# Moles, Mass, and Volume

## PURPOSE

**A** To determine how many years it would take to count a mole of popcorn.

**B** To determine the mass of a mole of popcorn, the mass of a mole of marbles, and the ratio of these molar masses.

**C** To determine the volume of an individual water molecule, the volume of a marble, and the ratio of these volumes.

## GOALS

- To gain an understanding of the mole and Avogadro's number.
- To gain an understanding of the molar mass and the density of a substance.
- To learn how to use the factor label method for solving mathematical problems.

## INTRODUCTION

Atoms are extremely small. How small? Consider aluminum, a substance familiar to you. You know it as furniture (lawn chairs), pie pans, soft drink cans, and foil. However, one atom of aluminum has a mass of $4.5 \times 10^{-23}$ g. There are about $3.3 \times 10^{23}$ atoms of aluminum in a soft drink can.

How do we count atoms and work with them when they are so incredibly small? We group them. Just as we often work with a dozen (12) items such as eggs, we work with **moles** of atoms. A mole is $6.02 \times 10^{23}$ of **anything**. It is a huge number. A mole of reams of copier paper (each 1.9 inches thick) stacked up would be $1.8 \times 10^{19}$ miles high, about 1/10 of the diameter of the Milky Way galaxy. It's only $9.2 \times 10^{7}$ miles from the earth to the sun. A mole of pennies is more money than the U.S. government spent in the $20^{\text{th}}$ century.

The number $6.02 \times 10^{23}$ is Avogadro's number. This honors Amedeo Avogadro, who recognized that equal volumes of gases at the same temperature and pressure contain equal numbers of molecules.

Since we have an extremely large number, the mole, and these infinitesimal particles, atoms, a mole of atoms is a convenient quantity to work with in a laboratory. A mole of helium atoms has a mass of 4 grams (a bit more than a peanut) and a mole of lead atoms has a mass of 207 grams (about the mass of a coffee mug). The mass of a mole of atoms of any element is called its **molar mass**. It has units of grams per mole (g/mol). The molar mass of atoms of each element is characteristic of that element, and is listed on the periodic table.

So far, we have talked about moles of atoms, which applies to elements. What about compounds? Compounds are combinations of elements, which can be expressed as formulas. For example, water contains two hydrogen atoms and one oxygen atom; its formula is $H_2O$. Its molar mass is the sum of the masses of the atoms in the formula:

 

$$\begin{array}{rcrl} \text{2 moles of H atoms} \times \text{1.0 g/mole of H atoms} & = & 2.0 & \text{g} \\ \text{1 mole of O atoms} \times \text{16.0 g/mole of O atoms} & = & \underline{16.0} & \text{g} \\ & & 18.0 & \text{g/mol of } H_2O \end{array} \qquad (1)$$

In chemistry, and the quantitative sciences generally, one must often set up calculations involving different units. It is good practice to use the "**conversion factor**" approach to do this. For example, in this experiment, you will be determining how many popcorn kernels you can count in 30 seconds. If you wanted to know how many kernels you could count in a minute, you would use a conversion factor: 1 min = 60 s, which can also be expressed as 60 s/min or 1 min/60 s. Thus, if you counted 25 kernels in 30 seconds, you could count 50 kernels in a minute:

$$1 \cancel{\text{min}} \times \frac{60 \cancel{\text{s}}}{\cancel{\text{min}}} \times \frac{25 \text{ kernels}}{30 \cancel{\text{s}}} = 50 \text{ kernels} \qquad (2)$$

The unit "s" appears in the numerator of one term of Equation 2, and in the denominator of another term. Algebraically, s/s = 1, just like a numerical value. The units cancel and do not appear in the result.

Although the example above shows a conversion between two units of time, conversion factors between units of different types are also useful. Molar mass, in g/mol, is such a unit. For example, suppose you had 5.0 g of water. How many moles of water is that?

$$5.00 \cancel{\text{g } H_2O} \times \frac{1.00 \text{ mol } H_2O}{18.0 \cancel{\text{g } H_2O}} = 0.278 \text{ mol } H_2O \qquad (3)$$

In Equation 3, g $H_2O$ appears in the numerator and denominator and cancels. This may seem cumbersome, but it is a useful way to keep track of things in more complicated problems. More examples will appear in subsequent labs.

The conversion factor approach, which is also called the **factor label method**, factor analysis, or dimensional analysis, is a very useful place to start if you aren't sure how to do a problem. Figure out what units the problem is asking for (moles of water in the example above) and set up the problem with the terms you are given, such that unwanted units cancel out. Add conversion factors, e.g., from seconds to minutes, if needed.

A very useful conversion factor relates mass and volume. It is **density**, mass per unit volume. In chemistry, it is usually expressed in g/mL (or its equivalent, g/cm$^3$). Pure water at 25°C has a density of 1.00 g/mL. One gram of water occupies exactly one milliliter. This is a useful relationship; memorize it.

