Amount of Substance

1. When hydrated strontium chloride is heated, the water of crystallisation is removed, leaving a residue of anhydrous strontium chloride.

A student carries out an experiment to find the value of **x** in the formula of hydrated strontium chloride, $SrCl_2 \bullet \mathbf{x}H_2O$.

The student's method is outlined below.

Step 1
Weigh an empty crucible.
Add $SrCl_2 \bullet \mathbf{x}H_2O$ to the crucible and reweigh.

Step 2
Heat the crucible and contents for 10 minutes.
Allow to cool and reweigh.

Step 3
Heat the crucible and residue for another 5 minutes.
Allow to cool and weigh the crucible and residue.

Repeat step 3 a further two times.

The student's results are shown below:

Mass of empty crucible / g	15.96
Mass of crucible + $SrCl_2 \bullet \mathbf{x}H_2O$ / g	18.65
First mass of crucible + residue / g	17.66
Second mass of crucible + residue / g	17.61
Third mass of crucible + residue / g	17.58
Fourth mass of crucible + residue / g	17.58

i. Calculate the value of **x** in $SrCl_2 \bullet \mathbf{x}H_2O$.

Give your answer to **2** significant figures.

x = ... **[3]**

ii. Suggest why the student takes four readings of the mass of the crucible and residue.

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[1]

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iii. Suggest **two** modifications to the method that would reduce the percentage uncertainty in the mass of the residue.

1

2

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[2]

2. Zinc reacts with hydrochloric acid, HC*l*(aq), as shown in the following equation.

$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$

A student investigates the rate of this reaction.

The student plans to react 50.0 cm^3 of 0.100 mol dm^{-3} HC*l* with 0.200 g of zinc (an excess).

Calculate the volume, in cm^3, of hydrogen that should be produced at RTP.

volume = ... cm^3 **[3]**

3(a). This question is about compounds of magnesium and phosphorus.

A student plans to prepare magnesium phosphate using the redox reaction of magnesium with phosphoric acid, H_3PO_4.

$$3Mg(s) + 2H_3PO_4(aq) \rightarrow Mg_3(PO_4)_2(s) + 3H_2(g)$$

i. In terms of the number of electrons transferred, explain whether magnesium is being oxidised or reduced.

---

[1]

ii. The student plans to add magnesium to 50.0 cm^3 of 1.24 mol dm^{-3} H_3PO_4.

Calculate the mass of magnesium that the student should add to react exactly with the phosphoric acid.

Give your answer to **three** significant figures.

mass of Mg = _____ g **[3]**

iii. How could the student obtain a sample of magnesium phosphate after reacting magnesium with phosphoric acid?

---

[2]

iv. Magnesium phosphate can also be prepared by reacting phosphoric acid with a compound of magnesium.

Choose a suitable magnesium compound for this preparation and write the equation for the reaction.

Formula of compound ---

Equation ---

[2]

(b). Phosphine, PH_3, is a gas formed by heating phosphorous acid, H_3PO_3, in the absence of air.

$$4H_3PO_3(s) \rightarrow PH_3(g) + 3H_3PO_4(s)$$

i. 3.20×10^{-2} mol of H_3PO_3 is completely decomposed by this reaction.

Calculate the volume of phosphine gas formed, in cm^3, at 100 kPa pressure and 200 °C.

volume of PH_3 = ---

cm^3 **[4]**

ii. When exposed to air, phosphine spontaneously ignites, forming P_4O_{10} and water.

Construct an equation for this reaction.

---

[1]

4. 1.00 tonne of ammonia is reacted with carbon dioxide to prepare the fertiliser urea, NH_2CONH_2.

$$2NH_3(g) + CO_2(g) \rightarrow NH_2CONH_2(s) + H_2O(1)$$

1.35 tonnes of urea are formed.

Calculate the percentage yield of urea.

Show **all** your working.

yield = ……% **[3]**

5. Bromine is a reactive element. It combines with other non-metals to form covalent compounds. Phosphorus tribromide, PBr_3, and iodine monobromide, IBr, are examples of covalent compounds used in organic synthesis.

PBr_3 can be prepared by heating bromine with phosphorus, P_4.

