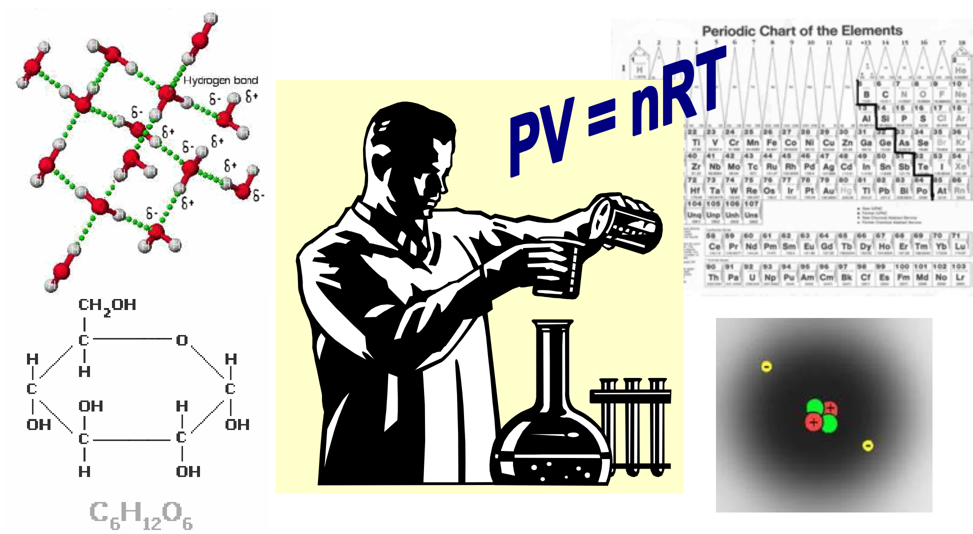
Project EASE

(Effective Alternative Secondary Education)

CHEMISTRY



MODULE 16

Stoichiometry

BUREAU OF SECONDARY EDUCATION
Department of Education
DepEd Complex, Meralco Avenue
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Module 16
Stoichiometry

Guess the number of grains of rice in a gallon container and win P 1,000,000.00.

What this module is about

A TV show requires texters to guess the number of grains of rice in a gallon container. The contestant whose guess is closest to the actual number will win the announced prize. How could you prepare for such a contest without actually counting the grains in a gallon of rice?

One way to get a good estimate is to count 100 grains of rice and weigh that sample. Weigh a gallon of rice. Then find the ratio of the number of grains of rice in the small sample (100 grains) to the number of grains of rice in the large sample which is the unknown. Suppose the 100 grains of rice weighed 0.012 kilograms and the gallon of rice weighed 2.0 kilograms. The unknown number of grains in a gallon can be calculated as

$$\frac{\text{X grains in a gallon}}{\text{100 grains}} = \frac{\text{2.00 kgs}}{\text{0.012 kgs}}$$

$$X = \text{16667 grains}$$

Why not weigh just one grain?
The calculation would be simpler but weighing one grain might be impossible with the balances available.

The situation is similar to counting atoms but the latter is much more difficult since individual atoms cannot be counted nor weighed in an ordinary manner. To count atoms, we use a constant called Avogadro's number which is equivalent to the MOLE.

Knowledge in mole concept is the key to relating mass, mole and number of particles in elements, compounds and chemical reactions. This is essential in chemical calculation which is known as stoichiometry.

This module has these lessons:

- **Lesson 1 – What is a Mole**
- **Lesson 2 – Mole-Mass Relationship**
- **Lesson 3 – Mass-Mass Relationship**
- **Lesson 4 – Percentage Composition of Elements in a Compound**

What you are expected to learn

After going through this module, you should be able to:

1. Define a mole.
2. Describe the relationship of mole, mass and number of particles.
3. Calculate the number of particles (atoms, ions, molecules) from moles or vice versa.
4. Convert number of moles to mass and vice versa.
5. Solve problems on mole-mass relationship.
6. Relate the coefficients of balanced equations to number of moles.
7. Solve problems on mass-mass relationship.
8. Determine mass percent composition of a compound from its formula.
9. Calculate the percent composition of elements in a compound.

How to learn from this module

Here are some helpful reminders before getting started:

1. Have a periodic table and calculator with you.
2. Take the pretest before proceeding to the lessons.
3. Perform the activities and read the discussions provided for in the lessons.
4. Answer the Self-Test. Compare your answers with the keys to correction.
5. Consult a dictionary if you are not sure of the meaning of some words used in this module.
6. Answer the posttest so that you will know how much you have learned from the lessons.
7. Keep an open mind to the new concepts you will be learning in this module.

Happy reading!

What to do before (Pretest)

Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. Which of the following represents a mole?
   a. 5 g of NaCl
   b. 6.02×10^{23} F atoms
   c. 3.01×102^{3} CH4 molecules
   d. 24 g graphite, C-atom

2. Which statement is **NOT** true?
   a. One mole of a substance contains a fixed number of particles.
   b. One mole each of different substances have different masses and different number of particles.
   c. One mole each of different substances have the same number of particles but they have different masses.
   d. The formula weight of the compound is equal to one mole of that substance.

3. Which statement is **NOT** true regarding the molecule $C_5H_8O_6$?
   a. One mole of $C_5H_8O_6$ contains 6.02×10^{23} particles.
   b. One mole of $C_5H_8O_6$ is equal to 168 g of $C_5H_8O_6$.
   c. The molar mass of $C_5H_8O_6$ is equal to one mole of $C_5H_8O_6$.
   d. 84 g of $C_5H_8O_6$ contains 6.02×10^{23} molecules.

4. Which is equivalent to one mole of SiH_4?
   a. 28 g SiH_4; 6.02×10^{23} particles
   b. 32 g SiH_4; 12.02×10^{23} particles
   c. 64 g SiH_4; 6.02×10^{23} particles
   d. 32 g SiH_4; 6.02×10^{23} particles

5. How many molecules are there in 2 moles of H_20_2?
   a. 2×10^{23}
   b. 6.02×10^{23}
   c. 12.04×10^{23}
   d. 6.02×10^{46}

6. How many hydrogen atoms are there in 72 mol of H atoms?
   a. 6.02×10^{23}
   b. 12.04×10^{24}
   c. 4.3×10^{25}
   d. 6.02×10^{46}

7. Which statement is correct?
   a. 4 g of CH_4 is equal to 4 moles of CH_4
   b. 4 g of CH_4 is equal to 1 mole of CH_4
   c. 4 moles of CH_4 is equal to 16 g of CH_4
   d. 4 moles of CH_4 is equal to 64 g of CH_4

8. What is the mass of one-half mole of SO_2?
   a. 8 g
   b. 12 g
   c. 24 g
   d. 32 g

9. How many moles are contained in 34g of NH_3?
   a. 1 mol b. 2 mol c. 17 mol d. 34 mol

10. What is the mass of 4.39 mol Na?
   a. 191 g b. 27.3 g c. 55.2 g d. 101 g

For questions 11 – 16, refer to the following equation

$$CS_2 + 2CaO \rightarrow CO_2 + 2CaS$$

11. How many moles of CO_2 are obtained from the reaction of 2 moles of CS_2?
   a. 0.5 mol b. 1.0 mol c. 1.5 mol d. 2.0 mol

12. How many moles of CO_2 are obtained from the reaction of 2 moles of CaO?
   a. 0.5 mol b. 1.0 mol c. 1.5 mol d. 2.0 mol

13. How many grams of CaS are obtained if 152 g of CS_2 is consumed in the reaction?
   a. 288 g b. 144 g c. 72 g d. 14.4 g

14. How many grams of CaS are obtained if 44 g of CO_2 is produced?
   a. 288 g b. 144 g c. 72 g d. 14.4 g

15. A mixture of 26 g CaO and 38 g of CS_2 are allowed to react. What is the limiting reagent?
   a. CaO b. CS_2 c. CO_2 d. CaS

16. What is the mass of the excess reagent?
   a. 38 g b. 26g c. 20 g d. 18 g

17. What is the percent composition of oxygen in CaO?
   a. 16% b. 29% c. 40% d. 50%

18. An organic compound contains 12.8% C, 2.1% H and 85.1% Br by mass. What is its empirical formula?
   a. CHBr b. CH_2Br c. $CHBr_2$ d. $C_2H_2Br_2$

19. What is the molecular formula of the compound in No.18 if the molecular mass is 188?
   a. CHBr b. CH_2Br c. $CHBr_2$ d. $C_2H_2Br_2$

20. What is the percent composition of oxygen in $Al_2(SO_4)_3$?
   a. 56% b. 33% c. 12% d. 5%

Key to answers on page 32.

