Name:

Volumetric Analysis	Objectives
1. Concentrations of Solutions	-define solution -define concentration -define molarity -express concentration of solutions in mol/L(molarity), g/L and also in **% (w/v)**, % (v/v), **% (w/w)** -appreciate the everyday use of % v/v e.g. in alcoholic beverages -calculate molarity from concentration in grams per litre and vice versa -calculate number of moles from molarity and volume **-perform simple calculations involving percentage concentrations** **-calculate the effect of dilution on concentration** -apply knowledge of concentrations of solutions to everyday examples -describe how colour intensity can be used as an indicator of concentration -Define a primary standard and a standard solution -prepare standard solution of sodium carbonate
3. Volumetric Analysis	*(balanced equations will be given in all volumetric problems)* -identify appropriate apparatus used in volumetric analysis -use correct titrimetric procedure when carrying out titrations -solve volumetric problems from first principles -carry out a titration between hydrochloric acid and sodium hydroxide solutions and use this titration to make a sample of sodium chloride (OL only) -standardise a hydrochloric acid solution using a standard solution of sodium carbonate **-calculate the relative molecular mass of a compound and of the amount of water of crystallisation in a compound from titration data** **(balanced equations will be given in all volumetric problems)** **-determine the concentration of ethanoic acid in vinegar** **-determine the amount of water of crystallisation in hydrated sodium carbonate**

Def^n: A ***solution*** is a homogeneous mixture of a solute and a solvent.

Def^n: The ***concentration*** of a solution is the amount of solute dissolved in a given volume of the solution.

1. **%(w/w)**
   Means grams of solute per 100 g of solution, or g/100g.
   E.g. saline solution, 1% (w/w) NaCl = 1g NaCl in 100cm^3 solution.

2. **%(w/v)**
   Means grams of solute per 100 cm^3 of solution, or g/100 cm^3.
   E.g. 37% (w/v) HCl = 37g HCl in 100cm^3 solution.

3. **%(v/v)**
   Means volume of solute per 100 cm^3 of solution, or cm^3/100 cm^3.
   E.g. Alcoholic drinks – Vodka's alcohol (ethanol) concentration is 37.5% (v/v) = 37.5 cm^3 ethanol in 100 cm^3 vodka.

4. **Parts per Million (ppm)**
   Means the concentration in mg/L. This is calculated by multiplying the concentration in g/L by 1000.
   1000mg = 1g.

5. **Molarity (M or mol/L)**

This is the main unit used in the chemistry course. This means the number of moles of solute in 1 litre of solution. E.g. A 0.125 M solution of $KMnO_4$ has 0.125 moles of $KMnO_4$ in 1 litre of litre solution.

Calculations

(a) mol/L to g/L

1. How many grams of $FeSO_4$ are present in a solution marked 0.35 M $FeSO_4$?

M_r of |$FeSO_4$ = (56) + (32) + 4(16) = 152
We have 0.35 mol/L $FeSO_4$
×152 [mol to g → × M_r]
=53.2 g/L

2. Calculate the concentration in grams per litre of bench hydrochloric acid whose concentration is 12 mol/L.

M_r of HCl = (1) + (35.5) = 36.5
We have 12 mol/L HCl
× 36.5 [mol to g → × M_r]
=438 g/L HCl

(b) g/L to mol/L

1. What is the molarity of a solution that contains 7.36 g of NaOH per litre of solution?

M_r of NaOH = (23) + (16) + (1) = 40
We have 7.36 g/L NaOH
÷ 40 [g to mol → ÷ M_r]
0.184 mol/L NaOH

2. Calculate the concentration of a solution containing 45 g of sulphuric acid in a litre of solution.

M_r of H_2SO_4 = 2(1) + (32) + 4(16) = 98
We have 45 g/L H_2SO_4
÷ 98 [g to mol → ÷ M_r]
0.4592 mol/L H_2SO_4

(c) How many moles in a certain volume, given the solution's molarity

1. Calculate how many moles of CH_3COOH are present in 25 cm^3 of 0.55 M CH_3COOH.

We have 0.55 mol/L CH_3COOH

$$\frac{0.55}{1000} \times 25$$

=0.01375 mol/25 cm^3 CH_3COOH

If question was phrased "Calculate how many **grams** of CH_3COOH are present in 25 cm^3 of 0.55 M CH_3COOH", we would then have to multiply 0.01375 by the M_r of CH_3COOH.

