

1. Quantitative Chemistry

1.1. The mole

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Quantitative chemistry answers

1. Quantitative Chemistry

1.1 The Mole

1.1.1 Moles and Mass

Work out the answers to the following simple calculations (1 t = 1 tonne = 1,000 kg);

1. No. of moles in 10.0 g of O_2 + the mass in g of 2.41 moles of H_2O =

(2 marks)

2. Mass in g of 0.2 moles of K_2CO_3 + mass in g of 0.5 moles of $MgCO_3$ =

(2 marks)

3. No. of moles in 12.4 t of $NaNO_3$ \div no. of moles in 12.4 t of $NaCl$ =

(2 marks)

4. No. of moles in 25.9 g of sodium – no. of moles in 25.9 g of sodium chloride =

(2 marks)

5. ? \times molar mass of in $g\ mol^{-1}$ of calcium carbonate = no. of moles in 4.2 kg of $SiCl_4$

(2 marks)

1. Quantitative Chemistry

1.1.2 Mass and concentration

Calculate the answers to the calculations below and place them (to the correct no. of sig. fig.) in the appropriate square. The arrows indicate the direction the numbers must follow. For the 10th mark complete the remainder of the Sudoku grid. (1 mark for each answer)

WARNING Take care with your significant figures and RAMs in order to avoid the wrong digit in the wrong square! (Relative atomic masses, H 1.0; O 16.0; Na 23.0; S 32.1; Cl 35.5; Fe 55.8; Cu 63.5)

a →			4	9	8	1	7	d ↓
9		c →	b ↓	3		8	2	
3	1	8		2	e ↓		4	
7	8	2	6			9		4
f ↓		4	g →			2	3	
	3	9		4		7	8	
	7	6	2		1	3	9	8
		3	9	h →				7
	9	1	3	8	7	i →		

- The concentration of a solution of 265 moles of NaOH dissolved in 1 dm³ of water (3 sig. fig.)
- The volume of water in dm³ needed to dilute 176 moles of HCl to make a 1 mol dm⁻³ solution (3 sig. fig.)
- The mass of H₂SO₄ that should be dissolved in 1 dm³ of water to make a solution of concentration 0.72 mol dm⁻³ (2 sig. fig.)
- The volume of water in cm³ that must be added to 0.56 g of anhydrous CuSO₄ to produce a 0.1 mol dm⁻³ solution (2 sig. fig.)
- The number of moles of ammonia that must be dissolved in 2,696 dm³ of water to produce 2.0 mol dm⁻³ ammonia solution (4 sig. fig.)
- The concentration in mol dm⁻³ of an accurate solution of concentration 16.48537 mol cm⁻³ (5 sig. fig.)
- The mass of FeSO₄·7H₂O that must be dissolved in 1,582 cm³ of water to form a solution of concentration 2.0 mol dm⁻³ (to 3 sig. fig.)
- The volume in dm³ of water that 10 moles of NaCl must be dissolved in to produce a 0.0155 mol dm⁻³ solution of brine (3 sig. fig.)
- The concentration in mol dm⁻³ of a solution of NaOH with a concentration of 18,480 kg m⁻³ (3 sig. fig.)

1. Quantitative Chemistry

1.1.3 Concentration and dilution

Place the answers to calculations 1 - 9 in order from left to right in the grid below to find which two solutions A - P react together. (1 mark for each correct answer)

Solution A	2	9	1	1	4	0	1	1	Solution I
Solution B	1	2	6	0	5	8	5	8	Solution J
Solution C	2	6	7	4	2	9	0	0	Solution K
Solution D	5	3	9	0	8	5	0	6	Solution L
Solution E	1	0	8	6	3	2	5	3	Solution M
Solution F	2	2	1	4	2	9	7	4	Solution N
Solution G	8	4	6	5	3	7	1	2	Solution O
Solution H	6	2	0	3	8	4	3	9	Solution P

