MOLECULAR MASS AND FORMULA MASS

Molecular mass = sum of the atomic weights of all atoms in the molecule.

Formula mass = sum of the atomic weights of all atoms in the formula unit.

MOLECULAR MASS AND FORMULA MASS

- Ammonium sulfate, $(NH_4)_2SO_4$
- Magnesium perchlorate, $Mg(ClO_4)_2$

- Carbon tetrachloride, CCl_4
- Diphosphorus pentoxide P_2O_5

16.00 amu + 12.01 amu + 16.00 amu = 44.01 amu

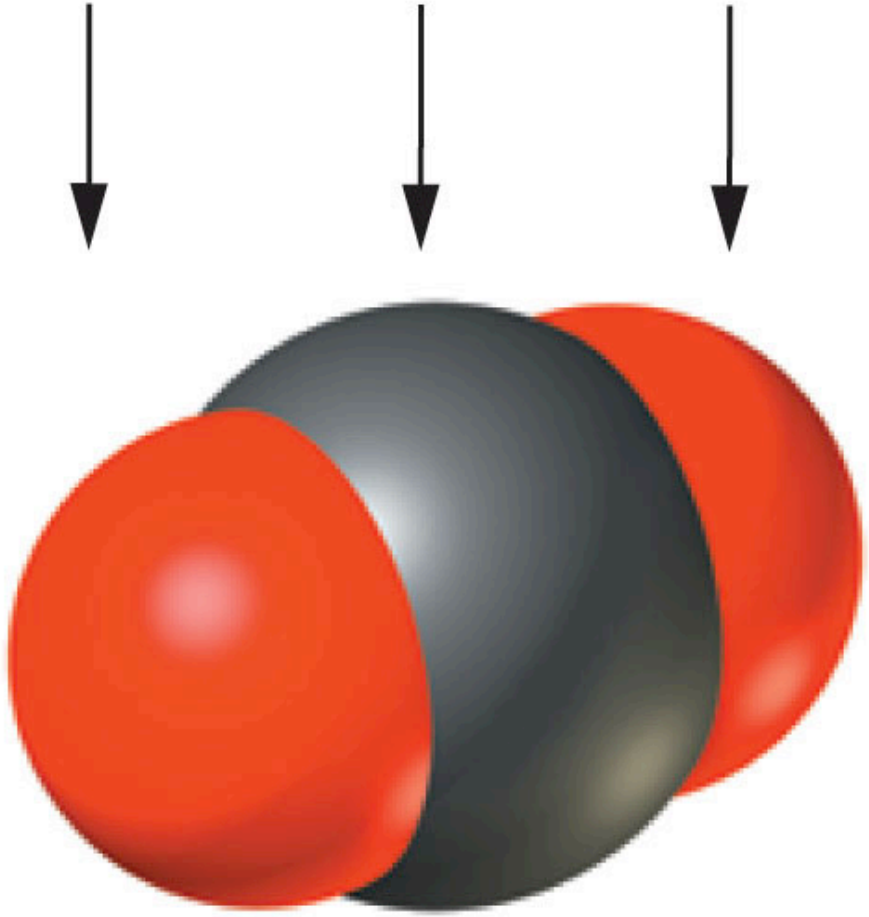


Fig. 7-1, p. 176

Counting Atoms

Chemistry is a quantitative science—we need a "counting unit."

MOLE

1 mole is the amount of substance that contains as many particles (atoms, molecules) as there are in 12.0 g of ^{12}C.

518 g of Pb, 2.50 mol

Particles in a Mole

Avogadro's Number

Amedeo Avogadro
1776-1856

6.0221415×10^{23}

There is Avogadro's number of particles in a mole of any substance.

MOLECULAR MASS AND MOLAR MASS

Molecular mass = sum of the atomic weights of all atoms in the molecule.

