CHAPTER 9

MOLAR MASS OF A GAS

THE MOLAR MASS OF ALMOST ANY GAS can be accurately determined within a single laboratory period using 60 mL plastic syringes. The mass of a plastic syringe is determined with no gas present and then again with the syringe filled with (a) air and (b) a sample of the pure gas. Two methods for calculating the MM of the gas from the Ideal Gas Law can be performed.

Overview

Students will start by generating one or more gases for study. Very nice results can be obtained for carbon dioxide (Chapter 1). Generally, heavier gases give the best results. Propane also gives excellent results. Samples of commercially available pure gases work especially well.

MOLAR MASS OF A GAS

INFORMATION FOR THE TEACHER

Suitability

This laboratory activity is suited for high school and university-level chemistry students.

Background skills required

Students should be able to:

- generate a gas as learned in Chapter 1
- measure quantities of liquid reagents
- use an analytical balance
- perform gas law calculations

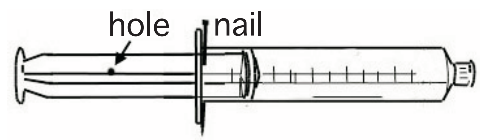
Time required

Students should be able to perform most of these experiments in a single 45 minute laboratory period.

Before the students arrive: Construct the molar mass devices

Materials needed for construction of the molar mass device

60 mL plastic syringe
syringe cap
finishing nail, 5 cm (2 inch)
drill and drill bit with a diameter slightly greater than the diameter of the nail



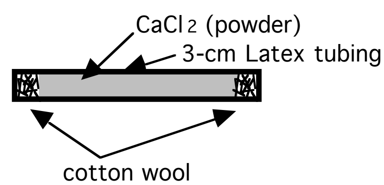
The special purpose syringe was first used in Chapter 2, Experiment 5. It is constructed by drilling holes through the plunger. Drill a hole in a position as shown in the figure below: the syringe will hold about 55 mL when the nail is flush with the rim of the barrel.

Materials needed for the experiment

Molar Mass of Gas device
analytical balance
additional 60 mL plastic syringes for generating gases
additional syringe caps
2 cm lengths of tubing, 1/8-inch (3.175 mm) ID
other materials required for generation of each gas

Materials needed for optional drying step

cotton balls (or 'puffs')
calcium chloride (anhydrous)[1]



Optional drying step

Gases prepared by our methods must be dried before use. This is accomplished by passing the gas sample through a 3 cm length of tubing that has been packed with pulverized anhydrous $CaCl_2$ and held in place by plugs of cotton as shown in the figure. The drying tube is used to connect the reactant syringe to the MM syringe, described below.

[1] Pulverized blue-colored Drierite (anhydrous $CaCl_2$) granules works especially well because the blue indicator turns pink in the presence of water. Available from Fisher Scientific 07-578-3A.

Teaching tips

1. The most common sources of error are (a) water drops that get into the molar mass syringe, and (b) accidentally switching the syringe caps.
2. Inserting and removing the nail is best done with two people.
3. The need to measure the mass of the syringe while under a vacuum confuses most people; they propose that with the plunger fully inserted, the syringe is "empty". They are forgetting that the mass of air inside the syringe but above the plunger seal contributes to the measured mass of the syringe.

Experimental results

We have studied eleven gases using this method and the results are collected below.

Gas	Actual MM (g/mol)	Commercial gas samples		Prepared gas samples	
		MM* (Calc. I)	MM* (Calc. II)	MM* (Calc. I)	MM* (Calc. II)
NH_3	17.0306	17.5 +/- 0.3 (2.9%)	17.4 +/- 0.2 (2.4%)		
C_2H_2	26.0379			25.8 +/- 1.3 (1.1%)	26.9 +/- 0.1 (3.2%)
N_2	28.014	27.5 +/- 1.1 (1.8%)	28.5 +/- 0.5 (1.5%)	29.1 +/- 0.7 (3.8%)	28.6 +/- 0.4 (1.9%)
NO	30.0061	31.0 +/- 0.4 (3.3%)	31.1 +/- 0.5 (3.5%)		
O_2	31.999	31.7 +/- 0.6 (1.1%)	32.2 +/- 0.1 (< 1%)	30.2 +/- 1.5 (5.6%)	31.5 +/- 0.1 (1.5%)
Ar	39.948	39.9 +/- 0.2 (< 1%)	39.9 +/- 0.4 (< 1%)	-	-
CO_2	44.010	43.0 +/- 2.2 (2.2%)	45.0 +/- 0.2 (2.2%)	42.5 +/- 1.4 (3.4%)	43.3 +/- 1.2 (1.5%)
N_2O	44.013	43.0 +/- 1.5 (2.2%)	44.4 +/- 0.2 (<1%)		
C_3H_8	44.0968	43.2 +/- 0.1 (2.1%)	43.3 +/- 0.5 (1.8%)	-	-
C_4H_{10}	58.1237	56.9 +/- 3.0 (2.1%)	58.3 +/- 1.0 (0.3%)	-	-
Cl_2	70.906	70.2 +/- 2.6 (1.0%)	71.8 +/- 1.6 (1.3%)		

* average of five trials +/- standard deviation[2] (% error)

[2] The formula for the standard deviation, σ, of n values is given here, where x represents the individual MM values, $\bar{x}$ represents the mean MM.

$$\sigma = \sqrt{\sum (x - \bar{x})^2 / (n-1)}$$

Website

This chapter is available at our gas website:

http://mattson.creighton.edu/Microscale_Gas_Chemistry.html

Instructions for your students

For classroom use by teachers. Copies of all or part of this document may be made for your students without further permission. Please attribute credit to Professors Bruce Mattson and Mike Anderson of Creighton University and this website.