- How many moles of NaCl must be dissolved in 0.5 dm³ of water to make a 4 mol dm⁻³ solution.
- How many moles of NaOH must be dissolved in 25,000 cm³ of water in order to make a solution with a concentration of 0.8 mol dm⁻³?
- What volume of water in dm³ must 8 moles of NaHCO₃ be dissolved in to make a solution with a concentration of 0.25 mol dm⁻³?
- What volume of water in cm³ must 3 moles of KMnO₄ be dissolved in, in order to make a solution with a concentration of 4 mol dm⁻³?
- A technician found that 2000 cm³ of a 4 mol dm⁻³ solution of copper sulphate was needed for the reaction to go to completion. How many moles of copper sulphate reacted?
- A student needs to add 8.75 × 10⁻³ moles of NaOH to neutralise the acid in his sample. How many cm³ of a 0.35 mol dm⁻³ solution should he add?
- A chemist wants to dilute a stock solution of 10 mol dm⁻³ NaOH to make a solution with a concentration of 1 mol dm⁻³. What volume of water must be added to 100 cm³ of the 10 mol dm⁻³ solution?
- Lucy wants to make up a solution with a concentration of 2 mol dm⁻³. What volume of water in dm³ must she add to 500 cm³ of 6 mol dm⁻³ stock solution?
- Alex must add what volume of water in cm³ to 45 cm³ of a 9 mol dm⁻³ solution of H₂SO₄ to make a 1.5 mol dm⁻³ solution?

Which two solutions need to be mixed in order to get a reaction?

1. Quantitative Chemistry

1.1.4 Moles summary

Mark the student's answers to the questions below (shown to the right). Mark all 10 correctly to get the full 10 marks.

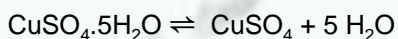
1. Magnesium reacts with acid as shown; $\text{Mg} + 2 \text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2$

- (a) How many moles of Mg reacts with 1 mole of HCl 1 mole
(b) How many moles of Mg must be reacted to produce 1 mole of H_2 1 mole

2. Potassium reacts with water to produce potassium hydroxide and hydrogen gas.

- (a) Write a balanced equation for the reaction $\text{K} + 2 \text{H}_2\text{O} \rightarrow \text{K}(\text{OH})_2 + \text{H}_2$
(b) How many moles of potassium must be reacted with an excess of water to produce 0.075 moles of potassium hydroxide? 0.075 moles

3. The dehydration of hydrated copper sulphate is a reversible reaction;

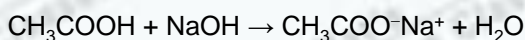


- (a) What mass water is produced when 0.25 moles of hydrated copper sulphate is heated? 22.5 g
(b) What mass of hydrated copper sulphate must be heated to produce 18 g of H_2O ? 249.6 g

4. The equation for the complete combustion of methane is; $\text{CH}_4 + 2 \text{O}_2 \rightarrow \text{CO}_2 + 2 \text{H}_2\text{O}$

- (a) How many moles of carbon dioxide would be produced by the complete combustion of 8 g of CH_4 ? 0.5 moles
(b) What mass of oxygen is needed for the complete combustion of 32 g of methane? 64 g

5. In an acid / base titration between ethanoic acid and sodium hydroxide the equation for the reaction is;



- (a) How many moles of NaOH is needed to neutralise 50 cm^3 of 0.1 mol dm^{-3} CH_3COOH ? 5×10^{-3} moles
(b) What volume of 0.1 mol dm^{-3} ethanoic acid is needed to neutralise 75 cm^3 of 0.125 mol dm^{-3} NaOH? 93.8 cm^3

1. Quantitative Chemistry

1.2 The ideal gas equation

The following balloons **all contain 10 g** of gas. Calculate the number of moles of each gas in the balloon and complete the conditions each balloon must be under ($R = 8.314 \text{ J K}^{-1} \text{ mol}^{-1}$)

(1 mark for each correct answer)

