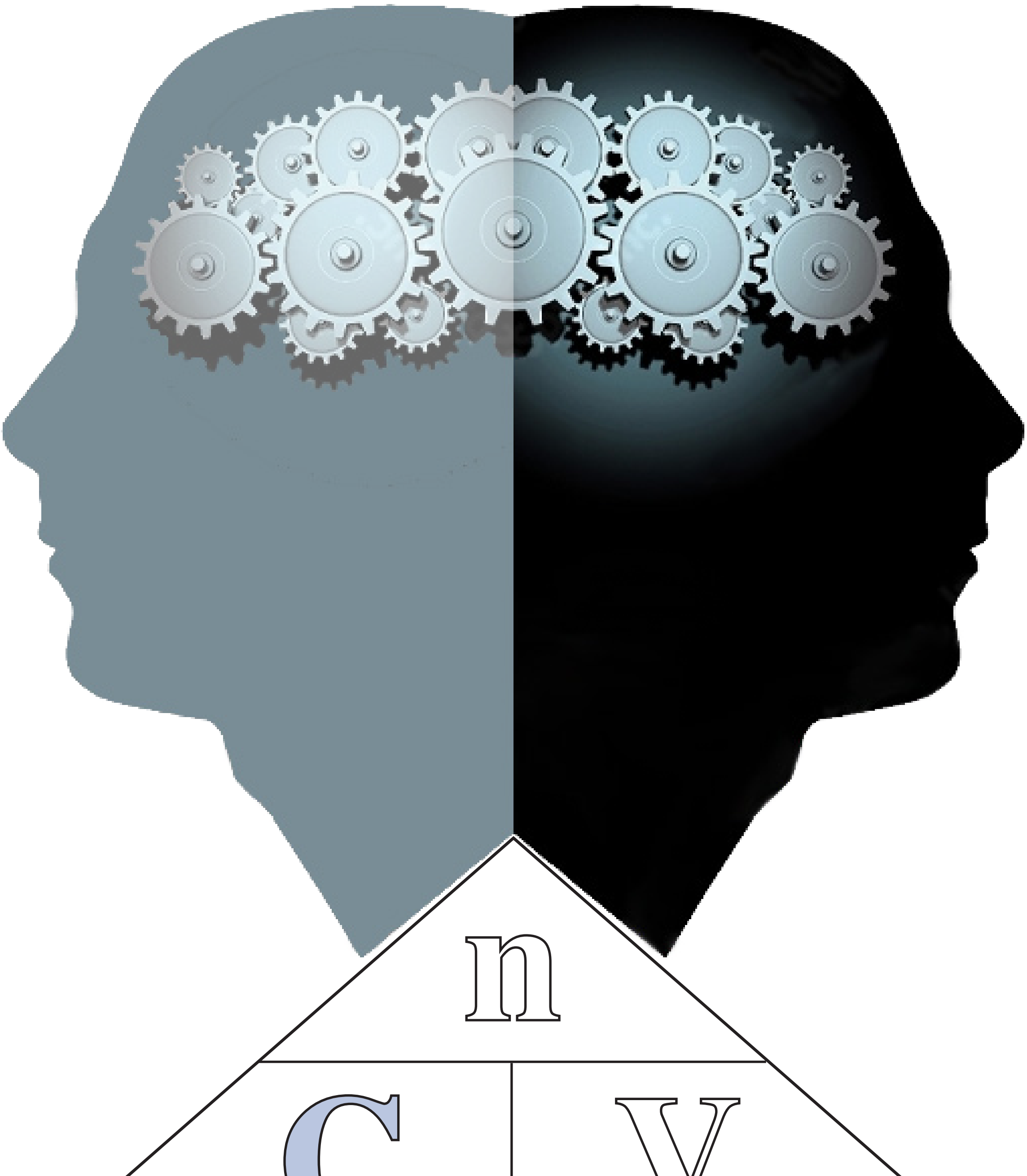
CHEMISTRY CALCULATIONS



1. Methods

These sheets belong to ______________________________

Introduction

This is the first of hopefully two booklets written to teach the calculations for National 5 Chemistry as taught in Scotland. The first booklet will describe methods for these calculations and give a few 'Self-Check' problems. The 2nd booklet will be questions extracted from previous exam papers (N5, Standard Grade & Intermediate 2) to show the questions in context.

