

5 Formulae, equations and amounts of substance

Answers to Exam practice questions

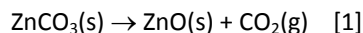
Pages 147–149 Exam practice questions

- 1 a) $\text{Cu}_2\text{S}(\text{s}) + 2\text{O}_2(\text{g}) \rightarrow 2\text{CuO}(\text{s}) + \text{SO}_2(\text{g})$
All numbers correct [1]
- b) $2\text{FeS}(\text{s}) + 3\text{O}_2(\text{g}) + 2\text{SiO}_2(\text{s}) \rightarrow 2\text{FeSiO}_3(\text{s}) + 2\text{SO}_2(\text{g})$
All five numbers correct [3], four numbers correct [2], three numbers correct [1]
- c) $4\text{Fe}(\text{NO}_3)_3(\text{s}) \rightarrow 2\text{Fe}_2\text{O}_3(\text{s}) + 12\text{NO}_2(\text{g}) + 3\text{O}_2(\text{g})$
All four numbers correct [3], three numbers correct [2], two numbers correct [1]
- 2 a) Molar mass of $\text{O}_2 = 32.0 \text{ g mol}^{-1}$ [1]
 $4.0 \text{ g O}_2 = 0.125 \text{ mol}$ [1]
 $0.125 \text{ mol contains } 0.125 \times 6.02 \times 10^{23} \text{ molecules} = 0.75 \times 10^{23} = 7.5 \times 10^{22} \text{ molecules}$ [1]
- b) Molar mass of $\text{K}_2\text{O} = (2 \times 39.1) \text{ g mol}^{-1} + 16.0 \text{ g mol}^{-1} = 94.2 \text{ g mol}^{-1}$ [1]
 $9.4 \text{ g K}_2\text{O} = 0.0998 \text{ mol}$ [1]
 $0.0998 \text{ mol K}_2\text{O contains } 0.0998 \times 6.02 \times 10^{23} \times 3 = 1.80 \times 10^{23} \text{ ions}$ [1]
- 3 a) $0.112 \times 10^{-3} \text{ g Fe}^{3+}$ and $12.40 \times 10^{-3} \text{ g NO}_3^-$ [1]
- b) $0.00201 \times 10^{-3} \text{ mol Fe}^{3+} = 2.01 \times 10^{-6} \text{ mol Fe}^{3+}$ [1]
 $0.200 \times 10^{-3} \text{ mol NO}_3^- = 2.00 \times 10^{-4} \text{ mol NO}_3^-$ [1]
- c) $12.1 \times 10^{17} = 1.21 \times 10^{18} \text{ Fe}^{3+} \text{ ions}$ [1]
 $1.20 \times 10^{20} \text{ NO}_3^- \text{ ions}$ [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 $\text{C}_3\text{H}_2\text{NO}_2$ [1]
- b) Sum of relative atomic masses in the empirical formula = 84 [1]
Molecular formula is $\text{C}_6\text{H}_4\text{N}_2\text{O}_4$. [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]
 $\text{Ag}^+(\text{aq}) + \text{I}^-(\text{aq}) \rightarrow \text{AgI}(\text{s})$ [1]
- b) Acid–base reaction [1] forming magnesium chloride, carbon dioxide and water. [1]
 $\text{MgCO}_3(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{MgCl}_2(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$ [1]
- c) Ionic precipitation [1] to form barium sulfate. [1]
 $\text{Ba}^{2+}(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) \rightarrow \text{BaSO}_4(\text{s})$ [1]

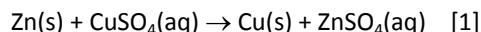
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d) Thermal decomposition [1] to give zinc oxide and carbon dioxide. [1]



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



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

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

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

c) Mass = 0.023 g [1]

8 a) i) Volume needed = 50 cm³ [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 (NH₄)₂SO₄ and FeSO₄ [1]

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

$$\text{Amount of FeSO}_4 \text{ required} = 5 \times 10^{-2} \text{ mol}$$

$$\text{Mass of FeSO}_4 \text{ required} = 5 \times 10^{-2} \text{ mol} \times 152 \text{ g mol}^{-1} = 7.6 \text{ g} \quad [1]$$

ii) Amount of ammonium iron(II) sulfate produced = 5 × 10⁻² mol [1]

$$\begin{aligned} \text{Molar mass of (NH}_4)_2\text{SO}_4 \cdot \text{FeSO}_4 \cdot 6\text{H}_2\text{O} &= M((\text{NH}_4)_2\text{SO}_4) + M(\text{FeSO}_4) + 6M(\text{H}_2\text{O}) \\ &= (132 + 152 + 108) \text{ g mol}^{-1} = 392 \text{ g mol}^{-1} \quad [1] \end{aligned}$$

$$\begin{aligned} \text{Maximum possible yield} &= 392 \text{ g mol}^{-1} \times 5 \times 10^{-2} \text{ mol} \\ &= 19.6 \text{ g} \quad [1] \end{aligned}$$

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 C₂H₄O. [1]