Hydrogen

No. of moles of hydrogen present; _____ moles

Pressure; 107,000 Pa **\therefore Temperature;** _____ K

Volume; $2.1 \times 10^{-2} \text{ m}^3$

Methane

No. of moles of methane present; _____ moles

Pressure; 73.3 kPa **\therefore Volume;** _____ m^3

Temperature; 353 K

Helium

No. of moles of helium present; _____ moles

Volume; 2.07 dm^3 **\therefore Pressure;** _____ Pa

Temperature; 373 K

Carbon dioxide

No. of moles of CO_2 present; _____ moles

Pressure; 149,000 Pa **\therefore Volume;** _____ m^3

Temperature; 64°C

Chlorine

No. of moles of chlorine present; _____ moles

Volume; $35,000 \text{ cm}^3$ **\therefore Temperature;** _____ $^\circ\text{C}$

Pressure; 89 kPa

1. Quantitative Chemistry

1.3 Molar gas volume

According to Avogadro's Law, as long as the pressure and temperature are kept the same, equal volumes of gases contain equal numbers of moles of gas. Under **standard temperature and pressure** (273 K and 101,325 Pa) **1 mole of any gas has a volume of 22.4 dm³**.

Use Avogadro's law to find out which gas syringes contain identical numbers of moles of gas.

(1 mark for each correct pairing, 1 mark for correct number of moles of gas)



Syringe A contains 105 cm³ of gas



Syringe F contains 48 mg of ammonia



Syringe B contains 5.6 dm³ of gas



Syringe G contains 0.61 g of bromine



Syringe C contains 63 cm³ of gas



Syringe H contains 0.27 g of butane
(C₄H₁₀)



Syringe D contains 0.085 dm³ of gas



Syringe I contains 7 g of nitrogen



Syringe E contains 1.24 × 10⁻⁴ m³ of
gas



Syringe J contains 0.16 g of air

1. Quantitative Chemistry

1.4 Empirical and molecular formulae

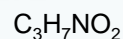
The technicians at the University have discovered a number of bottles containing amino acids which have lost their labels. In order to identify them, they carried out elemental analyses. Use the information provided to match the compound to its label;

(1 mark for each correct empirical formula, 1 mark for each correct match)

Amino Acid A

C 0.60 g; H 0.10 g; N 0.28 g;
O 0.48 g

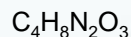
Alanine



Amino Acid B

C 36 g; H 7 g; N 14 g; O 16 g

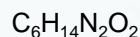
Aspartic acid



Amino Acid C

C 1.6 g; H 0.27 g; N 0.93 g;
O 1.6 g

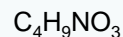
Lysine



Amino Acid D

C 40.3%; H 7.6%; N 11.8%;
O 40.3%

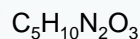
Threonine



Amino Acid E

C 40.4 %; H 7.9 %; N 15.7 %;
O 36.0 %

Glutamine



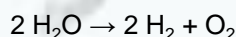
1. Quantitative Chemistry

1.5 Percentage yield and Atom economy

Percentage yield and atom economy are two numbers which help us gauge how efficient a reaction is for making a specific chemical. The atom economy tells us in theory how many atoms must be wasted in a reaction. The percentage yield tells us about the efficiency of the process.

1. Oxygen can be produced by a number of processes. Two possible processes are shown below;

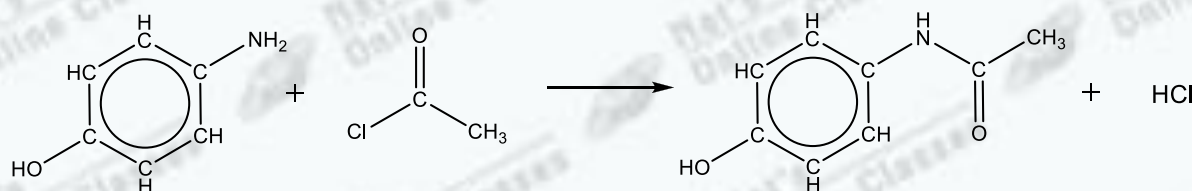
Electrolysis of water;



Catalytic decomposition of hydrogen peroxide; $2 \text{H}_2\text{O}_2 \rightarrow 2 \text{H}_2\text{O} + \text{O}_2$

By calculating the percentage atom economy of each process, decide which process is better for producing oxygen. (3 marks)

2. Two students complete the synthesis of paracetamol from 4-aminophenol as shown by the equation below;



4-aminophenol + ethanoyl chloride \rightarrow paracetamol + hydrogen chloride



Both students react 2 moles of 4-aminophenol with excess ethanoyl chloride.