It is assumed that you already know how to do the following:

- *write formulae for any kind of compound*
- *write & balance equations*
- *be able to find relative atomic masses (RAM) in a data booklet*

Contents

Formulae given in the Data Booklet

1. Formula Mass - all Units

*The **Formula Mass** of a substance is exactly what it says: it is the combined mass of **all the atoms** you can see in the formula for that substance. It can be done as follows:*

- *write formula (this is often done for you)*
- *determine **number** of atoms of **each** element*
- *use **Data Book** to find relative atomic masses (RAM)*
- *calculate **total mass** of substance*

Worked Example: *copper (II) carbonate* **$CuCO_3$**

1 x Cu	= 1 x 64	= 64	
1 x C	= 1 x 12	= 12	*formula mass = 124 amu*
3 x O	= 3 x 16	= 48	
		124	

*Notice the units are **amu** (atomic mass units) where:*

1 amu = mass of a proton

Test Yourself 1 Calculate the Formula Mass of each of these substances.

a)	*sodium sulphate*	Na_2SO_4	***h)***	*marble*	$CaCO_3$
b)	*magnesium nitrate*	$Mg(NO_3)_2$	***i)***	*water*	H_2O
c)	*aluminium oxide*	Al_2O_3	***j)***	*butane*	C_4H_{10}
d)	*glucose*	$C_6H_{12}O_6$	***k)***	*copper*	Cu
e)	*sulphuric acid*	H_2SO_4	***l)***	*salt*	NaCl
f)	*ammonium nitrate*	NH_4NO_3	***m)***	*ammonia*	NH_3
g)	*calcium hydroxide*	$Ca(OH)_2$	***n)***	*ethanol*	C_2H_5OH

2. Percentage Composition - Unit 3

*Very often we are only interested in **one** particular element within a compound. We may also want to compare different compounds. This is best done if we express the amount of an element as a **percentage**.*

- *write formula (this is often done for you)*
- *calculate **total mass** of the substance (**Formula Mass**)*
- *calculate (notice) what **part** is due to specific element*
- *express as a % using:*

% Element = (mass of element / formula mass) x 100

$$\% \; by \; mass = \frac{m}{GFM} \times 100$$

Worked Example: *potassium sulphate* **K_2SO_4**

2 x K	= 2 x 39	= **78**	*formula mass = 174 amu*
1 x S	= 1 x 32	= 32	
4 x O	= 4 x 16	= 64	%K = (78 / 174) x 100
		174	= 44.8 %

Test Yourself 2 Calculate the following % compositions.

a) *% **sodium** in sodium sulphate* Na_2SO_4

b) *% **magnesium** in magnesium nitrate* $Mg(NO_3)_2$

c) *% **aluminium** in aluminium oxide* Al_2O_3

d) *% **carbon** in glucose* $C_6H_{12}O_6$

e) *% **sulphur** in sulphuric acid* H_2SO_4

f) *% **nitrogen** in ammonium nitrate* NH_4NO_3

g) *% **calcium** in calcium hydroxide* $Ca(OH)_2$

3. Molar Mass (gFM) - Unit 1

This is a very simple, but very significant, step in many calculations and should present no extra problems. Quite simply you

- *calculate formula mass (in amu)*
- *convert to **molar mass** by converting to **grammes***

mass of 1 mole = formula mass in grammes = gfm

Worked Example: *potassium sulphate* **K_2SO_4**

2 x K	= 2 x 39	= 78	*formula mass = 174 amu*
1 x S	= 1 x 32	= 32	
4 x O	= 4 x 16	= 64	***Molar Mass = 174 g***
		174	***1 mole = 174 g***

*For the purposes of **doing calculations** it is enough to learn to perform this step. In the context of **understanding Chemistry**, it is important that you appreciate what '**a mole**' actually is. Your teacher may explain further.*

Test Yourself 3 Calculate the mass of ***1 mole*** for each substance below.

