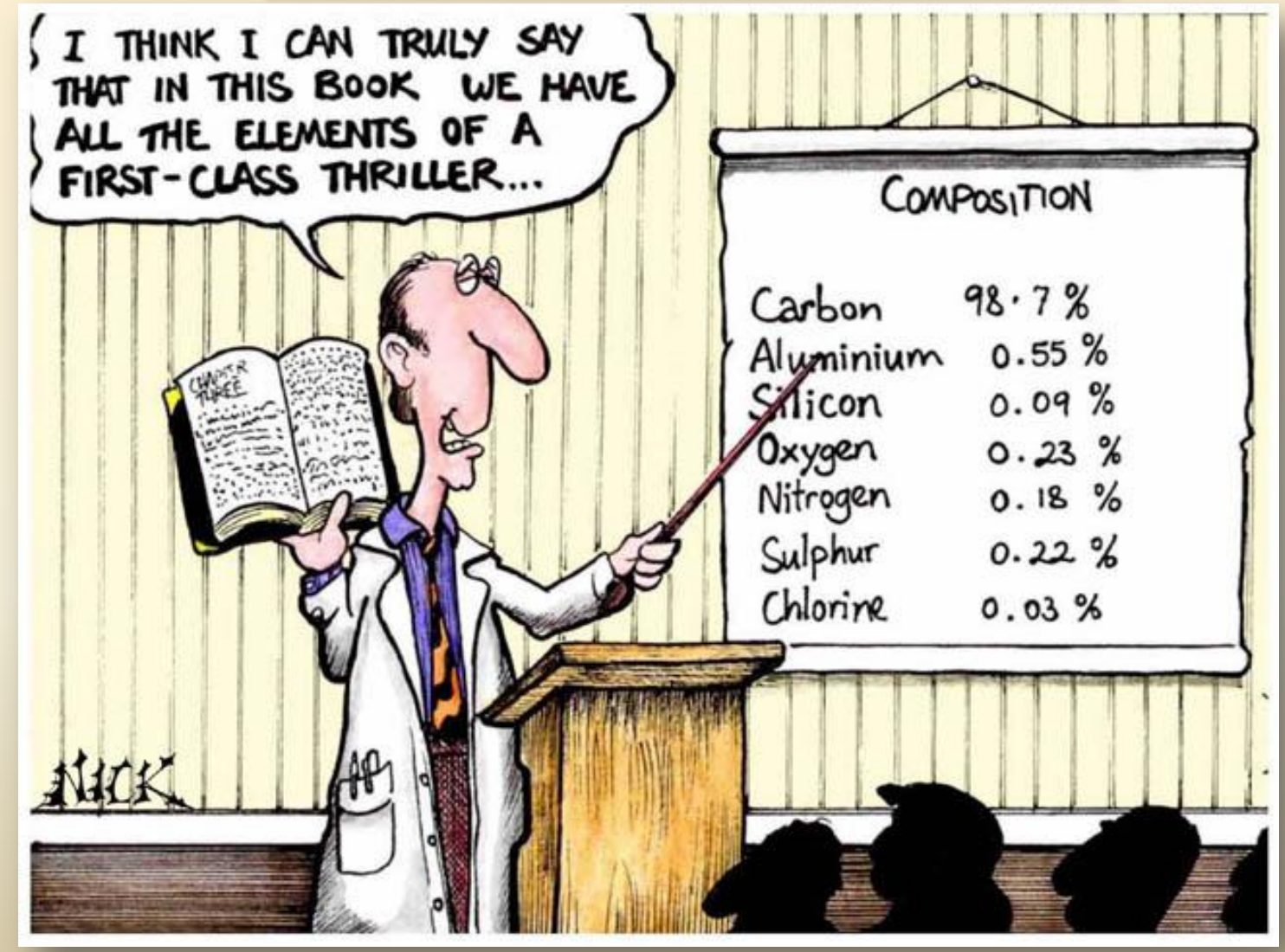
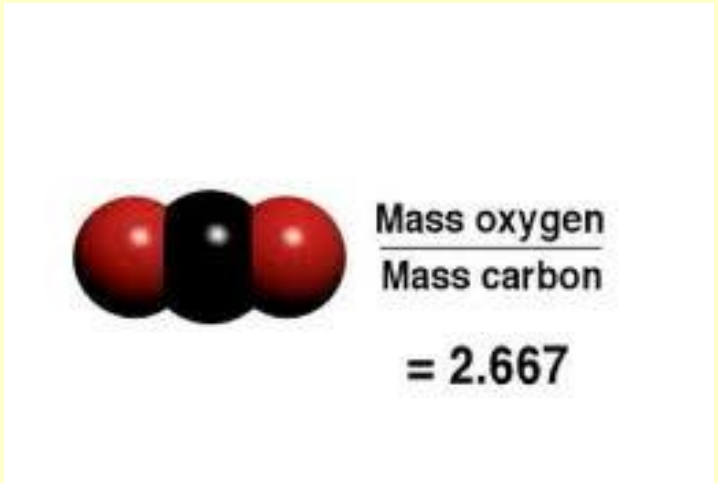
Percent Composition, Empirical and Molecular Formulas



