5 Formulae, equations and amounts of substance

Answers to Exam practice questions

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1 a) $Cu_2S(s) + 2O_2(g) \rightarrow 2CuO(s) + SO_2(g)$

All numbers correct [1]

b) $2FeS(s) + 3O_2(g) + 2SiO_2(s) \rightarrow 2FeSiO_3(s) + 2SO_2(g)$

All five numbers correct [3], four numbers correct [2], three numbers correct [1]

c) $4Fe(NO_3)_3(s) \rightarrow 2Fe_2O_3(s) + 12NO_2(g) + 3O_2(g)$

All four numbers correct [3], three numbers correct [2], two numbers correct [1]

2 a) Molar mass of O_2 = 32.0 g mol^{-1} [1]

4.0 g O_2 = 0.125 mol [1]

0.125 mol contains $0.125 \times 6.02 \times 10^{23}$ molecules = 0.75×10^{23} = 7.5×10^{22} molecules [1]

b) Molar mass of K_2O = (2×39.1) g mol^{-1} + 16.0 g mol^{-1} = 94.2 g mol^{-1} [1]

9.4 g K_2O = 0.0998 mol [1]

0.0998 mol K_2O contains $0.0998 \times 6.02 \times 10^{23} \times 3 = 1.80 \times 10^{23}$ ions [1]

3 a) 0.112×10^{-3} g Fe^{3+} and 12.40×10^{-3} g NO_3^- [1]

b) 0.00201×10^{-3} mol Fe^{3+} = 2.01×10^{-6} mol Fe^{3+} [1]

0.200×10^{-3} mol NO_3^- = 2.00×10^{-4} mol NO_3^- [1]

c) $12.1 \times 10^{17} = 1.21 \times 10^{18}$ Fe^{3+} ions [1]

1.20×10^{20} NO_3^- ions [1]

4 a) In 100 g of X there are 3.57 mol C, 2.36 mol H, 1.19 mol N and 2.37 mol O. [2]

C : H : N : O is 3 : 2 : 1 : 2. [1]

Empirical formula is $C_3H_2NO_2$ [1]

b) Sum of relative atomic masses in the empirical formula = 84 [1]

Molecular formula is $C_6H_4N_2O_4$. [1]

5 a) Precipitation [1]

b) Redox [1]

c) Thermal decomposition and redox [1]

d) Acid–base (neutralisation) [1]

6 a) Ionic precipitation [1] to form silver iodide. [1]

$Ag^+(aq) + I^-(aq) \rightarrow AgI(s)$ [1]

b) Acid–base reaction [1] forming magnesium chloride, carbon dioxide and water. [1]

$MgCO_3(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + CO_2(g) + H_2O(l)$ [1]

c) Ionic precipitation [1] to form barium sulfate. [1]

$Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$ [1]

d) Thermal decomposition [1] to give zinc oxide and carbon dioxide. [1]

$ZnCO_3(s) \rightarrow ZnO(s) + CO_2(g)$ [1]

e) Redox reaction (displacement) [1] to form copper metal and zinc sulfate solution. [1]

$Zn(s) + CuSO_4(aq) \rightarrow Cu(s) + ZnSO_4(aq)$ [1]

7 a) Concentration = $\frac{6.0}{1000}$ mol dm^{-3} = 6.0×10^{-3} mol dm^{-3} [1]

b) Relative formula mass of cholesterol = 386 [1]

concentration = $\frac{6 \times 386}{1000}$ g dm^{-3} = 2.3 g dm^{-3} [1]

c) Mass = 0.023 g [1]

8 a) i) Volume needed = 50 cm^3 [1]

ii) Removing drops of the mixture on a glass rod [1] then testing these drops with universal indicator paper [1].

b) i) Ammonium iron(II) sulfate contains equal amounts of moles of $(NH_4)_2SO_4$ and $FeSO_4$ [1]

Amount of ammonium sulfate prepared = $\frac{25}{1000} \times 2 = 5 \times 10^{-2}$ mol [1]

Amount of $FeSO_4$ required = 5×10^{-2} mol

Mass of $FeSO_4$ required = 5×10^{-2} mol × 152 g mol^{-1} = 7.6 g [1]

ii) Amount of ammonium iron(II) sulfate produced = 5×10^{-2} mol [1]

Molar mass of $(NH_4)_2SO_4.FeSO_4.6H_2O$ = $M((NH_4)_2SO_4) + M(FeSO_4) + 6M(H_2O)$

= (132 + 152 + 108) g mol^{-1} = 392 g mol^{-1} [1]

Maximum possible yield = 392 g mol^{-1} × 5×10^{-2} mol

= 19.6 g [1]