2. How many moles of HCl are present in 60 cm^3 of 0.4 M HCl?

We have 0.4 mol/L HCl

$\frac{0.4}{1000} \times 60$

=0.024 mol/60 cm^3 HCl

(d) Calculate moles per litre, given the mass of solute and volume of solution

1. Calculate the concentration in moles per litre of a solution containing 45 grams of sulphuric acid per 240 cm^3 of solution.

M_r of H_2SO_4 = 2(1) + (32) + 4(16) = 98
We have 45 g/240 cm^3 H_2SO_4
÷ 98 [g to mol → ÷ M_r]
=0.4592 mol/240 cm^3 H_2SO_4

$\frac{0.4592}{240} \times 1000$

=1.193 mol/L H_2SO_4

2. 7.6 g of anhydrous Na_2CO_3 is dissolved in deionised water and made up to 300 cm^3 of solution. Express the concentration of this solution in mol/L.

M_r of Na_2CO_3 = 2(23) + (12) + 3(16) = 106
We have 7.6 g/300 cm^3 Na_2CO_3
÷106 [g to mol → ÷ M_r]
=0.0717 mol/300 cm^3 Na_2CO_3

$\frac{0.0717}{300} \times 1000$

=0.239 mol/L Na_2CO_3

(e) Compound calculations (combinations of (a) to (d))

1. What mass of sodium hydroxide is contained in 25 cm^3 of a 1.5 M solution of sodium hydroxide?

M_r of NaOH = (23) + (16) + (1) = 40
We have 1.5 mol/L NaOH
× 40 [mol to g → × M_r]
= 60 g/L NaOH

$\frac{60}{1000} \times 25$

=1.5 g/25 cm^3 NaOH

2. What volume of 0.01 M $KMnO_4$ solution will contain 5 g of $KMnO_4$?

M_r of $KMnO_4$ = (39) + (55) + 4(16) = 158
We have 0.01 mol/L $KMnO_4$
× 158 [mol to g → × M_r]
= 1.58 g/L $KMnO_4$. This can be rewritten as 1.58 g/1000 cm^3 $KMnO_4$
÷1.58
= 1 g/632.9 cm^3 $KMnO_4$
×5
= 5 g/3164.6 cm^3 $KMnO_4$

Dilution of solutions

To find the volume of a concentrated solution needed to make a less concentrated solution, use the formula:

$$V_c \times M_c = V_d \times M_d$$

V_c = Volume of concentrated solution
M_c = Molarity of concentrated solution

V_d = Volume of dilute solution
M_d = Molarity of dilute solution

Examples:

1. What volume of 12 M HCl is needed to make up 500 cm^3 of 3 M HCl solution?

$$V_c \times M_c = V_d \times M_d$$
$$V_c \times 12 = 500 \times 3$$
$$\frac{500 \times 3}{12} = V_d$$
$$125\ cm^3 = V_d$$

2. 15 cm^3 of 2 M HNO_3 solution is diluted to 250 cm^3 in a volumetric flask. What is the new concentration of the nitric acid?

$$V_c \times M_c = V_d \times M_d$$
$$15 \times 2 = 250 \times M_d$$
$$\frac{15 \times 2}{250} = M_d$$
$$0.12\ M = M_d$$

Standard Solutions

Def^n: A **standard solution** is one whose concentration is accurately known.
Def^n: A **primary standard** is a substance that can be directly weighed and used to make a standard solution. It must:

- Be available in a pure and stable solid state
- Be soluble in water
- Have a high molecular mass
- Be anhydrous (no water of crystallisation)

Primary Standards: Na_2CO_3, NaCl

Not Primary Standards:

