Chemistry:
Transition from GCSE to AS level

Part 8 - Calculations in equations

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Summary

(i) For all pure substances

$$\text{moles} = \frac{\text{mass given}}{\text{mass of one mole}}$$

(ii) For gases (AQA)

$$n = \frac{pV}{RT}$$

(iii) For solutions

moles = volume in dm^3 x concentration

EQUATIONS

Equations **must** balance

When balancing an equation,

- never change a correct formula,
- change the numbers of moles by writing a number in front of a formula

For **Ionic Equations** the charges must balance as well as the atoms

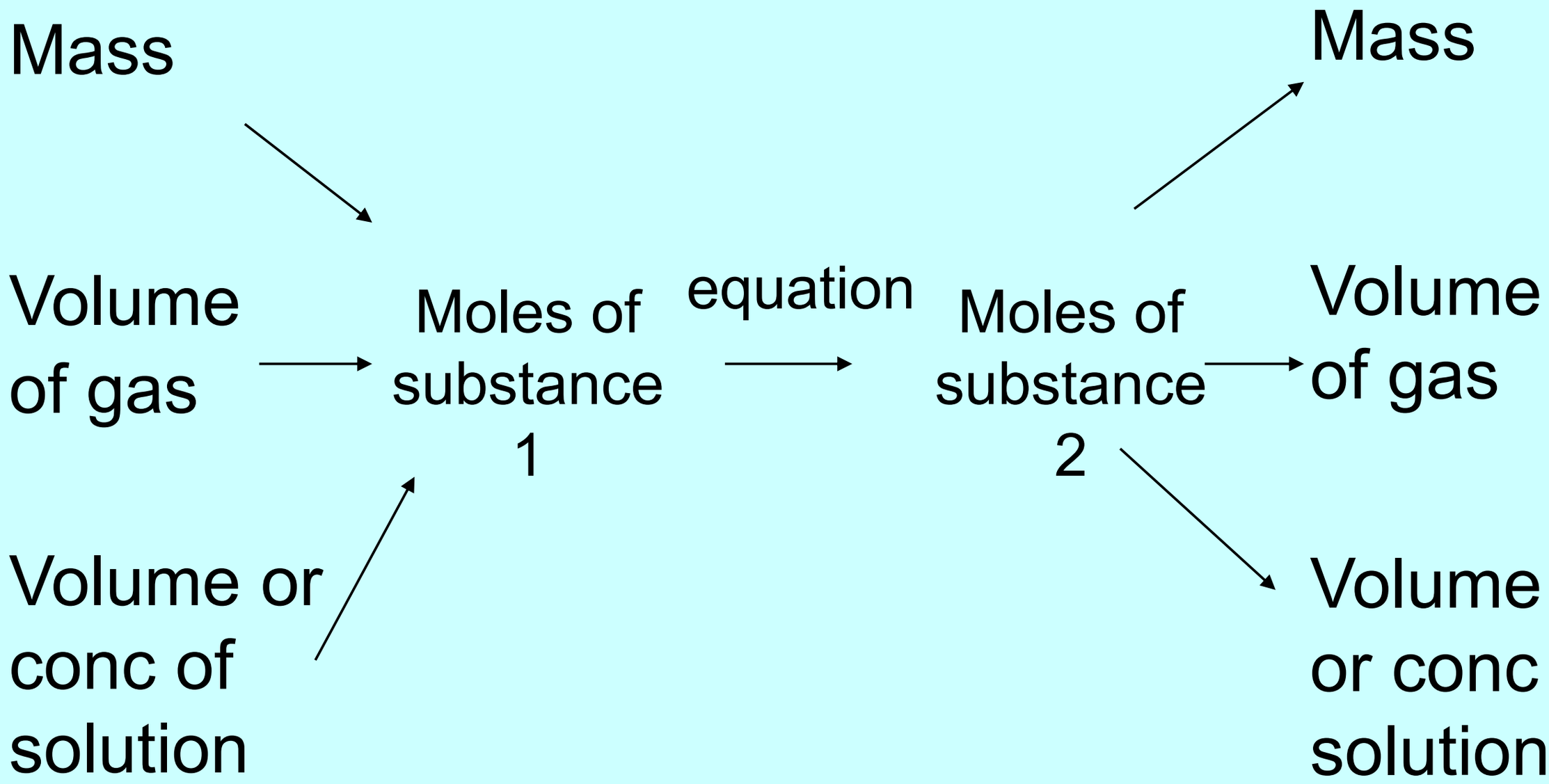
Calculations involving reactions will be wrong unless a balanced equation is written first.

