Unit 5

On completion of the unit you should be able to:

1. write the number of particles in a mole.
2. calculate the formula (or molecular) mass of compounds.
3. solve problems involving conversions between the mass, the number of moles, the number of formula units and the volume (for gaseous substances at standard temperature and pressure).
4. given the formula of a compound calculate the percent composition.
5. given the composition of a compound calculate the empirical formula.
6. given the composition and molecular mass of a molecular compound calculate the molecular formula.
7. express solution concentration in moles/liter.
8. do calculations involving solutions which have concentrations expressed in moles/liter.
9. solve dilution calculation.

Today's focus.

THE MOLE CONCEPT
5.1 **Mole concept**
Reading: Hebden – page 78
5.2 **Formula mass**
5.3 **Information in chemical formulae**
5.4 **From amu to gram**
5.5 **Molar mass**
Reading: Hebden – page 79
5.6 **Calculations involving Avogadro's number**
Reading: Hebden – page 81-88
5.7 **Molar volume of a gas**
Reading: Hebden – page 82
5.8 **Percent composition of compounds**
Reading: Hebden – page 90
5.9 **Empirical formula**
Reading: Hebden – page 91-95
5.10 **Molarity and solution preparation**
Reading: Hebden – page 96-98
5.11 **Solution dilution**
Reading: Hebden – page 99

Mole Concept

Avogadro's Number is 6.02×10^{23}

The **mole unit** is used to express:

1. A mass quantity
2. A counting quantity

1 water molecule

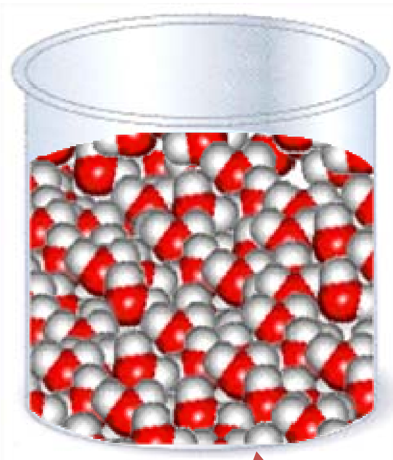
1 mole of water molecules

Conversion Factors:

6.02×10^{23} amu = 1 gram

(Scale up so that we can weigh in the lab)

6.02×10^{23} water molecules = 1 mole of water molecules



$\frac{\text{amu}}{\text{molecule}}$ ← **Formula Mass Units** → $\frac{\text{g}}{\text{mole}}$

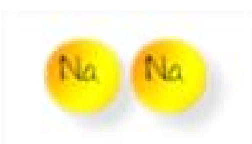
Information in Chemical Formulae

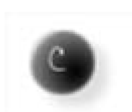
Sodium carbonate

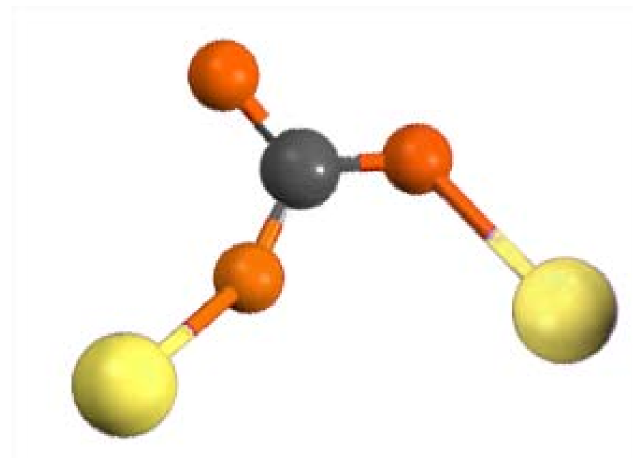
Na_2CO_3

What are the *parts* needed to make ONE formula unit of sodium carbonate?