HCl – it is a gas

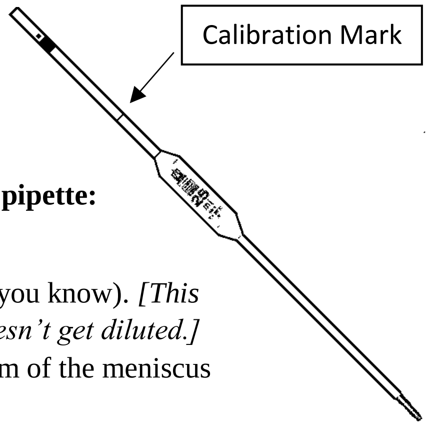
I_2 – it sublimes

H_2SO_4 – it absorbs moisture from air

NaOH – it absorbs CO_2 and moisture from air

$KMnO_4$ – it is reduced by sunlight

Equipment used in Titrations

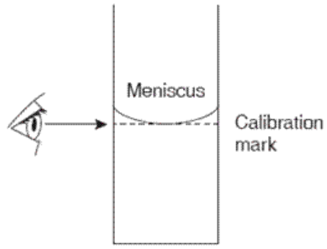


1. Pipette:

Used to accurately measure a known volume of liquids/solutions.

Procedure for cleaning, filling and transferring solutions using a pipette:

- Rinse with dionised water.
- Rinse with the solution it is to contain (name this solution if you know). *[This is done to remove the water, so the solution in the pipette doesn't get diluted.]*
- Using a pipette filler, fill pipette with solution until the bottom of the meniscus
- reaches the graduation mark, at eye level.
- Let the pipette drain under gravity, touching the tip of the pipette against the flask to remove the last drop stuck to the tip.

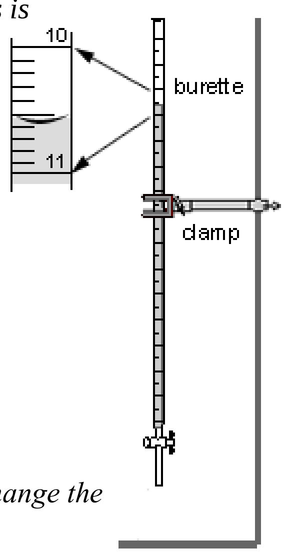


2. Burette:

Used to accurately measure the volume of liquid/solution added.

Procedure for cleaning and filling a burette:

- Rinse with deionised water.
- Rinse with the solution it is to contain (name this solution if you know). *[This is done to remove the water, so the solution in the burette doesn't get diluted.]*
- Clamp vertically.
- Using a funnel, fill the burette above the zero mark.
- Remove the funnel.
- Open the tap to bring the bottom of the meniscus to the zero mark, and to fill the jet below the tap.



3. Conical Flask:

A specially shaped flask that allows swirling without spilling the contents.

Procedure for cleaning the conical flask:

- Clean with deionised water only. *[Any water droplets remaining won't change the number of moles of reactant you add].*

Acid/Base Titrations:

1. To standardise a solution of HCl using a standard solution of Na_2CO_3.

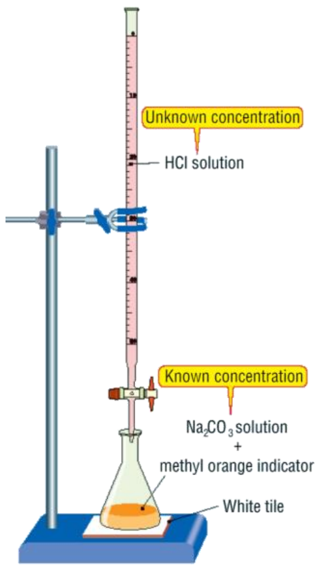
Acid: HCl – strong acid *Base:* Na_2CO_3 – weak base

Indicator: Methyl Orange (SAWBMO)

Colour change: Yellow to Red

Equation: $2HCl + Na_2CO_3 \rightarrow NaCl + H_2O + CO_2$

Ratio: 2 HCl : 1 Na_2CO_3



Sample calculation: (2012 HL Q1)

A student determined the concentration of a hydrochloric acid solution by titration with 25.0 cm^3 portions of a 0.05 M <u>primary standard</u> solution of anhydrous sodium carbonate. The portions of sodium carbonate solution were measured into a conical flask using a 25 cm^3 pipette. The hydrochloric acid solution was added from a burette. The mean titre was 20.8 cm^3.

