Experiment

21 Molar Mass of a Volatile Liquid

Objective

The molar mass (molecular weight) of a volatile liquid will be determined by measuring what weight of vapor of the liquid is needed to fill a flask of known volume at a particular temperature and pressure.

Introduction

The most common instrument for the determination of molar masses in modern chemical research is the **mass spectrometer**. Such an instrument permits very precise determination of molar mass and also gives a great deal of structural information about the molecule being analyzed; this is of great help in the identification of new or unknown compounds.

Mass spectrometers, however, are extremely expensive and take a great deal of time and effort to calibrate and maintain. For this reason, many of the classical methods of molar mass determination are still widely applied. In this experiment, a common modification of the ideal gas law will be used in the determination of the molar mass of a liquid that is easily evaporated.

The ideal gas law ($PV = nRT$) indicates that the observed properties of a gas sample [pressure (P), volume (V), and temperature (T)] are directly related to the quantity of gas in the sample (n, moles). For a given container of fixed volume at a particular temperature and pressure, only one possible quantity of gas can be present in the container:

$$n = \frac{PV}{RT}$$

By careful measurement of the weight of the gas sample under study in the container, the molar mass of the gas sample can be calculated, since the molar mass, M, merely represents the number of grams of the volatile substance per mole:

$$M = \frac{g}{n}$$

In this experiment, a small amount of easily volatilized liquid will be placed in a flask of known volume. The flask will be heated in a boiling water bath and will be equilibrated with atmospheric pressure. From the volume of the flask used, the temperature of the boiling water bath, and the atmospheric pressure, the number of moles of gas contained in the flask may be calculated. From the weight of liquid required to fill the flask with vapor when it is in the boiling water bath, the molar mass of the liquid may be calculated.

A major assumption is made in this experiment that may affect your results. We assume that the vapor of the liquid behaves as an *ideal gas*. Actually, a vapor behaves *least* like an ideal gas under conditions near which the vapor would liquefy. The unknown liquids provided in this experiment have been chosen, however, so that the vapor will approach ideal gas behavior.

Safety Precautions

- Safety eyewear approved by your institution must be worn at all times while you are in the laboratory, whether or not you are working on an experiment.
- Assume that the vapors of your liquid unknown are toxic. Work in a fume exhaust hood or other well-ventilated area.
- The liquid unknowns may be harmful to the skin, or may be absorbed through the skin. Avoid contact, and wash immediately if the liquid is spilled.
- A boiling water bath is used to heat the unknown liquid, and there may be a tendency for the boiling water to splash when the flask containing the unknown liquid is immersed in it. Exercise caution.
- Use tongs or a towel to protect your hands from hot glassware.

Apparatus/Reagents Required

250-mL Erlenmeyer flask and 600-mL beaker, aluminum freezer foil, needle or pin, oven (110 °C), unknown liquid sample

Procedure

Record all data and observations directly on the report page in ink.

Prepare a 250-mL Erlenmeyer flask by cleaning the flask and then drying it completely. The flask must be *completely dry*, since any water droplets present will vaporize under the conditions of the experiment and will adversely affect the results. An oven may be available for heating the flask to dryness, or your instructor may describe another technique.

Cut a square of thick (freezer) aluminum foil to serve as a cover for the flask. Trim the edges of the foil so that it neatly covers the mouth of the flask but does not extend far down the neck of the flask.

Prepare a beaker for use as a heating bath for the flask. The beaker must be large enough for most of the flask to be covered by boiling water when in the beaker. Add the required quantity of water to the beaker. Set up the beaker on a ring stand over a Bunsen burner, but do not begin to heat the water bath yet.

Weigh the dry, empty flask with its foil cover to the nearest mg (0.001 g).

Obtain an unknown liquid and record its identification number.

Add 3–4 mL of liquid to the dry Erlenmeyer flask. Cover the flask with the foil cover, making sure that the foil cover is tightly crimped around the rim of the flask. Punch a single small hole in the foil cover with a needle or pin.

Heat the water in the beaker to boiling. When the water in the beaker begins to boil, adjust the flame of the burner so that the water remains boiling but does not splash from the beaker.

Immerse the flask containing the unknown liquid in the boiling water so that most of the flask is covered with the water of the heating bath (see Figure 18-1). Clamp the neck of the flask to maintain the flask in the boiling water.