a)	*copper sulphate*	$CuSO_4$	***g)***	*pearl ash*	K_2O
b)	*potasium nitrate*	KNO_3	***h)***	*carbon dioxide*	CO_2
c)	*nickel(III) sulphide*	Ni_2S_3	***i)***	*ethane*	C_2H_6
d)	*sucrose*	$C_{12}H_{22}O_{11}$	***j)***	*oxygen*	O_2
e)	*nitric acid*	HNO_3	***k)***	*methanol*	CH_3OH
f)	*ammonium sulphate*	$(NH_4)_2SO_4$	***l)***	*iron (III) nitrate*	$Fe(NO_3)_3$

4. Molar Calculations - Unit 1

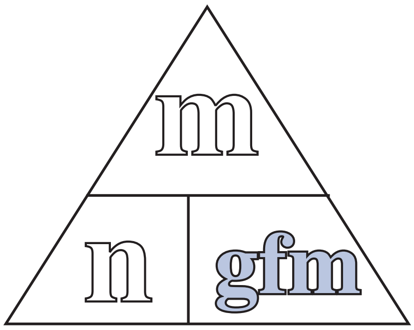
Typically, we start by weighing out chemicals but to allow us to compare the ***amounts of chemicals*** *present we need to* ***convert from masses to moles****. Again, we start by*

- *calculating formula mass (in amu)*
- *converting to* ***molar mass*** *by converting to* ***grammes***

number of moles = mass of chemical / gfm

$$n = m / gfm$$

$$n = \frac{m}{GFM}$$



Worked Example: *148g of* $Ca(OH)_2$

$Ca(OH)_2$

1 x Ca	= 1 x 40	= 40	*formula mass = 74 amu*
2 x O	= 2 x 16	= 32	
2 x H	= 1 x 1	= 2	***Molar Mass = 74 g***
		74	***1 mole = 74 g***

n = m / gfm

= 148 / 74

= 2 moles

There are 2 moles of $Ca(OH)_2$ *in 148g*

Test Yourself 4

How many moles in ***10 g*** of each substance below.

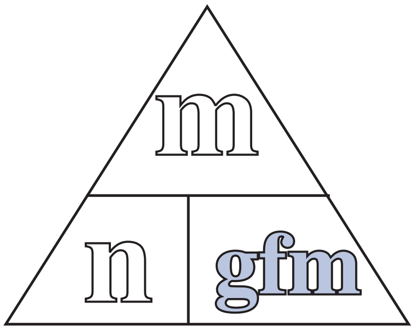
a)	*copper sulphate*	$CuSO_4$	***d)***	*pearl ash*	K_2O
b)	*potasium nitrate*	KNO_3	***e)***	*carbon dioxide*	CO_2
c)	*nickel(III) sulphide*	Ni_2S_3	***f)***	*ethane*	C_2H_6

At other times we will know the ***quantity of chemical*** *needed (in* ***moles****) but will need to express this as a* ***mass*** *in grammes.*

- *calculating formula mass (in amu)*
- *converting to* ***molar mass*** *by converting to* ***grammes***

mass of chemical = number of moles x gfm

$$m = n \times gfm$$



Worked Example: *mass of 2.5 moles of* ***$CaCO_3$***

1 x Ca	= 1 x 40	= 40	*formula mass = 100 amu*
1 x C	= 1 x 12	= 12	
3 x O	= 3 x 16	= 48	***Molar Mass = 100 g***
		100	***1 mole = 100 g***

m = n x gfm
= 2.5 x 100
= 250 g   *2.5 moles of $CaCO_3$ weighs 250g*

Test Yourself 5 Calculate the mass of each of the following.

a)	***1.5 moles*** *of sucrose*	$C_{12}H_{22}O_{11}$
b)	***2 moles*** *of oxygen*	O_2
c)	***0.2 moles*** *of nitric acid*	HNO_3
d)	***0.6 moles*** *of methanol*	CH_3OH
e)	***0.01 moles*** *of ammonium sulphate*	$(NH_4)_2SO_4$
f)	***0.3 moles*** *of iron (III) nitrate*	$Fe(NO_3)_3$

5. Using Balanced Equations - Unit 2

*A balanced equation tells us the **number of moles** of each reactant and product in a given reaction.*

A calculation based on a balanced equation can be broken down into stages:

- *write the **balanced equation** (usually given)*
- *underline the **substances involved** in the calculation*
- *extract from the equation the **number of moles of each substance***
- *replace number of moles with **calculated molar masses** (if necessary, change grams to other units eg kg, tonnes)*
- *use simple **proportion** to complete calculation*

