1.22 Concentration of Solutions

A solution is a mixture formed when a solute dissolves in a solvent. In chemistry we most commonly use water as the solvent to form aqueous solutions. The solute can be a solid, liquid or a gas.

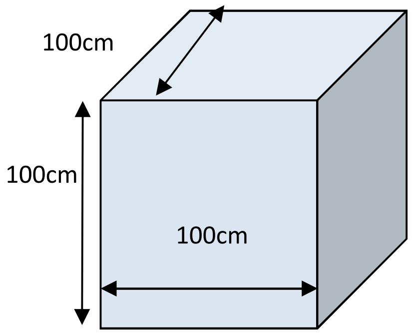
Molar concentration can be measured for solutions. This is calculated by dividing the amount in moles of the solute by the volume of the solution. The volume is measure is dm^3. The unit of molar concentration is mol dm^{-3} ; it can also be called molar using symbol M

Concentration = $\frac{\text{amount}}{\text{volume}}$

Unit of concentration: mol dm^{-3} or M
Unit of Volume: **dm^3**

Converting volumes

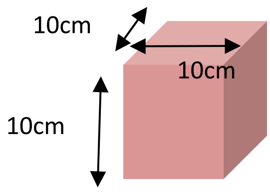
A m^3 is equivalent to a cube
100cmx100cmx100cm= 1000000cm^3



$1m^3$

A dm^3 is equivalent to a cube
10cmx10cmx10cm= 1000cm^3

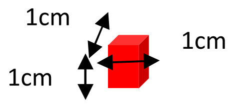
1dm^3 = 1litre



1dm^3 or 1 litre

A cm^3 is equivalent to a cube
1cmx1cmx1cm

1cm^3 = 1 ml



1cm^3

1 m^3 = 1000 dm^3 or 1000L
To convert m^3 into dm^3 multiply by 1000

1 dm^3 = 1000 cm^3 or 1000mL
To convert cm^3 into dm^3 divide by 1000

$cm^3 \rightarrow dm^3 \div 1000$
$cm^3 \rightarrow m^3 \div 1000\,000$
$dm^3 \rightarrow m^3 \div 1000$

Example 1 Calculate the concentration of the solution made by dissolving 5.00g of Na_2CO_3 in 250 cm^3 water.

amount = mass/*Mr*

= 5 / (23.0 x2 + 12 +16 x3)

= 0.0472 mol

conc= amount/volume

= 0.0472 / **0.25**

= 0.189 mol dm^{-3}

Example 2 Calculate the concentration of the solution made by dissolving 10kg of Na_2CO_3 in 0.50 m^3 water.

amount = mass/*Mr*

= 10 000 / (23.0 x2 + 12 +16 x3)

= 94.2 mol

conc= amount/volume

= 94.2 / **500**

= 0.19 mol dm^{-3}

Mass Concentration

The concentration of a solution can also be measured in terms of mass of solute per volume of solution

Mass Concentration = $\frac{\text{mass}}{\text{volume}}$

Unit of mass concentration: g dm^{-3}
Unit of Mass **g**
Unit of Volume: **dm^3**

To turn concentration measured in mol dm^{-3} into concentration measured in g dm^{-3} multiply by *M*r of the substance
conc in g dm^{-3} = conc in mol dm^{-3} x *M*r
The concentration in g dm^{-3} is the same as the mass of solute dissolved in $1dm^3$

Ions dissociating

When soluble ionic solids dissolve in water they will dissociate into separate ions. This can lead to the concentration of ions differing from the concentration of the solute.

If 5.86g (0.1 mol) of sodium chloride (NaCl) is dissolved in 1 dm^3 of water then the concentration of sodium chloride solution would be 0.1mol dm^{-3} .
However the 0.1mol sodium chloride would split up to form 0.1 mol of sodium ions and 0.1 mol of chloride ions. The concentration of sodium ions is therefore 0.1 mol dm^{-3} and the concentration of chloride ions is also 0.1 mol dm^{-3}

$NaCl(s) + aq \rightarrow Na^+(aq) + Cl^-(aq)$

0.1mol 0.1mol 0.1mol

If 9.53g (0.1 mol) of magnesium chloride ($MgCl_2$) is dissolved in 1 dm^3 of water then the concentration of magnesium chloride solution ($MgCl_2$ aq) would be 0.1mol dm^{-3} .
However the 0.1mol magnesium chloride would split up to form 0.1 mol of magnesium ions and 0.2 mol of chloride ions. The concentration of magnesium ions is therefore 0.1 mol dm^{-3} and the concentration of chloride ions is now 0.2 mol dm^{-3}