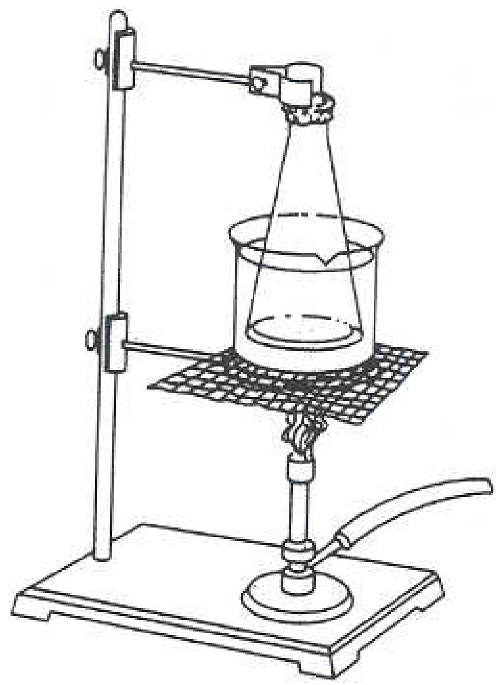

Figure 21-1. Apparatus for determination of the molar mass of a volatile liquid. Most of the flask containing the unknown liquid must be beneath the surface of the boiling water bath.

Watch the unknown liquid carefully. The liquid will begin to evaporate rapidly, and its volume will decrease. The amount of liquid placed in the flask is much *more* than will be necessary to fill the flask with vapor at the boiling water temperature. Excess vapor will be observed escaping through the pinhole made in the foil cover of the flask.

When it appears that all the unknown liquid has vaporized, and the flask is filled with vapor, continue to heat for 1 more minute. Then remove the flask from the boiling water bath; use the clamp on the neck of the flask to protect your hands from the heat.

Set the flask on the lab bench, remove the clamp, and allow the flask to cool to room temperature. Liquid will *reappear* in the flask as the vapor in the flask cools. While the flask is cooling, measure and record the exact temperature of the boiling water in the beaker, as well as the barometric pressure in the laboratory.

When the flask has cooled completely to room temperature, carefully dry the outside of the flask to remove any droplets of water. Then weigh the flask, foil cover, and condensed vapor to the nearest mg (0.001 g).

Repeat the determination by adding another 3-4-mL sample of unknown liquid. Reheat the flask until it is filled with vapor, cool, and reweigh the flask. The weight of the flask after the second sample of unknown liquid is vaporized should *agree* with the first determination within 0.05 g. If it does not, do a third determination.

When two acceptable determinations of the weight of vapor needed to fill the flask have been obtained, remove the foil cover from the flask (do not discard) and clean it out.

Fill the flask to the very rim with tap water; cover with the foil cover; and weigh the flask, cover, and water to the nearest 0.1 g. Determine the temperature of the tap water in the flask. Using the density of water at the temperature of the water in the flask, and the mass of water the flask contains, calculate the exact *volume* of the flask.

If no balance with the capacity to weigh the flask when filled with water is available, the volume of the flask may be approximated by pouring the water in the flask into a 1-L graduated cylinder and reading the water level in the cylinder.

Using the volume of the flask (in liters), the temperature of the boiling water bath (in kelvins), and the barometric pressure (in atmospheres), calculate the number of *moles* of vapor the flask is capable of containing. $R = 0.0821$ L atm/mol K.

Using the weight of unknown vapor contained in the flask, and the number of moles of vapor present, calculate the *molar mass* of the unknown liquid.

Name ____________________ Section ____________________

Lab Instructor ____________________ Date ____________________

Experiment 21 Molar Mass of a Volatile Liquid

PRE-LABORATORY QUESTIONS

1. The method used in this experiment is sometimes called the **vapor density method**. Beginning with the ideal gas equation, show how the *density* of a vapor may be determined by this method.

2. If 2.31 g of the vapor of a volatile liquid is able to fill a 498-mL flask at 100°C and 775 mm Hg, calculate the *molar mass* of the liquid. Calculate the *density* of the vapor under these conditions.

3. Why is a vapor unlikely to behave as an *ideal gas* near the temperature at which the vapor would *liquefy*?

Name ______________________ Section ______________

Lab Instructor ______________________ Date ______________

Experiment 21 Molar Mass of a Volatile Liquid

RESULTS/OBSERVATIONS

Identification number of unknown liquid ______________________

Mass of *empty* flask and cover ______________________

	Sample 1	*Sample 2*
Mass of flask/cover/vapor	______	______
Temperature of vapor, °C	______	______
Temperature of vapor, K	______	______
Pressure of vapor, mm Hg	______	______
Pressure of vapor, atm	______	______
Mass of flask/cover with water	______	______
Mass of water in flask	______	______
Temperature of water in flask	______	______
Density of water	______	______
Volume of flask,	mL ______	L ______
Moles of vapor in flask	______	______
Molar mass of vapor	______	______
Mean value of molar mass	______	

QUESTIONS

1. Two methods were described for determining the volume of the flask used for the molar mass determination. Which method will give a more precise determination of the volume? Why?

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2. It was important that the flask be completely *dry* before the unknown liquid was added so that water present would not vaporize when the flask was heated. A typical single drop of liquid water has a volume of approximately 0.05 mL. Assuming the density of liquid water is 1.0 g/mL, how many moles of water is in one drop of liquid, and what volume would this amount of water occupy when vaporized at 100°C and 1 atm?

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