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MOLAR MASS OF A GAS
INSTRUCTIONS FOR STUDENTS

General Safety Precautions

Always wear safety glasses. Gases in syringes may be under pressure and could spray liquid chemicals. Follow the instructions and only use the quantities suggested.

Toxicity

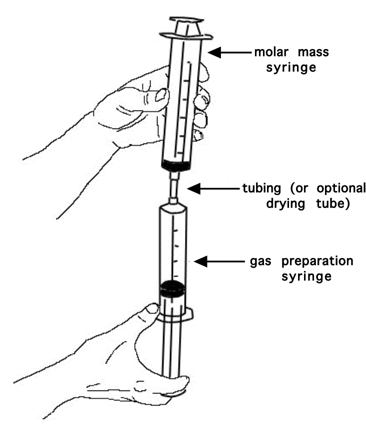
Refer to the appropriate chapter to learn more about the toxicity of each gas.

Instructions

Prepare or obtain a sample of a gas for study. Transfer the gas to a clean, dry syringe. If so instructed, dry the gas through a calcium chloride drying tube.

Insert the plunger fully into the device. Snap the syringe cap onto the syringe. Pull the plunger outward so that the nail can be inserted through the hole in the plunger. Two people are needed for this maneuver; one pulls the plunger back while the second inserts the nail through the hole. The nail should rest across the mouth of the barrel while holding the plunger in position. Measure the mass of the device on an analytical balance. Remove the nail and release the plunger. It should return to its former empty-syringe position inside the barrel. Remove the syringe cap. ***Important***! *You must use the same nail and syringe cap later in the experiment!* Remove the cap and fill the syringe with 60 mL air. Insert the nail through the hole, discharge excess air until the nail rests across the mouth of the syringe and cap with the same syringe cap. Using an analytical balance, determine the mass of the MM device filled with air.

Discharge the air. Transfer the gas to be studied to the MM syringe via syringe-syringe transfer using a short length of tubing or drying tube as shown at right. Discard the first 3 – 5 mL gas that is used to purge the air from the drying tube. Transfer slightly more gas than is needed so that the plunger hole is at least 1 mm beyond the top of the syringe. Insert the nail, remove the tube and gas generation syringe, push the plunger inward until the nail rests across the mouth of the syringe barrel, and recap the syringe with the same syringe cap used earlier.



Determine the mass of the MM device plus gas contents. Record the volume of the gas in the syringe by reading the volume from the inside edge of the rubber plunger seal inside the syringe barrel. Record the temperature and barometric pressure.

Calculation I

The molar mass of the gas can be calculated from the ideal gas law:

$$PV = nRT$$

$$n = \frac{m}{MM}$$

$$PV = \frac{m}{MM}RT$$

$$MM = \frac{mRT}{PV}$$

Good results require accurate values of temperature, pressure and syringe volume. A more accurate volume determination can be obtained by filling the MM syringe with water instead of gas and using the mass of water and its density to calculate the volume of the MM syringe. Note: The volume of the filled MM device should not change, so this measurement needs to be done only once.

Calculation II

Better results are obtained for the same experimental data by using the following MM ratio calculation. The equation for *MM* for Gas A, as derived above, can be converted to a ratio for two gases, A and B:

$$\frac{MM_A}{MM_B} = \frac{m_A}{m_B}$$

The advantage of this ratio method is that accurate values for temperature, pressure and syringe volume are not needed because they cancel at constant *T, P* and *V*. In our experiments, Gas A is the gas being studied and Gas B is air.

$$\frac{MM_{gas}}{MM_{air}} = \frac{m_{gas}}{m_{air}}$$

Using Dalton's law of partial pressures and the Ideal Gas law, the MM_{air} can be estimated from the mole fraction, *X*, of the constituent gases N_2, O_2, Ar, and CO_2, which collectively account for over 99.99% of air.

$$MM_{air} = X_{N_2} \times MM_{N_2} + X_{O_2} \times MM_{O_2} + X_{Ar} \times MM_{Ar} + X_{CO_2} \times MM_{CO_2} + \ldots$$

Using accepted values for *X*, we can estimate the 'molar mass' of air:

$$MM_{air} = 0.7808 \times 28.0134 + 0.2095 \times 31.9988 + 0.0093 \times 39.948 + 0.00037 \times 44.0098 + ..$$

$$MM_{air} = 28.964\ g\ mol^{-1}$$

Clean-up and Storage

At the end of the experiments, clean all syringe parts (including the plunger seal), caps and tubing with soap and water. Rinse all parts with distilled water. Be careful with the small parts because they can easily be lost down the drain. Important: Store plunger out of barrel.

Questions

1. Determine the molar mass by each method. Which one gives results closer to the actual value?
2. What sources of error are associated with each method and with the experiment in general?
3. Why would gases with larger molar masses give better results?
4. Why would gases that are water-soluble tend to give higher-than-expected results?

Advanced Questions

5. If the class is working with the same gas and sharing results, calculate the mean molar mass and standard deviation. The formula for the standard deviation, s, of ***n*** values is:

$$\sigma = \sqrt{\sum (x - \overline{x})^2 / (n - 1)}$$

where x represents the individual MM values, $\overline{x}$ represents the mean MM.

Summary of Materials and Chemicals Needed for Chapter 9. Molar Mass of a Gas Experiment.

Equipment required

This list summarizes all of the equipment necessary for performing the molar mass of a gas experiment described in this chapter.

Item	For Demo	For 5 pairs	For 10 pairs
Microscale Gas Chemistry Kit (See Chapter 1)	1	5	10
Special purpose syringe plus finishing nail, 5 cm	1	5	10