Molar mass = molecular weight in grams

Molar Mass

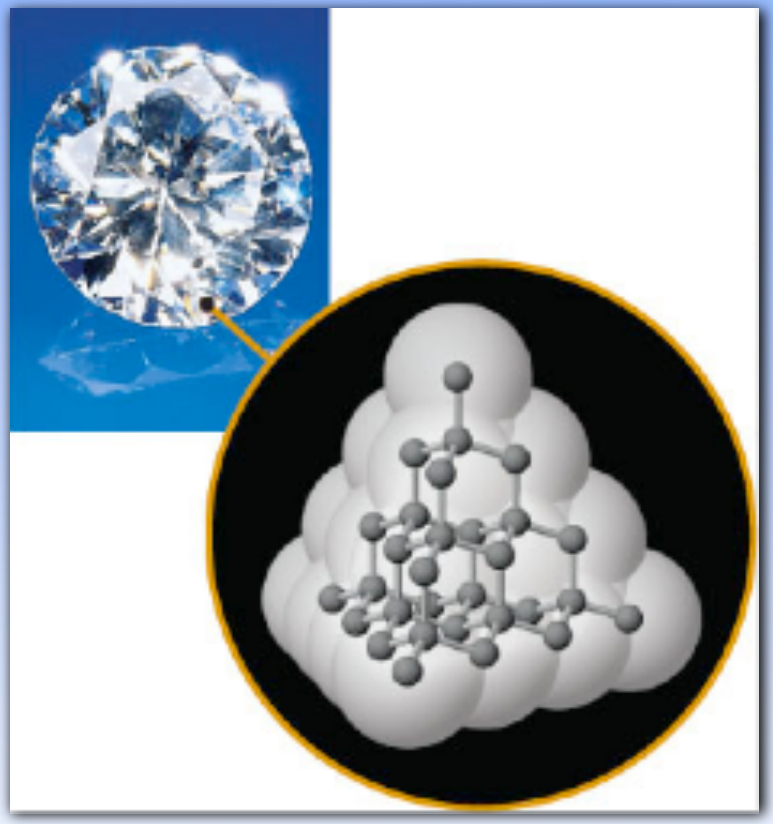
1 mol of ^{12}C
= 12.00 g of C
= 6.022×10^{23} atoms of C