If your score is

18-20 Very good. You have the option to skip the module but you are still encouraged to go through it.

14-17 Good! Go over the items that you find difficult and then you may proceed to the lessons in this module that you don't understand

0 -10 Don't worry about your score. Read this module. This module is prepared in order for you to understand the mole concept and stoichiometry.

So, what are you waiting for? Your journey begins here.....

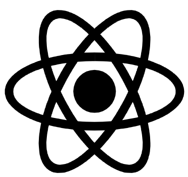
Lesson 1. What is a Mole

Atoms and molecules are incredibly small. There is no way of counting the number of atoms or molecules to get their mass. To understand the mole concept better, do this activity.

What you will do
Activity 1.1

Complete the table below with the information needed in the third column.

Substance	Collective Counting Word	Number of particles
	pair	
	dozen	

Substance	Collective Counting Word	Number of particles
	case	
	ream	
	mole	?

Key to answers on page 32.

The collective counting words above (i.e. pair, dozen) are used as convenient terms for often used number of items in everyday life. Just as the grocer finds selling eggs by the dozen more convenient than selling them individually, the chemist finds calculations (regarding number of atoms, molecules and ions) more convenient with **moles**. Because samples of matter typically contain so many atoms, a unit of measure called the *mole* has been established for use in counting atoms. For our purposes, it is most convenient to define the **mole** (abbreviated mol) as *the number equal to the number of carbon atoms in exactly 12 grams of pure* ^{12}C. A mole may be best thought of as 6.02×10^{23} items called Avogadro's number. *One mole of something consists of* 6.02×10^{23} *units of that substance.* Just as a dozen eggs is 12 eggs, a mole of eggs is 6.02×10^{23} eggs. A mole contains 6.02×10^{23} atoms in 12.00 g of ^{12}C-atoms.

$$1 \text{ mole } ^{12}C = 12.00\text{g } ^{12}C = 6.02 \times 10^{23} \ ^{12}C\text{-atoms}$$

The number of atoms of molecules of molecular elements or compounds, and formula units of ionic compounds can be converted to moles of the same substance using

Avogadro's number. The mass of one mole of a substance is numerically equal to the atomic weight of an atom of an element, the molecular weight of a compound or the formula weight of an ionic compound. The mass of one mole of a substance is called **molar mass**. To understand these statements better, read through the examples given below.

A. For atoms

Consider a mole of Helium atom. Its molar mass is 4.00 g/mol which is equivalent to its atomic weight. Therefore, one mole of He has a molar mass of 4.0 g/mol. One mole of He contains 6.02 x 10^{23} atoms. This can be represented as

1.00 mole of He = 4.00 g = 6.02 x 10^{23} He atoms

Try this. Find the molar mass of Zn atom.

First step: Look for the atomic weight of Zinc in the periodic table.
Second step: Remember, the mass of one mole of Zn is equal to its atomic weight.
Third Step: Therefore, one mole of Zinc atom has a molar mass of ___ g.
One mole of Zinc atom contains ___________ atoms.

Ans. 65.35 g/mol; 6.02 x 10^{23} atoms

B. For molecules

One mole of carbon tetrachloride (CCl_4) contains 1 carbon atom and 4 chlorine atoms. To get its molecular weight, we find

C = 1 atom x atomic weight = 1 (12.00) = 12.00
Cl = 4 atoms x atomic weight = 4 (35.5) = 142.1
The molecular weight of CCl_4 is 154.

Therefore, the mass of one mole of CCl_4 is 154 g. One mole of CCl_4 contains 6.02 x 10^{23} molecules. This can be represented as

1.00 mole CCl_4 = 154 g = 6.02 x 10^{23} CCl_4 molecules

Try this. Find the molar mass of CO_2.

First step Determine the atoms present and the number of each atom. For CO_2, we have
C = 1 atom; O = 2 atoms

Second step Find the atomic weight of each atom.
C = 1 atom x atomic weight = 1 (   ) = _________
O = 2 atoms x atomic weight = 2 (   ) = _________
The molecular weight is ________.

Therefore, the mass of one mole of CO_2 is ________. One mole of CO_2 contains ___________ molecules.

Ans. 44 g/mol; 6.02×10^{23} molecules

C. For Ionic Compounds

Sodium chloride (NaCl) is a famous ionic compound. In its solid state, this substance forms a three-dimensional array of charged particles. In such a case, molecular weight has no meaning, so the term *formula weight* is used instead.

One mole of NaCl contains one sodium ion and one chloride ion. To get its formula weight, we find

Na^+ = 1 ion x atomic weight = 1 (23) = 23
Cl^- = 1 ion x atomic weight = 1 (35.5) = 35.5
The formula weight of one mole of NaCl is 58.5 g.

Therefore the molar mass of NaCl is 58.5 g. One mole of NaCl contains 6.02×10^{23} NaCl ion pairs. This can be represented as

1.0 mole of NaCl = 58.5 g NaCl = 6.02×10^{23} NaCl ion pair

Try this. Find the molar mass of KBr

First step Determine the ions present and the number of each ion
For KBr, we have
K= 1 atom ; Br = 1 atom

Second step Find the atomic weight of each atom
K = 1 atom x atomic weight = 1 (   ) = __________
Br = 1 atom x atomic weight = 1 (   ) = __________
The formula weight is ________.

Therefore, the mass of one mole of KBr is ________. One mole of KBr contains ___________ KBr ion pairs.

Ans. 119 g ; 6.12×10^{23} ion pairs

The above representations show the relationship between mass, mole, and number of particles expressed as the Avogadro's number.

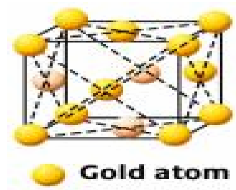
Remember this:

One mole of a substance = molar mass = 6.02×10^{23} particles

What you will do
Activity 1.2

Three students Ken, Hanz and Carla studied the information given in the boxes below. Analyze the statements given by the students. Put an X on the name of the student who gave the incorrect answer.

<table>
<tr>
<td>

6.02×10^{23} Cu atoms
1 mole Cu
Molar mass = 63.5 g/mol</td>
<td>
6.02×10^{23} H_2O molecules
1 mole H_2O
Molar mass = 18 g/mol</td>
</tr>
<tr>
<td>
6.02×10^{23} sugar molecules
1 mole $C_{12}H_{22}O_{11}$
Molar mass = 342 g/mol</td>
<td>

6.02×10^{23} gold atoms
1 mole Au
Molar mass = 197.9 g/mol</td>
</tr>
</table>

One mole of a substance contains a fixed number of particles.

One mole each of different substances have different masses and different number of particles

One mole each of different substances contains the same number of particles but they have different masses


Hanz


Carla


Ken

Key to answers on page 32.

What you will do

Self-Test 1.1

Complete the needed information on the table.

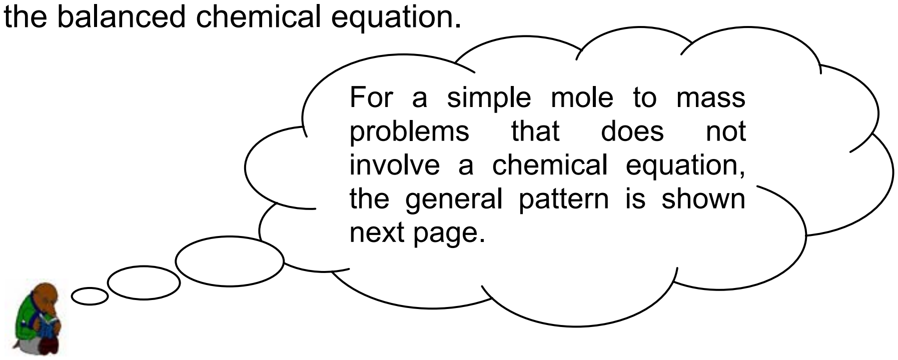
Substance	Molar mass (g)	Kind of Particle	Mass (g)	Number of moles	Number of particles
Water, H_2O			36		12.02×10^{23}
Gold, Au			197		6.02×10^{23}
Sugar, $C_{12}H_{22}O_{11}$		molecule		2	
Table salt, NaCl		Formula unit		3	
Sulfur, S				64	

Key to answers on page 33.