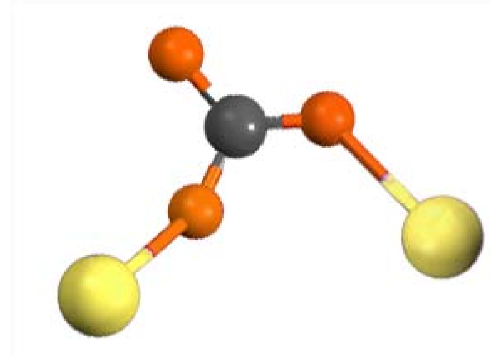
22.990	12.011	15.999
Na	C	O
11	6	8





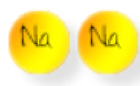
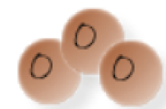


Information in Chemical Formulae



Na_2CO_3

Na : C : O

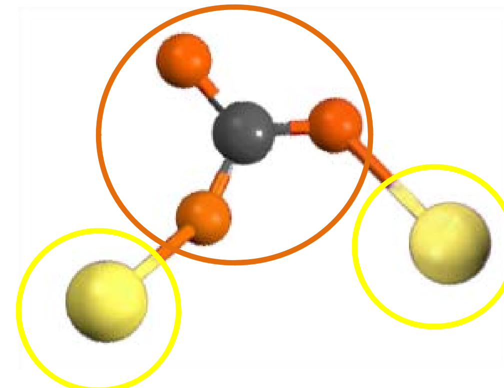
one formula unit	 **two** Na atoms	 **one** C atom	 **three** O atoms
one mole formula units	**2** moles (= 12.044 x 10^{23}) Na atoms	**1** mole (= 6.022 x 10^{23}) C atoms	**3** moles (= 18.066 x 10^{23}) O atoms

2 : 1 : 3

Information in Chemical Formulae

Number of ratio of ions: (parts)