12.00 g of ^{12}C is its

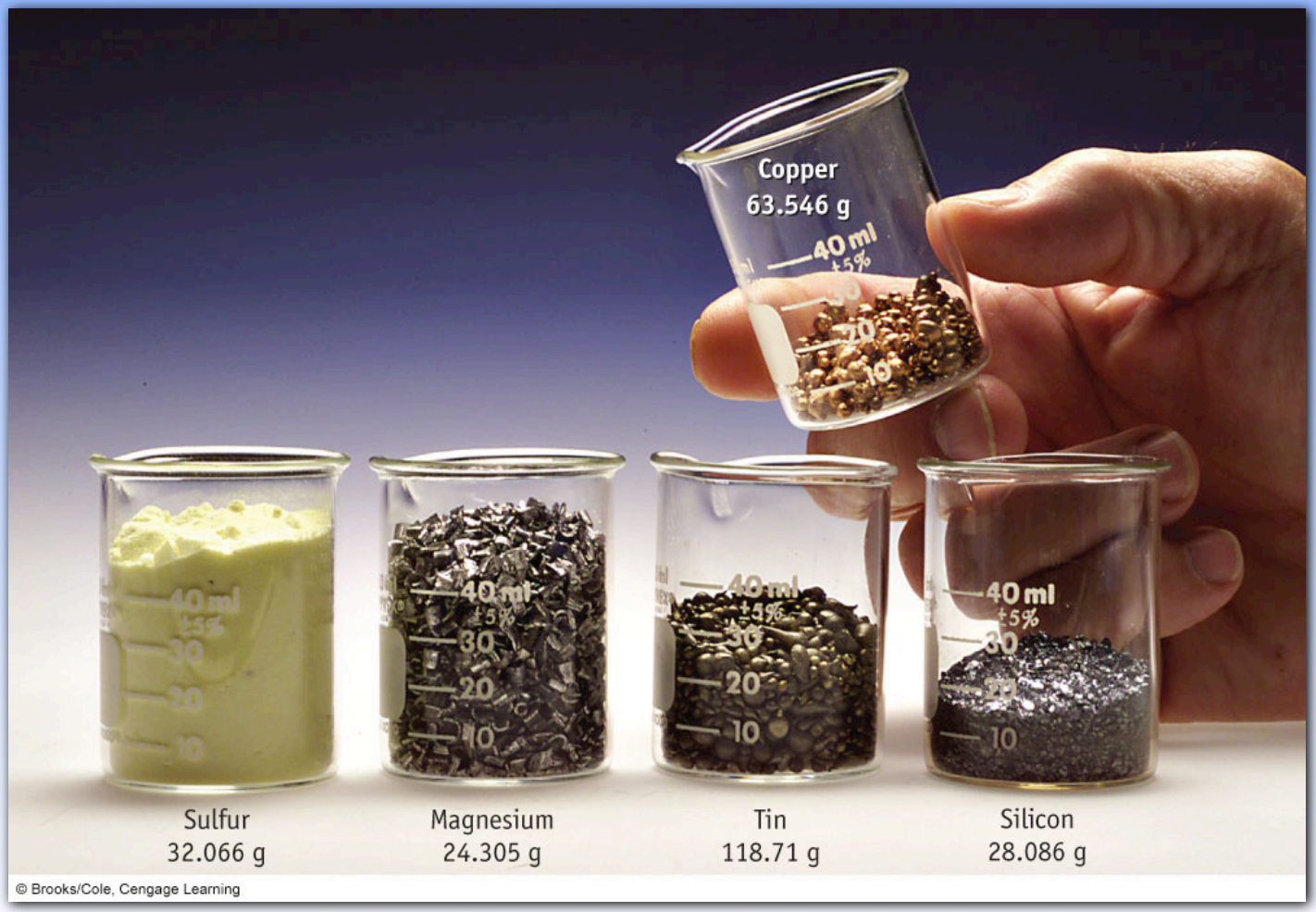
MOLAR MASS

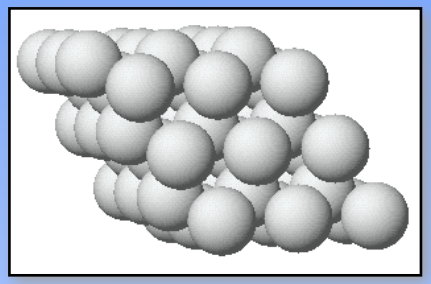
Taking into account all of the isotopes of C, the molar mass of C is

12.011 g/mol



One-mole Amounts





PROBLEM: What amount of Mg is represented by 0.200 g? How many atoms?

Mg has a molar mass of 24.3050 g/mol.

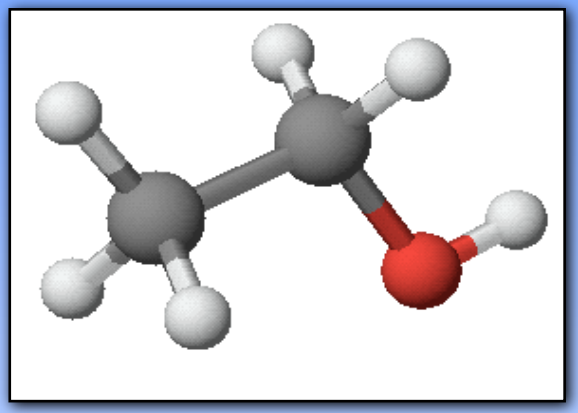
$$0.200\ \text{g} \left(\frac{1\ \text{mol}}{24.31\ \text{g}} \right) = 8.23 \times 10^{-3}\ \text{mol}$$

How many atoms in this piece of Mg?

$$8.23 \times 10^{-3}\ \text{mol} \left(\frac{6.022 \times 10^{23}\ \text{atoms}}{1\ \text{mol}} \right)$$

= 4.95×10^{21} atoms Mg

What is the molar mass of ethanol, C_2H_6O?