Lesson 2. Mole-Mass Relationship

The relationship between mass, number of moles and number of particles is essential in chemical calculations which is termed as **stoichiometry**. This is a necessary tool in obtaining the right information in terms of mass, mole and number of particles between reactants and products in a chemical reaction. The simplest calculation to be introduced is the mole-mass relationship. This is important in interconverting the moles of the substances to its corresponding mass and vice versa. It is wise to remember that the molar mass of the substance gives the mole-to-gram ratio of a substance. The formula weight of the compound is the mass of the compound.

The mole-mass relationship is essential in solving for the correct amount of substances in chemical reaction. It should be noted that in solving problems, the chemical reaction involved is a balanced chemical equation. From the equation, a mole ratio is determined. A mole ratio is just the ratio of one material in a chemical equation to another material in the same equation. The mole ratio uses the coefficients of the materials as they appear in the balanced chemical equation.



Cases	General Pattern
Case 1: No. of moles is known; mass is unknown	$\text{Mass} = \text{number of moles} \times \frac{\text{molar mass}}{\text{1 mol}}$
Case 2: Mass is known; no. of moles is unknown	$\text{Moles} = \text{mass of substance} \times \frac{\text{1 mol}}{\text{molar mass}}$

Case 1. Number of moles is known, mass is unknown

Q. What is the mass in grams of two moles of iron?

Solution Process:

Step 1. Identify the known and unknown

Known: two moles of Fe
Unknown: mass in grams of Fe

Step 2. Identify the case in the table above and copy the formula

Case 1

$$\text{Mass} = \text{number of moles} \times \frac{\text{molar mass}}{\text{1mol}}$$

Step 3. Substitute values in the equation

$$\text{Mass} = 2\,\text{moles of Fe} \times \frac{56\text{ g}}{\text{mol}} = 112\text{ g of Fe}$$

Case 2. Mass is known, Number of moles is unknown

Q. How many moles of the Be atom are there in 16.0 g of the Be-atom?

Solution Process:

Step 1. Identify the known and unknown

Known: 16.0 g of Be atom
Unknown: number of moles

Step 2. Identify the case in the table above and copy the formula

Case 2

$$\text{Moles} = \text{mass of substance} \times \frac{\text{1 mol}}{\text{molar mass}}$$

Step 3. Substitute values in the equation

$$\text{Moles} = 16.0\ \text{g of Be} \times \frac{1\,\text{mol}}{9\ \text{g}} = 1.78\ \text{moles}$$

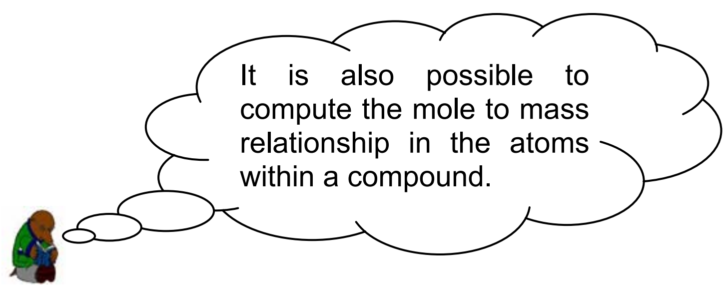
What you will do

Activity 2.1

Matching Type. Connect the question in Column A to its correct answer in Column B. Draw a line from the asked values in column A to the values in column B.

Column A	Column B
1. What is the mass of 0.042 mole C_8H_{18}?	a. 0.0178
2. What is the mass of 4.02 mol $Ba(NO_2)_2$?	b. 0.370
3. How many moles are there in 19.0 g of F_2?	c. 0.500
4. How many moles are there in 44.0 g of NaH_2PO_4?	d. 4.80
5. How many moles are there in 1.04 g NaCl?	e. 921

Key to answers on page 33.



The general pattern is

$$\text{No. of Moles} = \text{mass of substance} \times \frac{1\ \text{mol}}{\text{Molar mass}} \times \text{mole ratio of atom to compound}$$

Study the example given below.

Q. How many moles of Ca atoms are contained in 77.0 grams of $Ca(OH)_2$?

Solution Process:

Step 1. Identify the known and unknown.

Known: 77.0 g of $Ca(OH)_2$
Unknown: number of moles of Ca

Step 2. Find the number of moles by looking at the subscript of the atoms in the compound.

Ca = 1 mole ; O = 2 moles ; H = 2 moles

Step 3. Determine the mole ratio of Ca to $Ca(OH)_2$.

$$\frac{1 \text{ mol Ca}}{1 \text{ mol } Ca(OH)_2}$$

Step 4. Substitute values in the equation

$$\text{Moles} = \text{mass of substance} \times \frac{1\,\text{mol}}{\text{Molar mass}} \times \text{mole ratio of atom to compound}$$

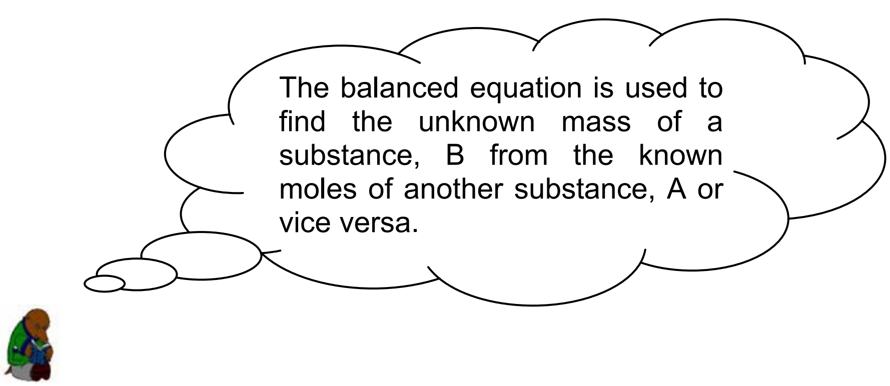
$$= 77.0 \text{ g } Ca(OH)_2 \times \frac{1 \text{ mol } Ca(OH)_2}{74 \text{ g } Ca(OH)_2} \times \frac{1 \text{ mol Ca}}{1 \text{ mol } Ca(OH)_2}$$

$$= 1.04 \text{ mol Ca}$$

Try this:

1. How many moles of S are there in 342.2 g of $Al_2(SO_4)_3$?
2. How many moles of oxygen?

Ans.: 1. 2 mol Sulfur
2. 12 mol Oxygen



The route for this conversion is:

$$\text{Mass} = \text{Moles A (known)} \times \text{mole ratio of A and B} \times \frac{\text{molar mass of B (unknown)}}{\text{1 mol of B}}$$

Study the example below:

Q. How many grams of octane C_8H_{18} in gasoline will be needed by the complete combustion with 12.5 moles of O_2? The equation is

$$C_8H_{18} + 12½\ O_2 \rightarrow 8CO_2 + 9H_2O$$

Solution Process:

Step 1. Identify the known and unknown

Known: 12.5 moles of O_2
Unknown: grams of octane C_8H_{18}

Step 2. Find the number of moles by looking at the coefficient before the compound

The coefficient of O_2 is 12.5; this means there are 12.5 moles of O_2 in the reaction
The coefficient of C_8H_{18} is 1; this means that 1 mol of C_8H_{18} is present