In this lab, you will do several experiments that will help you visualize how big a mole is, how small an atom is, and how to count by moles. You will use the conversion factor approach frequently in the calculations for this lab.

This experiment has three parts. In Part A, you will time yourself counting popcorn kernels and figure out how many years it would take to count a mole of kernels. In Part B, you will measure the mass of a dozen popcorn kernels and a dozen marbles. You will relate these masses to the masses of individual items, and to each other. In Part C, you will measure the volume of a mole of water molecules and the volume of a dozen marbles. Then you will calculate the volumes of an individual molecule and a single marble.

## EQUIPMENT

1 150 mL beaker

1 50 mL graduated cylinder

1 100 mL graduated cylinder

1 timer, good to 1 second

~50 uncooked popcorn kernels

12 marbles

1 deionized water squirt bottle

## REAGENTS

deionized water

## SAFETY

None of the materials being used in this experiment present a safety hazard. However, the work is being done in a laboratory and the usual rules about eye protection and proper clothing apply.

## WASTE DISPOSAL

Popcorn and marbles should go back to the proper containers in the set-up area.

## PRIOR TO CLASS

Please read Lab Safety[1].

Please read the following sections in Lab Equipment: Analytical Balance[2] and Graduated Cylinder under Volumetric Glassware[3].

Please review the following videos: Safety[4] and Analytical Balance[5].

## LAB PROCEDURE

Please print the worksheet for this lab. You will need this sheet to record your data.

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[1] ../safety/manual.html
[2] ../equipment/manual.html#balance
[3] ../equipment/manual.html#volumetricglassware
[4] ../movies/labsafety.html
[5] ../movies/balance.html

 

## Part A: How Big is a Mole?

**1** Obtain a small beaker and a jar of popcorn from the set-up area. If you have a watch with a second hand use it as your timer or use the clock on the wall in the lab.

**2** One person should act as the counter, the other as the timer. When the timer signals, the counter should start counting kernels, dropping them into the beaker one at a time. At the end of 30 seconds, stop counting and record the count in Table A.

**3** Repeat the experiment three more times, switching jobs as counter and timer for each trial. Record the results in Table A.

**4** Calculate the average number of kernels counted in the four trials, and enter the value in Table A.

## Part B: Molar Masses (Counting by Moles)

**1** Determine the mass of the beaker and record it in Table B.

**2** Place 12 popcorn kernels in the beaker, and determine the mass of the beaker plus popcorn. Record this mass in Table B.

**3** Calculate the mass of the popcorn by subtracting the mass of the beaker from the combined mass of the beaker and popcorn. Record the result in Table B.

**4** Use the mass of a dozen popcorn kernels to calculate the mass of a single kernel and enter this value in Table B.

**5** Repeat steps 1–4 using marbles instead of popcorn kernels.

## Part C: Volume, Mass, Density, and Moles

**1** Weigh a 50 mL graduated cylinder and record its mass in Table C.

**2** Fill the cylinder to the 18 mL mark with deionized water. Use the squeeze bottle for the last few drops. Try to get the bottom of the meniscus (the curved surface of the water) as close to the gradation for 18 mL as you can. Read the volume at the bottom of the meniscus and record it to the nearest 0.1 mL in Table C. It is more important that you record the volume exactly than that you have exactly 18.0 mL.

**3** Obtain the mass of the cylinder with the water in it; record the mass in Table C.

**4** Calculate the mass of the water and record it in Table C.

**5** Using the mass and the volume of the water, calculate the density of the water in g/mL and record your result in Table C.

**6** Fill the 100 mL graduated cylinder to the 50 mL graduation with deionized water. Record the initial volume of water to 0.1 mL in Table C.

**7** Place twelve marbles in the cylinder containing the water. Do this carefully, one marble at a time. Tilt the cylinder so the marble rolls down its side; avoid allowing water to splash out.

 

**8** Read the final volume of the water in the cylinder to 0.1 mL. Use the bottom of the meniscus for this value. Record the result in Table C.

**9** Calculate the volume of water displaced by the marbles, and record it in Table C.

**10** Using the mass of a dozen marbles from Part B and the volume of a dozen marbles, calculate the density of the marbles in g/mL and record your result in Table C.

**11** When you have completed your measurements, dry all your equipment and return it neatly to the set-up area where you found it.

**12** Before leaving, go to a computer in the laboratory and enter your results in the In-Lab assignment. If all results are scored as correct, log out. If not all results are correct, try to find the error or consult with your lab instructor. When all results are correct, note them and log out of WebAssign. The In-Lab assignment must be completed by the end of the lab period. If additional time is required, please consult with your lab instructor.

 