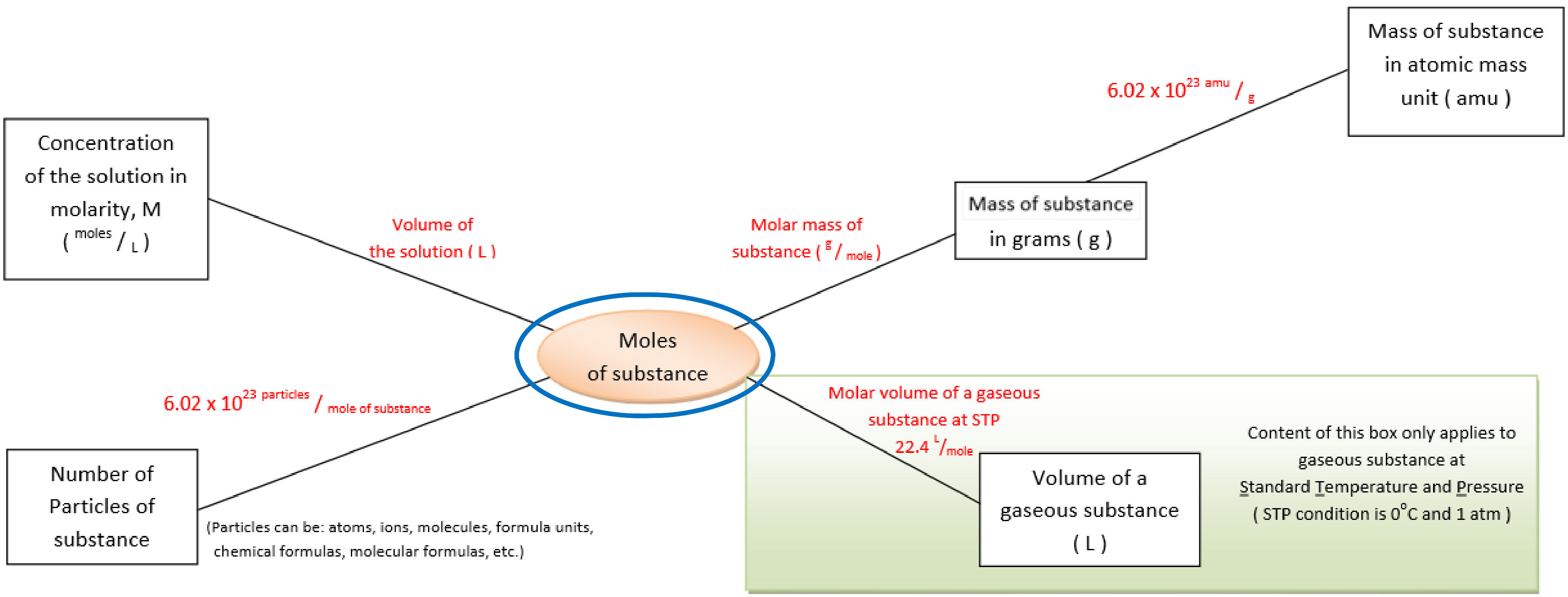
$$Na_2CO_3$$



Na^{+} : CO_3^{2-}

2 : 1

Expanded Road Map for "Mole - Mass - Volume - Particles" Calculations



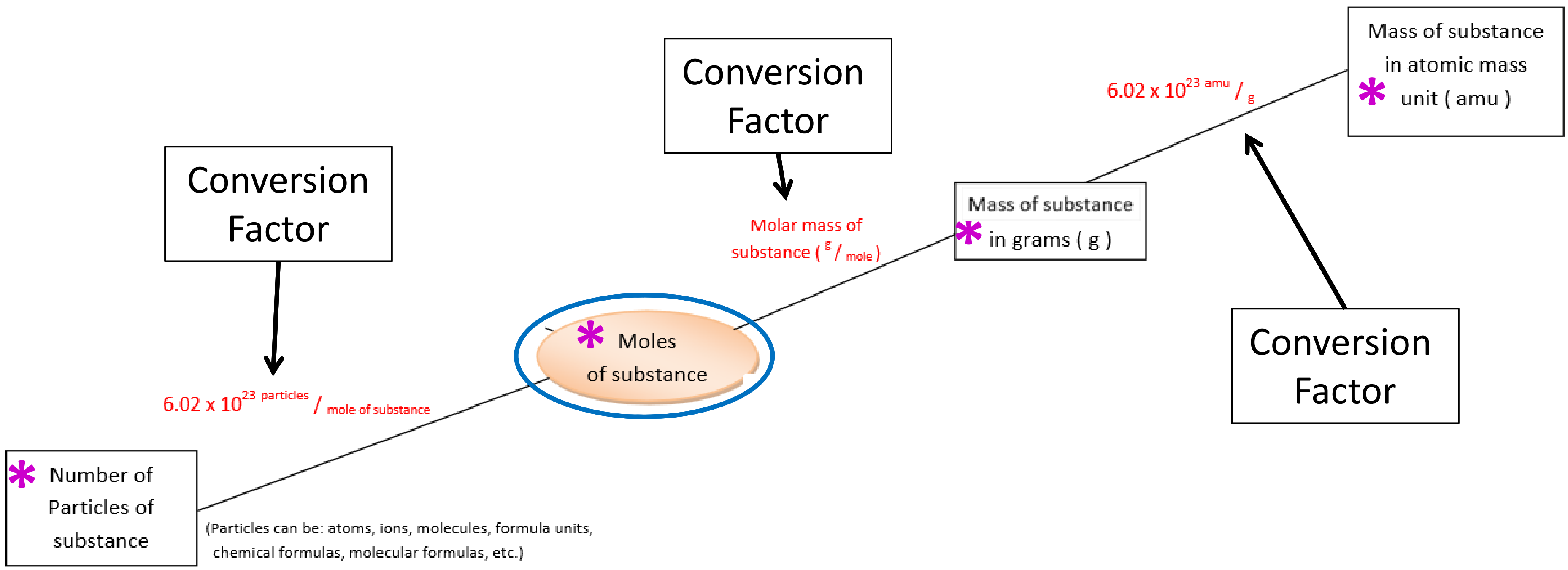
Particles can be:

- # of atoms,
- # of ions,

} Parts of a formula unit

- # of molecules,
- # of formula units

Expanded Road Map for "Mole - Mass - Volume - Particles" Calculations



Particles can be:

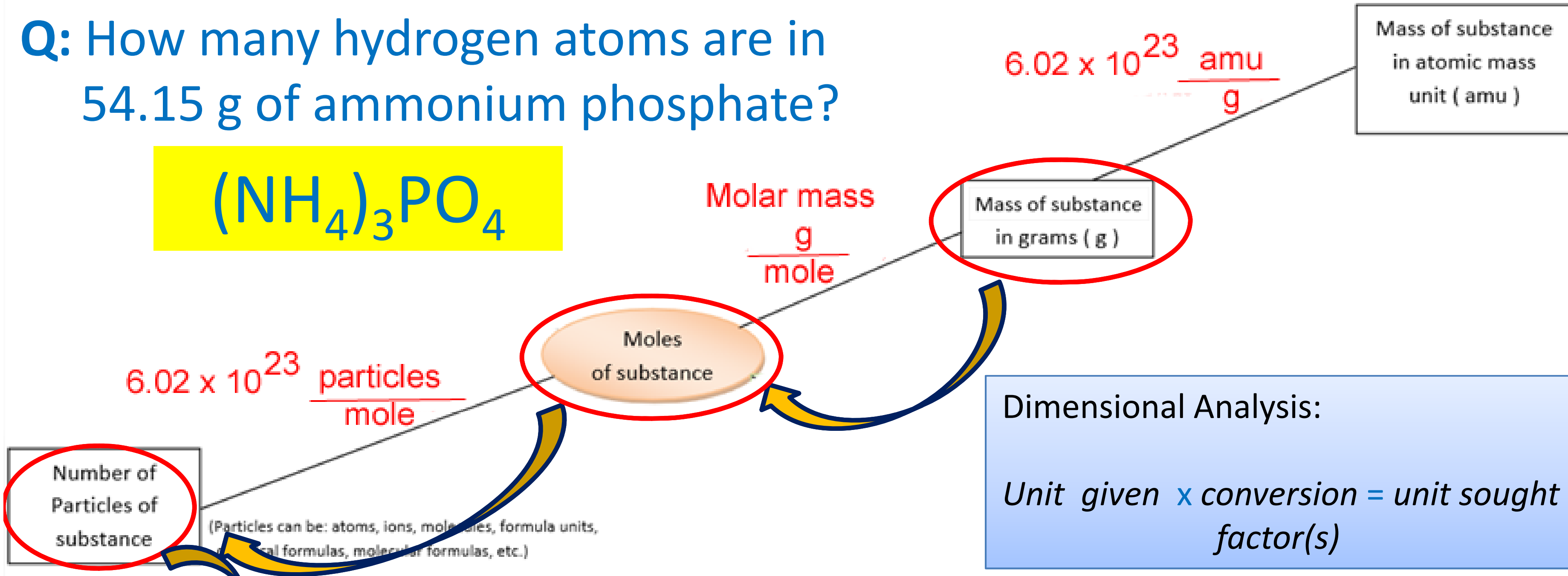
- # of atoms, } Parts of a formula unit
- # of ions, }
- # of molecules,
- # of formula units

* **In a problem, look for *unit given* and *unit sought*.**

Expanded Road Map for "Mole - Mass - Volume - Particles" Calculations

Q: How many hydrogen atoms are in 54.15 g of ammonium phosphate?

$(NH_4)_3PO_4$



Dimensional Analysis:

Unit given x conversion factor(s) = unit sought

Particles can be:

- # of atoms,
- # of ions,
- # of molecules,
- # of formula units

Do you expect the answer to be a big number or a small number?

Conversion Factor: Molar Mass = 149.05 $^{g}/_{mole}$

$$54.15\ \text{g}\ (NH_4)_3PO_4 \times \frac{1\ \text{mole}}{149.05\ \text{g}\ (NH_4)_3PO_4} \times \frac{6.02 \times 10^{23}\ (NH_4)_3PO_4}{\text{mole}} \times \frac{12\ \text{H atoms}}{(NH_4)_3PO_4} = \text{? H atoms}$$

A: 2.62×10^{24} H atoms

Percent Composition

This is an example of a theoretical calculation of *Percent Composition* of the elements in a the chemical formula.

$(NH_4)_3PO_4$

Formula Mass = 149.05 $^g/_{mole}$

Element	Mass Contribution to the formula mass	Percent Composition
Nitrogen	14.007 x 3 = 42.021 $^g/_{mole}$	$\frac{42.021 \frac{g}{mole}}{149.05 \frac{g}{mole}} \times 100 = 28.193\%$
Hydrogen	1.008 x 12 = 12.10 $^g/_{mole}$	$\frac{12.10 \frac{g}{mole}}{149.05 \frac{g}{mole}} \times 100 = 8.118\%$
Phosphorus	30.9738 x 1 = 30.9738 $^g/_{mole}$	$\frac{30.9738 \frac{g}{mole}}{149.05 \frac{g}{mole}} \times 100 = 20.781\%$
Oxygen	15.999 x 4 = 63.996 $^g/_{mole}$	$\frac{63.996 \frac{g}{mole}}{149.05 \frac{g}{mole}} \times 100 = 42.936\%$

100%

The percent composition of nitrogen in $(NH_4)_3PO_4$ is 28.193%. etc.