Step 3. Write the mole ratio of C_8H_{18} and O_2

$$\frac{1\ \text{mol}\ C_8H_{18}}{12.5\ \text{mol}\ O_2}$$

Step 4. Substitute values in the equation

$$\text{Mass} = \text{Moles A (known)} \times \text{mole ratio of A and B} \times \frac{\text{molar mass of B (unknown)}}{\text{1mol of B}}$$

$$= 12.5\ \text{moles of}\ O_2 \times \frac{1\ \text{mol}\ C_8H_{18}}{12.5\ \text{mol}\ O_2} \times \frac{114\ \text{g}\ C_8H_{18}}{1\ \text{mol}\ C_8H_{18}}$$

$$= 114\ \text{g}\ C_8H_{18}$$

$$\text{Mass} = \text{Moles A (known)} \times \text{mole ratio of A and B} \times \frac{\text{molar mass of B (unknown)}}{\text{1mol of B}}$$

$$= 12.5\ \text{moles of}\ O_2 \times \frac{1\ \text{mol}\ C_8H_{18}}{12.5\ \text{mol}\ O_2} \times \frac{114\ \text{g}\ C_8H_{18}}{1\ \text{mol}\ C_8H_{18}}$$

$$= 114\ \text{g}\ C_8H_{18}$$

Try this:

In the reaction $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

1. How many grams of methane, CH_4, is needed for the complete combustion with 6 moles of oxygen?
2. How many moles of CO_2 are produced from the reaction of 32 g of CH_4?

Ans.: 1. 48 g CH_4
2. 2 moles CO_2

What you will do

Self-Test 2.1

1. How many moles are there in 25 g of $C_5H_8O_2$?
2. How many grams of $C_5H_8O_2$ are there in 0.01 mole?
3. How many moles of Al are there in 20 g of $Al_2(C_2O_4)_3$?

For questions 4 and 5, refer to the following equation

$$Zn + 2KOH \rightarrow K_2ZnO_2 + H_2$$

4. How many moles of K_2ZnO_2 are produced from the reaction of 25 g of Zn?
5. How many grams of KOH are required to produce 50 g of K_2ZnO_2?

Key to answers on page 33.

Lesson 3. Mass-Mass Relationship

This lesson is the continuation of lesson 2. The general patterns used in lesson 2 are helpful in dealing with calculations in mass to mass relationship. In this case, an unknown mass of one substance can be calculated from the known mass of another substance.

It is important that the chemical equation under study is balanced. The coefficients in that equation give you the information such as the combining ratio of molecules and the mole ratios of compounds involved. The coefficients do not give the combining mass ratio thus, the need for stoichiometric calculations. In the equation,

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_20$$

This shows that

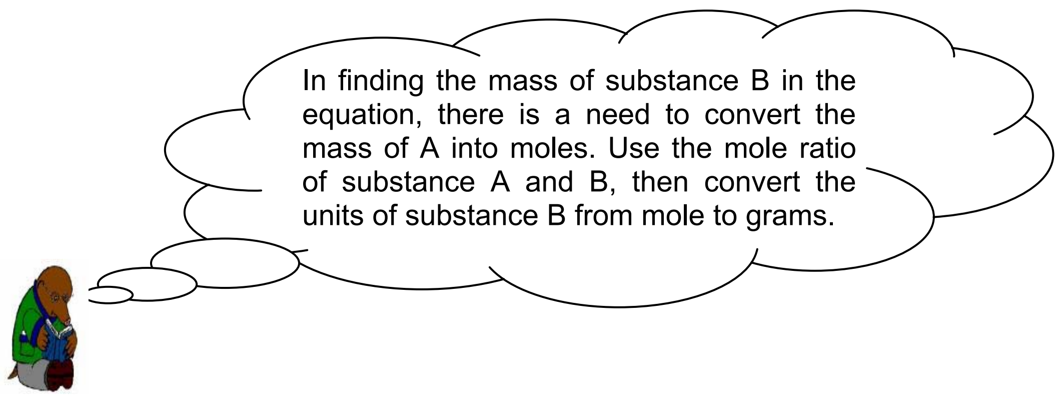
> 1 molecule of methane (CH_4) reacts with 2 molecules of oxygen (O_2) to give 1 molecule of carbon dioxide (CO_2) and 2 molecules of water (H_2O).

Furthermore, it shows that

> 1 mole of methane reacts with 2 moles of oxygen to give 1 mole of carbon dioxide and 2 moles of water.

By looking at the mole ratios from the equation, the number of moles in the reaction can be easily predicted if the quantity is varied. For example, 2 moles of methane should react with 4 moles of O_2 to give 2 moles of CO_2 and 4 moles of H_2O.

However, the equation does not say that 1 gram of methane reacts with 2 grams of oxygen to produce 1 gram of carbon dioxide and 2 grams of water.



In a general pattern, the mass of substance B can be determined following the mole ratios below.

$$\text{Mass A} \times \frac{\text{1 mole A}}{\text{Molar mass A}} \times \frac{\text{no. of moles B (mole ratio from chemical equation)}}{\text{no. of moles A}} \times \frac{\text{molar mass B}}{\text{1mole B}}$$

Q. Silicone (Si) is used in the fabrication of electronic components and computers. It is prepared by the decomposition of silane (SiH_4). The reaction is as follows

$$SiH_4 \rightarrow Si + 2H_2$$

What is the mass of SiH_4 needed to prepare 0.2173 g Si?

Solution Process:

Step 1. Identify the known and unknown

Known: 0.2173 g Si
Unknown: mass of SiH_4

Step 2. Find the number of moles from the coefficients before the compound in the equation

Si = 1 mole
SiH_4 = 1 mole

Step 3. Write the mole ratio of Si and SiH4

Hint: In writing mole ratios, the numerator should be the unknown substance

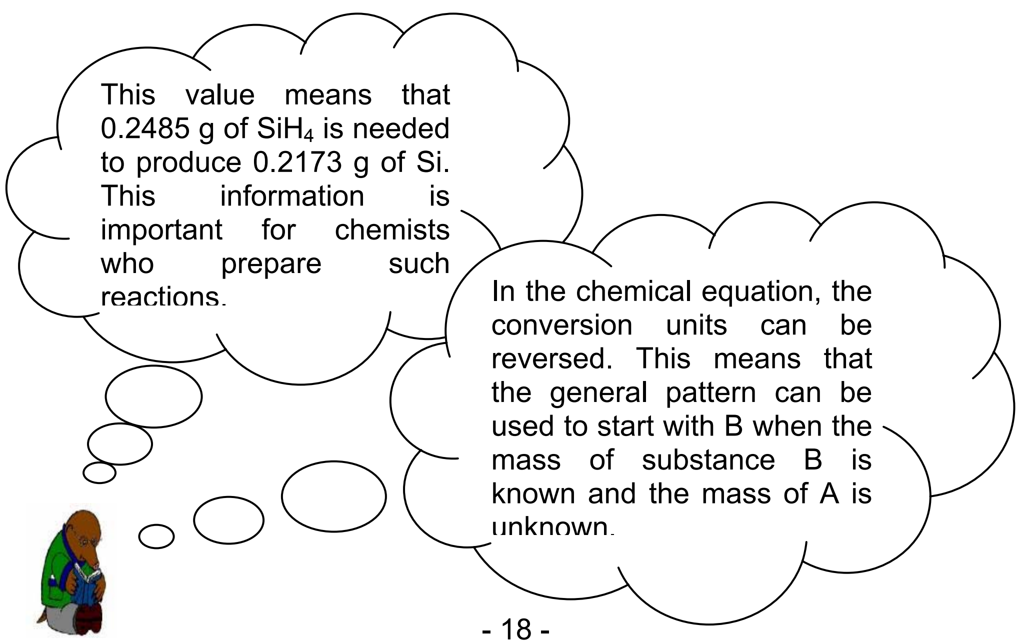
$$\frac{1 \text{ mole of } SiH_4}{1 \text{ mole of Si}}$$