Law of Definite Proportions

This law states that the elements in a chemical compound are always present in the same proportions by mass.

For example, the mass% of oxygen in water is always 88.8% and the mass of hydrogen is 11.2%.



Calculating Percentage Composition

- relative mass of each element in a compound

i) Using Mass Data

Ex. A compound with a mass of 50g is found to contain 32.3g of zinc and 17.7g of sulfur. What is the percentage composition of the compound?

ii) Calculating % Composition using formula

Steps to Solve for Percent Composition

(with example)

PCl_5 (Phosphorus Pentachloride)

1) Find the molar mass of all elements in the compound:

P = 30.974g

Cl = 5(35.453g) = 177.265g

2) Find the molecular mass:

PCl_5 = 30.974g + 177.265g = 208.239g

3) Divide each molar mass by the molecular mass and multiply by 100:

$$P = \frac{30.974g}{208.239g} \times 100 = 14.87\%$$

$$Cl = \frac{177.265g}{208.239g} \times 100 = 85.13\%$$

Therefore, Phosphorus Pentachloride is 14.87% P and 85.13% Cl by mass.

Calculating Percentage Composition

Ex. b) Determine the percentage composition of $Ca_3(PO_4)_2$.

Homework:

Practice: p.286 #1,2 and p.287 #3

Questions: p. 288 #1,2,4,5,7

Formulas

Empirical formula: the lowest whole number ratio of atoms in a compound.

Molecular formula: the true number of atoms of each element in the formula of a compound.

- molecular formula = $(\text{empirical formula})_n$
- molecular formula = $C_6H_6 = (CH)_6$
- empirical formula = CH

Formulas (continued)

Formulas for ionic compounds are ALWAYS empirical (lowest whole number ratio).

Examples:

$NaCl$ $Al_2(SO_4)_3$

$MgCl_2$ K_2CO_3

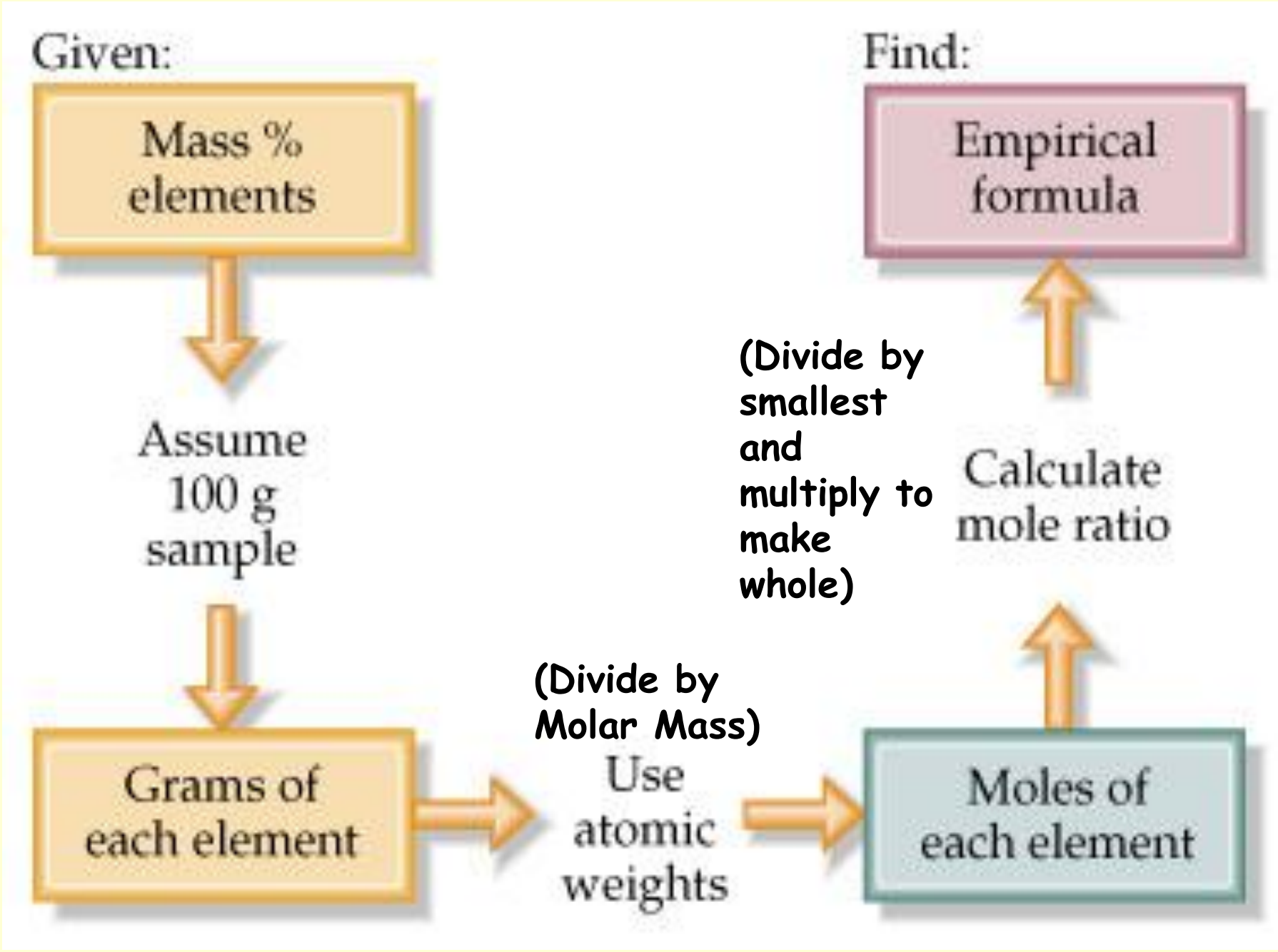
Formulas (continued)

Formulas for molecular compounds MIGHT be empirical (lowest whole number ratio).

Molecular:	H_2O	$C_6H_{12}O_6$	$C_{12}H_{22}O_{11}$
	↓	↓	↓
Empirical:	H_2O	CH_2O	$C_{12}H_{22}O_{11}$

Empirical Formula Determination

1. If given percentages of elements, assume you have 100 grams of the compound. Determine moles of each element in 100 grams of the compound.
2. Divide each value of moles by the smallest of the mole values.
3. Multiply each number by an integer to obtain all whole numbers.


Given:
Mass % elements
Assume 100 g sample
Grams of each element
(Divide by Molar Mass)
Use atomic weights
Moles of each element
Calculate mole ratio
(Divide by smallest and multiply to make whole)
Empirical formula
Find:

Sample Problem #1 Using a Table: What is the empirical formula for a compound with 48% C, 8% H, 28% N and 16% O?

Element	% Mass(g)	Atomic mass (Molar Mass)	Atomic ratio (Moles)	Simplest ratio Divide by smallest mole	Simplest whole no. ratio
C	48.0	12	$\frac{48.0}{12} = 4.0$	$\frac{4.0}{1.0} = 4$	4
H	8.0	1	$\frac{8.0}{1} = 8.0$	$\frac{8.0}{1.0} = 8$	8
N	28.0	14	$\frac{28.0}{14} = 2.0$	$\frac{2.0}{1.0} = 2$	2
O	16.0	16	$\frac{16.0}{16} = 1.0$	$\frac{1.0}{1.0} = 1$	1

Example #2: What is the empirical formula if there is 8.4g of Carbon, 2.1g of Hydrogen and 5.6g of Oxygen?