$MgCl_2(s) + aq \rightarrow Mg^{2+}(aq) + 2Cl^-(aq)$

0.1mol 0.1mol 0.2mol

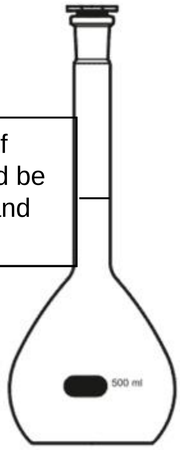
Questions

1.1) If 25.0 g of potassium nitrate (KNO_3) was dissolved in $750cm^3$ of water, what would be the molar concentration?
1.2) Calculate the concentration in mol dm^{-3} of 3.78 g of potassium iodide (KI) in 35 cm^3 of solution
1.3) Calculate the concentration in mol dm^{-3} of 5.10 kg of sodium bromide in 0.250 m^3 of solution
1.4)What mass of Na_2CO_3 would be needed to make $500cm^3$ of 0.250mol dm^{-3} solution?
1.5) If 8.20 g of $CaCl_2$ was dissolved in $50cm^3$ of water, what would be the concentration of chloride ions in mol dm^{-3}?
1.6) a)Calculate the mass of Borax Crystals $Na_2B_4O_7.10H_2O$ needed to make up $250cm^3$ of 0.100 mol dm^{-3} solution
b) Calculate the mass concentration of this solution be in g dm^{-3}
1.7) Calculate the mass of hydrated magnesium chloride ($MgCl_2.6H_2O$) needed to make up 500 cm^3 of a solution of 0.100 mol dm^{-3} of chloride ions
1.8) For drivers in the UK, the legal limit of the concentration of ethanol (molar mass 46.0 g mol^{-1}) in the blood is 80.0 mg per 100 cm^3. What is this equivalent to in concentration measured in mol dm^{-3} ?
1.9) How many moles of **ions** are present in 30 cm^3 of 0.050 mol dm^{-3} calcium chloride solution, $CaCl_2$(aq)
1.10) The concentration of blood glucose can be given in millimoles per dm^3 or mmol dm^{-3}. 5.0 mmol dm^{-3} is a normal value of the concentration. Glucose has a molar mass of 180 g mol^{-1}. What mass of glucose dissolved in 1 dm^3 of blood would give this normal reading?
1.11) A saturated aqueous solution of magnesium hydroxide contains 1.17 mg of $Mg(OH)_2$ in 100 cm^3 of solution. Assume the magnesium hydroxide is fully dissociated into ions. Calculate the concentration of magnesium ions in mol dm^{-3}

Making a solution

- Weigh the sample bottle containing the required mass of solid on a 2 dp balance
- Transfer to a beaker and reweigh sample bottle
- Record the difference in mass

Alternatively the known mass of solid in the weighing bottle could be transferred to beaker, washed and washings added to the beaker.



• Add 100 cm^3 of distilled water to the beaker. Use a glass rod to stir to help dissolve the solid.

•Sometimes the substance may not dissolve well in cold water so the beaker and its contents could be heated gently until all the solid had dissolved.

- Pour solution into a 250 cm^3 graduated flask via a funnel.
- Rinse beaker and funnel and add washings from the beaker and glass rod to the volumetric flask.

• make up to the mark with distilled water using a dropping pipette for last few drops.
• Invert flask several times to ensure uniform solution.

Remember to fill so the bottom of the meniscus sits on the line on the neck of the flask. With dark liquids like potassium manganate it can be difficult to see the meniscus.

Shake the volumetric flask thoroughly to ensure a uniform concentration

Graduated/volumetric flask

A graduated flask has one mark on the neck which the level to fill to get the accurate volume. Do not heat or put hot solutions in the volumetric flask because the heat would cause the flask to expand and the volume would then be incorrect.

Dilutions

Diluting a solution

- Pipette 25cm^3 of original solution into volumetric flask
- make up to the mark with distilled water using a dropping pipette for last few drops.
- Invert flask several times to ensure uniform solution.

Using a volumetric pipette is more accurate than a measuring cylinder because it has a smaller sensitivity error

Use a teat pipette to make up to the mark in volumetric flask to ensure volume of solution accurately measured and one doesn't go over the line

Calculating Dilutions

Diluting a solution will not change the amount of moles of solute present but increase the volume of solution and hence the concentration will lower

Amount = volume X concentration

If amount of moles does not change then
Original volume x original concentration = new diluted volume x new diluted concentration

so

$$\text{new diluted concentration} = \text{original concentration} \times \frac{\text{original volume}}{\text{new diluted volume}}$$

The new diluted volume will be equal to the original volume of solution added + the volume of water added.