The balanced equation for the titration reaction was:

$$\mathbf{2HCl} \quad + \quad \mathbf{Na_2CO_3} \quad \longrightarrow \quad \mathbf{2NaCl} \quad + \quad \mathbf{H_2O} \quad + \quad \mathbf{CO_2}$$

(*e*) Calculate, correct to two decimal places, the concentration of the hydrochloric acid solution in
(*i*) moles per litre,
(*ii*) grams per litre. (12)

(i) We have 0.05 mol/L Na_2CO_3

$$\frac{0.05 \times 25}{1000}$$

=0.00125 mol/25 cm^3 Na_2CO_3

HCl	:	Na_2CO_3
2	:	1
0.0025	:	0.00125

0.0025 mol/20.8 cm^3 HCl

$$\frac{0.0025 \times 1000}{20.8}$$

=0.12 mol/L HCl

(ii) M_r of HCl = (1) + (35.5) = 36.5

0.12 × 36.5 = 4.38 g/L HCl [mol to g → ×M_r]

2. To determine the concentration of ethanoic acid in vinegar

Acid: CH_3COOH – weak acid *Base:* NaOH – strong base

Indicator: Phenolphthalein (WASBPH)

Colour change: Pink to Colourless [*NOT "clear"!*]

Equation: $CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O$

Ratio: 1 CH_3COOH : 1 NaOH

Notes: Vinegar must be diluted beforehand because it is too concentrated. Make sure to multiply the concentration of the *dilute* vinegar by the dilution factor to find the concentration of the *original* vinegar.

Dilution factor = $\frac{\text{Volume of Diluted Vinegar}}{\text{Volume of Original Vinegar}}$

Clear vinegar should be used to ensure the endpoint is clearly seen.

Sample calculation: (2016 HL Q1)

To determine the concentration of ethanoic acid in a sample of vinegar, 25.0 cm^3 of the vinegar were diluted to 250 cm^3 and then the diluted vinegar was titrated with a previously standardised solution which contained 1.20 g of sodium hydroxide in 500 cm^3 of solution. On average, 18.75 cm^3 of the diluted vinegar were required to neutralise 25.0 cm^3 of this sodium hydroxide solution.

The equation for the titration reaction is:

$$\mathbf{CH_3COOH \quad + \quad NaOH \quad \rightarrow \quad CH_3COONa \quad + \quad H_2O}$$

(*c*) Calculate

(*i*) the number of moles of sodium hydroxide in each 25.0 cm^3 portion,

(*ii*) the number of moles of ethanoic acid per cm^3 of *diluted* vinegar. (12)

(*d*) Find the concentration of ethanoic acid in the *original* vinegar

(*i*) in terms of moles per litre,

(*ii*) as a percentage (w/v). (9)

(c)

(i) We have 1.20 g/500 cm^3 NaOH

M_r of NaOH = (23) + (16) + (1) = 40

1.20 ÷ 40 [g to mol → ÷M_r]

= 0.03 mol/500 cm^3 NaOH

$\frac{0.03 \times 25}{500}$

=0.0015 mol/25 cm^3 NaOH

(ii)

CH_3COOH	:	NaOH
1	:	1
0.0015	:	0.0015

0.0015 mol/18.75 cm^3 CH_3COOH (dilute)

$\frac{0.0015 \times 1}{18.75}$

=0.00008 mol/1 cm^3 CH_3COOH (dilute)

(d)

(i) 0.00008 mol/1 cm^3 CH_3COOH (dilute) Dilution Factor = $\frac{250}{25}$ = 10

×10

=0.0008 mol/1 cm^3 CH_3COOH (original)

×1000

= 0.8 mol/L CH_3COOH (original)

(ii) % (w/v) means g/100 cm^3

We have 0.8 mol/L CH_3COOH (original) M_r of CH_3COOH = (12) + 3(1) + (12) + (16) + (16) + (1) = 60

× 60 [mol to g → × M_r]

= 48 g/L CH_3COOH (original)

÷10

= 4.8 g/100 cm^3 CH_3COOH (original)

= 4.8 % (w/v)

3. To determine the amount of water of crystallisation in washing soda (hydrated sodium carbonate)

Acid: HCl – strong acid *Base:* Na_2CO_3 – weak base

Indicator: Methyl Orange (SAWBMO)

