Determining a Molar Volume

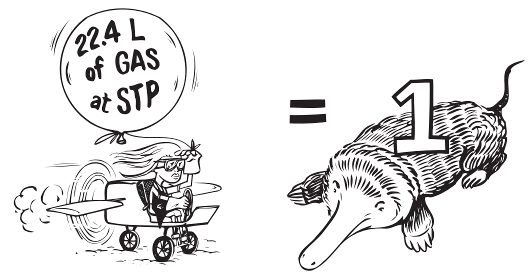
A Safer Experiment

Introduction

The traditional method for calculating molar volumes involves generating oxygen gas—potassium chlorate is heated with manganese dioxide, a catalyst, to produce oxygen gas. This method is quite hazardous because large amounts of oxygen gas are produced and potassium chlorate is a powerful oxidizer of organic materials including the rubber stopper used in the set-up. In fact, potassium chlorate is a frequent source of accidents on school premises. An easier and safer method presented in this laboratory activity for the calculation of molar volumes involves the use of carbon dioxide instead of oxygen gas.

Concepts

- Mole
- Molar volume
- Ideal gas law



Materials

Dry ice, solid carbon dioxide, CO_2, small piece about ¾″ square
Balance
Barometer
Erlenmeyer flask, Pyrex®, 125-mL
Graduated cylinder, 500-mL
Rubber stopper, to fit Erlenmeyer flask
Thermometer
Tongs or insulated gloves (Zetex™)

Safety Precautions

This activity requires the use of hazardous components and/or has the potential for hazardous reactions. Dry ice can cause frostbite; never touch dry ice directly with the skin; wear appropriate insulated gloves or use tongs whenever handling dry ice. Do not stopper the flask until all of the dry ice has sublimed. Failure to wait until all solid pieces are gone may cause the flask to shatter due to increased pressure. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Procedure

1. Place the stopper in the Pyrex Erlenmeyer flask and mass to the nearest 0.01 g. Record this mass in the data table as the mass of the stoppered flask plus air. Recall that the flask is not actually empty—it contains air.
2. Remove the stopper. Using tongs, or while wearing insulated gloves, place a small piece of dry ice in the Erlenmeyer flask. Do not stopper the flask at this point.
3. Gently swirl the flask to aid in the sublimation of the dry ice.
4. Immediately after the last bit of dry ice has just sublimated and disappeared, tightly stopper the flask. Mass the flask and record this mass in the data table as the mass of the stoppered flask plus CO_2.
5. Remove the stopper and fill the Erlenmeyer flask to the top lip with water. Stopper the flask again. Wipe any water off of the outside of the flask.
6. Remove the stopper from the flask. Pour the water into a large graduated cylinder and measure the volume of water. The volume of water is equal to the volume of air (Step 1) or CO_2 (Step 4) in the flask. Record this volume in liters in the data table.
7. Record the room temperature in degrees Kelvin and the atmospheric pressure in atm in the data table.
8. Record the density of air in the data table. The density of air is both temperature and pressure dependent. This value can be found in a chemistry textbook or reference manual if the temperature and pressure are known.
9. Calculate the mass of air in the flask by using the relationship that the density of air (Step 8) is equal to the mass of air

divided by the volume of air (Step 6).

$$\text{density of air} = \frac{\text{mass of air}}{\text{volume of air}}$$

$$\text{mass of air} = (\text{density of air}) \times (\text{volume of air})$$

10. Calculate the mass of CO_2 in the flask by subtracting the mass of the stoppered flask plus air (Step 1) from the mass of the stoppered flask plus CO_2 (Step 4).

$$\text{mass of } CO_2 = (\text{mass of stoppered flask plus air}) - (\text{mass of stoppered flask plus } CO_2)$$

11. Since molar volume is defined at STP (standard temperature and pressure), the experimental value for the volume of CO_2 from Step 6 must be corrected using the ideal gas law.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

where P_1 = the atmospheric pressure (Step 7)
T_1 = the room temperature (Step 7)
V_1 = the volume of CO_2 in the flask (Step 6)
P_2 = standard pressure (1 atm)
T_2 = standard temperature (273.15 K)
V_2 = the corrected volume of CO_2 for which we are solving