Thus a 50% yield produced 9.8 g [1]

9 a) In 100 g of Z there are 4.54 mol C, 9.1 mol H, [1] 2.28 mol O. [1]

C : H : O = 2 : 4 : 1 [1] Empirical formula is C_2H_4O. [1]

b) $n = \frac{pV}{RT}$ [1] = $\frac{95\,000\,\text{Pa} \times 0.0001\,\text{m}^3}{8.31\,\text{J mol}^{-1}\,\text{K}^{-1} \times 373\,\text{K}}$ [1] = 0.00306 mol [1]

Molar mass = 0.270 g ÷ 0.00306 mol = 88 g mol^{-1} [1]

Molecular formula is $C_4H_8O_2$ [1]

10 a) $Ca(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2(g)$

All symbols and formulae correct. [1]

Correctly balanced. [1]

All state symbols correct. [1]

b) Diagram showing Ca reacting with HCl(aq) in a conical flask [1] with a delivery tube to an inverted measuring cylinder over water. [1]

c) Filter the final solution to remove excess calcium. [1]

Collect the filtrate in an evaporating basin and heat it until crystals start to form at the edges of the solution. [1]

Set the solution aside to cool and crystallise. [1]

Dry the crystals using absorbent paper. [1]

d) The Ca is in excess, so the yield is limited by the amount of HCl(aq). [1]

Amount of HCl(aq) used = 2.5×10^{-2} mol [1]

2 mol of HCl produce 1 mol of calcium chloride.

So, maximum amount of calcium chloride produced = $\frac{1}{2} \times 2.5 \times 10^{-2}$ mol [1]

Maximum mass of product = $(0.5 \times 2.5 \times 10^{-2})$ mol $\times$ 219 g mol^{-1} = 2.74 g [1]

e) Some calcium chloride is lost during filtration. [1]

More calcium chloride is lost because the crystals are separated from a saturated solution of calcium chloride. [1]

Yet more calcium chloride is lost when the crystals are removed from the evaporating basin and dried. [1]

(Any 2 of 3 points.)

11 a) $M_2CO_3(s) + 2HCl(aq) \rightarrow 2MCl(aq) + CO_2(g) + H_2O(l)$ [1]

b) Amount of HCl = 0.0236 dm^3 $\times$ 0.150 mol dm^{-3} = 0.003 54 mol [1]

c) Amount of M_2CO_3 in the sample = 0.5 $\times$ 0.003 54 mol = 0.001 77 mol [1]

d) Molar mass of M_2CO_3 $= \dfrac{0.245\,g}{0.00177\,mol}$ [1] = 138 g mol^{-1}

Relative formula mass of M_2CO_3 = 138 [1]

e) Relative atomic mass of M = 0.5 $\times$ (138 – 60) = 39 [1]

f) M is potassium. [1]

12 a) $2NH_3 + NaOCl \rightarrow N_2H_4 + NaCl + H_2O$ [1]

Molar mass of the desired product = 32 g mol^{-1} [1]

Total molar mass of all products = 108.5 g mol^{-1} [1]

Atom economy = (32 $\div$ 108.5) $\times$ 100% $\approx$ 30% [1]

b) i) $C_2H_6 + Br_2 \rightarrow C_2H_5Br + HBr$ [1]

Molar mass of the desired product = 108.9 g mol^{-1} [1]

Total molar mass of all products = 189.8 g mol^{-1} [1]

Atom economy = (108.9 $\div$ 189.8) $\times$ 100% $\approx$ 57% [1]

ii) $C_2H_4 + HBr \rightarrow C_2H_5Br$ [1]

The two reactants add together to give a single product. All the reactant atoms end up as product atoms. [1] By inspection, the atom economy is 100%. [1]

c) This question assesses a student's ability to show a coherent and logically structured answer with linkages and fully sustained line of reasoning. Assess the quality of the answer taking into account both the key points made (*up to 4 marks*) and the logic and coherence of the discussion (*up to 2 marks*).

Points to make in the answer:

- Yields are calculated by considering only one reactant and one product.
- A reaction can have a high percentage yield but also make a lot of waste product.
- Processes should be designed so that the maximum amount of all the starting materials ends up in the product.
- This kind of reaction has a low atom economy.
- This means that there is a minimum of waste to get rid of.
- This reduces the cost of disposing of the waste.