Percent Composition

CHEM 0011

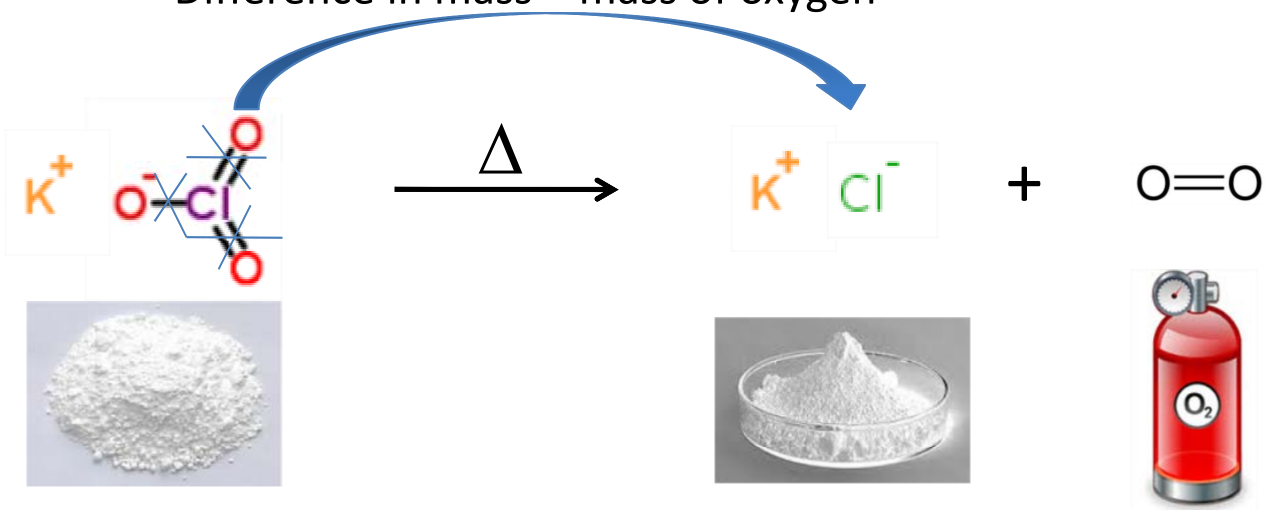
Experiment 6 – Percent Composition

Objectives

1. To observe the techniques involved to carry out the decomposition of a chemical, potassium chlorate, $KClO_3$, quantitatively.
2. To calculate the percentage of oxygen in potassium chlorate, $KClO_3$, theoretically and experimentally.
3. To verify the product of the decomposition reaction is potassium chloride, KCl.

Experimentally:

Difference in mass = mass of oxygen



Start with $KClO_3$ of a certain mass

After heating, solid remains should have less mass

Oxygen escaped

From a given chemical formula, we can generate a list of percent compositions of the elements that make up the compound.

Empirical Formula

The simplest formula for a compound that has the SIMPLEST whole number ratio of the atoms present.

Example: Water

H_2O

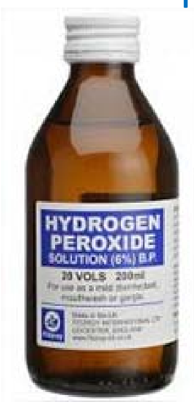
2 : 1

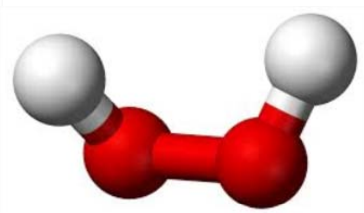
H_2O is the chemical formula of water.

Since this is the SIMPLEST whole number ratio of H:O.
Therefore, H_2O is also the empirical formula for water.

Empirical Formula

The simplest formula for a compound that has the SIMPLEST whole number ratio of the atoms present.





H_2O_2 is the chemical formula of hydrogen peroxide.

Example: Hydrogen peroxide

$$H_2O_2$$

2 : 2

The chemical formula is NOT the SIMPLEST whole number ratio of H:O.
Therefore, the empirical formula for hydrogen peroxide is HO.

Empirical Formula

The simplest formula for a compound that has the SIMPLEST whole number ratio of the atoms present.