1 mol contains

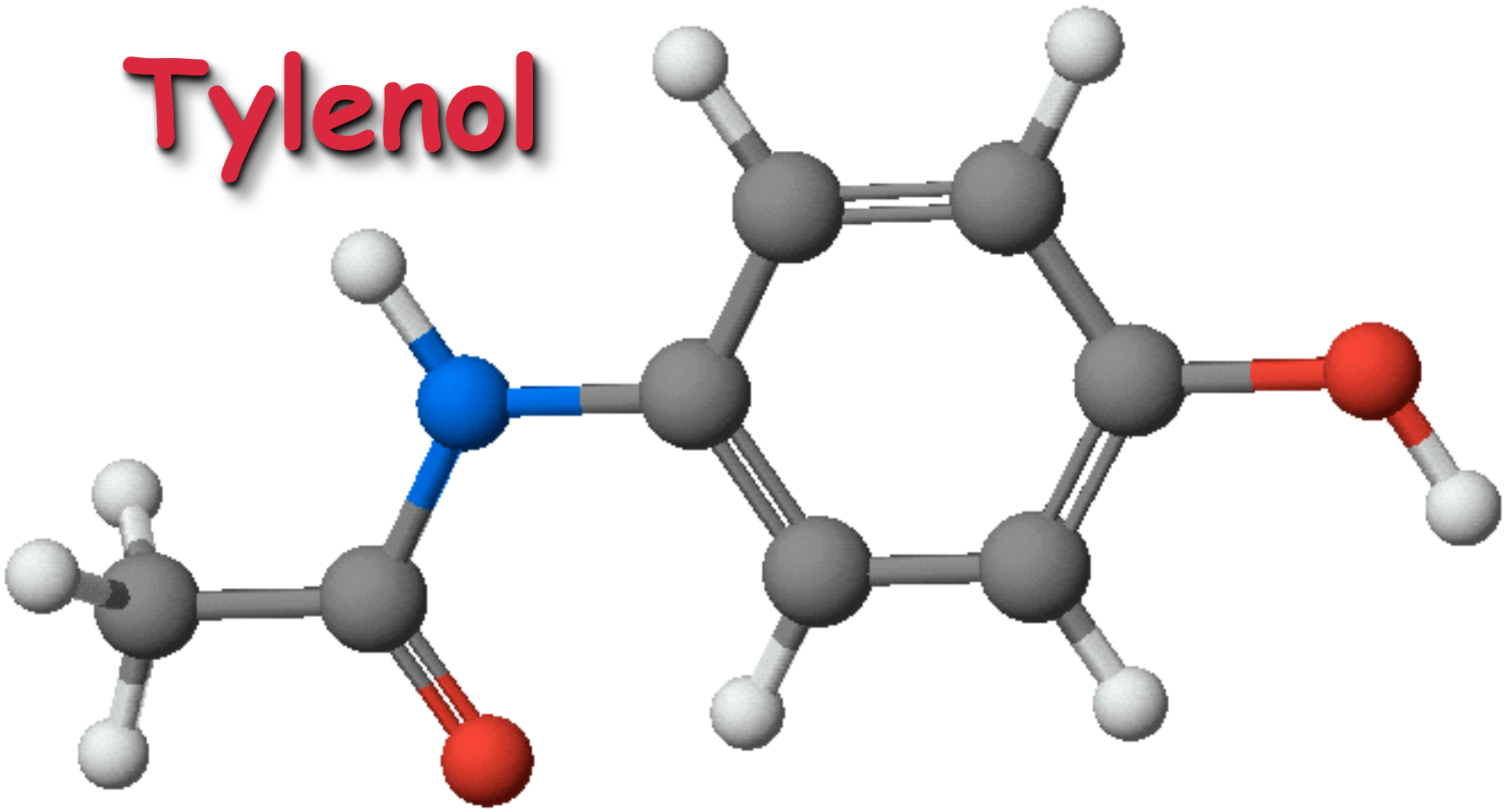
2 mol C (12.01 g C/1 mol) = 24.02 g C

6 mol H (1.01 g H/1 mol) = 6.06 g H

1 mol O (16.00 g O/1 mol) = 16.00 g O

TOTAL = molar mass = 46.08 g/mol

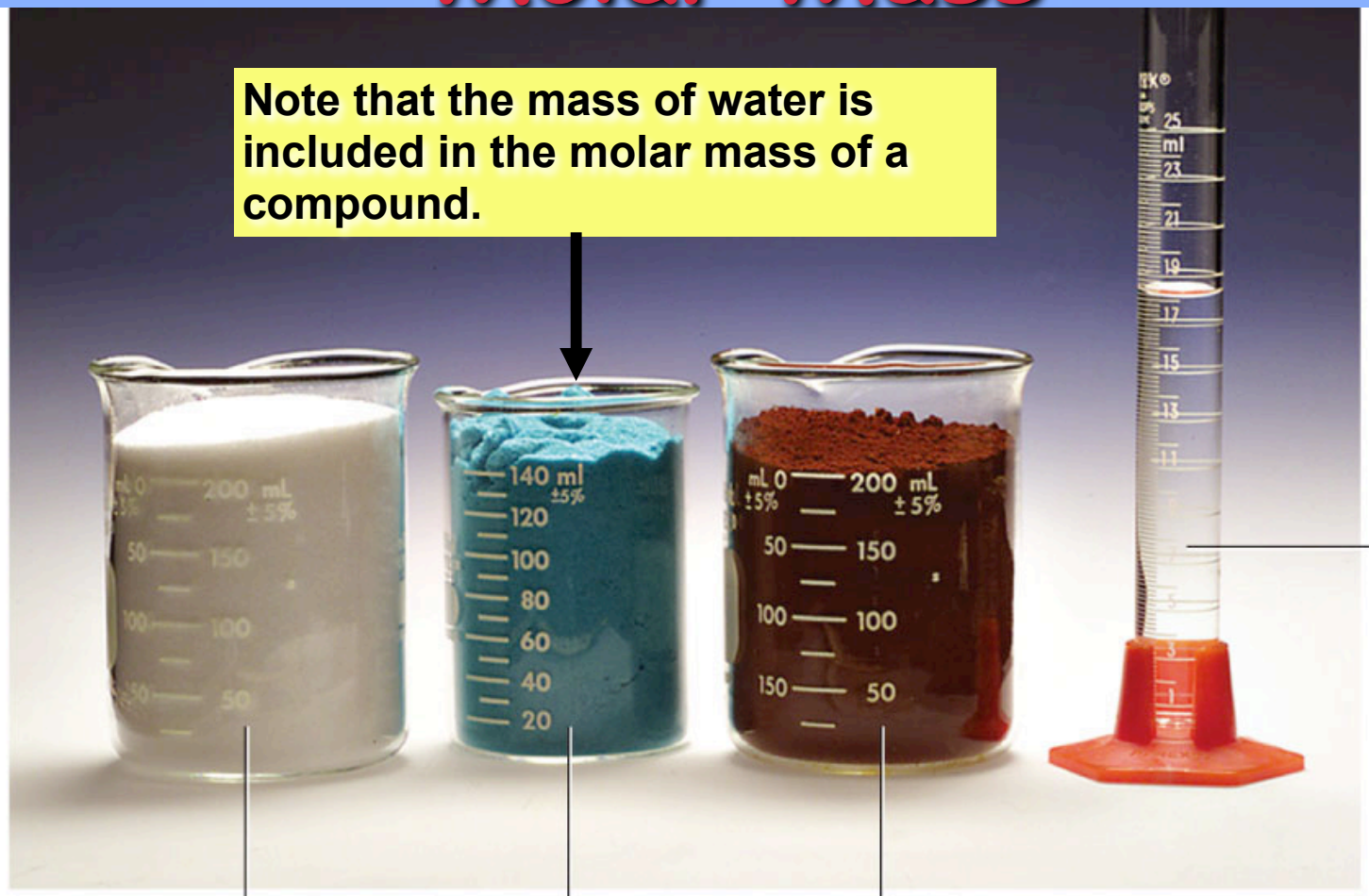
Tylenol



- Formula = $C_8H_9NO_2$
- Molar mass = 151.2 g/mol

Molar Mass

Note that the mass of water is included in the molar mass of a compound.



Percent Composition

- Percent composition is the percentage by mass of each element in the compound.
- $\%A = \frac{\text{mass of A}}{\text{mass of compound}} \times 100$
- Sum of percentages should equal 100

Percent Composition

A pure compound always consists of the same elements combined in the same proportions by weight.

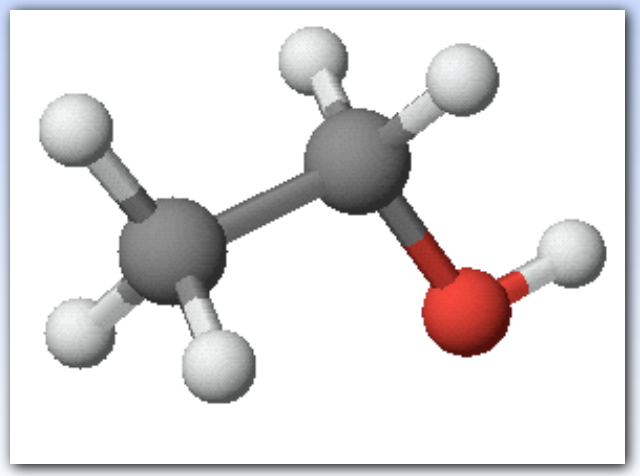
Therefore, we can express molecular composition as PERCENT BY WEIGHT

Ethanol, C_2H_6O

52.13% C

13.15% H

34.72% O



Percent Composition

Consider NO_2, Molar mass = ?

What is the weight percent of N and of O?

$$\text{Wt. \% N} = \frac{14.0\ \text{g N}}{46.0\ \text{g } NO_2} \times 100\% = 30.4\ \%$$

$$\text{Wt. \% O} = \frac{2(16.0\ \text{g O per mol } NO_2)}{46.0\ \text{g } NO_2} \times 100\% = 69.6\%$$