Example
50 cm^3 of water are added to 150 cm^3 of a 0.20 mol dm^{-3} NaOH solution. Calculate the concentration of the diluted solution.

$$\text{new diluted concentration} = \text{original concentration} \times \frac{\text{original volume}}{\text{new diluted volume}}$$

$$\text{new diluted concentration} = 0.20 \times \frac{0.150}{0.200}$$

$$= 0.15 \text{ mol dm}^{-3}$$

Questions

2.1) If 90.0cm^3 of water are added to 50.0 cm^3 of a 1.00 mol dm^{-3} HNO_3 solution, what will the concentration of the diluted solution be?

2.2) How much water would need to be added to 100 cm^3 of a 0.15 mol dm^{-3} NaOH solution to dilute it to a concentration of 0.05 mol dm^{-3} ?

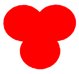
2.3) What volume of 0.1 mol dm^{-3} NaCl solution can be made by adding water to dilute 50 cm^3 of 10 mol dm^{-3} NaCl?

2.4) How much water would need to be added to dilute 25.0 cm^3 of a 12.0 mol dm^{-3} HCl solution to make a 0.500 mol dm^{-3} HCl solution?

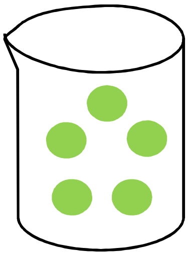
2.5) A student is provided with a 5.00 cm^3 sample of 1.00×10^{-2} mol dm^{-3} hydrochloric acid. The student is asked to prepare a hydrochloric acid solution with a concentration of 5.00×10^{-4} mol dm^{-3} by diluting the sample with water. How much water should they add?

Concentrations of mixtures

Adding a solid to a solution
If a second solid solute is added to an existing solution of a different solute then the new mixture will have a concentration for both solutes. If the two solutes do not react with each other then there will be no change in the amount of moles of either solute.

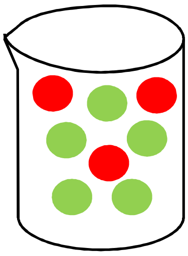


0.3 mol of solid NaCl



0.5 mol of KCl dissolved in $100 cm^3$ of water :concentration $0.05\ moldm^{-3}$

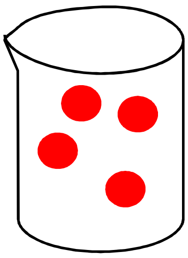
Add the solid NaCl to the KCl solution



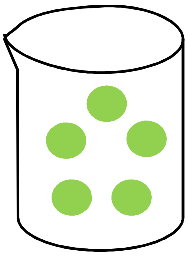
Now have 0.3 mol of NaCl and 0.5 mol of KCl dissolved in $100cm^3$ of water

In the mixture the concentration of NaCl is $0.03\ moldm^{-3}$ and the concentration of KCl is $0.05\ moldm^{-3}$. Note the concentration of KCl has not changed

Adding two different solutions together
If a second solution is added to an existing solution of a different solute then the new mixture will have a concentration for both solutes. If the two solutions do not react with each other then there will be no change in the amount of moles of either solute.

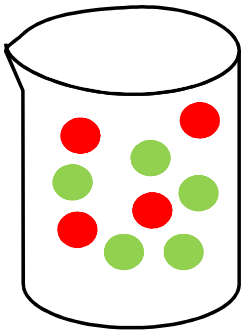


0.4 mol of NaCl dissolved in $100cm^3$ of water :concentration 0.04 $moldm^{-3}$



0.5 mol of KCl dissolved in $100cm^3$ of water :concentration 0.05 $moldm^{-3}$

Add the solution of NaCl to the KCl solution



Now have 0.4 mol of NaCl and 0.5 mol of KCl dissolved in $200cm^3$ of water

In the mixture the concentration of NaCl is $0.02\ moldm^{-3}$ and the concentration of KCl is $0.025\ moldm^{-3}$. Note the concentration of both solutions have halved

Questions
3.1) If 5.0g of Sodium chloride is added to 250 cm^3 of a solution of 0.10 mol dm^{-3} HCl, what will be the concentrations of NaCl and HCl after they are added together?
3.2) If $50cm^3$ of 0.10mol dm^{-3} potassium chloride solution is added to $150cm^3$ of 0.15 mol dm^{-3} HCl, what will be the concentrations of KCl and HCl after they are added together?
3.3) A student has a 0.10 mol dm^{-3} solution of NaCl and a 0.20 mol dm^{-3} solution of KCl. The student wants to make a mixture of the two solutions where the NaCl has a concentration of 0.075 mol dm^{-3} and the KCl has a concentration of 0.050 mol dm^{-3} when mixed together. What ratio of volume of NaCl to volume of KCl would make the new concentrations?

Density

Density is used in chemistry for pure substances rather than mixtures. Most commonly we would use it work out the mass of an known volume of a pure organic liquid such as ethanol, and then we would often convert the mass into amount in moles.

density =	**mass** / **volume**

Density is usually given in g cm^{-3}
Care needs to be taken if different units are used.

