# Stoichiometric Relationships Part three (answers)

IB CHEMISTRY SL/HL

| 25 | 16 | | 6 | 2 | 25 |
|---|---|---|---|---|---|
| **Mn** | **S** | **J** | **C** | **He** | **Mn** |
| Manganese | Sulfur | | Carbon | Helium | Manganese |
| 54.938045 | 32.065 | | 12.0107 | 4.002602 | 54.938045 |

**Syllabus objectives:**

**Understandings**

- The molar concentration of a solution is determined by the amount of solute and the volume of solution.
- A standard solution is one of known concentration.

**Applications and skills:**

- Solution of problems involving molar concentration, amount of solute and volume of solution.
- Use of the experimental method of titration to calculate the concentration of a solution by reference to a standard solution (this is covered in the lab part of the course).

**Solutions**

- Solutions are homogeneous mixtures.
- A solution is composed of a solute (usually a solid) dissolved in a solvent (usually water).

salt (solute) + water (solvent) → solution (salt water)



- Solutions can be dilute (less solute, more solvent) or concentrated (more solute, less solvent).

**Standard solutions (covered in the lab part of the course)**

- A standard solution is a solution that has a concentration that is known accurately.
- A primary standard solution is prepared using a substance of high purity which is dissolved in a known volume of solvent.
- A secondary standard solution refers to a solution that has its concentration determined by titration with a primary standard solution.
- When making up a standard solution it is important that the correct mass of substance is accurately measured. In addition, it is important that all the solute is transferred to the volumetric flask used to make up the solution.

**Calculating the concentration of a solution**

- The concentration of a solution can be expressed in mol $dm^{-3}$ or g $dm^{-3}$
- The equation for calculating concentration in mol $dm^{-3}$ is shown below.
- In this equation, **volume must be in $dm^3$** (to convert from $cm^3$ to $dm^3$, divide by 1000).

$$c\ (\text{mol dm}^{-3}) = \frac{\text{amount of solute (mol)}}{\text{volume of solution (dm}^3\text{)}}$$

$$C = \frac{n}{V}$$

C = concentration in mol $dm^{-3}$
n = amount in mol
V = volume in $dm^3$

$$n = CV \qquad V = \frac{n}{C}$$

- The equations for calculating concentration in g $dm^{-3}$ and ppm are shown below.

$$c\ (\text{g dm}^{-3}) = \frac{\text{mass of solute (g)}}{\text{volume of solution (dm}^3\text{)}}$$

$$c\ (\text{ppm}) = \frac{\text{mass of solute (g)}}{\text{mass of solution (g)}} \times 10^6$$

**Example:**
50.0 g of NaCl are dissolved in 100 $cm^3$ of water which is then made up to 500.0 $cm^3$ in a volumetric flask. Calculate the concentration of the solution in mol $dm^{-3}$ and g $dm^{-3}$.

In g $dm^{-3}$
C = mass of solute ÷ volume of solution
C = 50.0 ÷ (500.0 ÷ 1000)
C = 100.0 g $dm^{-3}$

In mol $dm^{-3}$
Convert from mass to amount in mol
n = m ÷ M
n = 50.0 ÷ 58.44 = 0.856 mol NaCl
C = n ÷ V
C = 0.856 ÷ (500 ÷ 1000)
C = 1.71 mol $dm^{-3}$

**Exercises:**

1. Calculate the concentration (in mol $dm^{-3}$ and g $dm^{-3}$) of these solutions:

   a) 10.6 g of sodium carbonate ($Na_2CO_3$) in 1.00 $dm^3$ of solution.

   n = m ÷ M
   n = 10.6 ÷ 105.99 = 0.100 mol $Na_2CO_3$
   C = n ÷ V
   C = 0.100 ÷ (1.00)
   C = 0.100 mol $dm^{-3}$

   C = 10.6 ÷ (1.00)
   C = 10.6 g $dm^{-3}$

   b) 117 g of sodium chloride (NaCl) in 5.00 $dm^3$ of solution.

   n = m ÷ M
   n = 117 ÷ 58.44 = 2.00 mol NaCl
   C = n ÷ V
   C = 2.00 ÷ 5.00
   C = 0.400 mol $dm^{-3}$

   C = 117 ÷ 5.00
   C = 23.4 g $dm^{-3}$

   c) 0.830 g of potassium iodide (KI) in 25.0 $cm^3$ of solution.

   n = m ÷ M
   n = 0.830 ÷ 166.00 = $5.00 \times 10^{-3}$ mol KI
   C = n ÷ V
   C = $5.00 \times 10^{-3}$ ÷ (25.0 ÷ 1000)
   C = 0.200 mol $dm^{-3}$

   C = 0.830 ÷ (25.0 ÷ 1000)
   C = 33.2 g $dm^{-3}$

2. Calculate the amount (in mol) of solute in each of the following solutions:

a) 0.250 $dm^3$ of 0.400 mol $dm^{-3}$ ammonium chloride solution.

n = CV

n = 0.400 × 0.250

n = 0.100 mol

b) 200.0 $cm^3$ of 0.800 mol $dm^{-3}$ sodium carbonate solution.