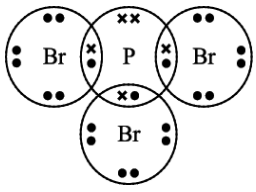
i. Write an equation for this reaction.

[1]

ii. How many molecules are present in 1.3535 g of PBr_3?

number of molecules = ……**[3]**

iii. The '*dot-and-cross*' diagram of a molecule of PBr_3 is given below.



Name the shape of this molecule and explain why the molecule has this shape.

name: _____

explanation: _____

_____

_____

[3]

6. An alkene **D** is a liquid at room temperature and pressure but can easily be vaporised.

When vaporised, 0.1881 g of **D** produces 82.5 cm^3 of gas at 101 kPa and 373 K.

Determine the molar mass and molecular formula of alkene **D**.

Show all your working.

molar mass = ... g mol^{-1}

molecular formula = ... **[5]**

7(a). Barium combines with oxygen, chlorine and nitrogen to form ionic compounds.

Barium oxide, BaO, has a giant ionic lattice structure.

i. State what is meant by the term *ionic bond*.

---

[1]

ii. Draw a '*dot-and-cross*' diagram to show the bonding in barium oxide.

Show outer electrons only.

iii. Calculate the number of barium ions in 1.50 g of barium oxide.

Give your answer in standard form and to **three** significant figures.

number of barium ions = ...

(b). Barium chloride, $BaCl_2$, is soluble in water.

i. Compare the electrical conductivities of solid and aqueous barium chloride.

Explain your answer in terms of the particles involved.

---**[2]**

ii. Describe the use of aqueous barium chloride in qualitative analysis.

---**[2]**

iii. Hydrated barium chloride can be crystallised from solution.

Hydrated barium chloride has the formula $BaCl_2 \cdot xH_2O$ and a molar mass of 244.3 g mol^{-1}.

Determine the value of x in the formula of $BaCl_2 \cdot xH_2O$.

Show your working.

x = ... **[2]**

8. By 2020, the EU has regulated that a car must emit less CO_2 per kilometre than in 2015. A typical car will need to emit 5.6×10^5 g less CO_2 in 2020 compared with 2015.

Calculate how much less petrol would be consumed by a typical car in 2020 to meet this regulation.

Give your answer in litres of petrol (1 litre of petrol has a mass of 700 g).

Assume that petrol is liquid octane and that complete combustion takes place, as in the equation below.

$$C_8H_{18}\ (l) + 12.5\ O_2\ (g) \rightarrow 8CO_2\ (g) + 9H_2O\ (l)$$

volume of petrol = ... litres **[4]**

9. Alkenes can be prepared from alcohols. Cyclopentene can be prepared from cyclopentanol as shown in the equation below.

A student plans to prepare 5.00 g of cyclopentene from cyclopentanol. The percentage yield of this reaction is 45.0%.

i. What is the name of this type of reaction?

---

[1]

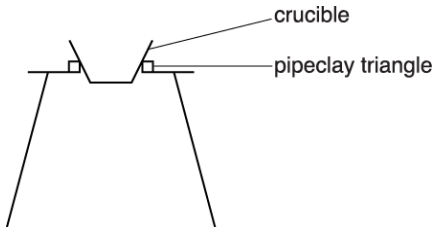
ii. Calculate the mass of cyclopentanol that the student should use.

Show your working.

mass of cyclopentanol = ... g **[3]**

10. A student carries out an experiment to determine the amount of water of crystallisation in the formula of hydrated salt. The student intends to remove the water by heating the hydrated salt.

A diagram of the apparatus used by the student is shown below.



- The student adds the hydrated salt to the crucible and weighs the crucible and contents.
- The student heats the crucible and contents and allows them to cool.
- The student weighs the crucible and residue.

The student's results are shown below.

Mass of crucible + hydrated salt / g	16.84
Mass of crucible + residue after heating / g	16.26

i. The maximum error in each mass measurement using the balance is ±0.005 g.

Calculate the percentage error in the mass of water removed.

percentage error =.....

ii. Suggest **one** modification that the student could make to their method to reduce the percentage error in the mass of water removed.