What are the weight percentages of N and O in NO?

Determining Formulas

In **chemical analysis** we determine the % by weight of each element in a given amount of pure compound and derive the **EMPIRICAL** or **SIMPLEST** formula.

PROBLEM: *A compound of B and H is 81.10% B. What is its empirical formula?*

A compound of B and H is 81.10% B. What is

- Because it contains only B and H, it must contain 18.90% H.
- In 100.0 g of the compound there are 81.10 g of B and 18.90 g of H.
- Calculate the number of moles of each constituent.

A compound of B and H is 81.10% B. What is

Calculate the number of moles of each element in 100.0 g of sample.

$$81.10\ \text{g B} \left(\frac{1\ \text{mol}}{10.81\ \text{g}}\right) = 7.502\ \text{mol B}$$

$$18.90\ \text{g H} \left(\frac{1\ \text{mol}}{1.008\ \text{g}}\right) = 18.75\ \text{mol H}$$

A compound of B and H is 81.10% B. What is

Take the ratio of moles of B and H. **Always divide by the smaller number.**

$$\frac{18.75 \text{ mol H}}{7.502 \text{ mol B}} = \frac{2.499 \text{ mol H}}{1.000 \text{ mol B}} = \frac{2.5 \text{ mol H}}{1.0 \text{ mol B}}$$