Step 4. Substitute values in the general pattern

$$\text{Mass B} = \text{Mass A} \times \frac{\text{1 mole A}}{\text{Molar mass A}} \times \frac{\text{no. of moles B}}{\text{no. of moles A}}(\text{mole ratio from equation}) \times \frac{\text{molar mass B}}{\text{1mole B}}$$

$$\text{Mass of } SiH_4 = 0.2173 \text{ g Si} \times \frac{\text{1 mole Si}}{\text{28 g Si}} \times \frac{1 \text{ mole } SiH_4}{\text{1 mole Si}} \times \frac{32 \text{ g } SiH_4}{1 \text{ mole } SiH_4}$$

$$= 0.2485 \text{ g } SiH_4$$



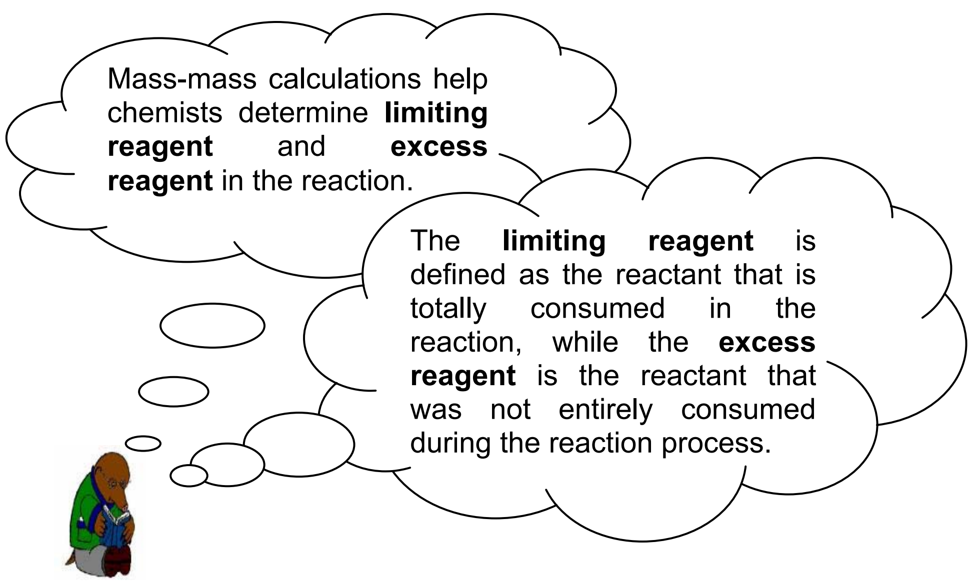
Try this:

For questions 1-3, refer to this equation

$$Fe_2O_3 \;+\; CO \;\rightarrow\; 2Fe \;+\; 3CO_2$$

1. Fifteen grams of Fe_2O_3 was allowed to react with CO. How much iron, Fe will be produced from the reaction?
2. If 8.4 g of CO completely reacted with Fe_2O_3, how much iron, Fe will be produced from the reaction?
3. If 10.5 g of Fe was produced from the reaction, what mass of CO completely reacted in the process?

Ans.: 1. 10.5 g Fe
2. 33.6g Fe
3. 7.875g CO



In the exercise provided above let us suppose that a scientist was given 30.0 grams of Fe_2O_3 and 16.80 grams of CO simultaneously. Which substance should be used completely and which substance would have an excess after reaction? A budding chemist can predict the answer using his/her knowledge in stoichiometry. Observe and study how to determine the limiting reagent and the excess reagent.

Step 1. Find the amount of the reactants in grams from its respective given masses.

<u>Solution A</u>. Using the mass of Fe_2O_3 find the expected mass of CO in the reaction

$$\text{Mass of CO} = 30.0 \text{ g of } Fe_2O_3 \times \frac{1.00 \text{ mole}}{160 \text{ g } Fe_2O_3} \times \frac{1.00 \text{ mole CO}}{1.00 \text{ mole } Fe_2O_3} \times \frac{28.0 \text{ g CO}}{1.00 \text{ mole CO}}$$

$$= 5.25 \text{ g CO}$$

Solution B. Using the mass of CO, find the expected mass of Fe_2O_3 in the reaction

$$\text{Mass of } Fe_2O_3 = 16.80 \text{ g of CO} \times \frac{1.00 \text{ mole CO}}{8.0 \text{ g } CO_2} \times \frac{1.00 \text{ mole } Fe_2O_3}{1.00 \text{ mole CO}} \times \frac{160 \text{ g } Fe_2O_3}{1.00 \text{ mole } Fe_2O_3}$$

$$= 336 \text{ g } Fe_2O_3$$

Step 2. Analyze the computed value from the given value.

From the calculation, it can be deduced that 5.25 g of CO is needed to react with 30.0 g of Fe_2O_3 while 336 g of Fe_2O_3 is needed to react with 16.80 g CO. It should be noted that only 30 g of Fe_2O_3 is available for the reaction.

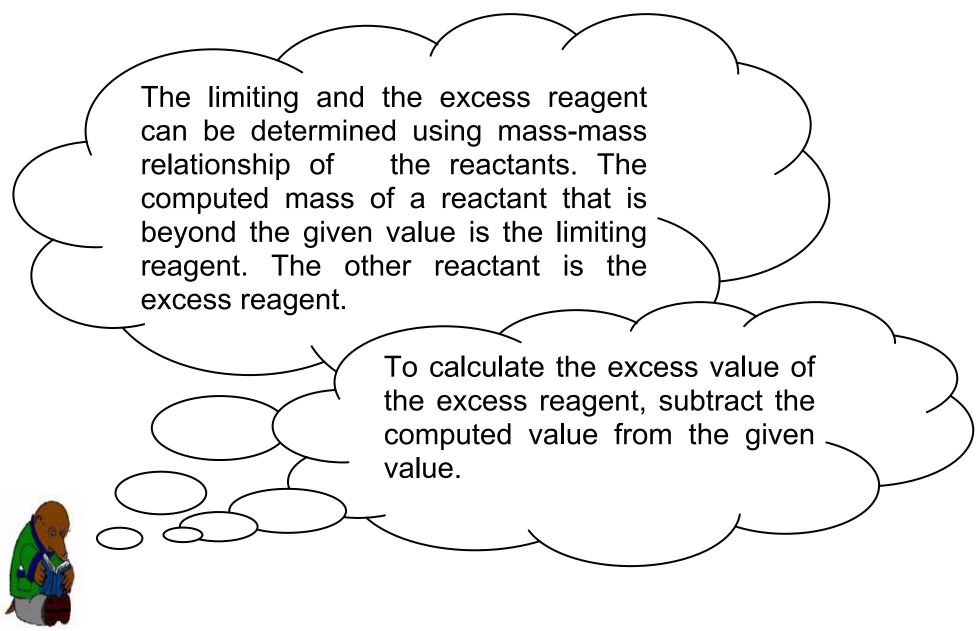
Step 3. Identify the limiting reagent and the excess reagent.

The amount of Fe_2O_3 limits the reaction, hence, Fe_2O_3 is the limiting reagent.
It follows that CO is the excess reactant.

Step 4. Compute the excess value of the excess reactant.

What is the excess value? Simply subtract the calculated amount from the given amount. In this example, it is the amount computed in Solution A.

Excess value of CO = 16.80 g CO – 5.25 g CO = 11. 55 g in excess



Try this:

A mixture of 3.00 g of Bi_2O_3 and 0.500 g C are used to produce bismuth and CO in the reaction

$$Bi_2O_3 + 3\,C \rightarrow 2Bi + 3\,CO$$

1. Determine the limiting reagent and the excess reagent.
2. What is the mass of the excess reagent?

Ans.:
1. *Limiting reagent – Bi, Excess reagent – C*
2. *Excess mass of C = 0.268 g*

What you will do

Self-Test 3.1

Solve the following problems:

1. Consider the reaction $Si + C \rightarrow SiC$

   a. What is the mole ratio of the reactants?
   b. If 2 moles of Si were consumed in the reaction, how many moles of SiC were produced?
   c. What mass of SiC will be produced if 0.500 g of Si reacted completely with C?

2. In the reaction $4HF + Si \rightarrow SiF_4 + 2H_2$

   a. What is the mole ratio of the reactants?
   b. What is the mole ratio of HF to SiF_4?
   c. If 4 moles of Si were consumed in the reaction, how many moles of HF were used?
   d. What mass of SiF_4 will be produced if 40 g of HF is used up in the reaction?
   e. What mass of Si is needed to produce 18 g of H_2?