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

$$\text{Molar mass} = 0.270 \text{ g} \div 0.00306 \text{ mol} = 88 \text{ g mol}^{-1} \quad [1]$$

Molecular formula is C₄H₈O₂ [1]

10 a) Ca(s) + 2HCl(aq) → CaCl₂(aq) + H₂(g)

All symbols and formulae correct. [1]

Correctly balanced. [1]

All state symbols correct. [1]

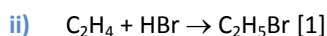
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- b)** Diagram showing Ca reacting with HCl(aq) in a conical flask [1] with a delivery tube to an inverted measuring cylinder over water. [1]
- c)** Filter the final solution to remove excess calcium. [1]
Collect the filtrate in an evaporating basin 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 = $(0.5 \times 2.5 \times 10^{-2}) \text{ mol} \times 219 \text{ g mol}^{-1} = 2.74 \text{ g}$ [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)** $\text{M}_2\text{CO}_3(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow 2\text{MCl}(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$ [1]
- b)** Amount of HCl = $0.0236 \text{ dm}^3 \times 0.150 \text{ mol dm}^{-3} = 0.00354 \text{ mol}$ [1]
- c)** Amount of M_2CO_3 in the sample = $0.5 \times 0.00354 \text{ mol} = 0.00177 \text{ mol}$ [1]
- d)** Molar mass of $\text{M}_2\text{CO}_3 = \frac{0.245 \text{ g}}{0.00177 \text{ mol}}$ [1] = 138 g mol^{-1}
Relative formula mass of $\text{M}_2\text{CO}_3 = 138$ [1]
- e)** Relative atomic mass of M = $0.5 \times (138 - 60) = 39$ [1]
- f)** M is potassium. [1]
- 12 a)** $2\text{NH}_3 + \text{NaOCl} \rightarrow \text{N}_2\text{H}_4 + \text{NaCl} + \text{H}_2\text{O}$ [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)** $\text{C}_2\text{H}_6 + \text{Br}_2 \rightarrow \text{C}_2\text{H}_5\text{Br} + \text{HBr}$ [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]

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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 = $0.141 \text{ g} \div 233.4 \text{ g mol}^{-1} = 6.04 \times 10^{-4} \text{ mol}$ [1]

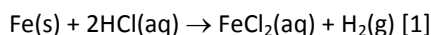
All the sulfate came from the sodium sulfate. [1]

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

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

Percentage of Na_2SO_4 in the sample = $(0.0858 \text{ g} \div 0.250 \text{ g}) \times 100\% = 34.3\%$ [1]

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



Amount of hydrogen formed = $(191 \text{ cm}^3 \div 24\,000 \text{ cm}^3 \text{ mol}^{-1})$ [1]

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

Mass of iron in the sample = $(191 \text{ cm}^3 \div 24\,000 \text{ cm}^3 \text{ mol}^{-1}) \times 55.8 \text{ g mol}^{-1} = 0.444(4) \text{ g}$ [1]

Percentage of iron in the sample = $(0.444 \text{ g} \div 0.500 \text{ g}) \times 100\% = 88.8\%$ [1]

- 14 $(\text{COOH})_2 + 2\text{NaOH} \rightarrow (\text{COONa})_2 + 2\text{H}_2\text{O(l)}$ [1]

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

$$= 0.0156 \text{ dm}^3 \times 0.160 \text{ mol dm}^{-3} \quad [1]$$

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

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

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

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

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

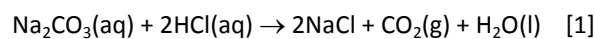
$$n = 2 [1]$$

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

$$\text{Mean titre} = 20.60 \text{ cm}^3 [1]$$

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

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



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

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

Amount of sodium carbonate in original sample

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

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

Mass of sample if it had been pure $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$

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

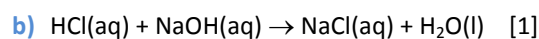
$$= 3.682 \text{ g} [1]$$

$$\text{Actual mass of sample} = 2.696 \text{ g}$$

$$\text{Loss in mass} = 0.986 \text{ g} [1]$$

$$\text{Loss in mass is } 26.8\% [1]$$

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.

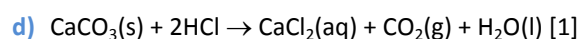


$$\text{Concentration of the acid in the } 250 \text{ cm}^3 \text{ graduated flask} = 0.0972 \text{ mol dm}^{-3} [1]$$

$$\text{Amount of excess HCl} = 0.0243 \text{ mol} [1]$$

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

$$\text{Amount of HCl that reacted with the egg shell} = 0.0237 \text{ mol} [1]$$



$$\text{Amount of CaCO}_3 \text{ in the sample} = 0.0118 \text{ mol} [1]$$

$$\text{Molar mass of CaCO}_3 = 100 \text{ g mol}^{-1}. [1]$$

$$\text{Mass of calcium carbonate in the sample} = 1.18 \text{ g} [1]$$

$$\text{Percentage of calcium carbonate in the egg shell} = 78.1\% [1]$$

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- 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]