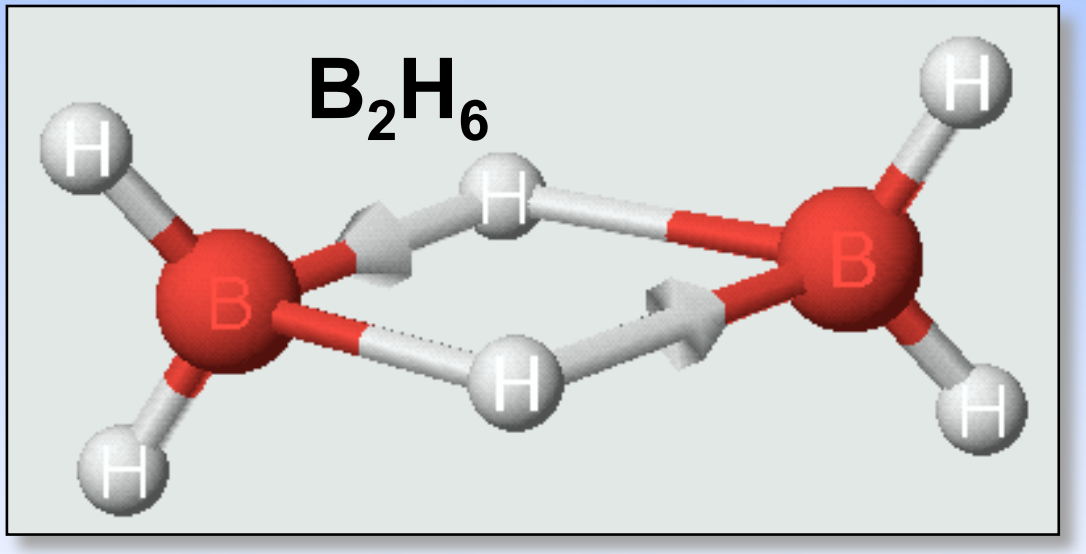
But we need a whole number ratio.

2.5 mol H/1.0 mol B = 5 mol H to 2 mol B

EMPIRICAL FORMULA = B_2H_5

A compound of B and H is 81.10% B. Its empirical formula is B_2H_5. What is

Is the molecular formula B_2H_5, B_4H_{10}, B_6H_{15}, B_8H_{20}, etc.?



B_2H_6 is one example of this class of compounds.

A compound of B and H is 81.10% B. Its empirical

We need to do an EXPERIMENT to find the MOLAR MASS.

Here experiment gives 53.3 g/mol

Compare with the mass of B_2H_5

= 26.66 g/unit

Find the ratio of these masses.

$$\frac{53.3 \text{ g/mol}}{26.66 \text{ g/unit of } B_2H_5} = \frac{2 \text{ units of } B_2H_5}{1 \text{ mol}}$$

Molecular formula = B_4H_{10}

The Empirical Formula

A sample is made up of 1.61 g P and 2.98 g F. Find the EF.

Determine the masses of each element:

1.61 g P 2.98 g F

Convert the masses into moles of each element:

$$1.61\ \cancel{g\ P} \times \frac{1\ mol\ P}{30.97\ \cancel{g\ P}} = 0.0520\ mol\ P$$

$$2.98\ \cancel{g\ F} \times \frac{1\ mol\ F}{19.00\ \cancel{g\ F}} = 0.157\ mol\ F$$

Express the moles as the smallest possible ratio:

$$\frac{0.0520}{0.0520} = 1.00 \qquad \frac{0.157}{0.0520} = 3.02$$

Write the EF using the values above as subscripts:

$$PF_3$$

The Empirical Formula

A compound is found to contain 20.0 % carbon, 2.2 % hydrogen and 77.8 % chlorine. Determine the EF.

Determine the masses of each element assuming 100 g:

20.0 g C 2.2 g H 77.8 g Cl

Convert the masses into moles of each element:

$$20.0\ \cancel{g}\ C \times \frac{1\ mol\ C}{12.01\ \cancel{g}\ C} = 1.67\ mol\ C$$

$$2.2\ \cancel{g}\ H \times \frac{1\ mol\ H}{1.008\ \cancel{g}\ H} = 2.18\ mol\ H$$

$$77.8\ \cancel{g}\ Cl \times \frac{1\ mol\ Cl}{35.45\ \cancel{g}\ Cl} = 2.19\ mol\ Cl$$

Express the moles as the smallest possible ratio:

$$\frac{1.67}{1.67} = 1.00 \qquad \frac{2.18}{1.67} = 1.30 \qquad \frac{2.19}{1.67} = 1.30$$

Write the EF using the values above as subscripts:

$$CH_{1.3}Cl_{1.3} = C_3H_4Cl_4$$

Must have a whole number ratio!

The Molecular Formula

Fructose is found to contain 40.0 % carbon, 6.71 % hydrogen and the rest oxygen. The molar mass of fructose is 180.16 g/mol. Determine the EF and molecular formula.