13 a) The amount of $BaSO_4$ precipitate = 0.141 g ÷ 233.4 g mol^{-1} = 6.04 × 10^{-4} mol [1]

All the sulfate came from the sodium sulfate. [1]

The amount of Na_2SO_4 in the sample was 0.000604 mol [1]

Mass of sodium sulfate in the sample = 0.000604 mol × 142.0 g mol^{-1} = 0.0858 g [1]

Percentage of Na_2SO_4 in the sample = (0.0858 g ÷ 0.250 g) × 100% = 34.3% [1]

b) Iron forms iron(II) chloride when it reacts with hydrochloric acid.

$Fe(s) + 2HCl(aq) \rightarrow FeCl_2(aq) + H_2(g)$ [1]

Amount of hydrogen formed = (191 cm^3 ÷ 24 000 cm^3 mol^{-1}) [1]

From the equation, 1 mol Fe reacts to give 1 mol hydrogen gas. [1]

Mass of iron in the sample = (191 cm^3 ÷ 24 000 cm^3 mol^{-1}) × 55.8 g mol^{-1} = 0.444(4) g [1]

Percentage of iron in the sample = (0.444 g ÷ 0.500 g) × 100% = 88.8% [1]

14 $(COOH)_2 + 2NaOH \rightarrow (COONa)_2 + 2H_2O(l)$ [1]

Amount of NaOH needed to neutralise 25.0 cm^3 of the acid solution

= 0.0156 dm^3 × 0.160 mol dm^{-3} [1]

Amount of the acid in 25.0 cm^3 of the solution = 0.5 × 0.0156 dm^3 × 0.160 mol dm^{-3} [1]

Concentration of the acid = $\frac{0.5 \times 0.0156\,\text{dm}^3 \times 0.160\,\text{mol dm}^{-3}}{0.025\,\text{dm}^3}$ = 0.0499 mol dm^{-3} [1]

Concentration of the original solution = $\frac{1.576\,\text{g}}{0.250\,\text{dm}^3}$ = 6.30 g dm^{-3} [1]

Molar mass of the acid = $\frac{6.30\,\text{g dm}^{-3}}{0.0499\,\text{mol dm}^{-3}}$ = 126.2 g mol^{-1} [1]

Molar mass of $(COOH)_2.nH_2O$ = 90 + ($n \times 18$) g mol^{-1} [1]

n = 2 [1]

15 The two accurate titres are: 20.65 cm^3 and 20.55 cm^3 [1]

Mean titre = 20.60 cm^3 [1]

Amount of acid needed to neutralise the carbonate in 20.0 cm^3 of the solution

= 0.0206 $dm^3 \times$ 0.10 mol dm^{-3} [1]

$Na_2CO_3(aq) + 2HCl(aq) \rightarrow 2NaCl + CO_2(g) + H_2O(l)$ [1]

Amount of sodium carbonate in 20.0 cm^3 of the solution

= 0.5 $\times$ 0.0206 $dm^3 \times$ 0.10 mol dm^{-3} [1]

Amount of sodium carbonate in original sample

= $\frac{250}{20} \times 0.5 \times 0.0206\ \text{dm}^3 \times 0.10\ \text{mol dm}^{-3}$ [1]

Molar mass of hydrated sodium carbonate = 286 g mol^{-1} [1]

Mass of sample if it had been pure $Na_2CO_3.10H_2O$

= $286\ \text{g mol}^{-1} \times \frac{250}{20} \times 0.5 \times 0.0206\ \text{dm}^3 \times 0.10\ \text{mol dm}^{-3}$

= 3.682 g [1]

Actual mass of sample = 2.696 g

Loss in mass = 0.986 g [1]

Loss in mass is 26.8% [1]

16 a) Calcium carbonate is insoluble in water. [1] It reacts too slowly for a direct titration. [1] An excess of acid is needed to ensure that all the calcium carbonate in the shell reacts completely in a reasonable time.

b) $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$ [1]

Concentration of the acid in the 250 cm^3 graduated flask = 0.0972 mol dm^{-3} [1]

Amount of excess HCl = 0.0243 mol [1]

c) Amount of HCl added to the sample of egg shell = 0.0480 mol [1]

Amount of HCl that reacted with the egg shell = 0.0237 mol [1]

d) $CaCO_3(s) + 2HCl \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$ [1]

Amount of $CaCO_3$ in the sample = 0.0118 mol [1]

Molar mass of $CaCO_3$ = 100 g mol^{-1}. [1]

Mass of calcium carbonate in the sample = 1.18 g [1]

Percentage of calcium carbonate in the egg shell = 78.1% [1]

e) A back titration is an procedure used when the reaction between the standard solution and the substance to be analysed is slow. [1] The procedure is to add a measured excess of the standard solution, allow time for the reaction to finish [1] and then to use a titration with a second standard solution to measure how much of the first standard solution remains unused. [1]