Chemical formula of the compound	H:O Ratio	Empirical Formula	*Multiple*
H_2O water	2:1	H_2O	1x
H_2O_2 hydrogen peroxide	2:2	HO	2x

What do we know from this:

1. Sometimes the chemical formula IS the empirical formula, sometimes it is not.
2. The chemical formula **IS** a *multiple* of the empirical formula. When the chemical formula is the empirical formula, the multiple is one.
3. If we know the empirical formula and we know the **molar mass** of the compound, then we can determine the chemical formula of the compound!

From Empirical Formula to Chemical Formula

Question: Hexane has a molar mass of 86.05 $^{g}/_{mole}$. The empirical formula of hexane is C_3H_7.
What is the chemical formula of hexane?

Chemical formula of the compound	C:H Ratio	Empirical Formula	*Multiple*
Hexane ?	3:7	C_3H_7	2

x2

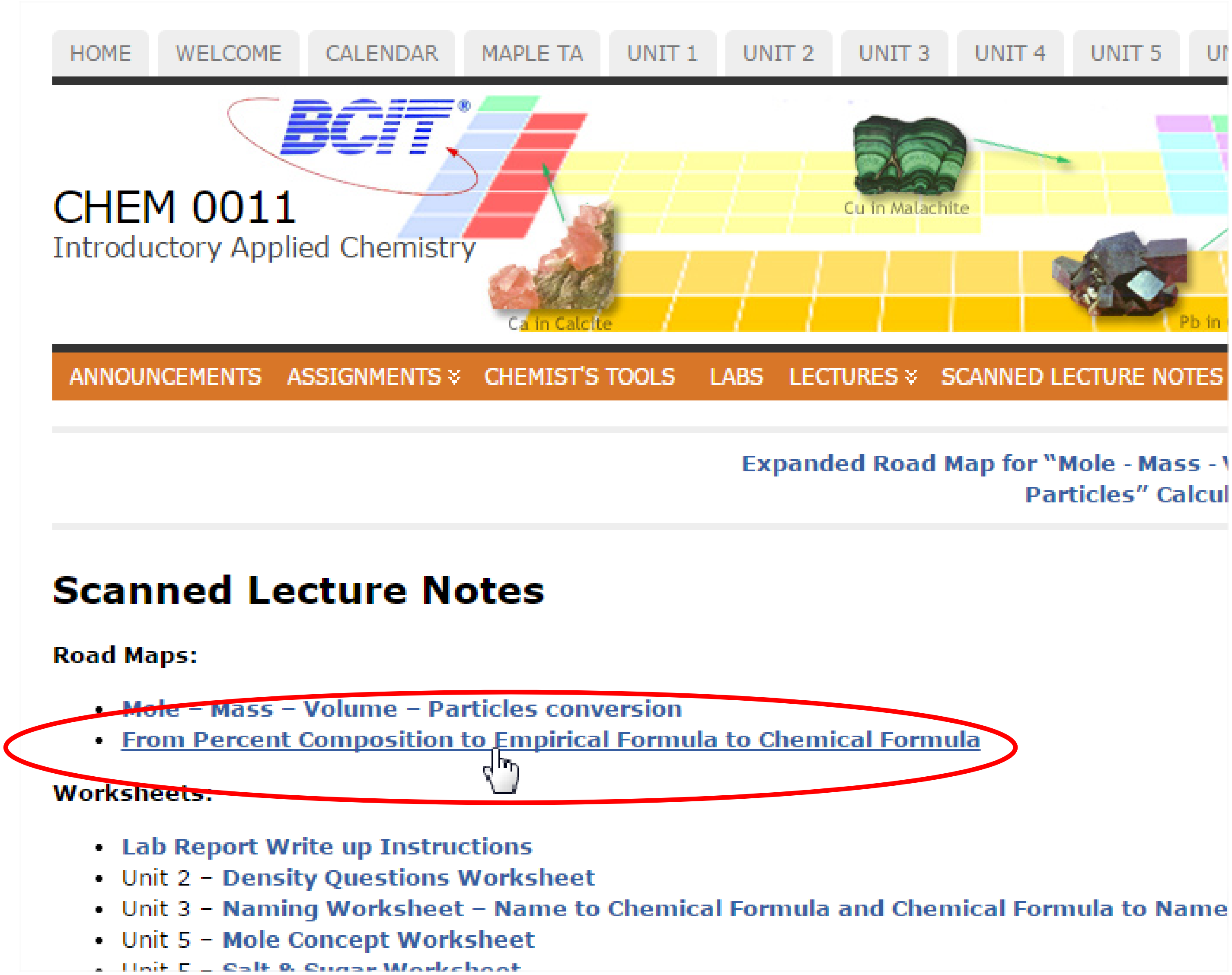
A: C_6H_{14}

Empirical formula has a mass of: (12.011 x 3) + (1.008x7) = 43.027 $^{g}/_{mole}$.