3. When a mixture of 38 g of CS_2 reacts with 40 g of CaO in the reaction

$$CS_2 + 2CaO \rightarrow CO_2 + 2CaS$$

   a. what is the limiting reagent and the excess reagent?
   b. what is the excess mass of the excess reagent?

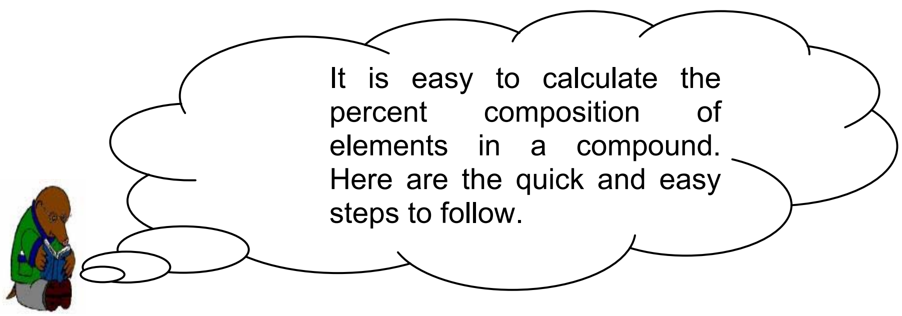
Key to answers on page 33.

Lesson 4. Percent Composition of Compounds

Suppose you invited 15 girls and 10 boys to your 15th birthday party. After blowing the candles on the cake, you sliced the cake equally for your guests. How much of the cake went to the boys?

You can easily say 15 slices went to the girls and 10 slices went to the boys, right? Another representation that you can make is by giving your answer in percent. You can say 60% of the cake went to the girls and 40% went to the boys. Percentage always equals 100.

The concept of percentage in chemistry is used to describe the composition of elements in a compound. It is vital to write the correct formula of the compound and from there the per cent by mass of an element in the compound can be determined.



Quick recipe:
Percent Composition of Elements in a Compound

3. Write down the chemical formula of the compound. The formula gives the number of moles of each element in the compound.
4. Find its molar mass.
5. Express the total mass of each element as a percentage of the molar mass. Remember, the sum of the percentage must be 100.

For example, calculate the percent composition of each element in $MgSO_4$.

Step 1. Write down the chemical formula of the compound. Write down the number of moles of each element in the compound.

Chemical Formula - MgSO4
No. of moles of each element

Mg - 1
S - 1
O - 4

Step 2. Find its molar mass. (MM = No. of moles x atomic weight)

Mg -1 x 24.31 = 24.31
S - 1 x 32.06 = 32.06
O - 4 x 16.00 = 64.00
Molar mass = 120.37

Step 3. Find the percent of each element

$$Mg = \frac{24.31g\ Mg}{120.37\ g\ MgSO_4} = 20.20\ \%$$

$$S = \frac{32.06\ g\ S}{120.37\ g\ MgSO_4} = 26.60\ \%$$

$$O = \frac{64.00\ g\ O}{120.37\ g\ MgSO_4} = 53.17\ \%$$

Add the percentages. It should be 100 or near its mark.

What you will do

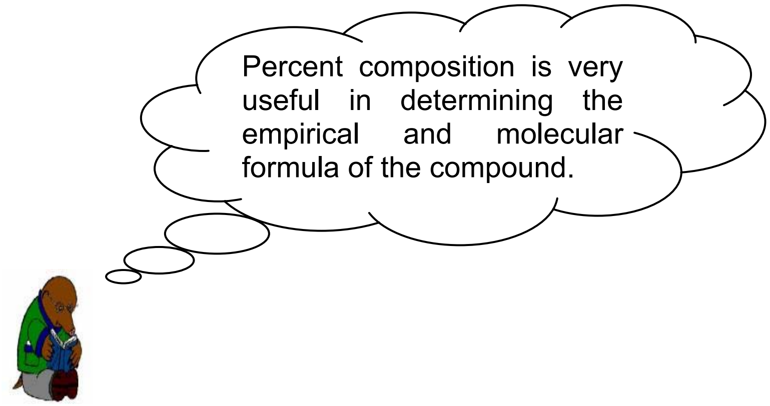
Activity 4.1

Calculate the percentage composition of oxygen in the compounds found in the boxes below. Draw the string of the balloon that corresponds to the oxygen composition in each compound.

26.67 | 77.42 | 58.54 | 57.14 | 72.73

CO | CO_2 | $(NO_3)^{-4}$ | C_3H_8O | $Ca(NO_3)_2$

Key to answers on page 33.



Empirical and Molecular Formula

The **empirical formula** of the compound gives the simplest whole-number ratio of atoms present in the compound based on the mass percentage of its elements. The **molecular formula** is the true formula of the compound. It gives the actual number of atoms of each element in the compound.

For example, for the compound, N_2H_4, the simplest whole-number ratio is NH_2. NH_2 is the empirical formula and N_2H_4 is the molecular formula.

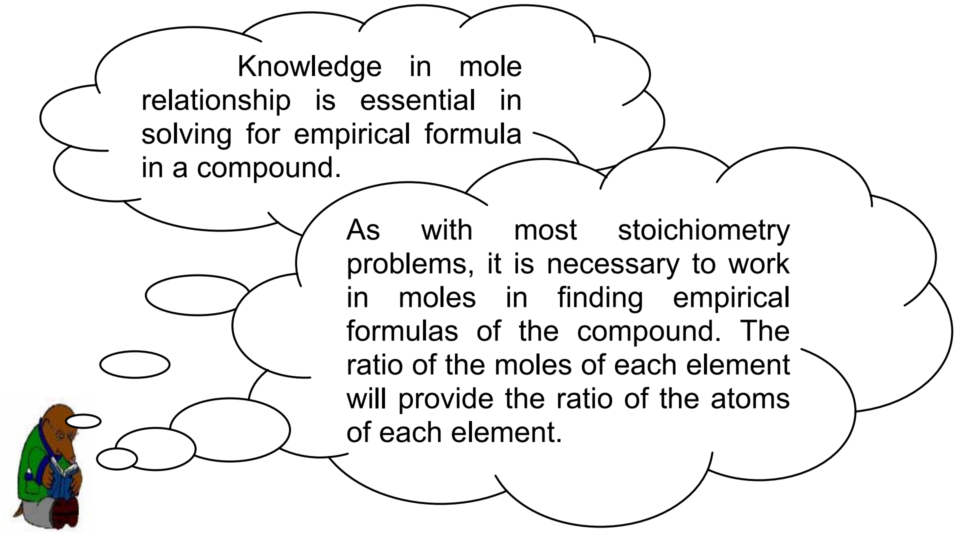
What you will do

Activity 4.2

Write the empirical formula of the following compounds:

1. $C_6H_{12}O_6$
2. H_2O_2
3. C_6H_6
4. Fe_2O_3
5. Ca_2O_2

Key to answers on page 34.



Recipe for
Finding Empirical Formulas

1. Convert the mass of each element to moles of each element using the atomic weight.
2. Find the ratio of the moles of each element by dividing the number of moles of each by the smallest number of moles.
3. Use the mole ratio to write the empirical formula.

Study problem 1:

Find the empirical formula for the oxide that contains 42.05 g of nitrogen and 95.95 g of oxygen.