---**[1]**

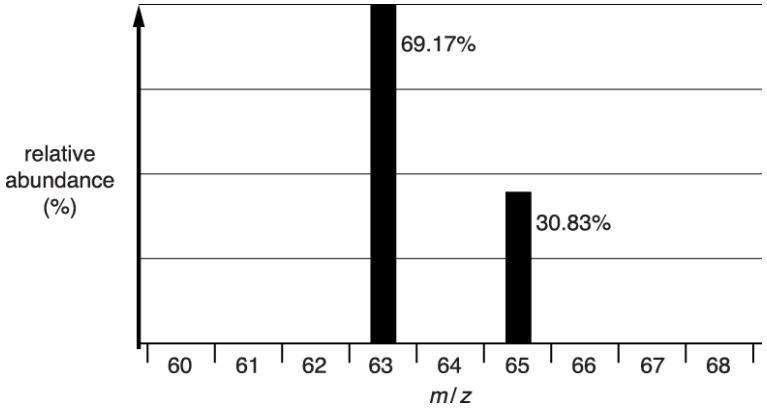
iii. The student is not sure that all the water of crystallisation has been removed.

How could the student modify the experiment to be confident that all the water of crystallisation has been removed?

---**[1]**

11. A twenty pence coin contains copper and nickel.

The copper used to make a batch of coins is analysed by mass spectrometry. The mass spectrum is shown below.



i. Calculate the relative atomic mass of the copper used to make the coins.

Give your answer to **two** decimal places.

relative atomic mass = ...

ii. One coin has a mass of 5.00 g and contains 84.0% of copper, by mass.

Calculate the number of copper atoms in one coin.

Give your answer in standard form and to **three** significant figures.

number of copper atoms = ...

12. This question is about several salts.

A hydrated salt, compound **A**, is analysed and has the following percentage composition by mass:

Cr, 19.51%; Cl, 39.96%; H, 4.51%; O, 36.02%.

Calculate the formula of compound **A**, showing clearly the water of crystallisation.

Show your working.

formula of compound **A** =..... **[3]**

13. A student reacts 35.0 cm^3 of 3.00×10^{-2} mol dm^{-3} $H_2SO_4(aq)$ with an excess of Al.

An equation for this reaction is shown.

$$2Al(s) + 3H_2SO_4(aq) \rightarrow Al_2(SO_4)_3(aq) + 3H_2(g)$$

Calculate the mass, in g, of $Al_2(SO_4)_3$ formed in solution.

Give your answer to **three** significant figures.

Show your working.

mass = ... g **[4]**

14. When magnesium nitrate, $Mg(NO_3)_2$, is heated, it decomposes as shown.

$$2Mg(NO_3)_2(s) \rightarrow 2MgO(s) + 4NO_2(g) + O_2(g)$$

A student heats 2.966 g of $Mg(NO_3)_2$, which decomposes as above.

Calculate the **total** volume of gas formed, in cm^3, at room temperature and pressure, RTP.

total volume of gas formed = ... cm_3 **[3]**

15(a). Calculate the amount, in mol, of nitrogen **atoms** in 5.117×10^{20} nitrogen **molecules**.

Give your answer in standard form.

amount of nitrogen atoms = ... mol **[2]**

(b). N_2O_3 reacts with water to form an acid as the only product. This reaction is **not** a redox reaction. The empirical formula of the acid formed is the same as the molecular formula.

i. State what is meant by the term *molecular formula*.

[1]

ii. Suggest the empirical formula of the acid formed.

empirical formula of acid = ... **[1]**

16(a). A student investigates the reaction between strontium carbonate and dilute nitric acid.

$$SrCO_3 + 2HNO_3 \rightarrow Sr(NO_3)_2 + CO_2 + H_2O$$

The rate of reaction is determined from the loss in mass over a period of time.

i. Explain why there is a loss in mass during the reaction.