Worked Example: *what **mass of iron** would be produced by reacting **300 tonnes of iron(III) oxide** with carbon monoxide in a blast furnace.*

$$\underline{Fe_2O_3} + 3CO \Longrightarrow \underline{2Fe} + 3CO_2$$

1 mole	$\Longrightarrow$	2 moles
160 g	$\Longrightarrow$	112 g (2 x 56g)
160 tonnes	$\Longrightarrow$	112 tonnes
1 tonne	$\Longrightarrow$	112 / 160 = 0.7 tonnes
300 tonnes	$\Longrightarrow$	300 x 0.7 = **210 tonnes**

*There are a variety of methods available for the final **proportion** calculation. The one shown is often referred to as the **unitary method**. Other methods include the **ratio method** and **scaling factor method**. Your teacher will help you find the best method for you.*

Test Yourself 6

a) *What mass of carbon dioxide is produced when 160 g of methane burns completely in air?*

$$CH_4 + 2O_2 \Longrightarrow CO_2 + 2H_2O$$

b) *Calculate the mass of magneium oxide produced when 100 g of magnesium carbonate decomposes completely on heating.*

$$MgCO_3 \Longrightarrow CO_2 + MgO$$

c) *Silicon carbide, SiC, which is used as an abrasive on sandpaper, is prepared using the chemical reaction.*

$$3C + SiO_2 \Longrightarrow 2CO + SiC$$

How many grams of SiC can be produced from 15.0 g of C?

d) *The chemical equation for the photosynthesis reaction in plants is*

$$6H_2O + 6CO_2 \Longrightarrow C_6H_{12}O_6 + 6O_2$$

How many grams of H_2O reacts with 20.0 g of CO_2 ?

e) *Decomposition of $KClO_3$ serves as a convenient laboratory source of small amounts of oxygen gas. The reaction is*

$$2KClO_3 \Longrightarrow 2KCl + 3O_2$$

What mass of $KClO_3$ must be heated to produce 8 g of O_2 ?

6. Concentration Of Solutions - Unit 1

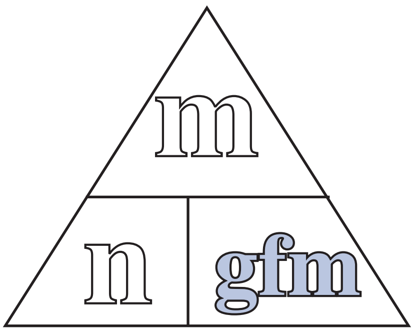
*With solutions we need to know **how much chemical** is dissolved in a given **amount of solution**. Typical units can be grammes per litre (g / l) or even milligrammes per millilitre (mg / ml)*

*However, to make comparisons between different chemicals easier, it is better to convert from weights into number of moles and express the concentration in **moles per litre** (**moles / l** or **mol l^{-1}**).*

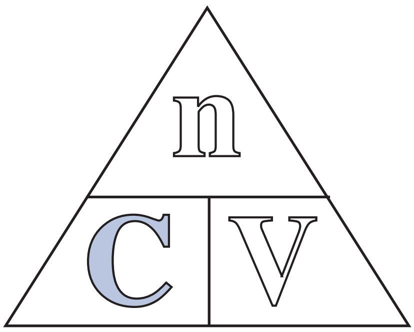
no. of moles = mass / gfm *then* ***conc. = moles / volume***

$$n = m / gfm \qquad C = n / V$$

*volumes must always be in **litres***



$n = CV$



Worked Example: *calculate the concentration of NaOH solution containing 12g of NaOH in 500 cm^3 of solution.*

NaOH ***Formula Mass*** *= 40 amu* ***molar mass****, gfm = 40 g*

moles of NaOH*,* n = mass / gfm

n = 12 / 40 = 0.3 moles

Concentration of NaOH*,* C = n / V

C = 0.3 / 0.5 (500 cm^3 in litres)

C = **0.6 moles / l** (0.6 M)

Test Yourself 7

Calculate the ***number of moles*** of chemical in each of the following solutions.