Solution Process:

Step 1. Convert the mass of each element to moles

$$\text{Moles N} = 42.05\text{ g N} \times \frac{1\text{mole N}}{14.00\text{g N}} = 3.00\text{ moles}$$

$$\text{Moles O} = 95.95\text{ g O} \times \frac{1\text{mole O}}{16.00\text{ g O}} = 5.99\text{ moles (round-off to 6.00 moles)}$$

Step 2. Find the mole ratio of the elements

The smallest number of moles in step 1 is Nitrogen so the mole ratio goes like this:

$$\text{Mole ratio N} = \frac{3.00\ \text{moles}}{3.00\ \text{moles}} = 1$$

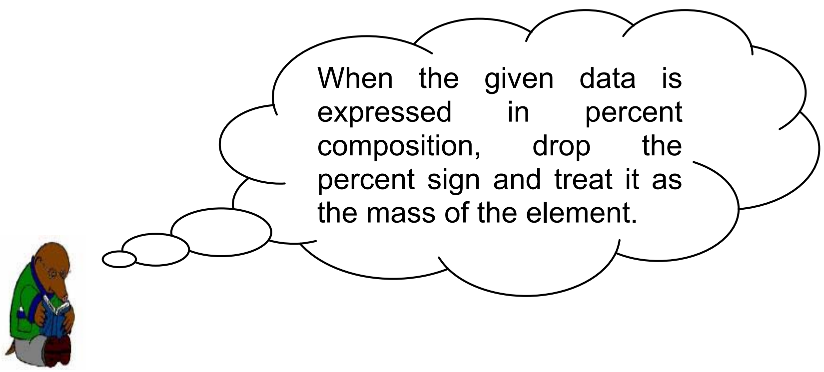
$$\text{Mole ratio O} = \frac{6.00\ \text{moles}}{3.00\ \text{moles}} = 2$$

Step 3. Use the mole ratio to get the empirical formula

Since the mole ratio of N is 1 and that of oxygen is 2, the empirical formula of the compound is NO_2.

Study problem 2.

The percent composition of DDT is 47.43% C, 2.56% H and 50.00% Cl. Find its empirical formula.



Solution Process:

Step 1. Drop the percent sign and convert the mass to number of moles

$$\text{Moles C} = 47.43\ \text{g C} \times \frac{1\ \text{mole C}}{12.00\ \text{g C}} = 3.952\ \text{moles C}$$

$$\text{Moles H} = 2.56\ \text{g H} \times \frac{1\ \text{mole H}}{1.00\ \text{g H}} = 2.560\ \text{moles H}$$

$$\text{Moles Cl} = 50.00\ \text{g Cl} \times \frac{1\ \text{mole Cl}}{35.45\ \text{g Cl}} = 1.410\ \text{moles Cl}$$

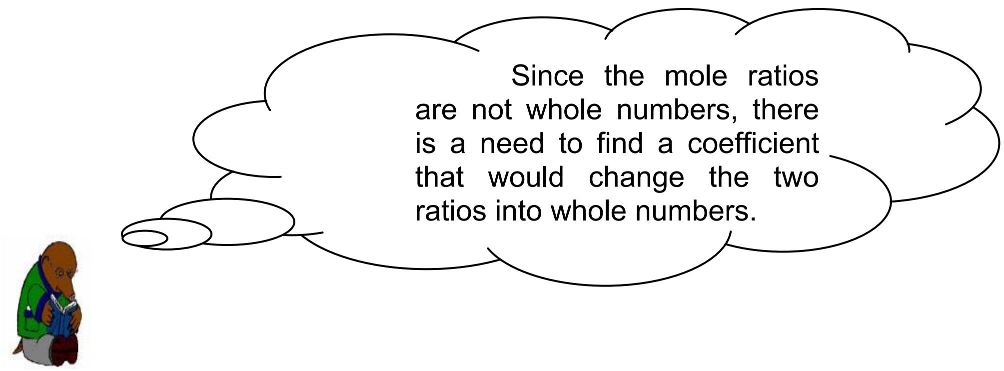
Step 2. Find the mole ratio

The smallest number of moles is for Cl so:

$$\text{Mole ratio of C} = \frac{3.952 \text{ moles}}{1.410 \text{ moles}} = 2.80$$

$$\text{Mole ratio of H} = \frac{2.560 \text{ moles}}{1.410 \text{ moles}} = 1.82$$

$$\text{Mole ratio of Cl} = \frac{1.410 \text{ moles}}{1.410 \text{ moles}} = 1$$



If we multiply all ratios with 5, the new mole ratios will be

C = 2.80 x 5 = 14
H = 1.80 x 5 = 9
Cl = 1 x 5 = 5

Step 3. Determine the empirical formula

The empirical formula for DDT is $C_{14}H_9C_5$. This is also the molecular formula of DDT.

Molecular Formula is the actual formula for a molecule.

Recipe for Finding the Molecular Formula
Find the mass of the empirical unit. Figure out how many empirical units are in a molecular unit. Write the molecular formula.

Study this problem:

A compound has an empirical formula of $ClCH_2$ and a molecular weight of 98.96 g/mol. What is its molecular formula?

Solution Process:

Step 1. Find the mass of the empirical unit.

Cl = 1 x 35.35 = 35.35
C = 1 x 12.00 =12.00
H = 2 x 1.000 = 2.00

The mass of the empirical unit is 49.45 g/mol.

Step 2. Get the ratio of the mass of the empirical from the molecular weight.

The ratio is 98.96 / 49.45 = 2

Step 3. Write the molecular formula.

Multiply the coefficient computed in step 2 to the empirical formula subscripts.
Thus, the molecular formula is $Cl_2C_2H_4$.

Try this

1. A detective analyzes a drug and finds that it contains 80.22% C and 9.62% H. Could the drug be pure tetrahydrocannabinol ($C_{21}H_{30}O_2$)?
2. Chemical analysis shows that a compound contains 87.5% N and 12.5% H. Determine the empirical formula and the molecular of the compound with a molecular weight of 32.

Ans.: 1. it is possible
2. EF = NH_2, MF = N_2H_4

What you will do

Self-Test 4.1

Answer the following questions:

1. Calculate the percent by weight of each element present in ammonium phosphate [$(NH_4)_3PO_4$].

2. Given the following mass percent composition of a compound, 49.5% C, 5.2% H, 28.8% N, 16.5% O
   a. Determine the empirical formula.
   b. What is the chemical formula for this compound if the molar mass is 194.2 g/mol?

3. Determine the empirical formula for a compound with the following elemental composition: 40.00% C, 6.72% H, 53.29% O. Find its molecular formula when its molar mass is 180 g/mol.

Key to answers on page 34.

Let's Summarize

This module is almost at its end. I hope you had a great time discovering what mole is and its application to chemical calculations. To help you remember the key concepts discussed, let us go through them one more time.

A. Mole is a term that refers to 6.02×10^{23} particles. It is the amount of substance as there are atoms in exactly 12 g of 12 Carbon.
   1. One mole of Mg atom contains 6.02×10^{23} atoms.
   2. One mole of H_2O molecule contains 6.02×10^{23} molecules.
   3. One mole of NaCl ion contains 6.02×10^{23} ion pairs.

B. 6.02×10^{23} is called the Avogadro's number.

C. The molar mass of a compound is the mass of one mole of that substance

   1. 24 g Mg = 1 mole of Mg
   2. 18 g H_2O = 1 mole of H_2O
   3. 58 g NaCl = 1 mole pf NaCl

D. Stoichiometric Calculations

   The steps in solving stoichiometric problems are:

   1. Determine the conversion ratio between the moles and the mass.
   2. Identify the mole ratio in a balanced equation.
   3. Calculate the molar mass of compounds using the atomic weights in the periodic table.

   Here is a diagram that would aid in solving stoichiometric problems

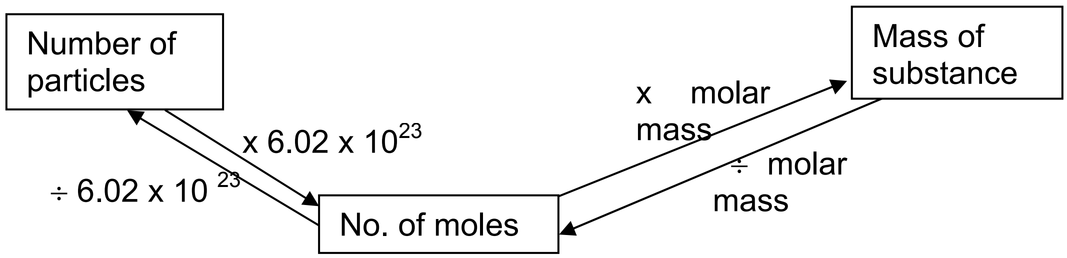


Figure 1. The general pattern in solving stoichiometric problems

1. Mole – Number of Particles Problems

   The number of moles multiplied by the Avogadro's number gives the number of particles. The number of particles divided by the Avogadro's number gives the number of moles of the substance.