USING EQUATIONS TO CALCULATE MASSES, VOLUMES and CONCENTRATIONS

All calculations will involve three essential steps plus a balanced equation.

1. Use the given mass or volume to find the number of moles of the first substance,
2. Using the ratio from the equation to find the number of moles of the other substance,
3. Convert moles into masses, volumes of gases or volumes of solutions as required.

Overall


Mass
Mass
Volume of gas
Moles of substance
equation 1
Moles of substance
Volume of gas
Volume or conc of solution
2
Volume or conc of solution
STEP 1
STEP 2
STEP 3

Mole ratio is 1 of acid : 2 of alkali

Example 1 What volume of 0.10 mol dm^{-3} H_2SO_4 neutralises 20.0 cm^3 of 0.30 mol dm^{-3} KOH ?

$$H_2SO_4 + 2KOH \rightarrow K_2SO_4 + 2\,H_2O$$

Step 1:

moles of KOH = vol in dm^3 x conc

$$= \frac{20}{1000} \times 0.30$$

$$= 6.0 \times 10^{-3}$$

Mole ratio 1 : 2

acid : alkali

Step 2: moles of H_2SO_4 = 3.00×10^{-3}

Step 3: volume of H_2SO_4 = $\frac{3.0 \times 10^{-3}}{0.1}$ (moles / concentration)

$$= 0.030\ dm^3 = \mathbf{30.0\ cm^3}$$

Example 2 What vol of CO_2 (measured at 25 °C and 100 kPa) is formed when 50 cm^3 0.50 mol dm^{-3} HCl react with excess $CaCO_3$?

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$$

Example 2 What vol of CO_2 (measured at 25 °C and 100 kPa) is formed when 50 cm^3 0.50 mol dm^{-3} HCl react with excess $CaCO_3$?

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$$

Step 1: moles of HCl = vol in dm^3 x concentration

$$= \frac{50}{1000} \times 0.50$$

$$= 2.50 \times 10^{-2}$$

Example 2 What vol of CO_2 (measured at 25 °C and 100 kPa) is formed when 50 cm^3 0.50 mol dm^{-3} HCl react with excess $CaCO_3$?

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$$

Step 1: moles of HCl = vol in dm^3 x concentration

$$= \frac{50}{1000} \times 0.50$$

$$= 2.50 \times 10^{-2}$$

Mole ratio 2:1

Step 2: moles of CO_2 = 1.25×10^{-2}

Example 2 What vol of CO_2 (measured at 25 °C and 100 kPa) is formed when 50 cm^3 0.50 mol dm^{-3} HCl react with excess $CaCO_3$?

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$$

Step 1: moles of HCl = vol in dm^3 x concentration

$$= \frac{50}{1000} \times 0.50$$

$$= 2.50 \times 10^{-2}$$

Step 2: moles of CO_2 = 1.25×10^{-2}

Step 3: volume of CO_2

$$= \frac{nRT}{p} = \frac{1.25 \times 10^{-2} \times 8.31 \times 298}{100\,000}$$

$$= 3.10 \times 10^{-4}\ m^3 = \mathbf{310\ cm^3}$$

Example 3 What mass of $CaCO_3$ is actually used in example (ii)?

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$$

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$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$$

Step 1: moles of HCl = vol in dm^3 x concentration

$$= \frac{50}{1000} \times 0.50$$

$$= 2.5 \times 10^{-2}$$

Example 3 What mass of $CaCO_3$ is actually used in example (ii)?

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$$

Step 1: moles of HCl = vol in dm^3 x concentration

$$= \frac{50}{1000} \times 0.50$$

$$= 2.5 \times 10^{-2}$$

Mole ratio 2:1

Step 2: moles of $CaCO_3$ = 1.25×10^{-2}

M_r of $CaCO_3$ = 100.0

Example 3 What mass of $CaCO_3$ is actually used in example (ii)?