a) ***25 cm³*** *of a* ***1.0 mol l⁻¹*** *solution*

b) ***50 cm³*** *of a* ***0.5 mol l⁻¹*** *solution*

c) ***250 cm³*** *of a* ***0.25 mol l⁻¹*** *solution*

d) ***500 cm³*** *of a* ***0.01 mol l⁻¹*** *solution*

e) ***25 cm³*** *of a* ***0.1 mol l⁻¹*** *solution*

f) ***100 cm³*** *of a* ***0.2 mol l⁻¹*** *solution*

Test Yourself 8

Calculate the ***mass of chemical*** present in each of the following solutions. (*Use your answers to* ***TY 7***).

a)	***25 cm^3*** *of a* ***1.0 mol l^{-1}*** *solution*	*of*	*hydrochloric acid*	*HCl*
b)	***50 cm^3*** *of a* ***0.5 mol l^{-1}*** *solution*	*of*	*sodium hydroxide*	*NaOH*
c)	***250 cm^3*** *of a* ***0.25 mol l^{-1}*** *solution*	*of*	*sulphuric acid*	H_2SO_4
d)	***500 cm^3*** *of a* ***0.01 mol l^{-1}*** *solution*	*of*	*calcium hydroxide*	$Ca(OH)_2$
e)	***25 cm^3*** *of a* ***0.1 mol l^{-1}*** *solution*	*of*	*nitric acid*	HNO_3
f)	***100 cm^3*** *of a* ***0.2 mol l^{-1}*** *solution*	*of*	*ammonia*	NH_3

Test Yourself 9

Calculate the ***concentration*** (in *mol l^{-1}*) of each of the following solutions.

a)	***3.65 g***	*of* ***HCl***	*in* ***1000 cm^3*** *of a hydrochloric acid solution*
b)	***3.65 g***	*of* ***HCl***	*in* ***100 cm^3*** *of a hydrochloric acid solution*
c)	***6.62 g***	*of* $Pb(NO_3)_2$	*in* ***250 cm^3*** *of a lead(II) nitrate solution*
d)	***1.00 g***	*of* ***NaOH***	*in* ***250 cm^3*** *of a sodium hydroxide solution*
e)	***1.96 g***	*of* H_2SO_4	*in* ***250 cm^3*** *of a sulphuric acid solution*
f)	***1.58 g***	*of* $KMnO_4$	*in* ***250 cm^3*** *of a potassium manganate solution*

7. Titrations - Unit 1

A Titration is a practical method of using one chemical of ***known*** *concentration to determine the* ***unknown*** *concentration of another.*

Usually the chemicals are ***acids*** *(containing* ***H^+*** *ions) and* ***alkalis*** *(containing* ***OH^-*** *ions).*

At the ***end-point****, where the* ***indicator*** *changes colour, the solution is* ***neutralised*** *so;*

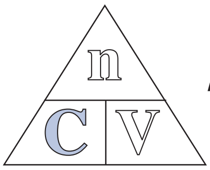
moles of H^+ ions = moles of OH^- ions

Worked Example: *it took* ***12.5 cm^3 of 0.2 M NaOH*** *to neutralise* ***10 cm^3 of sulphuric acid****. Calculate the concentration of the acid.*

Method 1: *most suitable if*

- *equation is given / written*
- *question is broken into parts*

Step 1*:* *start with '****known****' -* ***know*** *the concentration* ***and*** *the volume -* ***calculate*** *number of moles*



$n = C \times V$

$n = 0.2 \times 0.0125$ *(12.5 cm^3 in litres)*

$n = 0.0025$ *moles of NaOH*

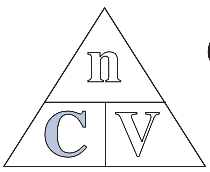
Step 2*:* *convert to '****unknown****' - use* ***balanced equation*** *to convert to* ***number of moles*** *of other chemical.*

$$2\,NaOH \quad + \quad H_2SO_4 \Longrightarrow Na_2SO_4 \quad + \quad 3H_2O$$

2 mole $\Longrightarrow$ *1 mole*

0.0025 $\Longrightarrow$ *0.00125 moles of H_2SO_4*

Step 3*:* ***calculate*** *concentration of '****unknown****'*



$C = n / V$

$C = 0.00125 \; / \; 0.010$ *(10 cm^3 in litres)*

$C =$ ***0.125 moles / l*** *(0.125 M)*

Method 2: *most suitable if*
- *equation is **not** given / written*
- *question is **not** in parts*

