EXPERIMENT 4

HAVE A BLAST FINDING MOLAR MASS

An Ideal Gas Experiment

Contents:

ADAM

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Teacher Guide

HAVE A BLAST FINDING MOLAR MASS

An Ideal Gas Experiment

AGE LEVEL

This experiment is designed for ages 14-18. It can be adapted for ages 11-13.

SUBJECTS

Gases and the Kinetic-Molecular Theory, science as inquiry and data analysis.

PURPOSES

1. To demonstrate the use of the Ideal Gas Law, Daltons' Law of Partial Pressures, and the Kinetic Theory of Gases by:

   A. Measuring pressure, volume and temperature and using the ideal gas equation to calculate the amount of gas (moles). Then, using the measured mass of the gas and the calculated number of moles to determine the molar mass of the unknown gas. (Ideal Gas Law)

   B. Considering how mixtures of gases behave and calculating the pressure of the unknown gas based on the composition of the mixture. (Dalton's Law of Partial Pressures)

   C. Applying the Kinetic-Molecular Theory of gases to experimental observations and the gas laws.

2. To determine the molar mass and formula of a gas from the measured properties of gases.

3. To have students analyze data that has been collected using laboratory equipment (balances).

TIME NEEDED

One laboratory period. Additional time may be required for analysis of data and additional discussions.

ACTIVITY OVERVIEW

Students collect and measure a sample of the gas inside an AirDR® can to determine the molar mass of the gas. With some additional information, students can determine the molecular formula of the gas and get some clue as to the identity of the gas.

This lesson is designed to be easily and quickly integrated into existing curriculum. It comes complete with a three-page student handout, vocabulary lists, plus extensions and assessment tools with answer keys. This Adam Equipment experiment is appropriate for remedial, review, reinforcement or extension purposes.

HELPFUL ADVICE TO MAXIMIZE SAFETY AND STUDENT SUCCESS

1. As always, students should be encouraged to wear safety goggles during any laboratory experiment.

2. Use the dust remover in a well-ventilated area and follow other safety instructions on the container.

3. Discuss the accuracy of centigram balances.

SCIENCE SKILLS AND ABILITIES

UNIFYING CONCEPTS AND PROCESSES

The experiment should facilitate and enhance the learning of scientific concepts and principles, providing a big picture of scientific ideas by examining:

- Evidence, models, and explanation. (Ages 14-18)
- Change, constancy, and measurement. (Ages 10-18)

SCIENCE AS INQUIRY

Abilities necessary to do scientific inquiry:

- Develop descriptions, explanations, predictions and models using evidence and explanations. (Ages 10-13)
- Formulate scientific explanations and models using logic and evidence. (Ages 14-18)
- Using mathematics in scientific inquiry. (Ages 10-18)

PHYSICAL SCIENCE

Understanding the structure and property of matter. (Ages 14-18)

HISTORY AND THE NATURE OF SCIENCE

Nature of scientific knowledge. (Ages 14-18)

DATA ANALYSIS, PROBABILITY AND DISCRETE MATHEMATICS

Understand and apply data collection, organization and representation to analyze and sort data. (Ages 10-18)

GEOMETRY AND MEASUREMENT

Understand and apply appropriate units of measure, measurement techniques, and formulas to determine measurements. (Ages 10-18)

KEY VOCABULARY

BAROMETRIC PRESSURE: The pressure of the atmosphere often expressed in terms of atmospheres, or mm of Hg (the height of a supported column of mercury).

DALTON'S LAW OF PARTIAL PRESSURE: The pressure of a gas mixture is the sum of the partial pressures of the individual components of the gas mixture.

DISPLACEMENT: When one object/substance takes the place of another object/substance.

EMPIRICAL FORMULA: The smallest whole-number ratio of atoms present in a compound.

IDEAL GAS: A hypothetical gas that strictly obeys the postulates of the Kinetic Theory.

IDEAL GAS LAW: $PV = nRT$

The product of the pressure and volume of a gas is directly proportional to the number of moles of the gas and the absolute temperature.