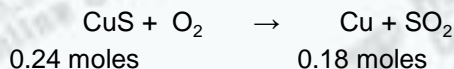
Student 1 makes 1.5 moles of paracetamol.

Student 2 makes 220 g of paracetamol.

Which student has the better percentage yield?

(4 marks)

3. Copper can be made by either roasting copper sulphide or by the reduction of copper carbonate with carbon. The equations for the two processes are shown below.



By comparing the percentage atom economy and the percentage yields of the processes as shown, evaluate which is the better method from an industrial viewpoint.

(3 marks)

1. Quantitative Chemistry

1.6 Titration calculations

On Friday 23rd June the police found John Smith collapsed at his dining table over his plate of fish and chips. He had been poisoned. Police took vinegar samples from the three local fish and chip shops and, in an attempt to isolate the origin of poor John's fish and chips, analysed the concentration of the ethanoic acid in the vinegar by titration against NaOH of known concentration.

Help the police out by calculating the concentration of ethanoic acid in each of the vinegar samples;

(2 marks for each correct concentration)

Vinegar sample taken from John Smith's dinner

Acid: 25.0 cm³ of vinegar

Base: 0.100 mol dm⁻³ NaOH

Indicator: Phenolphthalein

Initial burette reading / cm³	12.45	1.30	8.55
Final burette reading / cm³	32.45	19.80	27.00
Titre / cm³	20.00	18.50	18.45

Vinegar sample from "The Godfather"

Acid: 20.0 cm³ of vinegar

Base: 0.150 mol dm⁻³ NaOH

Indicator: Phenolphthalein

Initial burette reading / cm³	0.05	0.25	24.50
Final burette reading / cm³	10.50	10.30	34.60
Titre / cm³	10.55	10.05	10.10

Vinegar sample from "The Plaice"

Acid: 25.0 cm³ of vinegar

Base: 0.125 mol dm⁻³ NaOH

Indicator: Phenolphthalein

Initial burette reading / cm³	2.35	3.55	4.00
Final burette reading / cm³	17.85	18.30	18.80
Titre / cm³	15.50	14.75	14.80

Vinegar sample from "Battersea Cod's Home"

Acid: 20.0 cm³ of vinegar

Base: 0.100 mol dm⁻³ NaOH

Indicator: Phenolphthalein

Initial burette reading / cm³	0.00	1.35	1.85
Final burette reading / cm³	15.45	16.15	16.60
Titre / cm³	15.45	14.80	14.75

John Smith's fish and chips had come from

(2 marks)

1. Quantitative Chemistry

Answers

1.1. The mole

1.1.1. Moles and maths

- 43.7
- 69.8
- 0.688
- 0.683
- 0.25

1.1.2. Moles and concentration

a→ 2	6	5	4	9	8	1	7	d↓ 3
9	4	c→ 7	b↓ 1	3	6	8	2	5
3	1	8	7	2	e↓ 5	6	4	9
7	8	2	6	1	3	9	5	4
f↓ 1	5	4	g→ 8	7	9	2	3	6
6	3	9	5	4	2	7	8	1
4	7	6	2	5	1	3	9	8
8	2	3	9	h→ 6	4	5	1	7
5	9	1	3	8	7	i→ 4	6	2

1.1.3. Concentration and dilution

Solution A	2	9	1	1	4	0	1	1	Solution I
Solution B	1	2	6	0	4	9	6	2	Solution J
Solution C	2	6	7	4	3	5	1	1	Solution K
Solution D	5	3	9	0	5	0	6	2	Solution L
Solution E	1	0	8	7	3	8	5	3	Solution M
Solution F	2	2	1	2	9	9	1	2	Solution N
Solution G	8	4	0	2	8	3	9	8	Solution O
Solution H	6	2	5	2	4	3	2	2	Solution P

1.1.4. Moles summary

- 1 mole ✗ (correct answer, 0.5 moles)
 - 1 mole ✓
- $K + 2 H_2O \rightarrow K(OH)_2 + H_2$ ✗ (correct answer; $2 K + 2 H_2O \rightarrow 2 KOH + H_2$)
 - 0.075 moles ✓
- 22.5 g ✓
 - 249.6 g ✗ (correct answer; 49.9 g)
- 0.5 moles ✓
 - 64 g ✗ (correct answer; 128 g)
- 5×10^{-3} moles ✓
 - 93.8 cm^3 ✓