*At the **end-point**, where the **indicator** changes colour, the solution is **neutralised** so;*

moles of H^+ ions = moles of OH^- ions

$$n_{H+} = n_{OH-}$$

$$n_{ACID} = C_{ACID} \times V_{ACID} \qquad n_{ALK} = C_{ALK} \times V_{ALK}$$

but,

each acid has a different number of H^+ ions	*each alkali has a different number of OH^- ions*
HCl, $p_{ACID} = 1$	*NaOH,* $p_{ALK} = 1$
H_2SO_4, $p_{ACID} = 2$	$Ca(OH)_2$, $p_{ALK} = 2$
H_3PO_4, $p_{ACID} = 3$	

$$n_{H+} = C_{ACID} \times V_{ACID} \times p_{ACID} \qquad n_{OH-} = C_{ALK} \times V_{ALK} \times p_{ALK}$$

$$n_{H+} = n_{OH-}$$

so,

$$\boxed{C_{ACID} \times V_{ACID} \times p_{ACID} = C_{ALK} \times V_{ALK} \times p_{ALK}}$$

Worked Example: *it took **12.5 cm³ of 0.2 M NaOH** to neutralise **10 cm³ of H_2SO_4**. Calculate the concentration of the acid.*

use

$$C_{ACID} \times V_{ACID} \times p_{ACID} = C_{ALK} \times V_{ALK} \times p_{ALK}$$

$$C_{ACID} \times 10 \times 2 = 0.2 \times 12.5 \times 1$$

$$C_{ACID} \times 20 = 2.5$$

$$C_{ACID} = 2.5 / 20 = 0.125\ M$$

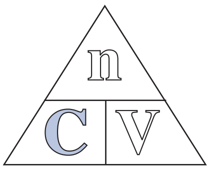
Method 3: *most suitable if*

- *equation is given*
- *question is **not** in parts*

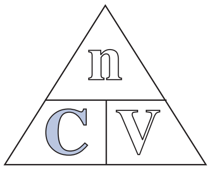
*In general we titrate to balance the acidity and alkanity. **Sometimes** it is as simple as**:***

moles of acid = moles of alkali

$$n_{ACID} = n_{ALK}$$



$$C_{ACID} \times V_{ACID} = C_{ALK} \times V_{ALK}$$



*but, as equations show, only **sometimes** are the **moles of acid** and **moles of alkali** equal.*

$$HCl + NaOH \rightarrow Na_2SO_4 + 3H_2O$$

1= mole of acid | *1= mole of alkali*

often, they are not

$$H_2SO_4 + 2\,NaOH \rightarrow Na_2SO_4 + 3H_2O$$

1= moles of acid (n_{ACID}) | *2= moles of alkali (n_{ALK})*

We can allow for this by including an extra term in our equation

$$\frac{C_{ACID} \times V_{ACID}}{n_{ACID}} = \frac{C_{ALK} \times V_{ALK}}{n_{ALK}}$$

This is the 'preferred' method for N5 exams and this is the formula given in the Data Book.

Worked Example: *it took **12.5 cm^3 of 0.2 M NaOH** to neutralise **10 cm^3 of H_2SO_4**. Calculate the concentration of the acid.*

$$\frac{C_{ACID} \times V_{ACID}}{n_{ACID}} = \frac{C_{ALK} \times V_{ALK}}{n_{ALK}}$$

$$\frac{C_{ACID} \times 10}{1} = \frac{0.2 \times 12.5}{2}$$

$$\frac{C_1V_1}{n_1} = \frac{C_2V_2}{n_2}$$

$$C_{ACID} \times 10 = 1.25$$

$$C_{ACID} = 0.125 \text{ mol } l^{-1}$$

Test Yourself 10

Calculate the ***concentration*** (in *mol l⁻¹*) of the first named solution from the given results of a titration.