KINETIC THEORY OF GASES: Theory that explains macroscopic observations of gases in microscopic terms. This theory has 3 basic assumptions:

1. The size of the gas molecules are infinitely small compared to the volume occupied by the gas.

2. Gas molecules undergo elastic collisions (no energy loss) with the container and other gas molecules.

3. Gas molecules are in constant motion and are governed by the laws of motion including $KE = \frac{1}{2} mv^2$.

GRAM: A fundamental unit of mass used in the metric system (equal to the weight of one cubic centimeter of distilled water at 4°C) 1 gram = 100 centigrams.

MASS: A measurement that reflects the amount of matter (more precisely, the sample's weight divided by acceleration due to gravity).

MOLAR MASS: The mass of one mole of a substance, usually expressed in grams or kilograms. Molar mass is a characteristic commonly used to help identify a gas.

MOLECULAR FORMULA: The chemical formula that indicates the actual type and number of atoms in a molecule of a molecular substance.

MOLECULE: The smallest particle of an element or compound that retains the chemical properties of the element or compound and is capable of independent existence.

PNEUMATIC TROUGH: A trough with a perforated shelf that is used, when filled with water or mercury, to collect gases.

VAPOR PRESSURE: The partial pressure of a gas in equilibrium with a condensed form (solid or liquid) of the same substance.

VOLUME: 1. The amount of space an object takes up. 2. The amount of space a container can hold.

SAMPLE DATA

DATA LOG

Original mass of can	390.45 g	
Final mass of can	389.66 g	
Mass of gas collected	0.79 g	
Volume of gas collected	246 mL	0.246 L
Temperature of water	18.7°C	297.7 K
Barometric pressure	1.012 atm	
Water vapor pressure	16.2 mm Hg	0.0213 atm

CALCULATIONS OF MOLAR MASS (M):

$$PV = \frac{mRT}{M} \quad (0.991\ atm)(0.246L) = \frac{0.79\ g\ (0.0821\ atm\ L/mol\ K)(291.7K)}{M}$$

$$M = 77$$

EMPIRICAL FORMULA CALCULATIONS:

(given percent composition of C,H and F)

$$\frac{36.36g\ C}{}\ \Big|\ \frac{1\ mol\ C}{12\ g\ C} = 3.03\ mol\ C \div 3.03 = 1$$

$$\frac{6.06g\ H}{}\ \Big|\ \frac{1\ mol\ H}{1\ g\ H} = 6.06\ mol\ H \div 3.03 = 2$$

$$\frac{57.58g\ F}{}\ \Big|\ \frac{1\ mol\ F}{19\ g\ F} = 3.03\ mol\ F \div 3.03 = 1$$

Empirical formula is CH_2F; empirical mass = 33 g

MOLECULAR FORMULA CALCULATIONS:

$$\frac{Molar\ mass}{Empirical\ mass} = \frac{77}{33} = 2.3 \qquad \text{Rounding to a whole number (considering laboratory errors), this number is 2.}$$

Molecular Formula = $C_2H_4F_2$ difluoroethane

ANSWER KEY FOR STUDENT ASSESSMENT SHEET

ANALYSIS

1. $PV = \dfrac{mRT}{M}$ $\quad$ $(0.991 \text{ atm})(0.246 \text{L}) = \dfrac{0.79 \text{ g} (0.0821 \text{ atm L/mol K})(291.7 \text{K})}{M}$

$$M = 77 \text{ g}$$

2. $\dfrac{36.36\text{g C}}{} \Big| \dfrac{1 \text{ mol C}}{12 \text{ g C}}$ $\quad = \quad 3.03 \text{ mol C} \quad \div \quad 3.03 \quad = \quad 1$

$\dfrac{6.06\text{g H}}{} \Big| \dfrac{1 \text{ mol H}}{1 \text{ g H}}$ $\quad = \quad 6.06 \text{ mol H} \quad \div \quad 3.03 \quad = \quad 2$

$\dfrac{57.58\text{g F}}{} \Big| \dfrac{1 \text{ mol F}}{19 \text{ g F}}$ $\quad = \quad 3.03 \text{ mol F} \quad \div \quad 3.03 \quad = \quad 1$

Empirical formula is CH_2F; empirical mass $= 33$ g

$\dfrac{\text{Molar mass}}{\text{Empirical mass}} = \dfrac{77}{33} = 2.3$ $\quad$ Rounding to a whole number (considering laboratory errors), this number is 2.