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$$

Step 1: moles of HCl = vol in dm^3 x concentration

$$= \frac{50}{1000} \times 0.50$$

$$= 2.5 \times 10^{-2}$$

Step 2: moles of $CaCO_3$ = 1.25×10^{-2}

M_r of $CaCO_3$ = 100.0

Step 3: mass of $CaCO_3$ = $1.25 \times 10^{-2} \times 100.0$

= **1.25g**

The Periodic Table of the Elements

1	2											3	4	5	6	7	0
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*	*(12)*	*(13)*	*(14)*	*(15)*	*(16)*	*(17)*	*(18)*
							1.0 **H** hydrogen 1										4.0 **He** helium 2
6.9 **Li** lithium 3	9.0 **Be** beryllium 4											10.8 **B** boron 5	12.0 **C** carbon 6	14.0 **N** nitrogen 7	16.0 **O** oxygen 8	19.0 **F** fluorine 9	20.2 **Ne** neon 10
23.0 **Na** sodium 11	24.3 **Mg** magnesium 12											27.0 **Al** aluminium 13	28.1 **Si** silicon 14	31.0 **P** phosphorus 15	32.1 **S** sulfur 16	35.5 **Cl** chlorine 17	39.9 **Ar** argon 18
39.1 **K** potassium 19	40.1 **Ca** calcium 20	45.0 **Sc** scandium 21	47.9 **Ti** titanium 22	50.9 **V** vanadium 23	52.0 **Cr** chromium 24	54.9 **Mn** manganese 25	55.8 **Fe** iron 26	58.9 **Co** cobalt 27	58.7 **Ni** nickel 28	63.5 **Cu** copper 29	65.4 **Zn** zinc 30	69.7 **Ga** gallium 31	72.6 **Ge** germanium 32	74.9 **As** arsenic 33	79.0 **Se** selenium 34	79.9 **Br** bromine 35	83.8 **Kr** krypton 36
85.5 **Rb** rubidium 37	87.6 **Sr** strontium 38	88.9 **Y** yttrium 39	91.2 **Zr** zirconium 40	92.9 **Nb** niobium 41	96.0 **Mo** molybdenum 42	[97] **Tc** technetium 43	101.1 **Ru** ruthenium 44	102.9 **Rh** rhodium 45	106.4 **Pd** palladium 46	107.9 **Ag** silver 47	112.4 **Cd** cadmium 48	114.8 **In** indium 49	118.7 **Sn** tin 50	121.8 **Sb** antimony 51	127.6 **Te** tellurium 52	126.9 **I** iodine 53	131.3 **Xe** xenon 54
132.9 **Cs** caesium 55	137.3 **Ba** barium 56	138.9 **La** * lanthanum 57	178.5 **Hf** hafnium 72	180.9 **Ta** tantalum 73	183.8 **W** tungsten 74	186.2 **Re** rhenium 75	190.2 **Os** osmium 76	192.2 **Ir** iridium 77	195.1 **Pt** platinum 78	197.0 **Au** gold 79	200.6 **Hg** mercury 80	204.4 **Tl** thallium 81	207.2 **Pb** lead 82	209.0 **Bi** bismuth 83	[209] **Po** polonium 84	[210] **At** astatine 85	[222] **Rn** radon 86
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Key

relative atomic mass
symbol
name
atomic (proton) number

140.1 **Ce** cerium 58	140.9 **Pr** praseodymium 59	144.2 **Nd** neodymium 60	[145] **Pm** promethium 61	150.4 **Sm** samarium 62	152.0 **Eu** europium 63	157.3 **Gd** gadolinium 64	158.9 **Tb** terbium 65	162.5 **Dy** dysprosium 66	164.9 **Ho** holmium 67	167.3 **Er** erbium 68	168.9 **Tm** thulium 69	173.0 **Yb** ytterbium 70	175.0 **Lu** lutetium 71
232.0 **Th** thorium 90	231.0 **Pa** protactinium 91	238.0 **U** uranium 92	[237] **Np** neptunium 93	[244] **Pu** plutonium 94	[243] **Am** americium 95	[247] **Cm** curium 96	[247] **Bk** berkelium 97	[251] **Cf** californium 98	[252] **Es** einsteinium 99	[257] **Fm** fermium 100	[258] **Md** mendelevium 101	[259] **No** nobelium 102	[262] **Lr** lawrencium 103

* **58 – 71** Lanthanides

† **90 – 103** Actinides

Use this for the task on the next page

CONCENTRATION CALCULATIONS - REACTIONS

For each question, you **must** write a balanced equation before attempting the calculation.