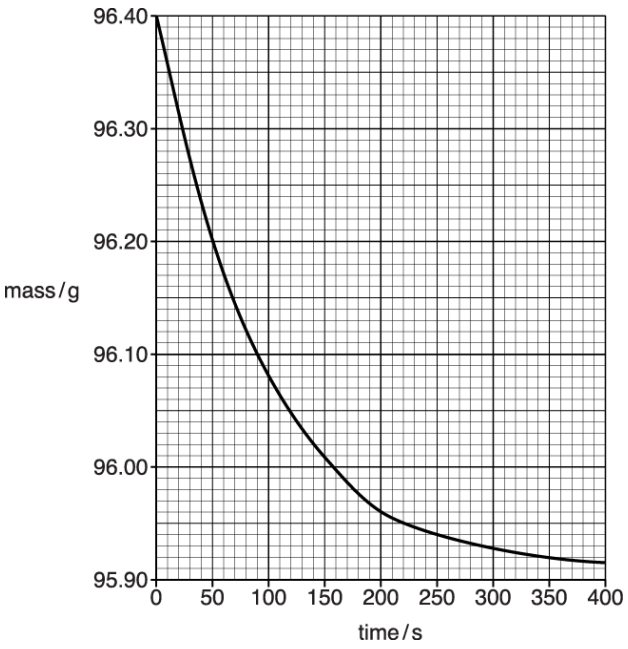
[1]

ii. An excess of strontium carbonate, $SrCO_3$, is mixed with 20.0 cm^3 of 1.25 mol dm^{-3} nitric acid, HNO_3.

Calculate the mass of $SrCO_3$ that reacts with the HNO_3.

mass = ... g **[3]**

(b). The student plots a graph of total mass (reagents + container) against time.



i. Describe and explain the change in the rate of the reaction during the first 200 seconds of the experiment.

[2]

ii. Using the graph, calculate the rate of reaction, in g s^{-1}, at 200 seconds.

Show your working on the graph.

rate of reaction = ... g s^{-1} **[2]**

(c). Outline a method that could be used to obtain the results that are plotted on the graph.

Your answer should include the apparatus required and the procedure for the experiment.

[3]

17. Nitrogen forms several different oxides.

N_2O is a useful anaesthetic and NO has been linked to the depletion of ozone in the stratosphere.

N_2O is supplied as a compressed gas in steel cylinders for use as an anaesthetic.
The cylinders are stored at 20.0 °C.

Calculate the gas pressure, in Pa, in a 2.32 dm^3 steel cylinder containing 187 g of N_2O gas.

Give your answer in standard form to **three** significant figures.

pressure = ... Pa **[4]**

18(a). Group 2 elements are metals that react with oxygen and water.

A student reacts a Group 2 metal, M, with water.

$$M(s) + 2H_2O(l) \rightarrow M(OH)_2(aq) + H_2(g)$$

The student measures the volume of hydrogen gas produced.

0.162 g of the metal produces 97.0 cm^3 of gas measured at room temperature and pressure.

i. Draw a labelled diagram of the apparatus that can be used to carry out this experiment.

[2]

ii. Identify the Group 2 metal, M.

Show your working.

Group 2 metal = …… **[3]**

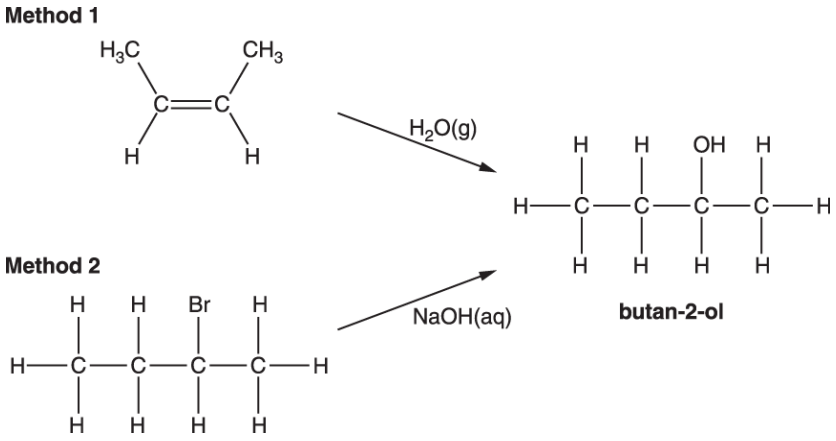
(b). The student plans to repeat the experiment using the same mass of a Group 2 metal from further down the group.

