

Percentage Composition

The percentage of each element present in a compound, known as its **percentage composition**, can be calculated:

$$\% \text{ Element} = \frac{(\text{No. atoms of element})(\text{RAM of element})}{\text{Molar mass of compound}} \times 100$$

Work through the following examples carefully to make sure you understand how these questions can be asked before trying the exercises below.

Examples:

1. Calculate the percentage composition of sulphuric acid (H_2SO_4).

$$M_{(\text{H}_2\text{SO}_4)} = 2(1) + 32 + 4(16) = 98 \text{ g.mol}^{-1}$$

$$\% \text{ H} = \frac{(2)(1 \text{ g.mol}^{-1})}{(98 \text{ g.mol}^{-1})} \times 100 = \underline{2,04\%}$$

$$\% \text{ S} = \frac{(1)(32 \text{ g.mol}^{-1})}{(98 \text{ g.mol}^{-1})} \times 100 = \underline{32,65\%}$$

$$\% \text{ O} = \frac{(4)(16 \text{ g.mol}^{-1})}{(98 \text{ g.mol}^{-1})} \times 100 = \underline{65,31\%}$$

2. Calculate the percentage composition of water crystallisation in copper sulphate crystals.

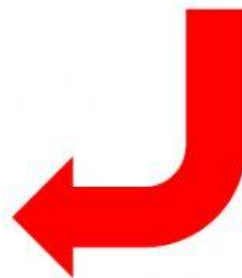
Formula: $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$

$$M_{(\text{CuSO}_4 \cdot 5\text{H}_2\text{O})} = 63,5 + 32 + 4(16) + 5[2(1) + 16] = 249,5 \text{ g.mol}^{-1}$$

Note: We haven't been asked about the CuSO_4 part of the crystal – the question only asked for the % H_2O . So we just take the H_2O part on its own compared to the total molar mass. There are 5 H_2O molecules, so it will be $5 \times M(\text{H}_2\text{O})$ on the top and M for the total molecule ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) on the bottom.

$$M_{(H_2O)} = 2(1) + 16 = 18 \text{ g.mol}^{-1}$$

$$\% H_2O = \frac{5 \times 18}{249,5} \times 100 = \mathbf{36,07\%}$$



3. Calculate how many grams of nitrogen are present in 10 g of ammonium nitrate.

Formula: NH_4NO_3

$$M_{(NH_4NO_3)} = 14 + 4(1) + 14 + 3(16) = 80 \text{ g.mol}^{-1}$$

$$\% N = \frac{2 \times 14}{80} \times 100 = 35\%$$

$\therefore$ 10 g of NH_4NO_3 contains 35% of Nitrogen

$$= 10 \text{ g} \times 35\%$$

$$= 10 \times \left(\frac{35}{100}\right)$$

$$= 3,5 \text{ g of Nitrogen}$$

Exercise: Question 9

Calculate the percentage composition of each of the following

9.1 $C_{12}H_{22}O_{11}$ Cane Sugar

$$M(C_{12}H_{22}O_{11}) = 12(12) + 22(1) + 11(16) = \quad \text{g.mol}^{-1}$$

$$\% C = \frac{(12 \times 12)}{\quad} \times 100 = \quad \%$$

$$\% H = \frac{(22 \times \quad)}{\quad} \times 100 = \quad \%$$

TWO decimal places

$$\% \text{ O} = (11 \times \quad) \times 100 = \quad \%$$

Make sure all your percentages add up to 100% to check if you have made a mistake!

9.2 NH_4NO_3 Ammonium Nitrate

$$M(\text{NH}_4\text{NO}_3) = \quad + (\quad \times \quad) + \quad + (\quad \times \quad) = \quad \text{g.mol}^{-1}$$

$$\% \text{ N} = (\quad \times \quad) \times 100 = \quad \%$$

(Hint: Check carefully – how many N's are there in the formula??!)

$$\% \text{ H} = (\quad \times \quad) \times 100 = \quad \%$$

$$\% \text{ O} = (\quad \times \quad) \times 100 = \quad \%$$

9.3 $\text{Fe}(\text{NO}_3)_2$ Iron II Nitrate

$$M(\text{Fe}(\text{NO}_3)_2) = \quad + 2[\quad + (3 \times \quad)] = \quad \text{g.mol}^{-1}$$

$$\% \text{ Fe} = (\quad \times \quad) \times 100 = \quad \%$$

$$\% \text{ N} = (\quad \times \quad) \times 100 = \quad \%$$

$$\% \text{ O} = (\quad \times \quad) \times 100 = \quad \%$$

Determine the percentage of copper in each of the following:

(Note: Only %Cu has been asked for, so you don't need to calculate the other elements)

9.4 CuCl_2

$$M(\text{CuCl}_2) = \quad \text{g.mol}^{-1}$$

$$\% \text{ Cu} = \quad \times 100 = \quad \%$$

9.5 $\text{Cu}(\text{NO}_3)_2$

$$M(\text{Cu}(\text{NO}_3)_2) = \quad \text{g.mol}^{-1}$$

$$\% \text{ Cu} = \quad \times 100 = \quad \%$$

9.6 $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$

$$M(\text{CuSO}_4 \cdot 5\text{H}_2\text{O}) = \quad + \quad + (4 \times \quad) + (5 \times \quad) = \quad \text{g.mol}^{-1}$$