Colour change: Yellow to Red

Equation: 2HCl + Na_2CO_3 → NaCl + H_2O + CO_2

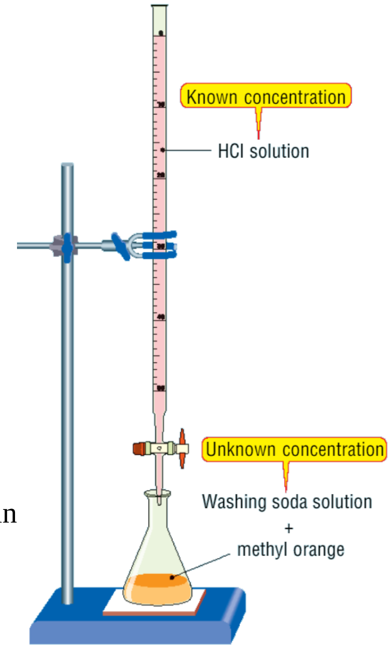
Ratio: 2 HCl : 1 Na_2CO_3

Notes: Same as titration number 1, just with extra calculations.

The crystals are made up of $Na_2CO_3.xH_2O$. We need to find 2 things:

1- the percentage of water of crystallisation, and
2- the value of *x*.

These calculations can also come up for other compounds – not just in in this experiment, e.g. finding the percentage water of crystallisation and value for *x* in hydrated copper (II) sulphate, $CuSO_4.xH_2O$.



Sample Calculation:

An experiment was carried out to determine the percentage water of crystallisation and the degree of water of crystallisation, **x**, in a sample of hydrated sodium carbonate crystals (**$Na_2CO_3.xH_2O$**). An 8.20 g sample of the crystals was weighed accurately on a clock glass and then made up to 500 cm^3 of solution in a volumetric flask. A pipette was used to transfer 25.0 cm^3 portions of this solution to a conical flask. A previously standardised 0.11 M hydrochloric acid (**HCl**) solution was used to titrate each sample. A number of accurate titrations were carried out. The average volume of hydrochloric acid solution required in these titrations was 26.05 cm^3.

The titration reaction is described by the equation:

$$\mathbf{Na_2CO_3 + 2HCl \longrightarrow 2NaCl + CO_2 + H_2O}$$

(*d*) From the titration figures, calculate the concentration of sodium carbonate (**Na_2CO_3**) in the solution in

(*i*) moles per litre,

(*ii*) grams per litre. (9)

(*e*) Calculate the percentage water of crystallisation present in the crystals and the value of **x**, the degree of hydration of the crystals. (12)

(d)

(i) We have 0.11 mol/L HCl

$$\frac{0.11 \times 26.05}{1000}$$

=0.0028655 mol/26.05 cm^3 HCl

HCl	:	Na_2CO_3
2	:	1
0.0028655	:	0.00143275

0.00143275 mol/25 cm^3 Na_2CO_3

$$\frac{0.00143275 \times 1000}{25}$$

=0.05731 mol/L Na_2CO_3

(ii) M_r of Na_2CO_3 = 2(23) + (12) + 3(16) = 106

× 106 [mol to g → × M_r]

=6.07486 g/L Na_2CO_3

(e)

(i) **Percentage water of crystallisation = $\frac{\text{Mass of water in your sample}}{\text{Mass of your sample}}$ × 100**

We had 6.07486 g/L Na_2CO_3 but we only made 500 cm^3 of the solution.

÷2

=3.03743 g/500 cm^3 Na_2CO_3 in our solution.

But we weighed out 8.20g of crystals.

The extra mass is the mass of water.

8.20 – 3.03743

= 5.16257g of water in our crystals

% water of crystallisation = $\frac{5.16257}{8.20} \times 100$

(ii)

$$\frac{\boldsymbol{Mass\ of\ Na_2CO_3}}{\boldsymbol{M_r\ of\ Na_2CO_3}} = \frac{\boldsymbol{Mass\ of\ xH_2O}}{\boldsymbol{M_r\ of\ xH_2O}}$$

M_r of xH_2O = x[2(1) + (16)] = 18x

$$\frac{3.03743}{106} = \frac{5.16257}{18x}$$

$$x = \frac{5.16257 \times 106}{18 \times 3.03743}$$

x = 10 [round to a whole number if possible]

This means our crystals are actually made up of $Na_2CO_3.10H_2O$