1.2 The ideal gas equation

Hydrogen; 5 moles, 54 K

Methane; 0.625 moles, 0.025 m^3

Helium; 2.5 moles, 3,745 kPa

Carbon dioxide; 0.227 moles, $4.27 \times 10^{-3} \text{ m}^3$

Chlorine; 0.141 moles, 2387 °C

1.3 Molar gas volume

Syringe A links with **syringe H**; no. of moles = 4.7×10^{-3} moles

Syringe B links with **syringe I**; no. of moles = 0.25 moles

Syringe C links with **syringe F**; no. of moles = 2.8×10^{-3} moles

Syringe D links with **syringe G**; no. of moles = 3.8×10^{-3} moles

Syringe E links with **syringe J**; no. of moles = 5.5×10^{-3} moles

1.4 Empirical and molecular formulae

Amino acid A has an empirical formula of $C_5H_{10}N_2O_3$ and is therefore **glutamic acid**

Amino acid B has an empirical formula of C_3H_7NO and is therefore **lysine**

Amino acid C has an empirical formula of $C_4H_8N_2O_3$ and is therefore **aspartic acid**

Amino acid D has an empirical formula of $C_4H_9NO_3$ and is therefore **threonine**

Amino acid E has an empirical formula of $C_3H_7NO_2$ and is therefore **alanine**

1.5 Atom economy

1. Electrolysis of water; $2 \text{H}_2\text{O} \rightarrow 2 \text{H}_2 + \text{O}_2$ Atom economy = $32 / 36 \times 100\% = 88.9\%$

Catalytic decomposition of hydrogen peroxide; $2 \text{H}_2\text{O}_2 \rightarrow 2 \text{H}_2\text{O} + \text{O}_2$

$$\text{Atom economy} = 32 / 68 \times 100\% = 47.1\%$$

\therefore producing oxygen by the electrolysis of water has the better atom economy

2. Student 1's percentage yield = $1.5 \text{ moles} / 2 \text{ moles} \times 100\% = 75\%$ (1 mark)

Student 2's percentage yield;

Molar mass of paracetamol = 151.0 g mol^{-1}

\therefore no. of moles paracetamol made by student 2 = $220 \text{ g} / 151.0 \text{ g mol}^{-1} = 1.46 \text{ moles}$ (1 mark)

\therefore student 2's percentage yield = $1.46 \text{ moles} / 2 \text{ moles} \times 100\% = 73\%$ (1 mark)

\therefore student 1 has the better percentage yield (1 mark)

3. Roasting CuS: Atom economy = 49.8% Percentage yield = 75%

Reduction of CuCO_3 : Atom economy = 49.0% Percentage yield = 64%

\therefore obtaining copper from CuS is the better method based on the atom economy of the process and the percentage yields given.

(1 mark for both atom economy's correct; 1 mark for both percentage yields correct; 1 mark for the evaluation)

1.6 Titration calculations

Concentration of vinegar taken from **John Smith's dinner**;

Average titre = 18.475 cm^3

No. of moles of NaOH = $1.85 \times 10^{-3} \text{ moles}$

\therefore Concentration of vinegar = **$0.0739 \text{ mol dm}^{-3}$**

Concentration of vinegar taken from **"The Godfather"**;

Average titre = 10.075 cm^3

No. of moles of NaOH = $1.51 \times 10^{-3} \text{ moles}$

\therefore Concentration of vinegar = **$0.0756 \text{ mol dm}^{-3}$**

Concentration of vinegar taken from **"The Plaiice"**;

Average titre = 14.775 cm^3

No. of moles of NaOH = $1.85 \times 10^{-3} \text{ moles}$

∴ Concentration of vinegar = **0.0739 mol dm⁻³**

Concentration of vinegar taken from “**Battersea Cod’s Home**”;

Average titre = 14.775 cm³

No. of moles of NaOH = 1.48×10^{-3} moles

∴ Concentration of vinegar = **0.0739 mol dm⁻³**

Therefore, John Smith’s fish and chips had come from either “**The Plaice**” or “**Battersea Cod’s Home**”