Unit 1

THE CORE PRINCIPLES OF CHEMISTRY

4 Calculations from chemical equations

Remember:

- Put words into your calculation so that both you and the examiner can follow the calculation through. Not only will this help you, it will enable the examiner to award 'consequential' marks, should you make an error early in the calculation.
- Check the number of significant figures for each answer. The data are almost always given to three significant figures, so the answers should also be given to three significant figures.
- Do not confuse decimal places with significant figures. For example, 0.012 is a number to three decimal places, but to two significant figures. When counting significant figures in numbers less than 1, do not count the zeros before or immediately after the decimal point.
- Putting units into the calculation acts as a check to see if you have used the correct 'formula'. For instance, if you thought that moles = mass × molar mass, the units of amount of substance (moles) would come out as $g \times g\,mol^{-1}$ or $g^2\,mol^{-1}$, which is absurd.
- Always think about the magnitude of your answer and see if it is reasonable. If not, check your working. When you have finished, redo the calculation on your calculator to check that you have not made a calculator error.
- If the volume of 1 mol of gas is given in dm^3, convert gas volumes from cm^3 to dm^3. Do this by dividing the volume in cm^3 by 1000. The dm^3 volume is smaller than the cm^3 volume.
- Convert solution volumes in cm^3 to volumes in dm^3 before multiplying by the concentration. The volume in dm^3 equals the volume in cm^3 divided by 1000.

1 molar mass of $Fe_2(SO_4)_3 = (2 \times 55.8) + 3 \times [32.1 + (4 \times 16.0)] = 399.9\,g\,mol^{-1}$

molar mass of $Fe(OH)_3 = 55.8 + (3 \times 17.0) = 106.8\,g\,mol^{-1}$

$$\text{amount of } Fe_2(SO_4)_3 \text{ (in moles)} = \frac{\text{mass}}{\text{molar mass}} = \frac{12.7\,g}{399.9\,g\,mol^{-1}} = 0.03176\,mol$$

$$\text{moles } Fe(OH)_3 = \text{moles } Fe_2(SO_4)_3 \times \frac{\text{number of } Fe(OH)_3 \text{ in equation}}{\text{number of } Fe_2(SO_4)_3 \text{ in equation}}$$

$$= 0.03176\,mol \times 2 = 0.06352\,mol$$

mass of $Fe(OH)_3$ = moles × molar mass = $0.06352\,mol \times 106.8\,g\,mol^{-1} = 6.78\,g$

It is a good idea to work out the molar masses of the two substances involved before starting the rest of the calculation.

2 molar mass of $AgNO_3 = 107.9 + 14.0 + (3 \times 16.0) = 169.9\,g\,mol^{-1}$

$$\text{amount (in moles) of } AgNO_3 = \frac{\text{mass}}{\text{molar mass}} = \frac{12.6\,g}{169.9\,g\,mol^{-1}} = 0.07416\,mol$$

ratio of $Cu:AgNO_3 = 1:2$

so, amount of copper = $\frac{1}{2} \times 0.07416 = 0.03708\,mol$

mass of copper needed = moles × molar mass

$$= 0.03708\,mol \times 63.5\,g\,mol^{-1} = 2.35\,g$$

The answer 2.35 g was obtained keeping all the numbers on the calculator during the calculation. If the rounded up value of 0.0371 mol is used, the answer 2.36 g is obtained. Either would score full marks.

A common error is to calculate the molar mass of $AgNO_3$ as $2 \times 170\,g\,mol^{-1}$ because there are 2 moles of it in the equation. This is wrong. The number of moles of a substance depends only on its mass and *not* on the reaction. The stoichiometry comes into play when moles of one substance are converted to moles of another substance. This type of calculation can be done either by mass ratio or by converting to moles, then using the reaction stoichiometry and finally converting back to mass. The second method fits all types of calculation, so is the better one to use.