1. What volume of 0.5 mol dm^{-3} sodium hydroxide will just neutralise 20 cm^3 of 1.0 mol dm^{-3} nitric acid ?

2. What volume of 0.4 mol dm^{-3} hydrochloric acid will just neutralise 25 cm^3 0.1 mol dm^{-3} potassium hydroxide ?

3. 25 cm^3 of 0.2 mol dm^{-3} sodium hydroxide solution just neutralises 50 cm^3 of nitric acid. What is the concentration of the acid ?

4. 40 cm^3 of a solution of nitric acid reacted with 4.2g of magnesium carbonate. Calculate the concentration of the acid.

5. An excess of magnesium is added to 50 cm^3 of 2 mol dm^{-3} hydrochloric acid.
   What volume of hydrogen (measured at room temperature and pressure) is formed ?
   What mass of magnesium is used up ?

6. An excess of calcium carbonate is added to 20 cm^3 of 1.0 mol dm^{-3} nitric acid.
   What volume of carbon dioxide (measured at room temperature and pressure) is formed ?
   What mass of calcium carbonate is used up ?

7. What volume of 1.0 mol dm^{-3} sulphuric acid will just neutralise 8g of copper(II) oxide ?
   What mass of copper(II) sulphate is formed ?

8. 50 cm^3 of a solution of hydrochloric acid will just neutralise 8g of magnesium oxide.
   What is the concentration of the hydrochloric acid and what mass of magnesium chloride will be formed ?

9. What volume of 0.5 mol dm^{-3} sodium hydroxide will just neutralise 50 cm^3 2.0 mol dm^{-3} sulphuric acid ?

10. What volume of 0.1 mol dm^{-3} sulphuric acid will react exactly with 100 cm^3 0.5 mol dm^{-3} sodium hydroxide ?

Pause this presentation while you complete the exercise on the previous page.

When complete move to the next page where you can check your answers.

Answers: Concentrations - Equations

1) 40 cm^3 2) 6.25 cm^3 3) 0.1 mol dm^{-3} 4) 2.5 mol dm^{-3}

5) 1.2 dm^3, 1.2g 6) 240 cm^3, 1 g 7) 100 cm^3, 16g 8) 8 mol dm^{-3}, 19g

9) 400 cm^3 10) 250 cm^3

Having checked your work you will have either:

1. Completed the task correctly - well done :)

2. Made some mistakes - which you now understand (having seen the correct answer) - that's OK as you have 'learned from your mistakes'

3. Do not understand the answer - if this is the case you **must** seek assistance from your teacher (if you do not then you will ***never*** understand this and this may be a building block for later work!)

Limiting reactants:

You need to calculate the amount of product produced from each reactant.

The smaller mass will produced from the limiting reactant !

Try the exercise after the data sheet and identify the limiting reactant.

The Periodic Table of the Elements

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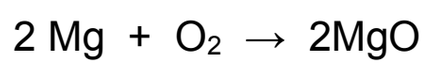
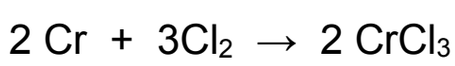
Limiting Reagent Calculations

1. What mass of magnesium oxide is formed from 3.00 g of magnesium and 8.00 g of oxygen?



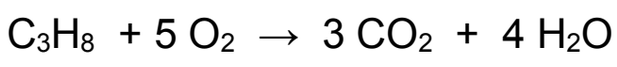
$$2\ Mg + O_2 \rightarrow 2MgO$$

2. What mass of chromium chloride is formed when 4.16 g of chromium reacts with 35.5 g of chlorine?



$$2\ Cr + 3Cl_2 \rightarrow 2\ CrCl_3$$

3. What mass of carbon dioxide is formed when 2.64 g of propane (C_3H_8) reacts with 9.60 g of oxygen ?



$$C_3H_8 + 5\ O_2 \rightarrow 3\ CO_2 + 4\ H_2O$$

4. What mass of lithium hydroxide is formed from 0.49 g of lithium and 9.00 g of water?

$$2\ Li + 2\ H_2O \rightarrow 2\ LiOH + H_2$$

5. What mass of aluminium sulfate is formed from 40.8 g of aluminium oxide and 78.4 g of sulfuric acid?

$$Al_2O_3 + 3\ H_2SO_4 \rightarrow Al_2(SO_4)_3 + 3\ H_2O$$

Pause this presentation while you complete the exercise on the previous page.