Molecular Formula $= C_2H_4F_2$ $\quad$ difluoroethane

CONCLUSIONS

1. In the can, the gas is pressurized. Under increased pressure, the difluoroethane experiences strong enough forces of attraction to condense the gas into a liquid. The pressure drops back to atmospheric pressure when the gas is released from the can. The sample being released then expands and vaporizes into a gas.

2. If any air remains in the graduated cylinder, the volume of that air would be incorporated into the lab measurement of the volume of gas collected. The recorded measurement for the volume of the gas would be larger than the true volume of the gas. Error in this measurement would cause additional errors as laboratory calculations are performed.

3. Gases are characterized as having low densities due to a small mass per unit volume. Our sample of gas released has a small mass compared to the total mass of the gas in the can. The gas released from the pressurized can expands to occupy a much larger volume under normal atmospheric conditions. So, to get a measurable amount of gas in grams, with any degree of accuracy, a rather large volume of gas should be collected.

4. The graduated cylinder is initially filled with water. Both water and the gas being collected are forms of matter. Matter is defined as having mass and occupying space. The matter being collected is a gas with a lower density than the water in the graduated cylinder, so the gas will rise to the top of the graduated cylinder. Needing space to occupy, the gas will displace the water in the graduated cylinder, pushing the water out of the graduated cylinder as the gas takes over the space once occupied by the water. For a gas to be collected by water displacement, the gas should not be soluble in the water or react with the water.

5. When a gas is collected by water displacement, the gas collected is not a pure gas but a mixture of gas plus some water vapor. Depending on the temperature of the water in the graduated cylinder, some molecules of liquid water can go into the vapor phase. The water vapor would be measured along with the gas being collected. To accurately measure the pressure of the gas being collected, the pressure of the water vapor molecules must be subtracted from the total pressure.

Before recording the volume of gas collected, the height of the graduated cylinder needs to be adjusted so the level of the water inside the graduated cylinder is the same as the level of water in the pneumatic trough or bucket being used. The pressure of the gas or gases inside the graduated cylinder is then equal to the atmospheric pressure in the room. Atmospheric pressure can be recorded from a barometer.

REAL WORLD APPLICATIONS

1. A tank of propane is under increased pressure and the molecules of the gas are compressed with less space between the particles. There is an increased number of molecules in the volume of the propane tank. Opening the valve to the propane tank releases small masses of propane, but the volume of the propane really increases when the propane is no longer under pressure. One tank of propane might last through the entire summer of grilling!

2. Under the same conditions of temperature and pressure, a certain volume of hydrogen in a balloon will contain the same number of molecules as the same volume of carbon dioxide in a balloon. So why does the hydrogen balloon rise while the carbon dioxide balloon sinks, if the number of molecules are identical? Obviously, it is the molecules themselves that are different. A molecule of hydrogen (2.0 grams/mole of hydrogen) is more than 20 times lighter than a molecule of carbon dioxide (44.0 grams/mole of carbon dioxide). Air, which is primarily nitrogen and oxygen, has an approximate mass of 29 grams/mole. Therefore, the balloon filled with hydrogen would rise. The balloon does not weigh as much as the equivalent volume of air. The balloon filled with carbon dioxide would sink because the carbon dioxide weighs more than the air displaced by the balloon.

POSSIBLE EXTENSIONS

This experiment can be repeated using other gas samples that have low solubility in water. Try collecting a sample of gas from a small butane fuel cylinder used to refill butane lighters. These can be purchased in the cigarette/cigar section of a local supermarket. Repeat the laboratory procedure and collect data. Calculate the molar mass of the gas by using the ideal gas equation.