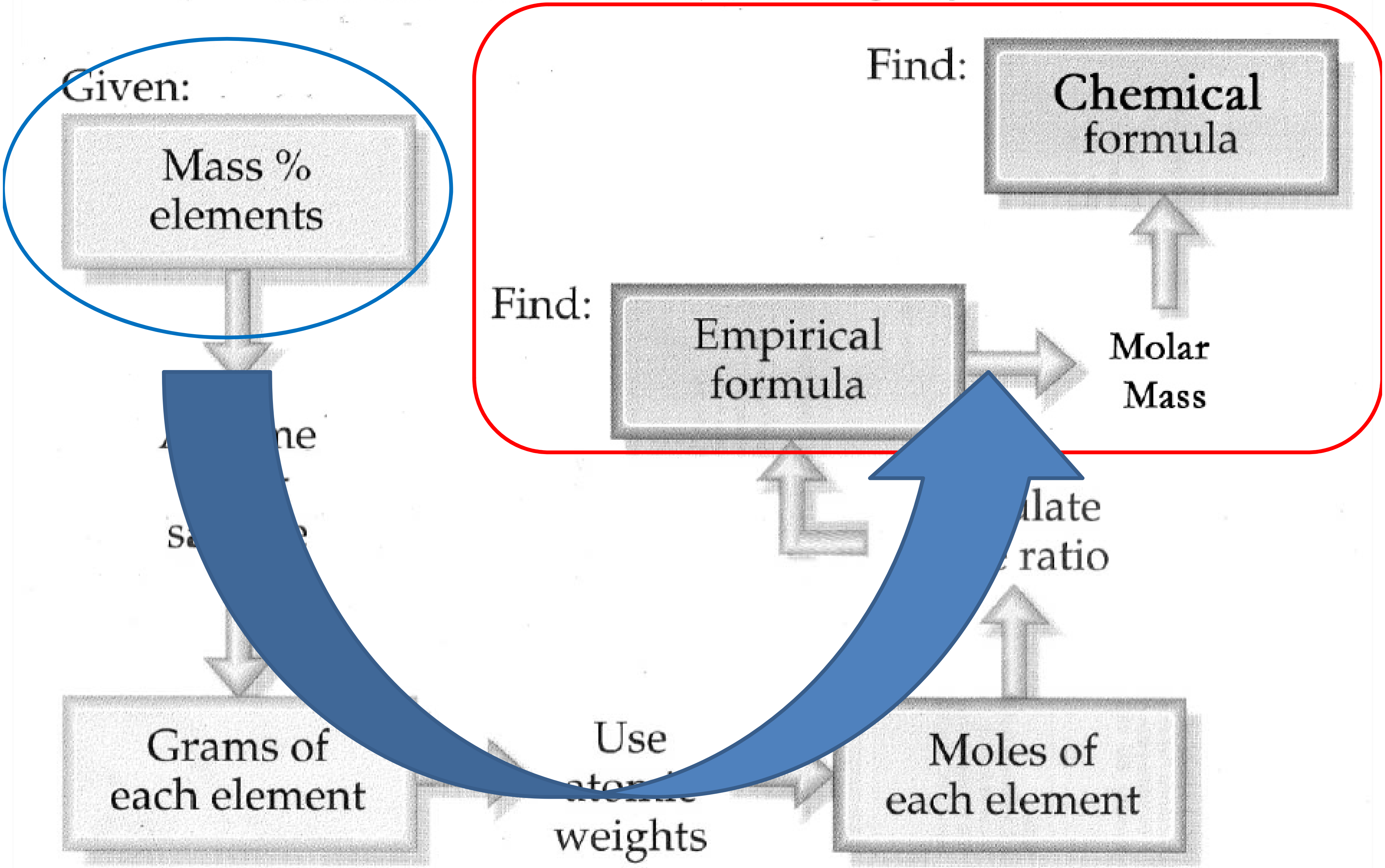
To determine the multiple,

$$Multiple = \frac{\text{molar mass of compound}}{\text{empirical formula mass}} = \frac{86.05\ \frac{g}{mole}}{43.027\ \frac{g}{mole}} = 2$$

