

NAME \_\_\_\_\_

SECTION \_\_\_\_\_

PARTNERS \_\_\_\_\_

DATE \_\_\_\_\_

## MOLES, MOLECULES, FORMULAS

This activity is designed to introduce a convenient unit used by chemists and to illustrate uses of the unit.

### Part I: What Is a Mole And Why Are Chemists Interested in It?

Counting things is a normal part of everyday life. How many days left until vacation? How many eggs do I need for the recipe? If large numbers of things are involved, we use grouping strategies to make the numbers easier to manage. For example, 4 more *weeks* until vacation, tells us that there are twenty-eight days. One *dozen* eggs is the common way of expressing the quantity 12. Half of a dozen of anything would be 6 units. One *gross* is 144 items (12 dozen) and a *ream* of paper contain 500 sheets.

Chemist are faced with a unique problem when dealing with numbers of atoms or molecules. The particles are so small that any amount of them that we are able to physically handle contains a number of particles so large that there is nothing else in our experience that contains so many units. This *incredibly large number calls for a special counting group - the MOLE*.

**A MOLE is  $6.022 \times 10^{23}$  particles.** This is often referred to as *Avogadro's number*. Let's make sure we understand how big this is. One mole of the element carbon has a mass of 12.01 grams. The smallest particle of an element is an atom. So one mole of carbon contains 602,200,000,000,000,000,000,000 atoms of carbon.

Look for the element carbon on the periodic table. Do you notice anything special about the value 12.01? Explain \_\_\_\_\_

The mass of one mole of the element magnesium is 24.30 grams. How many atoms does a sample of magnesium with a mass of 24.30 grams contain? \_\_\_\_\_

Stated in general terms, the mass of one mole of any element is equal to the \_\_\_\_\_ of that element expressed in grams. The mass of a mole of any element can be found by looking on \_\_\_\_\_.

The mass of 0.5000 moles of carbon is \_\_\_\_\_ and contains \_\_\_\_\_ atoms of carbon.

*Remember when dividing numbers written in scientific notation the number portion is divided*

normally and the exponents are subtracted.  $6.022 \times 10^{23}$  divided by 2 is the same as  $6.022 \times 10^{23}/2 \times 10^0$ . So the answer is found by dividing 6.022 by 2 = 3.011 and the subtracting exponent 0 from exponent 23. The answer in scientific notation is  $3.011 \times 10^{23}$  atoms of carbon.

**Calculator tip:** for exponential notation use the EE or EXP key (not  $10^\wedge$ )

If you have a bottle containing 8.10 grams of magnesium, how many Mg atoms are present in the bottle? Show your work. What is different about this problem compared to the last one involving carbon?

Remember that some elements, when alone, exist in the form of diatomic molecules:  $H_2$ ,  $O_2$ ,  $N_2$ ,  $I_2$ ,  $F_2$ ,  $Cl_2$ ,  $Br_2$ . Their smallest piece is a molecule containing two atoms. If one mole of oxygen were required for an experiment you would be using  $O_2$  the gas. One mole of  $O_2$  would have a mass of \_\_\_\_\_ and contain \_\_\_\_\_ particles (molecules).

The characteristic unit of the compound  $CO_2$  is a molecule. Each  $CO_2$  molecule has \_\_\_\_\_ atoms. In order to find the mass of one molecule of  $CO_2$ , it is necessary to add together the atomic masses of each of the atoms in the compound. Atomic masses are expressed in atomic mass units (a.m.u.)

$$\begin{array}{rcl} C = 12.01 \text{ a.m.u. per atom} \times 1 \text{ atom} & = & 12.01 \text{ a.m.u.} \\ O = 16.00 \text{ a.m.u. per atom} \times 2 \text{ atoms} & = & + \underline{32.00 \text{ a.m.u.}} \\ & & 44.01 \text{ a.m.u.} \end{array}$$

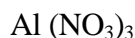
**Note:** The conversion between a.m.u. and grams is  $1 \text{ a.m.u.} = 1.66 \times 10^{-24} \text{ g}$ , therefore:

$$\frac{44.01 \text{ a.m.u.}}{1 \text{ molecule } CO_2} \times \frac{6.022 \times 10^{23} \text{ molecules } CO_2}{1 \text{ mole } CO_2} \times \frac{1.66 \times 10^{-24} \text{ g}}{1 \text{ a.m.u.}} = \underline{44.00 \text{ g } CO_2} \text{ (close!)}$$

44.01 a.m.u. is the mass of one molecule of  $CO_2$  while 44.01 g is the mass of one mole of  $CO_2$  (or  $6.022 \times 10^{23}$  molecules of  $CO_2$  or  $[3 \times 6.02 \times 10^{23}]$  total number of atoms). The numerical value from the periodic table is the same but the units depend on whether you are referring to one unit (atom or molecule) or a mole of the units.

**The molar mass of any substance is the mass of  $6.022 \times 10^{23}$  units of the substance.**

Find the molar masses of the following compounds. Show your work.



If you know that a dozen tennis balls has a mass of 1.00 lbs, how would you find the mass of one tennis ball?

Using the same mathematical approach, what is the mass in grams of one magnesium atom? Show all work. What is the mass in grams of one molecule of  $\text{H}_2\text{SO}_4$ ?

## Part II. Using Moles to Find Formulas

Suppose you had exactly one mole of carbon, 12.01 grams and you chemically combined all of it with oxygen. In other words, you burned it completely.