Determine the masses of each element assuming 100 g:

40.0 g C **6.71 g H** **53.29 g O**

Convert the masses into moles of each element:

$$40.0\ \text{g C} \times \frac{1\ \text{mol C}}{12.01\ \text{g C}} = 3.33\ \text{mol C}$$

$$6.71\ \text{g H} \times \frac{1\ \text{mol H}}{1.008\ \text{g H}} = 6.66\ \text{mol H}$$

$$53.29\ \text{g O} \times \frac{1\ \text{mol O}}{16.00\ \text{g O}} = 3.33\ \text{mol O}$$

Express the moles as the smallest possible ratio:

$$CH_2O$$

The Molecular Formula

Fructose is found to contain 40.0 % carbon, 6.71 % hydrogen and the rest oxygen. The molar mass of fructose is 180.16 g/mol. Determine the EF and molecular formula.

Determine the mass of the EF (CH_2O):

$$12.01\ g/mol + 2(1.008\ g/mol) + 16\ g/mol = 30.03\ g/mol$$

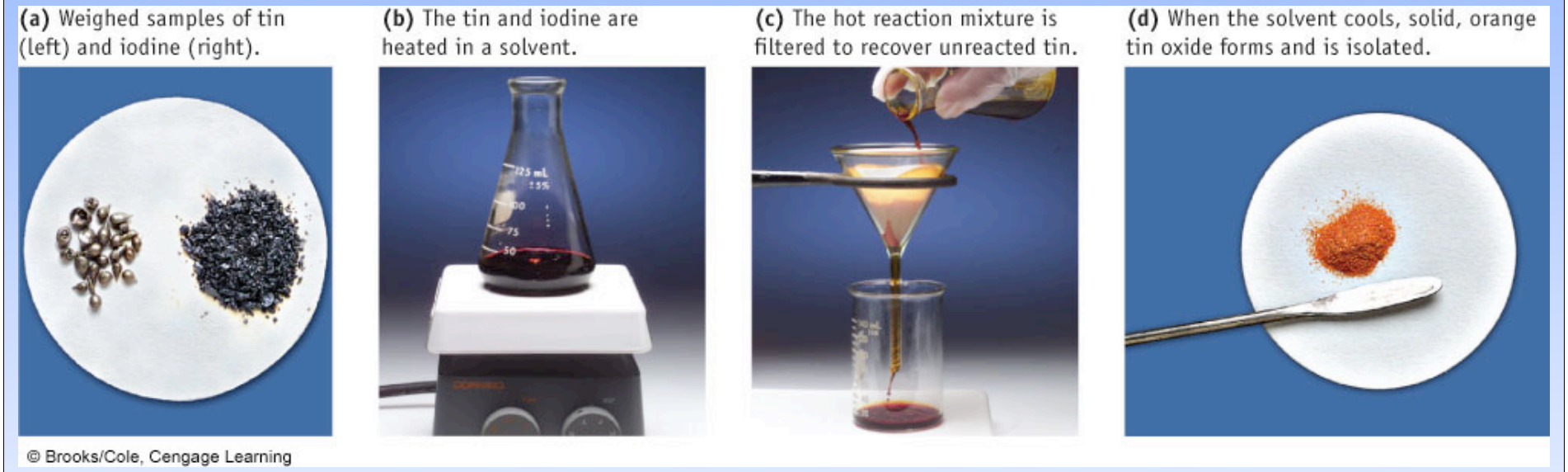
Determine the number of EF units in the molecule:

$$\frac{\text{Molar mass compound}}{\text{Molar mass EF}} = \frac{180.16\ g/mol}{30.03\ g/mol} = 6$$

Write the molecular formula:

$$(CH_2O)_6 = C_6H_{12}O_6$$

DETERMINE THE FORMULA OF A COMPOUND OF Sn AND I



Sn(s) + some I_2(s) f SnI_x

Data to Determine the formula of a Sn—I Compound

- Reaction of Sn and I_2 is done using excess Sn.
- Mass of Sn in the beginning = 1.056 g
- Mass of iodine (I_2) used = 1.947 g
- Mass of Sn remaining = 0.601 g

Tin and Iodine Compound

Find the mass of Sn that combined with 1.947 g I_2.

Mass of Sn initially = 1.056 g

Mass of Sn recovered = 0.601 g

Mass of Sn used = 0.455 g

Find moles of Sn used:

$$0.455 \text{ g Sn} \left(\frac{1 \text{ mol}}{118.7 \text{ g}} \right) = 3.83 \times 10^{-3} \text{ mol Sn}$$

Tin and Iodine Compound

Now find the number of moles of I_2 that combined with 3.83×10^{-3} mol Sn. Mass of I_2 used was 1.947 g.

$$1.947 \text{ g } I_2 \left(\frac{1 \text{ mol } I_2}{253.81 \text{ g } I_2} \right) = 7.671 \times 10^{-3} \text{ mol } I_2$$

How many mol of **iodine atoms**?

$$7.671 \times 10^{-3} \text{ mol } I_2 \left(\frac{2 \text{ mol I atoms}}{1 \text{ mol } I_2} \right)$$

$$= 1.534 \times 10^{-2} \text{ mol I atoms}$$

Tin and Iodine Compound

Now find the ratio of number of moles of moles of I and Sn that combined.

$$\frac{1.534 \times 10^{-2} \text{ mol I}}{3.83 \times 10^{-3} \text{ mol Sn}} = \frac{4.01 \text{ mol I}}{1.00 \text{ mol Sn}}$$

Empirical formula is SnI_4

Percent Composition

If you know the percent composition of a compound, you can find the amount of any element in a known amount of the compound.