Use the following data to calculate the empirical formula: carbon, 82.76%; hydrogen, 17.24%. Find the empirical formula and the empirical mass. Then, use the molar mass and the empirical mass of the gas to calculate the molecular formula of butane.

TEACHER PREPARATION

No advance preparation needed, except for buying the cans of gas and getting out the equipment for students to use.

ADDITIONAL RESOURCES

Visit adamequipment.com/education regularly for new classroom resources.

ABOUT ADAM EQUIPMENT

Adam Equipment's world headquarters is located in Milton Keynes, United Kingdom, with facilities in the United States, Australia, South Africa and China. The company's balances have been trusted by professionals worldwide for 40 years. Contact Adam Equipment at education@adamequipment.com or online at www.adamequipment.com/education.

ADAM EQUIPMENT BALANCES RECOMMENDED FOR THIS EXPERIMENT

Highland Portable Precision Balance
Models recommended for this experiment:
HCB 602H or HCB 1002 (600g or 1000g capacity x 0.01g readability)

Complete with more features and accessories than any other in its class, Adam Equipment's Highland Portable Precision Balances have what it takes for school and college applications. The reliable Highland provides the latest in weighing technology, 15 weighing units with four weighing modes and it is easy enough for novice students. It features Adam's unique patented ShockProtect™ overload protection to withstand up to 200kg, and HandiCal™ internal calibration with built-in mass. Calibrate whenever you want without external masses or use your own masses. USB and RS-232 interfaces are both included with cables. The rechargeable battery (adapter/charger included), removable draft shield and brilliant backlit display with capacity tracking make Highland the most complete portable precision balance available. Available in seven models from 150g x 0.001g to 3000g x 0.1g. For complete product details, visit www.adamequipment.com/education.

GETTING INVOLVED IN ADAM EQUIPMENT'S EXPERIMENTS

Feedback On This Adam Experiment

If you have feedback on this Adam Experiment that would be valuable to other teachers, we encourage you to share your thoughts. Please email your comments to Adam's education division at education@adamequipment.com.

Submitting Your Own Experiment

If you have an idea for a useful educational resource that you would like to share with other teachers, Adam Equipment is interested in hearing from you. Initial submissions need to include only a simple description of the activity with the activity's purpose, subject, and grade level. Please contact Adam's education division by e-mail at education@adamequipment.com to determine if your particular activity will fit into our experiment library. Adam Equipment will respond promptly to all inquiries.
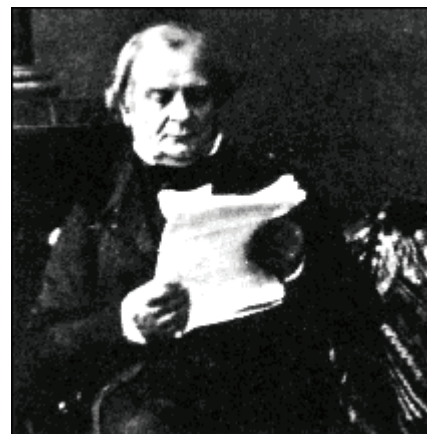
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Student Section

HAVE A BLAST
FINDING MOLAR MASS

An Ideal Gas Experiment

INTRODUCTION

You can easily identify some common gases based on their unique characteristics and behavior. For example, a laboratory test for oxygen involves combustion. A glowing splint or any other burning substance will burn better in pure oxygen than it does in air (oxygen supports combustion). Carbon dioxide will extinguish a glowing splint or a flame (carbon dioxide does not support combustion). When a burning splint is brought to the mouth of a test tube filled with hydrogen gas, there is a characteristic hydrogen "bark." Hydrogen is flammable. When hydrogen burns, the only product formed is water.

How are other gases identified?

Take two identical balloons and fill one with hydrogen, the other with carbon dioxide gas. Both balloons will contain the same number of molecules of gas (mole concept); however, the hydrogen balloon will rise while the CO_2 balloon will sink if released in the air (density concept).

