

Molar Mass of a Volatile Liquid

Objective

The molar mass 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 chemistry 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 (moles, n). 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:

$$n = PV/RT$$

By careful measurement of the mass 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, g, of the volatile substance per mole:

$$M = g/\text{mole}$$

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 mass of liquid required to fill the flask with vapor when it is in a 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

- Wear safety glasses at all times while in the laboratory.
- Assume that the vapors of your liquid unknown are toxic. Work with an exhaust fan and in a well ventilated area.
- The unknown may also be flammable. All heating is to be done on a hot plate. NO OPEN FLAMES.
- The liquid unknowns may be harmful to skin. Avoid contact, and wash immediately if the liquid is spilled.
- A boiling water bath is used to heat the liquid, and there may be a tendency for the water to splash when the flask containing the unknown liquid is inserted. Exercise caution.

Apparatus/Reagents Required

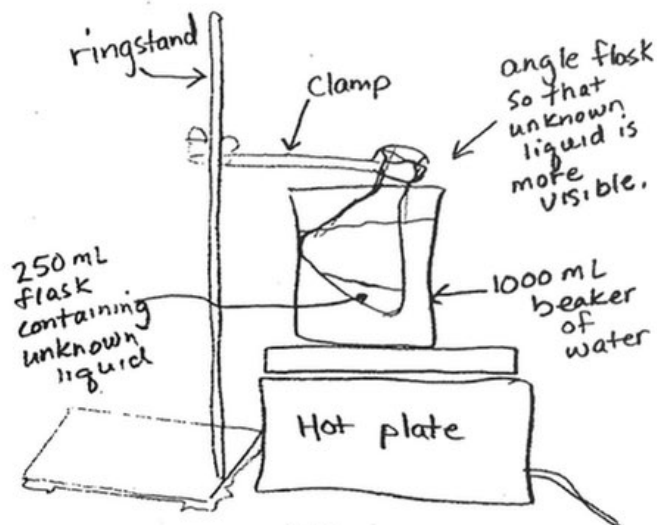
250 mL Erlenmeyer flask	oven (110°C)
1000 mL beaker	unknown liquid sample
Aluminum freezer foil	hot plate
Needle or pin	ring stand and clamp

Procedure

1. Prepare a 250 mL Erlenmeyer flask by cleaning the flask and then drying it completely. The flask must be completely dry, since any water present will vaporize under the conditions of the experiment and will adversely affect the results. An oven may be available for the heating the flask to dryness.
2. 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 nearly covers the mouth of the flask but does not extend far down the neck.
3. Prepare a large 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. Use a second flask the same size as the clean dry one to help you get the amount of water correct. Set up the beaker on a hot plate, but do not begin to heat the water yet.
4. Weigh the dry, empty flask with its foil cover to the nearest mg (.001 g).
5. Obtain an unknown liquid and record its identification number.
6. 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 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 temperature of the hotplate so that the water remains just under the boiling point. Try to keep the temperature of the water between 99 and 100°C.
- Immerse the flask containing the unknown liquid in the hot water bath so that most of the flask is covered with the water of the heat bath (See Figure 1). Clamp the neck of the flask to maintain the flask in the boiling water.

Figure 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 make 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 it for 1-2 more minutes. Time carefully. Then remove the flask from the hot 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 bath, 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 (.001 g).
- Repeat the determination by adding another 3-4 mL of the 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 .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 and clean it out.

15. 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 mg (.001 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 weight of water the flask contains, calculate the exact volume of the flask.
16. 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.

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 mmHg, what is the molecular weight of the liquid? What is 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?
4. A compound which has the empirical formula CH_2Br , has a vapor density of 6.00 g L^{-1} at 375 K and 0.983 atm. Using these data, determine the following:
 - (i) The molar mass of the compound
 - (ii) The molecular formula of the compound

Calculations

1. Calculate the moles of vapor in the flask for trial 1 and for trial 2. Show all work.
2. Calculate the mass of vapor in the flask for trial 1 and trial 2. Show all work.
3. Calculate the molar mass of the vapor for trial 1 and trial 2.
4. Calculate the mean molar mass of the vapor.
5. Calculate density of vapor in the flask for trial 1 and trial 2.
6. Calculate the mean density of vapor.
7. Obtain the identity of the unknown liquid from your teacher. Write the name of the unknown liquid, the chemical formula of the unknown liquid and calculate the molar mass of the unknown liquid.
8. Calculate the percent error for the experimental molar mass.

Post-Lab Questions

1. Two methods were described for determining the volume of the flask used for the molar mass determination (steps 15 and 16). Which method will give a more **precise** determination of the volume? Explain.
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 water has a volume of approximately .05 mL. Assuming the density of liquid water is 1.0 g/mL, how many moles of water are in one drop of liquid, and what volume would this amount of water occupy when vaporized at 100.0°C and 1 atm?

3. Two measurements that were needed for this experiment were the temperature of the vapor and the pressure of the vapor. How were these measured? What assumptions were made in the determination of these values? What are the chemical principles that allow us to make these assumptions?
4. Discuss the error that would result if the flask was removed from the boiling water bath too soon.
5. Volatile liquids with lower boiling points often give better results than those with higher boiling points. Suggest a reason for this.
6. What effect would vapor condensation around the neck of the flask (between the foil and the flask) have on the reported molar mass?
7. Some liquids have enough attractions between molecules to form dimers. (Dimers are molecules formed from the combination of identical molecules, $A + A \rightarrow A_2$.) What effect would this have on the experimental molar mass?

Mass of flask, foil, Cu wire	90.457 g
Temp. of vapor	100.5 °C
Mass of flask, foil, Cu wire & condensed vapor	90.8488 g
Vol. of flask	154 mL
Barometric Pressure	746.5 mmHg

Compound is 85.7% C
14.3% H