How many g of potassium are in 154.6 g of K_2S? (MW = 110.26 g/mol)

Method 1:

$$154.6 \text{ g } K_2S \times \frac{78.2 \text{ g K}}{110.26 \text{ g } K_2S} = 109.6 \text{ g K}$$

0.7092

Method 2:

Use the percent composition as a conversion factor, g K/100 g K_2S

$$154.6 \text{ g } K_2S \times \frac{70.92 \text{ g K}}{100 \text{ g } K_2S} = 109.6 \text{ g K}$$

Both methods are equally valid!

Avogadro's Number: Use it Wisely!

How many molecules of CO_2 are in 123.4 g of CO_2?

$$123.4\ \text{g } CO_2 \times \frac{1\ \text{mol } CO_2}{44.01\ \text{g } CO_2} \times \frac{6.02 \times 10^{23}\ \text{molecules}}{1\ \text{mol } CO_2}$$

$$= 1.69 \times 10^{24}\ \text{molecules } CO_2$$

How many O atoms are in 123.4 g of CO_2?

$$123.4\ \text{g } CO_2 \times \frac{1\ \text{mol } CO_2}{44.01\ \text{g } CO_2} \times \frac{6.02 \times 10^{23}\ \text{mcs } CO_2}{1\ \text{mol } CO_2} \times \frac{2\ \text{O atoms}}{1\ \text{mc } CO_2}$$

$$= 3.37 \times 10^{24}\ \text{O atoms}$$

compounds convert directly to molecules

elements convert directly to atoms

compounds to atoms take an extra step!

Avogadro's Number: Use it Wisely!

How many total atoms are in 4.5 g of H_2SO_4?

$$4.5\ \text{g } H_2SO_4 \times \frac{1\ \text{mol } H_2SO_4}{98.06\ \text{g } H_2SO_4} \times \frac{6.02 \times 10^{23}\ \text{mcs } H_2SO_4}{1\ \text{mol } H_2SO_4} \times \frac{7\ \text{atoms}}{1\ \text{mc } H_2SO_4}$$

$$= 1.93 \times 10^{23}\ \text{atoms}$$

How many H atoms are in 4.5 g of H_2SO_4?

$$4.5\ \text{g } H_2SO_4 \times \frac{1\ \text{mol } H_2SO_4}{98.06\ \text{g } H_2SO_4} \times \frac{6.02 \times 10^{23}\ \text{mcs } H_2SO_4}{1\ \text{mol } H_2SO_4} \times \frac{2\ \text{H atoms}}{1\ \text{mc } H_2SO_4}$$

$$= 5.53 \times 10^{22}\ \text{H atoms}$$

A question using this concept will be on the exam!!!

Practice Problems: Molar Mass

1. Find the molar mass of the following compounds:
   a. C_3H_7OH
   b. cobalt(III) bromide
   c. silicon dioxide
   d. $C_8H_9NO_2$ (active ingredient in Tylenol)

2. Find the number of moles of each substance:
   a. 11.23 g iodine
   b. 3.32 g beryllium nitrate
   c. 0.477 g C_9H_{20}
   d. 659 g C_2H_5OH

Practice Problems: Avogadro's #

Find the number of grams in the following compounds:

a. 4.30×10^{22} molecules of C_6H_{14}

b. 6.77×10^{24} atoms of aluminum

c. 5.445 moles of ammonium hydroxide

Practice Problems: Mass Relationship

1. Potassium sulfate is found in some fertilizers as a source of potassium. How many grams of potassium can be obtained from 143.6 g of the compound?

Practice Problems: Percent Composition

1. Calculate the percent composition of each compound:

   a. octane (C_8H_{18})
   b. aluminum acetate
   c. calcium dihydrogen phosphate
   d. chromium(II) chloride

Practice Problems: Empirical Formula

1. A compound is found to contain 63 % manganese and 37 % oxygen. Find the empirical formula of the compound.

2. A compound contains 42.05 g of nitrogen and 95.95 g of oxygen. Find its empirical formula.

3. A compound has 68.85 % carbon, 4.95 % hydrogen and 26.20 % oxygen and has a molar mass of 366 g/mol. What is the empirical formula for this compound? What is the molecular formula?