Earth's gravity acts on the gas in each balloon. Since the number of gas molecules in each balloon is the same, it must be the mass of those gas particles which causes one balloon to rise (lighter gas particles) and the other balloon to sink (heavier gas particles). If the mass of the particles in the two balloons differs, molar mass is a unique characteristic of the gas in each balloon. The molar mass is a characteristic that can be used to identify the gas. How would you determine the molar mass if you did NOT know the identity of the gas and you had no formula for the gas?

Emile Clapeyron
Author of the Ideal Gas Law

*A French engineer and physicist who is one of the founders of thermodynamics.
In recognition of his many contributions, his is one of the 72 names engraved on the Eiffel Tower.*

PURPOSE

How are gases identified? Solid and liquid substances can often be identified by physical properties such as appearance, density, melting point and boiling point. Identifying a gas is not as easy unless it has a characteristic odor, color, or behavior. By conducting this experiment, you'll have a blast using the Ideal Gas Law to calculate the molar mass of an unknown gas to identify it.

WHAT YOU NEED

- Full can of AirDR® or similar product
- 30-40 cm of rubber tubing
- Pneumatic trough or small plastic bucket
- 250 mL graduated cylinder
- Room temperature tap water, for trough & cylinder

- Thermometer
- Metric ruler
- Barometer
- Safety goggles
- HCB 602H or 1002 balance

STUDENT PROCEDURE

1. Record the mass of a can of AirDR® using a centigram balance.

2. Attach rubber tubing to the nozzle on the can.

3. Fill a 250 mL graduated cylinder completely full of water, invert it and place it inside a pneumatic trough which is filled at least half-way with water. Be sure the cylinder contains no air bubbles (This can also be done in a small plastic bucket).

4. Hold the rubber tubing from the can under the water and below the mouth of the inverted cylinder and press the release button on the can. Make sure <u>all</u> the bubbles of the gas are going up into the cylinder.

5. Collect approximately 250 mL of gas in the graduated cylinder. Remove rubber tubing then re-mass the can of AirDR®. Record.

6. Measure the height difference, if any, between the water in the trough and that remaining in the graduated cylinder. If possible, adjust the position of the cylinder in the water so that the water levels inside and outside the cylinder are the same. Record the volume of gas collected.

7. Measure the temperature of the water (it will be assumed that the gas will be at the same temperature) and read the atmospheric pressure from a barometer.

STUDENT WORKSHEET

NAME: _____ CLASS: _____ DATE: _____

Hypothesis: _____
_____
_____

Data Log:

Original mass of can	g
Final mass of can	g
Volume of gas collected	mL
Temperature of water	°C
Barometric pressure	
Water vapor pressure	

Ideal Gas Equation

$$PV = nRT$$

P = absolute pressure
V = absolute volume
n = number of moles
R = universal gas constant
T = absolute temperature

Analysis:

1. Calculate the molar mass of the gas using the ideal gas equation.

2. The percentage composition of the gas in the can is as follows: carbon, 36.36%, hydrogen, 6.06%, and fluorine, 57.58%. Calculate the empirical formula and then using the calculated molar mass, see if you can get a whole-number multiple of the empirical formula for the molecular formula of the gas.

Conclusions:

1. How do you explain the fact that the gas is a liquid in the can, but a gas when it is collected?

2. Why is it important that the graduated cylinder used to collect the gas be completely filled with water?

3. Why is it necessary to collect a large volume of gas if the balance being used only measures to the nearest 0.01g?

4. What is water displacement and why can this gas be collected in this manner?

5. Why did you have to consider water vapor pressure, and possibly a height difference between the water levels inside and outside the graduated cylinder?

Real World Application:

1. How can a grill tank hold enough propane to cook all summer long?

2. If you fill one balloon with a certain amount of hydrogen and another with the same amount of carbon dioxide, why does the hydrogen balloon rise while the CO_2 balloon sinks?