the piece of plastic tubing to the shorter valve connector on the rubber stopper prior to the start of class (as shown here). Threaded Luer-lock connectors are attached to both ends of the plastic tubing. Connect one of these to the valve stem with a 1/2 clockwise turn.



5. Even though this procedure requires students to calculate changes in total gas pressure due to changes in temperature, we felt it was less complicated than connecting the container to a vacuum pump or aspirator. Your students may be surprised when the pressure actually drops below the original air pressure at low temperatures.
6. The Vernier temperature calibrations (for the Stainless Steel Temperature Probe or Direct-Connect Temperature Probe) that are stored in the DataMate program work well for this experiment.

The stored pressure calibrations (for the Gas Pressure Sensor or Pressure Sensor) also work well for this experiment.

7. Discuss with your students the relationship between vapor pressure and the rates of evaporation and condensation. It is important for students to relate the resulting equilibrium to the stabilizing of the pressure they observe in the experiment. Remind them to look for the presence of some remaining liquid once equilibrium is reached, since there can be no equilibrium without some liquid being present. There is little chance of all of the liquid

## Experiment 10

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evaporating; approximately 1-2 mL of liquid will be delivered, but only about 0.05 mL will actually evaporate at the highest temperature.

### 8. HAZARD ALERTS:

Methanol: Flammable; dangerous fire risk; toxic by ingestion (ingestion may cause blindness). Hazard Code: B—Hazardous.

Ethanol: Dangerous fire risk; flammable; addition of denaturant makes the product poisonous—it cannot be made non-poisonous; store in a dedicated flammables cabinet or safety cans. If a flammables cabinet or safety cans are not available, store in a Flinn *Saf-Stor*<sup>®</sup> Can. Hazard Code: C—Somewhat hazardous.

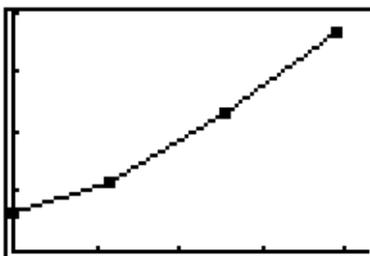
The hazard information reference is: Flinn Scientific, Inc., *Chemical & Biological Catalog Reference Manual, 2000*, P.O. Box 219, Batavia, IL 60510. See *Appendix F* of this book, *Chemistry with Calculators*, for more information.

## ANSWERS TO QUESTIONS

- The vapor pressure of methanol increased as temperature increased, although not linearly (the curve gets steeper as temperature increases). As temperature increases, more molecules have enough kinetic energy to overcome the intermolecular force of attraction between molecules in the liquid.
- Methanol has the higher vapor pressure. Although both molecules have hydrogen-bonding capability due to the -OH functional group, methanol has a lower molecular weight (32 amu) than ethanol (46 amu). As a result, methanol has weaker dispersion forces between molecules, and evaporates more easily.

## SAMPLE DATA AND CALCULATIONS

Atmospheric pressure		101.6 kPa			
Substance	Methanol				Ethanol
Trial	1	2	3	4	1
Temperature (°C)	25.7°C	38.8°C	11.5°C	0.0°C	25.7°C
Temperature (K)	298.8 K	311.9 K	284.6 K	273.1 K	298.8 K
Measured pressure	117.0 kPa	130.6 kPa	104.5 kPa	97.0 kPa	110.0 kPa
Air pressure	no correction 101.6 kPa	corrected $\frac{(101.6)(312)}{(299)}$ 106.0 kPa	corrected $\frac{(101.6)(285)}{(299)}$ 96.8 kPa	corrected $\frac{(101.6)(273)}{(299)}$ 92.5 kPa	no correction 101.6 kPa
Vapor pressure	117.0 – 101.6 15.4 kPa	130.6 – 106.0 24.6 kPa	104.5 – 96.8 7.7 kPa	97.0 – 92.5 4.5 kPa	110.0 – 101.6 8.4 kPa



Vapor Pressure (Methanol) vs. Celsius Temperature

## EXTENSION

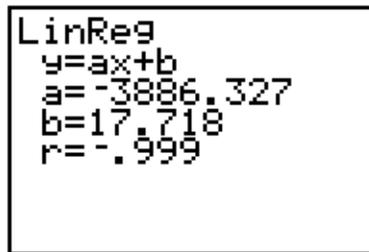
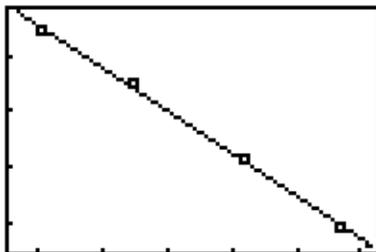
Using the slope obtained from the graph of  $\ln$  vapor pressure vs.  $1/\text{temperature (K)}$  for methanol (see the sample graph and regression statistics on the next page), the heat of vaporization can be calculated, in kJ/mol.

$$\Delta H_{\text{vap}} = -m \cdot R = -(-3886 \text{ K})(8.31 \text{ J/mol} \cdot \text{K}) = 32290 \text{ J/mol} = 32.3 \text{ kJ/mol}$$

This value compares favorably with the accepted heat of vaporization of methanol, 34.4 kJ/mol.

*Experiment 10*

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*ln Vapor Pressure vs. Reciprocal of Kelvin Temperature*