n = CV

n = 0.800 × (200.0 ÷ 1000)

n = 0.160 mol

c) 300.0 $cm^3$ of 4.00 mol $dm^{-3}$ sodium hydroxide solution.

n = CV

n = 4.00 × (300.0 ÷ 1000)

n = 1.20 mol

3. Calculate the mass of solute in the following solutions:

a) 2.00 $dm^3$ of 0.200 mol $dm^{-3}$ potassium hydroxide (KOH) solution.

n = CV

n = 0.200 × 2.00

n = 0.400 mol

m = nM

m = 0.400 × 56.11

m = 22.6 g KOH

b) 200.0 $cm^3$ of 0.100 mol $dm^{-3}$ sodium carbonate ($Na_2CO_3$) solution.

n = CV

n = 0.100 × (200.0 ÷ 1000)

n = 0.0200 mol

m = nM

m = 0.0200 × 105.99

m = 2.12 g $Na_2CO_3$

c) 25.0 $cm^3$ of 0.0500 mol $dm^{-3}$ copper(II) sulphate ($CuSO_4 \bullet 5H_2O$) solution.

n = CV

n = 0.0500 × (25.0 ÷ 1000)

n = $1.25 \times 10^{-3}$ mol

m = nM

m = $1.25 \times 10^{-3} \times 249.72$

m = 0.312 g $CuSO_4 \bullet 5H_2O$

**Parts per million (ppm) exercises**

1. 25.0 grams of a chemical is dissolved in 75.0 grams of water. Calculate the concentration of the solution in ppm.
   ppm = (25.0 ÷ 100.0) × $10^6$
   = 250000 ppm

2. 17.0 grams of sucrose is dissolved in 183 grams of water. Calculate the concentration of the solution in ppm.
   ppm = (17.0 ÷ 200) × $10^6$
   = 85000 ppm

3. 35.0 grams of ethanol is dissolved in 115 grams of water. Calculate the concentration of the solution in ppm.
   ppm = (35.0 ÷ 140) × $10^6$
   = 233333 ppm

4. The solubility of NaCl is 284 grams per 100.0 grams of water. Calculate the concentration of the solution in ppm.
   ppm = (284 ÷ 384) × $10^6$
   = 7400000 ppm

5. The solubility of AgCl is 0.008 grams per 100.0 grams of water. Calculate the concentration of the solution in ppm.
   ppm = (0.008 ÷ 100.008) × $10^6$
   = 80 ppm

6. A certain pesticide has a toxic solubility of 5.00 grams per kg (1000g). Calculate the concentration of the solution in ppm.
   ppm = (5.00 ÷ 1005) × $10^6$
   = 4980 ppm

**More practice examples**

1. What volume of 2.00 mol $dm^{-3}$ HCl reacts completely with 5.00 g of magnesium? What volume of hydrogen gas will be produced at STP?

$$Mg_{(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_{2(g)}$$

*n* Mg = 5.00 ÷ 24.31 = 0.206 mol
Ratio of Mg to HCl is 1:2
0.206 mol of Mg reacts with 2 × 0.206 = 0.412 mol of HCl
V = n ÷ C
V = 0.412 ÷ 2.00
V = 0.206 $dm^3$ (206 $cm^3$) HCl

Ratio of Mg to $H_2$ is 1:1
0.206 mol of Mg produces 0.206 mol of $H_2$
1 mol of gas at STP = 22.7 $dm^3$
0.206 × 22.7 = 4.68 $dm^3$ $H_2$

2. What volume of 1.00 mol $dm^{-3}$ HCl reacts completely with 10.00 g of calcium carbonate ($CaCO_3$)? What volume of carbon dioxide gas will be produced at STP?

$$CaCO_{3(s)} + 2HCl_{(aq)} \rightarrow CaCl_{2(aq)} + CO_{2(g)} + H_2O_{(l)}$$

*n* $CaCO_3$ = 10.00 ÷ 100.09 = 0.100 mol
Ratio of $CaCO_3$ to HCl is 1:2
0.100 mol of $CaCO_3$ reacts with 2 × 0.100 = 0.200 mol of HCl
V = n ÷ C
V = 0.200 ÷ 1.00
V = 0.200 $dm^3$ (200 $cm^3$) HCl

Ratio of $CaCO_3$ to $CO_2$ is 1:1
0.100 mol of $CaCO_3$ produces 0.100 mol of $CO_2$
1 mol of gas at STP = 22.7 $dm^3$
0.100 × 22.7 = 2.27 $dm^3$ $CO_2$

3. Sodium hydroxide (NaOH) reacts with hydrochloric acid (HCl) according to the following equation:

$$NaOH_{(aq)} + HCl_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$$

What volume of 0.500 mol $dm^{-3}$ HCl reacts with 25.0 $cm^3$ of 2.00 mol $dm^{-3}$ NaOH solution?

*n* NaOH = 2.00 × (25.0 ÷ 1000) = 0.0500 mol
Ratio of NaOH to HCl is 1:1
0.0500 mol of NaOH reacts with 0.0500 mol of HCl
V = n ÷ C
V = 0.0500 ÷ 0.500
V = 0.100 $dm^3$ (100 $cm^3$) HCl