a) ***25 cm³*** *of* ***sodium hydroxide*** *reacts with*
21.0 cm³ *of a* ***0.2 mol l⁻¹ hydrochloric acid***

$$NaOH + HCl \Longrightarrow NaCl + H_2O$$

b) ***25 cm³*** *of* ***sodium hydroxide*** *reacts with*
17.0 cm³ *of a* ***0.1 mol l⁻¹ sulphuric acid***

$$2NaOH + H_2SO_4 \Longrightarrow Na_2SO_4 + 2H_2O$$

c) ***20 cm³*** *of* ***hydrochloric acid*** *reacts with*
23.6 cm³ *of a* ***0.1 mol l⁻¹ sodium hydroxide***

$$NaOH + HCl \Longrightarrow NaCl + H_2O$$

d) ***25 cm³*** *of* ***nitric acid*** *reacts with*
15.0 cm³ *of a* ***0.2 mol l⁻¹ ammonia (ammonium hydroxide)***

$$NH_4OH + HNO_3 \Longrightarrow NH_4NO_3 + H_2O$$

e) ***10 cm³*** *of* ***calcium hydroxide*** *reacts with*
17.6 cm³ *of a* ***0.02 mol l⁻¹ sulphuric acid***

$$Ca(OH)_2 + H_2SO_4 \Longrightarrow CaSO_4 + 2H_2O$$

f) ***25 cm³*** *of* ***potassium hydroxide*** *reacts with*
21.0 cm³ *of a* ***0.2 mol l⁻¹ sulphuric acid***

$$2KOH + H_2SO_4 \Longrightarrow K_2SO_4 + 2H_2O$$

Answers

TY1	***a)***	*142 amu*	***b)***	*148.5 amu*	***c)***	*102 amu*	***d)***	*180 amu*
	e)	*98 amu*	***f)***	*70 amu*	***g)***	*74 amu*	***h)***	*100 amu*
	i)	*18 amu*	***j)***	*58 amu*	***k)***	*63.5 amu*	***l)***	*58.5 amu*
	m)	*17 amu*	***n)***	*70 amu*				
TY2	***a)***	*31.5 %*	***b)***	*18.8 %*	***c)***	*52.9 %*	***d)***	*40 %*
	e)	*32.7 %*	***f)***	*35 %*	***g)***	*54.1 %*		
TY3	***a)***	*159.5 g*	***b)***	*101 g*	***c)***	*213 g*	***d)***	*342 g*
	e)	*63 g*	***f)***	*132 g*	***g)***	*94 g*	***h)***	*44 g*
	i)	*30 g*	***j)***	*32 g*	***k)***	*32 g*	***l)***	*212 g*
TY4	***a)***	*0.063 moles*	***b)***	*0.099 moles*	***c)***	*0.047 moles*		
	d)	*0.106 moles*	***e)***	*0.227 moles*	***f)***	*0.333 moles*		
TY5	***a)***	*513 g*	***b)***	*64 g*	***c)***	*12.6 g*		
	d)	*19.2 g*	***e)***	*1.32 g*	***f)***	*72.6 g*		
TY6	***a)***	*440 g*	***b)***	*47.9 g*	***c)***	*16.7 g*		
	d)	*8.2 g*	***e)***	*20.4 g*				
TY7	***a)***	*0.025 moles*	***b)***	*0.025 moles*	***c)***	*0.0625 moles*		
	d)	*0.005 moles*	***e)***	*0.0025 moles*	***f)***	*0.02 moles*		
TY8	***a)***	*0.9125 g*	***b)***	*1.0 g*	***c)***	*6.125 g*		
	d)	*0.37 g*	***e)***	*0.1575 g*	***f)***	*0.34 g*		
TY9	***a)***	$0.1\ mol\ l^{-1}$	***b)***	$1.0\ mol\ l^{-1}$	***c)***	$0.08\ mol\ l^{-1}$		
	d)	$0.1\ mol\ l^{-1}$	***e)***	$0.08\ mol\ l^{-1}$	***f)***	$0.04\ mol\ l^{-1}$		
TY10	***a)***	$0.168\ mol\ l^{-1}$	***b)***	$0.136\ mol\ l^{-1}$	***c)***	$0.118\ mol\ l^{-1}$		
	d)	$0.12\ mol\ l^{-1}$	***e)***	$0.0352\ mol\ l^{-1}$	***f)***	$0.336\ mol\ l^{-1}$		