Percent Composition → Empirical Formula → Chemical Formula Road Map

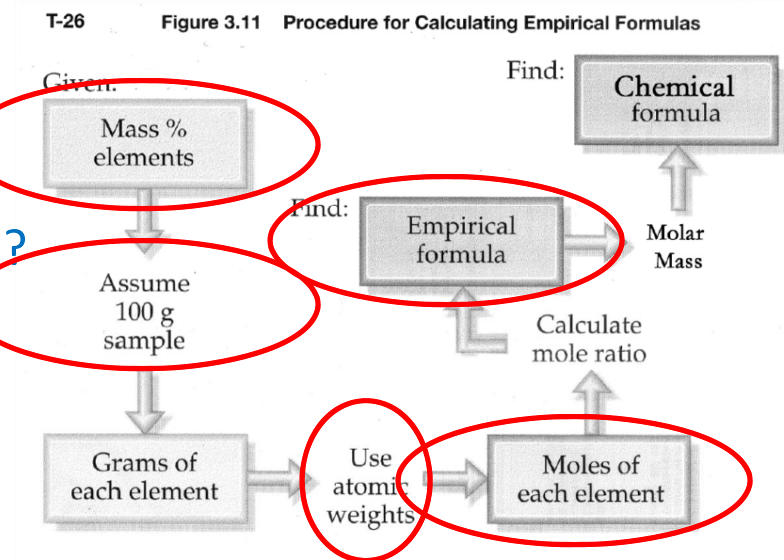


T-26 **Figure 3.11** **Procedure for Calculating Empirical Formulas**



Question: A sample was sent to the lab and the analysis comes back showing us that the following mass percent of the elements was found. What is the empirical formula?

15.88% Carbon
2.22 % Hydrogen
63.42% Oxygen
18.50% Nitrogen



Elements	100 g	Moles of Elements	Mole Ratio
C	15.88 g	$15.88\ g \cdot \frac{mole}{12.011 g}$ = 1.322 moles	$\frac{1.322}{1.320} = 1$ x 3 = **3**
H	2.22 g	$2.22\ g \cdot \frac{mole}{1.008\ g}$ = 2.203 moles	$\frac{2.22}{1.320} = 1.667 = \frac{5}{3}$ x 3 = **5**
O	63.42 g	$63.42\ g \cdot \frac{mole}{15.999\ g}$ = 3.964 moles	$\frac{3.964}{1.320} = 3$ x 3 = **9**
N	18.50 g	$18.50\ g \cdot \frac{mole}{14.007\ g}$ = 1.320 moles	$\frac{1.320}{1.320} = 1$ x 3 = **3**

Divide through by the smallest number

Answer: $C_3H_5O_9N_3$ **(Nitroglycerine or TNT)**

CHEM 0011
Introductory Applied Chemistry

« Lecture (Wk 5) – Unit 5 (5.11)

Expanded Road Map for "Mole - Mass - Volume - Particles" Calculations »

Scanned Lecture Notes

Road Maps:

- Mole – Mass – Volume – Particles conversion
- From Percent Composition to Empirical Formula to Chemical Formula

Worksheets:

- Lab Report Write up Instructions
- Unit 2 – Density Questions Worksheet
- Unit 3 – Naming Worksheet – Name to Chemical Formula and Chemical Formula to Name
- Unit 5 – Mole Concept Worksheet
- Unit 5 – Salt & Sugar Worksheet
- Unit 5 – Percent Composition, Empirical Formula, Chemical Formula Worksheet
- Unit 5 – Solution Worksheet – Maple TA Type Questions
- Unit 5 – Solution Dilution Worksheet
- Unit 6 – From Combustion Analysis of C, H, O containing compounds to Empirical Formula to Chemical Formula – Maple TA type problem in Assignment 7
- Unit 6 – Single Replacement Reactions Worksheet (Watch animation here)

Do the *Percent Composition, Empirical Formula, Chemical Formula* Worksheet. Answers will be posted later in the week.

Try some practice problems in Maple TA.

Use Dimensional Analysis in ALL your calculations!!