

Molar Volume and Molecular Weight of Gases

Molar Volume

General Definition of Molar Volume

In [chemistry](#), the **molar volume** of a substance is the [volume](#) of one [mole](#) of that substance. It can be computed as the substance's [molecular](#) (or [atomic](#)) weight divided by its [density](#). The [SI unit](#) for volume is the cubic meter, m^3 . Thus, the SI unit of molar volume is **cubic meters per mole** ($\text{m}^3 \text{mol}^{-1}$). Molar volume can also be expressed in $\text{cm}^3 \text{mol}^{-1}$. A cubic centimeter (cm^3) is a measure of volume one million times smaller than a cubic meter.

Numerical Definition of Molar Volume

The molar volume for an ideal gas at STP is $22.414 \text{ L mol}^{-1}$

Thus, one mole of an ideal gas at STP occupies 22.414 liters. This value has been known for about 200 years. The value is actually known to several more decimal places, but three decimal places will provide sufficient precision for our calculations. Using $PV = nRT$, you can calculate the value for molar volume of an ideal gas. V is the unknown, and $n = 1 \text{ mol}$. Set P and T equal to their STP values, and use $R = 0.08206 \text{ L atm mol}^{-1} \text{ K}^{-1}$.

The Molecular Weight of Air

The physical behavior of gases is described by various laws, which have resulted from hundreds of years of experimentation. Most general chemistry textbooks describe many applications of the ideal gas equation, $PV = nRT$. This equation provides a very useful, general description of the physical behavior of “ideal” gases. Although real gases rarely behave in a completely “ideal” manner, this equation will provide a good basis for the investigation you are performing in the laboratory this week. When any three of the four variables in this equation (pressure, volume, temperature, and moles of gas) are known, the equation may be rearranged and easily solved to determine the fourth. The gas constant, R , is usually expressed as $0.082057 \text{ L atm / K mol}$, although it can be expressed in different units.

When describing the physical behavior of a gas, it is important to remember that gases are fluids. We are used to thinking of liquids as fluids, but gases may also be so defined. Fluids are substances that flow and can change shape to “fill” their container easily. Under standard temperature and pressure conditions (STP), 0°C and 1 atm , gases exist as discrete isolated particles in large volumes of empty space. Because of the low concentration (number/volume) of the molecules present and the almost negligible attraction and repulsion between the particles, increasing the pressure forces them to occupy a significantly smaller volume of space. For this reason, gases are called compressible fluids, whereas liquids are described as incompressible fluids.

Archimedes’ principle describes one property of fluids; they exert a **buoyant force** on objects wholly or partially immersed in them. Air, being a fluid, exerts a buoyant force on objects

submerged in it. Balloons that are filled with a gas that is less dense than air will float if the weight of the balloon and the gas inside is less than the weight of the air it displaces. Your group will use this principle—along with your ingenuity—to determine the average molar mass of the air in your lab room.

Safety

Always, always wear **safety glasses** when experimental work is being done anywhere in the laboratory. Your TA can remove you from the lab if you fail to wear safety glasses.

Dry ice should not be touched with your bare hands; dry ice "burns" can result.

Do not overfill balloons!

Gas cylinders contain gas that is under high pressure and they should be handled with great care. This type of container is very sturdy and well adapted for the purpose it serves. It MUST remain firmly clamped and strapped into the bracket specifically designed to secure it. NEVER attempt to unfasten or move the cylinder, and do not attempt to adjust the pressure gauge in any way. If the cylinder were to become loose, topple over, and the valve broken, it would function as a rocket! THERE ARE INSTANCES WHERE GAS CYLINDERS HAVE BEEN PROPELLED THROUGH CINDERBLOCK WALLS AND ANYTHING ELSE IN THEIR PATH. Your TA will show you how to fill your Mylar balloons using the balloon valve on the gas cylinder.

Prelab

Please answer the following questions in your lab notebook. This assignment is due at the beginning of lab. You will not be allowed to start the experiment until this assignment has been completed and submitted to your TA.

- List the chemicals you will use for this week's experiment. For each chemical, list specific safety precaution(s) that must be followed. To find specific safety information, obtain a Materials Safety Data Sheet (MSDS) on the chemical of interest. MSDSs can be found through an internet search (e.g., google) or from the following website: www.hazard.com Read the MSDS and find specific safety concerns for each chemical. Be sure to include the route(s) of entry and the possible acute and chronic effects of exposure, if given.
- Using your own words, complete the OBJECTIVE and PROCEDURE sections in your lab notebook. (See the [Maintaining Your Laboratory Notebook](#) link on the lab website to learn what these lab notebook sections entail.)
- Also, please write out answers to the questions below.
 1. What are the three states of matter?
 2. Define the terms that describe transitions from one phase to another phase by drawing a simple phase diagram and labeling it accordingly.

Laboratory Part A

Molar Volume of Carbon Dioxide Gas

Description

By studying a sample of carbon dioxide, you will determine the molar volume of gaseous CO_2 . Using balloons, you will determine the molar volume of carbon dioxide at STP by making three mass measurements and recording the temperature and atmospheric pressure. You will use the concept of buoyancy to determine the volume of the sample of gas, and correct the molar volume to STP.

Materials

Plan how your group will use the materials listed below to determine the molar volume of CO_2 .