Solve for the corrected volume of CO_2 and record this value in the data table.

$$V_2 = \frac{P_1V_1T_2}{T_1P_2}$$

12. Record the molecular mass of CO_2 in g/mole in the data table (44 g/mole).
13. Use the following relationship to calculate the molar volume from the mass of CO_2 (Step 10), the corrected volume of CO_2 (Step 11), and the molecular mass of CO_2 (Step 12):

$$\frac{V_2}{\text{molar volume}} = \frac{\text{mass of } CO_2}{\text{molecular mass of } CO_2}$$

$$\text{molar volume} = \frac{V_2 \times \text{molecular mass of } CO_2}{\text{mass of } CO_2}$$

14. Record the theoretical value for molar volume in the data table (22.414 liters).
15. Calculate the percent error between your calculated molar volume (Step 13) and the theoretical molar volume (Step 14):

$$\text{Percent error} = \frac{|\text{calculated molar volume} - \text{theoretical molar volume}|}{\text{theoretical molar volume}} \times 100\%$$

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. Allow the dry ice to sublime in a well-ventilated area.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Constancy, change, and measurement

Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, structure and properties of matter

Step 1	Mass of stoppered flask plus air, g	
Step 4	Mass of stoppered flask plus CO_2, g	
Step 6	Volume of air or CO_2 in flask, L	
Step 7	Room temperature, K	
Step 7	Atmospheric pressure, atm	
Step 8	Density of air, g/mL	
Step 9	Mass of air, g	
Step 10	Mass of CO_2, g	
Step 11	Corrected volume of CO_2, L	
Step 12	Molecular mass of CO_2, g/mole	
Step 13	Molar volume, L	
Step 14	Theoretical molar volume, L	
Step 15	Percent error	

Tips

- Dry ice is commonly available from ice cream stores, especially just before Halloween. It is usually sold by the pound.
- Good results are generally obtained. In one experiment, 200 students obtained values for the molar volume from 19.6 – 22.7 liters. The majority of students obtained values right around 22.4 liters.
- More accurate results may be obtained by massing the water instead of measuring its volume in Step 6. The density of water (at its specific temperature) would then be used to calculate the volume.
- A variation on this experiment involves using the known molar volume (22.4 liters) to calculate the molecular weight of CO_2 (Step 13).

Discussion

Avogadro's hypothesis is one of the most important gas principles. The principle states: equal volumes of all gases under the same conditions (identical temperature and pressure) contain the same number of molecules. In other words, if samples of different gases at the same conditions contain the same number of molecules, then the volume of each of these gas samples must be equal.

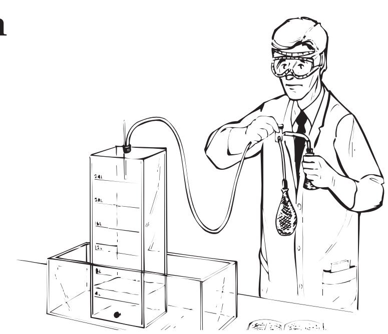
Assuming that one mole of gas is at standard conditions (1 atm and 273.15 K), then the volume of that gas sample is 22.414 liters. This value is calculated using the ideal gas equation (PV = nRT). When the volume of gas is one mole, the term *molar volume* is used.

Acknowledgment

We would like to extend a special thanks to Judith A. Douville, Eastern Connecticut State University, Willimantic, CT, who provided us with the instructions for this activity.

How Much Is a Mole?—The Mole Eudiometer is available from Flinn Scientific, Inc.

The Mole Eudiometer is a physical device for the *visual display* of one mole to provide students with a better understanding of the mole concept. The Mole Eudiometer is easy to use. Simply fill the chamber with water, close the system, introduce one mole of gas, and observe the 22.4 liter volume of water displacement.



Catalog No.	Description
AP6385	How Much Is a Mole?—The Mole Eudiometer

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.