$$\% \text{ Cu} = \quad \times 100 = \quad \%$$

9.7 What is the mass of carbon present in 454 g propane with the chemical formula of C_3H_8 ?

Step 1: Calculate %C

$$M(\text{C}_3\text{H}_8) = \quad \text{g.mol}^{-1}$$

$$\% \text{ C} = \quad \times \quad \times 100 = \quad \%$$

Step 2: Calculate mass of C

$$\%C \times 454 \text{ g} = \text{mass C}$$

$$\frac{\quad}{100} \times 454 = \quad \text{g}$$

9.8 What is the mass of iron present in 25 g of iron III oxide (Fe_2O_3)?

$$M(\text{Fe}_2\text{O}_3) = \quad \text{g.mol}^{-1}$$

$$\% \text{ Fe} = \frac{\quad}{\quad} \times 100 = \quad \%$$

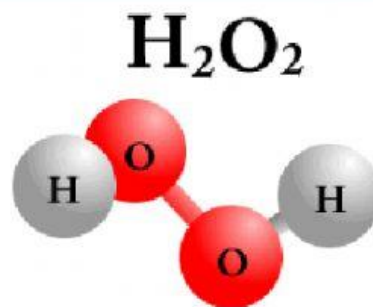
$$\text{Mass Fe} = \frac{\quad}{100} \times \quad = \quad \text{g}$$

Empirical Formula

The **empirical formula** is the simplest whole number ratio of atoms in a compound.

The **molecular formula** tells the actual number of each kind of atom in a molecule.

For example – **hydrogen peroxide** has the chemical formula H_2O_2 . This means that every molecule contains 2x H and 2x O. If you simplify this down, it would just be HO but that is not a true representation of what the molecule looks like.



We call **HO** the Empirical Formula (the simplest form) and **H₂O₂** the Molecular Formula (the true form). The molecular formula is a multiple of the empirical formula, so $\text{H}_2\text{O}_2 = 2 \times (\text{HO})$.

Other examples:

- **Empirical** formula e.g. HgCl , P_2O_5
- **Molecular** formula e.g. Hg_2Cl_2 , P_4O_{10}

The empirical formula of a compound can be calculated if its percentage composition per mass is known.

Examples

Eg 1) **A compound is made up of 36,5% sodium, 24,8% sulphur and 38,1% oxygen. Calculate the empirical formula.**

Answer:

Express the percentage as a mass:

In 100 g:
 $\text{Na} = 36,5 \text{ g}$
 $\text{S} = 24,8 \text{ g}$
 $\text{O} = 38,1 \text{ g}$

Convert the mass of each element to number of moles:

$$\begin{aligned} n(\text{Na}) &= \frac{m}{M} = \frac{36.5 \text{ g}}{23 \text{ g.mol}^{-1}} = 1,59 \text{ mol} && \div 0,78 = 2 \\ n(\text{S}) &= \frac{m}{M} = \frac{24.8 \text{ g}}{32 \text{ g.mol}^{-1}} = 0,78 \text{ mol} && \div 0,78 = 1 \\ n(\text{O}) &= \frac{m}{M} = \frac{38.1 \text{ g}}{16 \text{ g.mol}^{-1}} = 2,38 \text{ mol} && \div 0,78 = 3 \end{aligned}$$

Divide each answer by the smallest no. of moles to get the ratio

Actual mole ratio 1,59 : 0,78 : 2,38 ($\div 0,78$)
Simplified 2 : 1 : 3

2Na : 1S : 3O The empirical formula is **Na₂SO₃**

Eg 2a) A compound is made up of 26,76% carbon, 71,11% oxygen and 2,22% hydrogen per mass.

Answer:

In 100g

C = g
O = g
H = g

$$n(\text{C}) = \frac{m}{M} = \frac{26.76 \text{ g}}{12 \text{ g.mol}^{-1}} = 2,23 \text{ mol} \quad \div \quad = 1$$

$$n(\text{O}) = \frac{m}{M} = \frac{71.11 \text{ g}}{16 \text{ g.mol}^{-1}} = 4,44 \text{ mol} \quad \div \quad = 2$$

$$n(\text{H}) = \frac{m}{M} = \frac{2.22 \text{ g}}{1 \text{ g.mol}^{-1}} = 2,22 \text{ mol} \quad \div \quad = 1$$

Mole ratio 1: 2 : 1
 CO₂H

b) If the relative formula mass (M) of the compound is 90, calculate the molecular (true) formula of the compound.

The empirical formula is CO₂H

$$M(\text{CO}_2\text{H}) = 12 + (2 \times 16) + 1 = 45 \text{ g.mol}^{-1}$$

$$M(\text{True formula}) = 90 \text{ g.mol}^{-1} \text{ (given in question)}$$

Molecular (true) mass is **double** the empirical formula mass.

$$\frac{\text{True mass}}{\text{empirical mass}} = \frac{90}{45} = 2$$

Therefore the molecular formula = $2 \times \text{CO}_2\text{H} = \text{C}_2\text{O}_4\text{H}_2$

Question 5 (Do in back of chemistry notebooks)

Use the method laid out in Example 1 to find the empirical formulae of the compounds having the following percentage composition:

5.1 H = 11,1%
O = 88,9%

5.2 Mg = 20%
S = 26,7%
O = 53,3%

5.3 K = 56,5%
C = 8,7%
O = 34,8%

5.4 Ca = 24,4%
N = 17,1%
O = 58,5%

5.5 Al = 34,6%
O = 61,5%
H = 3,9%

5.6 Na = 17,6%
Cr = 39,7%
O = 42,7%

5.7 C = 48,7%
H = 8,1%
O = 43,2%

5.8 C = 81,8 %
 H = 18,2%

Question 6

Follow example 2 to help you find the (a) empirical formulae and (b) molecular formulae of the following compounds from the given information:

6.1 C = 92,3%
 H = 7,7 %

The true mass of the above compound is = 78,06g.mol⁻¹

6.2 C = 54,5%
 H = 9,1%
 O = 36,4%

The true mass of the above compound is = 132,12 g.mol⁻¹