Example : How many molecules of ethanol are there in a 0.500 dm^3 of ethanol (CH_3CH_2OH) liquid ? The density of ethanol is 0.789 g cm^{-3}

Mass$_{ethanol}$ = density x volume
= 0.789 x 500
= 394.5g

amount = mass/Mr
= 394.5/ 46.0
= 8.576 mol

Number of molecules = amount x 6.02 x 10^{23}
= 8.576 x 6.02 x 10^{23}
= 5.16 x10^{24} (to 3 sig fig)

Questions

4.1) A chemist needed to add 0.100mol of ethanol (CH_3CH_2OH) to a reaction mixture.
What volume of ethanol should she measure out? The density of ethanol is 0.789 g cm^{-3}

4.2) A saturated solution of sodium chloride is described as 0.360kg NaCl per 1kg of Water. If the density of water is 1 g cm^{-3}, what would be the molar concentration of saturated sodium chloride in mol dm^{-3}

4.3) An oil has a density of 0.91 g cm^{-3}. A droplet of the oil has a volume of 5.0×10^{-2} cm^3.
The approximate Mr of the oil is 880. Calculate the number of molecules of oil in the droplet

4.4)The density of calcium is 1.55 g cm^{-3}
Calculate its molar volume, i.e. the volume (in m^3) occupied by 1 mol.

4.5) A fighter plane holds 0.2230 m^3 of hydrazine (N_2H_4) and 0.860 m^3 of methanol (CH_3OH) in its fuel tank. Density of N_2H_4 = 1.021 g cm^{-3} Density of CH_3OH = 0.7918 g cm^{-3}
a) What is the total mass of the two substances?
b) What is the total number of molecules in the fuel tank?

4.6) Concentrated hydrochloric acid is sold as a 38% by mass solution with a density of 1.2 g cm^{-3}. Calculate the concentration of this solution in mol dm^{-3}

4.7) Given that the density of pure water is 1.0 kg dm^{-3}, calculate the concentration of pure water in mol dm^{-3}.

Parts per million (ppm)

Concentrations can be given also in parts per million. This is often used for gases in the atmosphere or in exhausts, and pollutants in water.

$$\text{parts per million (ppm) of substance, by mass} = \frac{\text{mass of substance in mixture}}{\text{total mass of mixture}} \times 1000\,000$$

Example : Blood plasma typically contains 20 parts per million (ppm) of magnesium, by mass. Calculate the mass of magnesium, in grams, present in 100 g of plasma.

$$\text{parts per million (ppm) of substance, by mass} = \frac{\text{mass of substance in mixture}}{\text{total mass of mixture}} \times 1000\,000$$

$$20 = \frac{\text{mass of substance in mixture}}{100} \times 1000\,000$$

mass of substance in mixture = 20 x100/1000 000
= 2×10^{-3} g

5.1) 1 kg of a solution contains 0.100 mol of calcium ions, Ca^{2+}. What is the concentration of the calcium ions by mass in parts per million (ppm)?

5.2) A solution contains 76 ppm of a solute. Calculate the mass of the solute dissolved in 1 kg of this solution.

5.3) A solution contains 187 ppm of a solute. Calculate the mass of the solute dissolved in 0.5 kg of this solution.

Answers

1.1) 0.330 mol dm^{-3}
1.2) 0.65 mol dm^{-3}
1.3) 0.198 mol dm^{-3}
1.4) 13.3g
1.5) 2.95mol dm^{-3}
1.6) a) 9.53g
b) 38.1 g dm^{-3}
1.7) 5.08g
1.8) 0.0174 mol dm^{-3}
1.9) 4.5×10^{-3} mol
1.10) 0.9 g dm^{-3}
1.11) 2.01×10^{-4} mol dm^{-3}

2.1) 0.357mol dm^{-3}
2.2) 200 cm^3
2.3) 5 dm^3
2.4) 575cm^3
2.5) 95cm^3

3.1) NaCl = 0.34mol dm^{-3} HCl = 0.10mol dm^{-3}
3.2) KCl = 0.025mol dm^{-3} HCl = 0.1125mol dm^{-3}
3.3 ratio 3NaCl : 1 KCl

4.1) 5.83cm^3
4.2) 6.15 mol dm^{-3}
4.3) 3.1×10^{19}
4.4) 2.59×10^{-5} m^3 mol^{-1}
4.5) a) 908 kg
b) 1.71×10^{28}
4.6) 12.5 mol dm^{-3}
4.7) 55.5 mol dm^{-3}

5.1) 4010ppm
5.2) 0.076g
5.3) 0.0935g