3 molar mass of $NaNO_3 = 23.0 + 14.0 + (3 \times 16.0) = 85.0\,g\,mol^{-1}$

amount of $NaNO_3 = \frac{\text{mass}}{\text{molar mass}} = \frac{33.3\,g}{85.0\,g\,mol^{-1}} = 0.392\,mol$

ratio of $O_2:NaNO_3 = 1:2$

so, amount of oxygen $= \frac{1}{2} \times 0.392 = 0.196\,mol$

volume of oxygen = moles × molar volume

$= 0.196\,mol \times 25.0\,dm^3\,mol^{-1}$

$= 4.90\,dm^3$

4 amount (moles) of hydrogen, $H_2 = \frac{\text{mass}}{\text{molar mass}} = \frac{3000\,g}{2.0\,g\,mol^{-1}} = 1500\,mol$

ratio of $NH_3:H_2 = 2:3$

so, theoretical amount (moles) of ammonia produced $= \frac{2}{3} \times 1500 = 1000\,mol$

theoretical yield (mass) of NH_3 = moles × molar mass

$= 1000\,mol \times 17\,g\,mol^{-1}$

$= 17\,000\,g$

percentage yield $= \frac{\text{actual yield of product} \times 100}{\text{theoretical yield of product}} = \frac{2550\,g \times 100}{17\,000\,g} = 15.0\%$

e When calculating the percentage yield, the yields can be expressed in moles or in mass units. Calculating both yields in moles gives:

actual amount (moles) of $NH_3 = \frac{2550\,g}{17.0\,g\,mol^{-1}} = 150\,mol$

so, percentage yield $= \frac{150\,mol \times 100}{1000\,mol} = 15.0\%$

The percentage yield is *not* $\frac{\text{mass of product} \times 100}{\text{mass of reactant}}$.

5 amount (in moles) = concentration × volume

$= 0.0545\,mol\,dm^{-3} \times \frac{23.4}{1000}\,dm^3 = 0.00128\,mol$

e Be careful about units. The concentration is in mol *dm*$^{-3}$, but the volume is in *cm*^{3}. The volume in cm^3 must be divided by 1000 to convert it into a volume in dm^3.

6 volume $= \frac{\text{moles}}{\text{concentration}} = \frac{0.00164\,mol}{0.106\,mol\,dm^{-3}} = 0.0155\,dm^3 = 15.5\,cm^3$

e Volumes of solutions less than 1 dm^3 are usually expressed in cm^3.

7 amount (moles) of $H_2C_2O_4.2H_2O$ = concentration × volume

$= 0.0500\,mol\,dm^{-3} \times \frac{500}{1000}\,dm^3 = 0.0250\,mol$

molar mass of $H_2C_2O_4.2H_2O = 2.0 + (2 \times 12.0) + (4 \times 16.0) + (2 \times 18.0) = 126.0\,g\,mol^{-1}$

mass of hydrated ethanedioic acid needed = moles × molar mass

$= 0.0250\,mol \times 126.0\,g\,mol^{-1} = 3.15\,g$

8 a amount (moles) of Fe $= \frac{\text{mass}}{\text{molar mass}} = \frac{4.50\,\text{g}}{55.8\,\text{g mol}^{-1}} = 0.0806\,\text{mol}$

amount of copper(II) sulfate = concentration × volume in dm^3

$= 2.00\,\text{mol dm}^{-3} \times 0.0500\,\text{dm}^3 = 0.100\,\text{mol}$

As 0.100 is greater than 0.0806, iron is the limiting reagent.

e As the substances react in a 1:1 ratio, the one with fewer moles is the limiting reagent.

b ratio of Cu to Fe in the equation = 1:1

so, amount (moles) of copper = amount of iron = 0.0806 mol

mass of copper = moles × molar mass = $0.0806\,\text{mol} \times 63.5\,\text{g mol}^{-1} = 5.12\,\text{g}$

c Copper sulfate is in excess, so the solution will still be blue.

e If copper sulfate had been the limiting reagent, the solution would be colourless at the end of the reaction.