Chemicals

Dry ice

Equipment

Round latex balloons

Rubber stoppers

Top-loading balance

Thermometer (or Vernier temperature probe)

Vernier pressure sensor

Questions

1. The total apparent mass of the balloon, stopper, and carbon dioxide *gas* is much less than the total mass of the balloon, stopper, and *solid* carbon dioxide. Why? (Hint: Consider the role of displaced air on the apparent mass of a carbon dioxide gas-filled balloon.)
2. The accepted value for molar volume of an ideal gas at STP is 22.414 L. Compute the absolute difference between the accepted value and the average value obtained from this experimental data.
3. Identify possible sources of error in this experiment.

References

Handbook of Chemistry and Physics, The Chemical Rubber Publishing Co., Cleveland, OH.
[You may use this reference, which is often referred to simply as "the CRC handbook," to find the density of air at the temperature and pressure in the laboratory. Look up "density of air" in the index.]

Laboratory Part B

Molecular Weight of Air

Description

By making measurements on a sample of pure *helium*—a gas with a well-known molar mass—your group will determine the “molecular weight,” or average molar mass, for the *air* in the Chemistry 190 lab room!

Materials

As a team, you will design and plan the procedure for your investigation. Which instruments and procedures are appropriate to an investigation in which a helium-filled balloon is used to determine the molecular weight of air?

Instrumentation and Equipment

Top-loading balance
Large overflow tank
2 L volumetric cylinder
Mylar balloon and plastic tie
Thermometer (or Vernier temperature probe)
Vernier pressure sensor
Typical laboratory glassware

Questions to Discuss as you Plan

Think about what Δm represents in the following equation. How is this useful?

$$\Delta m = n(\text{molar mass of air}) - n(\text{molar mass of He})$$

What equations describing the physical behavior of gases may prove useful?

In these equations, what variables can you determine through physical measurements?

What are the known values of the constant(s) used in these equations?

What information can you obtain from the Periodic Table of the Elements?

Part B1: Finding Δm

1. Using the top-loading balance, obtain the combined mass of the empty Mylar balloon and plastic tie. (How much would you expect the balloon to weigh filled with air? Try it if you like!)
2. Carefully, with the help of your TA, fill the Mylar balloon with helium. **Care should be taken to avoid overfilling the balloon.** It should be completely expanded to fill the volume but not stretched tight. When full, twist the neck of the balloon closed and fasten it using the plastic tie. Obtain the mass of the filled balloon assembly on the top-loading balance.
3. Find the difference in mass (Δm), of the balloon empty and filled with helium.
4. Repeat steps 2 and 3 two more times. Find the average difference in mass, Δm , and record your team's value on the board. ***Think about how you would expect a balloon filled with helium to behave in air (and in helium). Why would it behave this way?***

As a group, discuss the data that has been collected. Is there anything unusual about the change in mass? Is it what you expected? What does Δm represent? Could Δm be related to Archimedes' principle?

Part B2: Finding the Molecular Weight of Air

In this part of today's investigation, you will be using the equipment available to you in the lab room, your knowledge of the ideal gas equation ($PV = nRT$), and the data for Δm you collected in Laboratory Part 1. You have the all tools necessary to design and execute an investigation to provide you with the molecular weight of air. Read carefully through the material on this section before planning and executing your determination. After you have developed a plan, discuss it with your TA.

Consider some physical properties you might be able to use to calculate the molecular weight of air. Your TA can assist you in measuring the ambient pressure and temperature using the [Vernier hardware](#) in conjunction with [LoggerPro software](#). Also, recall that the volume of an object can usually be measured using the water displacement method.

Using the Vernier Hardware for Ambient Pressure and Temperature Measurements

A Vernier pressure sensor is available in the lab, which can measure pressure changes in gases, but can also easily measure the current atmospheric pressure. The procedure for setting up this sensor is as follows:

1. Plug the cord from the Pressure Sensor box into one of the four channels (CH1, CH2, etc.) on the LabPro box.
2. Go to the Setup pull-down menu and select "Set Up Sensors" followed by "Show All Interfaces." A Dialog Box will open which shows the four channels along with a series of boxes that show which probe is plugged into each port. Right click on the box corresponding to the Channel you're using for the pressure sensor. Select "Choose Sensor" and follow through the menus until you find "Pressure Sensor." A tiny picture of the pressure sensor should appear in the box corresponding to the selected Channel.
3. You will see the present atmospheric pressure displayed.
4. The Vernier temperature probe can be set up in an analogous fashion.

Using the Water Displacement Method for Volume Measurements

A sizeable overflow tank (scientists call it a "trash can with a spout") is available in the lab should you wish to obtain the volume of a large object. The procedure for using this tank is straightforward:

1. Place the overflow tank in or over a large sink (if it is not already there) and fill the tank until water just begins to spill out the overflow spout. When water ceases to flow from the spout, you are ready to begin. If a few drops of water are remaining at the mouth of the overflow tube, remove these before you start your measurement.
2. Place a large, empty container below the spout.
3. Place the object, whose volume you wish to measure, inside the tank. Gently push it down until all of it is just submerged. (Try not to measure the volume of your hand along with the object.) (If you are measuring the volume of a filled balloon, be sure that no gas can escape from the neck of the balloon as you are taking the measurement. This would change the volume you wished to measure.) Hold the object below the surface until water stops overflowing.
4. Remove the object from the tank.
5. Measure the volume of the overflow water, which will be the same as the volume of the submerged object.

Calculate an accepted value for the average molecular mass of dry air. Use this value to calculate the % error in your experimentally determined value for the molecular weight of air. In your group report, briefly explain the factors that you think contributed to the error in your experimental value. Also, include a value for the actual mass of the He in the balloon, as well as calculations for the densities of air and helium.