ATOM	MASS	MOLAR MASS	MOLES	(mole) SMALLEST MOLE	RATIO
C	8.4	12.0	0.7	$\frac{0.7}{0.35}$ 2	2
H	2.1	1.0	2.1	$\frac{2.1}{0.35}$ 6	6
O	5.6	16.0	0.35	$\frac{0.35}{0.35}$ 1	1

TO GET SMALLEST MOLE, DIVIDE BY LOWEST MOLE.

Empirical Formula Determination

Ex.3 Adipic acid contains 49.32% C, 43.84% O, and 6.85% H by mass. What is the empirical formula of adipic acid?

Solution: Treat % as mass (assuming we have 100g), and convert grams to moles.

$$\frac{49.32\,g\,carbon}{}\left|\frac{1\,mol\,carbon}{12.01\,g\,carbon}\right.=4.107\,mol\,carbon$$

$$\frac{6.85\,g\,hydrogen}{}\left|\frac{1\,mol\,hydrogen}{1.01\,g\,hydrogen}\right.=6.78\,mol\,hydrogen$$

$$\frac{43.84\,g\,oxygen}{}\left|\frac{1\,mol\,oxygen}{16.00\,g\,oxygen}\right.=2.74\,mol\,oxygen$$

Empirical Formula Determination

2. Divide each value of moles by the smallest of the values.

Carbon: $$\frac{4.107\,mol\,carbon}{2.74\,mol} = 1.50$$

Hydrogen: $$\frac{6.78\,mol\,hydrogen}{2.74\,mol} = 2.47$$

Oxygen: $$\frac{2.74\,mol\,oxygen}{2.74\,mol} = 1.50$$

Empirical Formula Determination

3. Multiply each number by an integer to obtain all whole numbers.

Carbon: 1.50	Hydrogen: 2.50	Oxygen: 1.00
x 2	x 2	x 2
3	5	2

Empirical formula: $C_3H_5O_2$

Finding the Molecular Formula

The empirical formula for adipic acid is $C_3H_5O_2$. The molar mass of adipic acid is 146 g/mol. What is the molecular formula of adipic acid?

1. Find the molar mass of the empirical formula - $C_3H_5O_2$

$3(12.01\ g) + 5(1.01) + 2(16.00) = 73.08\ g$

Finding the Molecular Formula

The empirical formula for adipic acid is $C_3H_5O_2$. The molar mass of adipic acid is 146 g/mol. What is the molecular formula of adipic acid?

M = 3(12.01 g) + 5(1.01) + 2(16.00) = 73.08 g

2. Divide the molar mass of the molecular formula (given) by the mass calculated for the empirical formula.

$$\frac{146}{73} = 2$$

Finding the Molecular Formula

The empirical formula for adipic acid is $C_3H_5O_2$. The molar mass of adipic acid is 146 g/mol. What is the molecular formula of adipic acid?

3. Multiply the empirical formula by this number to get the molecular formula.

$$\frac{146}{73} = 2$$

$(C_3H_5O_2) \times 2 = C_6H_{10}O_4$

Finding the Formula of a Hydrate

- A hydrate is any salt that has water chemically bonded to the ions in the crystal structure is a hydrate or hydrated crystal.
  - Copper(II) sulfate pentahydrate is a hydrate.
  - Hydrated copper(II) sulfate is deep blue in color.

  - Other examples include:
- Calcium chloride dihydrate = $CaCl_2 \bullet 2H_2O$
- Chromium (III) nitrate hexahydrate = $Cr(NO_3)_3 \bullet 6H_2O$

What is the compound called after the water has been removed?

- Anhydride (noun)
  - The light blue powder is the anhydride.
- Anhydrous (adjective)
  - Anhydrous copper(II) sulfate is left in the test tube after heating (water removed)

Percent Composition and Formula of Hydrate

- A 5.0 gram sample of $Cu(NO_3)_2 \cdot nH_2O$ is heated, and 3.9 g of the anhydrous salt remains. What is the value of n?

1. Amount of water lost

5.0 g hydrate
- 3.9 g anhydrous salt
1.1 g water

2. Percent of water

$$\frac{1.1 \text{ g water}}{5.0 \text{ g hydrate}} \times 100 = 22\ \%$$

3. Amount (moles) of water

n = 0.22 x 18.02 = 4.0

4. The formula is $Cu(NO_3)_2 \cdot 4H_2O$

OR USE CHART METHOD