When complete move to the next page where you can check your answers.

3 STEP METHOD

① What mass of magnesium oxide is formed from 3.00 g of magnesium and 8.00 g of oxygen?

$$2Mg + O_2 \longrightarrow 2MgO$$

from 3.00 g magnesium

① $N^o\ mols\ (Mg) = \frac{3}{24} = \frac{1}{8}$

② RATIO $mols\ (Mg) : mols\ (MgO) = 2:2 \therefore 1:1$

fewer mols ✱ $\therefore N^o\ mols\ (MgO) = \frac{1}{8}$

③ $Mass\ (MgO) = N^o\ mols \times M_r = \frac{1}{8} \times (24+16) = \frac{1}{8}(40) =$

$= 5.00\ g\ (3\ sf)$

smaller mass of product

from 8.00 g oxygen

① $N^o\ mols\ (O_2) = \frac{8}{(2\times16)} = \frac{8}{32} = \frac{1}{4}$

② RATIO $mols\ (O_2) : mols\ (MgO) = 1:2$

✱ $\therefore N^o\ mols\ (MgO) = \frac{1}{4} \times 2 = \frac{1}{2}$

③ $Mass\ (MgO) = N^o\ mols \times M_r = \frac{1}{2} \times (24+16) = \frac{1}{2}(40)$

$= 20.0\ g\ (3\ sf)$

$\therefore$ Magnesium is the limiting reagent

$\therefore$ mass of $MgO = 5.00\ g\ (3\ sf)$

RATIO METHOD

① What mass of magnesium oxide is formed from 3.00 g of magnesium and 8.00 g of oxygen?

$$\overset{3}{2Mg} + \overset{8}{O_2} \longrightarrow \overset{x}{2MgO}$$

$2 \times 24 = 48$ $\quad 2 \times 16 = 32$ $\quad 2(24+16) = 2(40) = 80$

Magnesium $\quad \frac{3}{48} = \frac{x}{80} \quad \therefore x = \frac{3}{48} \times 80$

$\therefore x = 5.00\ g$ (3 sig fig)

oxygen $\quad \frac{8}{32} = \frac{x}{80} \quad \therefore x = \frac{8}{32} \times 80$

$x = 20.0\ g$ (3 sig fig)

Smaller mass of product

$\therefore$ Magnesium is the limiting reagent

mass of MgO = 5.00 g (3 sf)

3 STEP METHOD

(2) What mass of chromium chloride is formed when 4.16 g of chromium reacts with 35.5 g of chlorine?

$$2Cr + 3Cl_2 \rightarrow 2CrCl_3$$

From 4.16 g chromium

(1) N° mols $(Cr) = \frac{4.16}{52} = 0.08$

(2) RATIO mols (Cr) : mols $(CrCl_3) = 2:2 \therefore 1:1$

* $\therefore$ N° mols $(CrCl_3) = 0.08$

fewer mols

(3) mass $(CrCl_3)$ = N° mols × M_r = $0.08 \times (52 + (3 \times 35.5)) = 0.08 \times 158.5$

$= 12.68 = 12.7$ g (3 sf)

smaller mass of product

From 35.5 g chlorine

(1) N° mols $(Cl_2) = \frac{35.5}{(2 * 35.5)} = \frac{35.5}{71} = \frac{1}{2} = 0.5$

(2) RATIO mols (Cl_2) : mols $(CrCl_3) = 3:2$

Xs ! * $\therefore$ N° mols $(CrCl_3) = 0.5 \times \frac{2}{3} = 0.333$

(3) mass $(CrCl_3)$ = N° mols × M_r = $0.333 \times (52 + (3 \times 35.5)) = 0.333 \times 158.5$

$= 52.833 = 52.8$ (3 sf)

$\therefore$ chromium is the limiting reagent

mass of $CrCl_3 = 12.7$ g (3 sf)

RATIO METHOD

③ What mass of CO_2 is formed when 2.64 g propane (C_3H_8) reacts with 9.60 g of oxygen?