9 a $2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$

e The stoichiometric ratio is not 1:1, so the amount of sodium sulfate that would be produced from both sodium hydroxide and sulfuric acid reacting completely has to be calculated. The limiting reagent is the one that gives the smaller amount of product.

b molar mass of sodium hydroxide = $23.0 + 16.0 + 1.0 = 40.0\,\text{g mol}^{-1}$

amount (moles) of NaOH $= \frac{\text{mass}}{\text{molar mass}} = \frac{21.5\,\text{g}}{40.0\,\text{g mol}^{-1}} = 0.5375\,\text{mol}$

amount (moles) of Na_2SO_4 that would be produced if NaOH were the limiting reagent $= \frac{1}{2} \times 0.5375 = 0.269\,\text{mol}$

amount (moles) of H_2SO_4 = concentration × volume in dm^3

$= 1.00\,\text{mol dm}^{-3} \times 0.500\,\text{dm}^3 = 0.500\,\text{mol}$

amount (moles) of Na_2SO_4 that would be produced if H_2SO_4 were the limiting reagent = 0.500 mol, which is more than 0.269 mol from NaOH

Therefore, sodium hydroxide is the limiting reagent.

c molar mass of $Na_2SO_4 = (2 \times 23.0) + 32.1 + (4 \times 16.0) = 142.1\,\text{g mol}^{-1}$

mass of sodium sulfate produced = moles × molar mass

$= 0.269\,\text{mol} \times 142.1\,\text{g mol}^{-1} = 38.2\,\text{g}$

d Sodium hydroxide is the limiting reagent, so there will be an excess of sulfuric acid. Therefore, red litmus will stay red and blue litmus will turn red.

e Even though there are more moles of sodium hydroxide than sulfuric acid, the sodium hydroxide is the limiting reagent because 2 moles of it are needed for every mole of sulfuric acid.

Chapter Summary Worksheet (textbook CD-ROM)

1 The answer is D. There are two ways of calculating the answer:

amount (moles) Mg $= \dfrac{6.075}{24.3} = 0.25 =$ moles $MgCl_2$

mass of $MgCl_2 = 0.25\,\text{mol} \times \text{molar mass} = 0.25 \times 95.3 = 23.825\,\text{g}$

or

24.3 g of Mg produces 95.3 g of $MgCl_2$

so 6.075 g produces $95.3 \times \dfrac{6.075}{24.3} = 23.825$ g of $MgCl_2$

e Option A used some atomic numbers rather than atomic masses. The formula for magnesium chloride is $MgCl_2$ — option B used MgCl and C used Mg_2Cl.

2 The answer is D.

amount (moles) $= \dfrac{\text{mass}}{\text{molar mass}} = 0.0250$

there are 5 ions per formula, so there are $5 \times 0.025 = 0.125$ mol of ions

number of ions $= 0.125 \times 6.02 \times 10^{23} = 7.53 \times 10^{22}$

e Option A is the number of moles, B is the moles of ions and C is the number of 'molecules' or ion groups.

3 The answer is A.

$$\text{amount (moles) of rubidium} = \frac{\text{mass}}{\text{atomic mass}} = \frac{8.55\,\text{g}}{85.5\,\text{g mol}^{-1}} = 0.100\,\text{mol}$$

mass of 0.100 mol of $RbO_2 = 0.100\,\text{mol} \times 117.5\,\text{g mol}^{-1} = 11.75\,\text{g}$

so A is the correct answer

4 The answer is B.

$$\text{amount (moles) of CuO} = \frac{\text{mass}}{\text{molar mass}} = \frac{7.95\,\text{g}}{79.5\,\text{g mol}^{-1}} = 0.100\,\text{mol}$$

theoretical yield = 0.100 mol × molar mass of hydrated copper sulfate

$= 0.1 \times 249.6 = 24.96\,\text{g}$

$$\text{percentage yield} = \frac{\text{actual yield of product}}{\text{theoretical yield of product}} \times 100 = \frac{23.0 \times 100}{24.96} = 92.1 = 92\%\ \text{to two significant figures}$$

so B is the correct answer.

5 The answer is B.

$$\text{amount (moles) of Al} = \frac{\text{mass}}{\text{atomic mass}} = \frac{1.076\,\text{g}}{27.0\,\text{g mol}^{-1}} = 0.03985\,\text{mol}$$

amount (moles) of hydrogen $= \frac{3}{2} \times 0.03985 = 0.05978\,\text{mol}$

so volume $= 0.05978 \times 24.0 = 1.43\,\text{dm}^3$