2. Mole – Mass Problems

   The number of moles multiplied by the molar mass of the substance gives the mass of the substance. The given mass of the substance divided by the molar mass of the substance gives the number of moles.

3. Mass – Mass Problems

   The mass – mass problems is an extension of the simple mole–mass solution. This involves two substances in a balanced equation. Convert mass of substance A to moles, then find the mole ratio of substance A and substance B in the balanced chemical equation, then convert moles of substance B to mass of substance B as desired.

   The equation below represents the solution to mass-mass problems

$$\text{Mass A} \times \frac{\text{1 mole A}}{\text{Molar mass A}} \times \frac{\text{no. of moles B (mole ratio from chemical equation)}}{\text{no. of moles A}} \times \frac{\text{molar mass B}}{\text{1 mole B}}$$

E. Applications of Mole Problems

Knowledge in mole and solving stoichiometric problems is helpful in:

1. Finding the limiting reagent and excess reagent in the chemical process.

   The limiting reagent is the reactant that is totally consumed in the reaction. The excess reagent is the reactant that is not totally consumed in the reaction. The excess mass of the excess reagent can be theoretically calculated.

2. Finding the empirical and molecular formula of the compound:

The percent composition of the compound can be calculated by taking the weight of an element divided by the molar mass of the compound.

From the percent composition of the elements in a compound, treated as mass of the element, the number of moles of that element can be determined. The number of moles of each atom will then be divided by the smallest number of moles. The coefficients that can be calculated are the subscripts of the corresponding atoms present in the compound.

The molecular formula of the compound can be determined by dividing the molecular weight of the compound by the empirical molecular weight. The answer is then multiplied to the subscripts of the existing atoms in the empirical formula.

Posttest

Multiple Choice. Choose the letter of the best answer. Write the chosen letter on a separate sheet of paper.

1. Which statement is correct?
    a. One mole of different substances have the same masses and different number of particles.
    b. The formula weight of the compound determines the number of particles in a compound.
    c. One mole of a substance contains a fixed number of particles.
    d. One mole of a substance is not equal to 6.02×10^{23} things.

2. Which is equivalent to one mole?
    a. 27.0 g aluminum pan
    b. 0.12 g diamond
    c. 1.75 g silicon chip
    d. 8.0 g magnesium ribbon

3. Which is equivalent to one mole of $Ca(NO_3)_2$?
    a. 40 g $Ca(NO_3)_2$; 6.02×10^{23} particles
    b. 164 g $Ca(NO_3)_2$; 12.04×10^{23} particles
    c. 328 g $Ca(NO_3)_2$; 6.02×10^{23} particles
    d. 164 g $Ca(NO_3)_2$; 6.02×10^{23} particles

4. Which statement is correct regarding the molecule H_2O?
    a. one mole of H_2O contains 18.06×10^{23} particles
    b. one mole of H_2O is equal to twice its molar mass
    c. one mole of H_2O has 18 particles
    d. one mole of H_20 contains 6.02×10^{23} particles

5. How many molecules are there in two moles of $C_5H_8O_6$?
   a. 2×10^{23}
   b. 6.02×10^{23}
   c. 12.04×10^{23}
   d. 6.02×10^{46}

6. How many sodium atoms are there in 46 g Na atom?
   a. 2×10^{23}
   b. 6.02×10^{23}
   c. 12.04×10^{23}
   d. 6.02×10^{46}

7. Which statement is correct?
   a. 4 g of NH_3 is equal to 4 moles of NH_3
   b. 4 g of NH_3 is equal to 1 mole of NH_3
   c. 4 moles of NH_3 is equal to 17 g of NH_3
   d. 4 moles of NH_3 is equal to 68 g of NH_3

8. What is the mass of 1.5 moles of CH_4?
   a. 16 g b. 24 g c. 32 g d. 40 g

9. How many moles are contained in 24 g Mg?
   a. 1 mol b. 2 mol c. 24 mol d. 48 mol

10. What is the mass of 2.5 mol $CaCl_2$?
   a. 40 g b. 70 g c. 120 g d. 275 g

For questions 11 – 16 refer to this equation:

$$Zn + 2AgCl \rightarrow ZnCl_2 + 2Ag$$

11. How many moles of $ZnCl_2$ are obtained from the reaction of 2 moles of Zn?
   a. 0.5 mol b. 1.0 mol c. 1.5 mol d. 2.0 mol

12. What is the mass obtained of Ag from the reaction of 3 moles of AgCl?
   a. 2.5 g b. 3.5 g c. 4.5 g d. 5.5g

13. How many grams of $ZnCl_2$ are obtained when 40g of Zn is consumed in the reaction?
   a. 40 g b. 65 g c. 83 g d. 135 g

14. How many grams of Ag are obtained if 25 g $ZnCl_2$ are produced?
   a. 40 g b. 65 g c. 83 g d. 135 g

15. A mixture of 20 g Zn and 30 g AgCl were allowed to react. What is the limiting reagent?
   a. Zn b. AgCl c. ZnCl2 d. Ag

16. What is the mass of the excess reagent?
   a. 6.82 g b. 13.2 g c. 20 g d. 30 g

17. What is the percent composition of sulfur in Na_2SO_4?
   a. 19 % b. 23% c. 45% d. 33%

18. An organic compound contains 57.1% C, 38% S, 4.9% H by mass. What is its empirical formula?
    a. CHS   b. C_2H_2S c. C_4H_4S d. $C_8H_8S_2$

19. What is the molecular formula of the compound in no. 18 if the molecular mass is 168g?
    a. CHS   b. C_2H_2S c. C_4H_4S d. $C_8H_8S_2$

20. Which among these compounds has the greatest oxygen composition?
    a. NaOH   b. KOH   c. K_3PO_4 d. Na_2SO_4

Key to answers on page 34.

Key to Answers

Pretest

1. b	6. c	11. d	16. d
2. b	7. d	12. b	17. b
3. d	8. d	13. a	18. b
4. d	9. b	14. b	19. d
5. c	10. a	15. a	20. a

Lesson 1

Activity 1.1

1. a pair of shoes – 2
2. dozen eggs – 12 pieces
3. case of softdrinks – 12 bottles
4. ream of paper – 500 sheets

Activity 1.2

Carla

Self-Test 1.1

Substance	Molar Mass	Kind of Particle	Mass (g)	Number of moles	Number of particles
water	18 g	molecule		2	
gold	197 g	atom		1	
sugar	342 g		684		12.04×10^{23}
salt	58 g		174		18.06×10^{23}
sulfur	32 g	atom	2048		1.2×10^{27}

Lesson 2

Activity 2.1

1. d
2. e
3. c
4. b
5. a

Self-Test 2.1

1. 0.25 mol
2. 1.0 g
3. 0.126 mol
4. 0.38 mol
5. 45.7 g

Lesson 3

Self-Test 3.1

1. a. 1:1 b. 2 moles c. 0.018g
2. a. 4:1 b. 4:1 c. 16 mols d. 2080 g e. 126 g
3. a. Limiting reagent CaO, Excess Reagent CS_2
   b. 10.86 g CS_2

Lesson 4

Activity 4.1

1. CO – 57.14 %
2. CO_2 – 72.73%
3. $(NO_3)^-$ – 77.42 %
4. C_3H_8O – 26.67 %
5. $Ca(NO_3)_2$ – 58.54 %

Activity 4.2

1. CH_2O
2. HO
3. CH
4. Fe_2O_3
5. CaO

Self-Test 4.1

1. N = 28.19; H = 8.11; P = 20.77; O = 42.93
2. $C_4H_5N_2O$
3. CH_6O, $C_6H_{12}O_6$

Posttest

1. c	6. c	11. d	16. b
2. a	7. d	12. c	17. b
3. d	8. b	13. c	18. c
4. d	9. a	14. a	19. d
5. c	10.d	15. b	20. d

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