2.64 9.00 X

$C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$

$(3\times12)+(8\times1)$ $5\times(2\times16)$ $3(12+(2\times16))$

$= 36+8$ 5×32 $3(44)$

$= 44$ $= 160$ $= 132$

propane (C_3H_8) $\frac{2.64}{44} = \frac{X}{132}$

$\therefore X = \frac{2.64}{44} \times 132 = 0.06 \times 132 =$

$X = 7.92$ g (3 sig fig)

oxygen $\frac{9.60}{160} = \frac{X}{132}$

$\therefore X = \frac{9.60}{160} \times 132 = \frac{0.06}{0.0560} \times 132$

$= 7.425$

$\therefore X = 7.92$ g (3 sig fig)

smaller mass of product

∴ oxygen is the limiting reagent

∴ mass of CO_2 = 7.92 g (3 sig fig)

3 STEP METHOD

(4) What mass of lithium hydroxide is formed from 0.49 g of lithium and 9.00 g of water?

$$2Li + 2H_2O \longrightarrow 2LiOH + H_2$$

From 0.49 g Lithium

① N^o mols $(Li) = \frac{0.49}{7} = 0.07$

② RATIO mol (Li) : mols $(LiOH) = 2:2 \therefore 1:1$

* $\therefore$ N^o mols $(LiOH) = 0.07$

fewer mols

③ mass $(LiOH) = N^o$ mols $\times M_r = 0.07 \times (7+16+1) = 0.07 \times 24$

$= 1.68$ g (3 sf)

smaller mass of product

From 9.00 g Water

① N^o mols $(H_2O) = \frac{9}{(2\times1)+16} = \frac{9}{18} = 0.5$

② RATIO mols (H_2O) : mols $(LiOH) = 2:2 \therefore 1:1$

Xs ! * $\therefore$ N^o mols $(LiOH) = 0.5$

③ mass $(LiOH) = N^o$ mols $\times M_r = 0.5 \times (7+16+1) = 0.5 \times 24$

$= 12.0$ g (3 sf)

Lithium is the limiting reagent

mass of LiOH = 1.68 g

RATIO METHOD

(5) What mass of aluminium sulfate is formed from 40.8 g of aluminium oxide and 78.4 g of sulfuric acid?

$$\underset{40.8}{Al_2O_3} + 3\underset{78.4}{H_2SO_4} \longrightarrow \underset{X}{Al_2(SO_4)_3} + 3H_2O$$

Al_2O_3: $(2\times27)+(3\times16)$ = $54+48$ = 102

$3H_2SO_4$: $3[(2\times1)+32+(4\times16)]$ = $3[2+32+64]$ = $3(98)$ = 294

$Al_2(SO_4)_3$: $(2\times27)+3[32+(4\times16)]$ = $54+3[32+64]$ = $54+3(96)$ = 342

Aluminium oxide (Al_2O_3) $\quad \frac{40.8}{102} = \frac{X}{342}$

$\therefore X = \frac{40.8}{102} \times 342 = 0.4 \times 342 = 136.8$

$\therefore X = 137$ g (3 sf)

Sulfuric acid (H_2SO_4) $\quad \frac{78.4}{294} = \frac{X}{342}$

$\therefore X = \frac{78.4}{294} \times 342 = \frac{4}{15} \times 342 = 91.2$

$\therefore X = 91.2$ g (3 sf)

Smaller mass of product
$\therefore$ Sulfuric acid (H_2SO_4) is the limiting reagent

$\therefore$ mass of aluminium sulfate = 91.2 (3 sf)

Having checked your work you will have either:

1. Completed the task correctly - well done :)

2. Made some mistakes - which you now understand (having seen the correct answer) - that's OK as you have 'learned from your mistakes'

3. Do not understand the answer - if this is the case you **must** seek assistance from your teacher (if you do not then you will ***never*** understand this and this may be a building block for later work!)

When you’re confident with this topic move onto part 9:

Percentage yield