Write the chemical equation for the reaction. \_\_\_\_\_

For every single atom of carbon, how many single atoms of oxygen are needed to form one molecule of the product carbon dioxide? \_\_\_\_\_

How many atoms of carbon are in one mole of carbon? \_\_\_\_\_

How many atoms of oxygen would be needed to form one mole of  $\text{CO}_2$ ? \_\_\_\_\_

What is the mass of the oxygen needed to react with one mole of carbon? \_\_\_\_\_

What would be the final mass of the  $\text{CO}_2$ ? \_\_\_\_\_

Let's suppose that you did not know ahead of time what the formula for the carbon dioxide product was. Maybe when carbon burns it forms  $\text{CO}$  or  $\text{CO}_3$  or perhaps  $\text{C}_2\text{O}_3$ . If you had burned 12.01 grams of carbon, collected all the gas that was formed and found its mass to be 44.01 grams, you would then know that the mass of the oxygen that added to the carbon was \_\_\_\_\_ grams.

$$32.00 \text{ grams of oxygen} \times \frac{1 \text{ mole of oxygen atoms}}{16.00 \text{ g of oxygen}} = 2 \text{ moles of oxygen atoms}$$

This information can be used to figure out the formula of the gas.

1 mole of carbon and 2 moles of oxygen combined to form a compound. For every one atom of carbon there are two atoms of oxygen. The formula could be  $\text{CO}_2$ . **The subscripts in a formula tell us the relative number of moles of the elements in the compound.** Please note that the actual molecular formula could be  $\text{C}_2\text{O}_4$  since the relative number of C to O in this compound is also 1:2.

If we know the masses of all of the elements that combined to form a compound and convert those masses to number of moles, and convert the values to whole numbers, we will know the relative number of moles for each element in the compound. These values are the subscripts in the **empirical formula** or the **simplest formula**.

In the following laboratory exercise, you will determine the empirical formula of the compound formed by the combination of the elements magnesium and oxygen. You will find the empirical formula in the way that we figured out the empirical formula of carbon dioxide, that is, by combining magnesium with oxygen and finding the mass of the oxide product. This is easier to do than finding the empirical formula of  $\text{CO}_2$  because the magnesium oxide is a solid. Because magnesium will react with nitrogen as well as oxygen, we cannot do the procedure in one step.

### PROCEDURE

- Before you begin reading the procedure- write down three pieces of data that you know you will have to collect during the activity in order to determine the empirical formula of magnesium oxide.
  - \_\_\_\_\_
  - \_\_\_\_\_
  - \_\_\_\_\_
- During the experiment, on the data sheet provided, construct a data table, show calculations, and clearly indicate the results and your conclusion. Write balanced equations for the all chemical changes that occur.
- Clean a crucible and cover. Place the crucible into a triangle on a ring and heat it in the hottest part of the Bunsen burner flame until bottom of crucible is red-hot. Continue heating for another minute (this eliminates any volatile impurities). USING CRUCIBLE TONGS place the crucible and cover on a fireproof fiber board to cool. For our purposes, cool means being able to pick it up comfortably without using the tongs.
- Find the mass of the heated crucible and cover.



5. Obtain a total of about 10 cm of Mg ribbon and clean it by stroking it with fine steel wool to remove any corrosion (oxidation product). Cut the ribbon into smaller pieces and place all of them into the crucible. Since the Mg tends to fly off as the ribbon is snipped it is recommended that you cut the ribbon at a sharp angle right over the crucible. Put the cover back on the crucible and re-mass.
6. Heat the covered crucible containing the Mg strongly for about **five minutes**. During the heating use the tongs to lift the cover off slightly every minute for a few seconds. This admits air into the crucible without allowing any oxide to escape. Next, remove the cover and heat strongly for another minute. Allow the crucible to cool. While heating, write any reactions for magnesium with oxygen and nitrogen on the data sheet.
7. Cool, replace cover, find final mass.

## **DATA SHEET**

### **Chemical Reaction:**

Heating magnesium in air (magnesium and oxygen)

### **Data**

### **Results**

## Extension Activity

1. We know that if we burn C completely we will get  $\text{CO}_2$ . The previous activity showed us how to get the empirical formula or simplest formula for a compound by finding the masses of all the elements in the compound and converting those masses to moles and dividing all of the moles by the lowest number of moles.

So, for carbon dioxide we would know that the empirical formula is  $\text{CO}_2$  or two oxygens for every one carbon atom. But the actual or molecular formula could be  $\text{C}_2\text{O}_4$ , since this also has a ratio of 1 to 2 carbons to oxygens.

### How can we find the molecular formula or actual formula if we know the empirical formula?

If I had one mole of  $\text{CO}_2$  it would have a mass of about 44 grams.

If the actual formula was  $\text{C}_2\text{O}_4$  the mass of a mole would be 88 grams.

There are ways of finding out the molar mass of a compound. One way is to use an instrument called a mass spectrometer. A sample of the compound is placed in the instrument and the relative masses of the elements are determined. In common types of empirical and molecular formula problems you will have to be told the molar mass. If you already have the empirical formula you find the empirical mass (molar mass of the empirical formula). Then, divide the molar mass by the empirical mass to get a whole number. Multiply the empirical formula by this number to get the molecular formula.

Example:  $\text{CH}_2$  = empirical formula      56.0 g/mole = molar mass  
14.0g = empirical mass    (12.0g (1 C atom) + 2.0g (2 H atoms) = 14.0)  
Molar Mass/Empirical Mass =  $56/14 = 4$   
So  $\text{C}_4\text{H}_8$  is the molecular formula.

### ***Try the following problem.***

*A compound made of oxygen and nitrogen when analyzed is found to have a composition of 1.52g of N and 3.47g of O. The molar mass is known to be between 90 and 95g. Determine its molecular formula and its precise molar mass.*