Predict whether the volume of hydrogen produced would be greater than, less than or the same as the volume in the first experiment.

Explain your answer.

[1]

19(a). Butan-2-ol can be prepared using two different methods.



Comment on the atom economy of each method, giving your reasons.

[2]

(b). A student uses **Method 2** to prepare 3.552 g of butan-2-ol from 2-bromobutane.
The percentage yield of butan-2-ol is 80.0%.

Calculate the mass of 2-bromobutane that the student uses.
Give your answer to **three** significant figures.

mass of 2-bromobutane = ... g **[3]**

20(a). Europium, atomic number 63, reacts with oxygen at room temperature.

$$4Eu + 3O_2 \rightarrow 2Eu_2O_3$$

Calculate the volume of oxygen, in cm^3, required to fully react with 9.12 g of europium at room temperature and pressure.

Volume = ... cm^3 **[2]**

(b). A compound of thulium, atomic number 69, has the following composition by mass:

O 30.7% S 15.4% Tm 53.9%

i. State what is meant by the term *empirical formula*.

[1]

ii. Determine the empirical formula of the compound.

Show your working.

Empirical formula = ... **[2]**

21. Hydrated strontium chloride, $SrCl_2 \cdot 6H_2O$, has a molar mass of 266.6 g mol^{-1}.

A student heats 5.332 g of $SrCl_2 \cdot 6H_2O$.

The $SrCl_2 \cdot 6H_2O$ loses some of its water of crystallisation forming 3.892 g of a solid product.

Use the information above to determine the formula of the solid product.

Show your working.

formula of solid product = ... **[3]**

22. This question is about compounds used in fertilisers.

A compound used as a fertiliser has the following composition by mass:

C, 20.00%; H, 6.67%; N, 46.67%; O, 26.66%.

Calculate the empirical formula of this compound.

empirical formula = ... **[2]**

23(a). An aqueous solution of aluminium chloride can be prepared by the redox reaction between aluminium metal and dilute hydrochloric acid.

A student reacts 0.0800 mol of aluminium completely with dilute hydrochloric acid to form an aqueous solution of aluminium chloride.

The equation for this reaction is shown below.

$$2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)$$

Calculate the volume of hydrogen gas formed, in dm3, at room temperature and pressure.

volume of hydrogen gas formed = ... dm^3 **[2]**

(b). Calculate the mass of $AlCl_3$ formed.

Give your answer to **three** significant figures.

mass of $AlCl_3$ formed = ... g **[2]**

(c). Calculate the volume, in cm^3, of 1.20 mol dm^{-3} hydrochloric acid needed to react completely with 0.0800 mol of aluminium.

volume = ... cm^3 **[2]**

24. 1-Bromobutane (M_r, 136.9) can be made from a reaction of butan-1-ol, C_4H_9OH, as shown in the equation below.

$$C_4H_9OH + KBr + H_2SO_4 \rightarrow C_4H_9Br + KHSO_4 + H_2O$$

i. Calculate the atom economy for the formation of 1-bromobutane in this reaction.

atom economy = ... % **[1]**

ii. Suggest a reactant, other than a different acid, that could be used to improve the atom economy of making 1-bromobutane by the same method.

[1]

iii. A student prepares a sample of 1-bromobutane.

5.92 g of butan-1-ol are reacted with an excess of sulfuric acid and potassium bromide.

After purification, 9.72 g of 1-bromobutane are collected.

Calculate the percentage yield.

Give your answer to **three** significant figures.

percentage yield = ... % **[3]**

25. In an experiment, a scientist prepared a 0.500 g sample of a salt made by neutralisation.

Analysis of the sample gave the following data.

Element	Mass present / g
hydrogen	0.025
oxygen	0.300
nitrogen	0.175

i. Calculate the empirical formula of the salt.

empirical formula = ... **[2]**

ii. Suggest the formula of the acid and base that the scientist used to prepare this salt.

acid: _____

base: _____

[1]

26 (a). Butane, C_4H_{10}, is a highly flammable gas, used as a fuel for camping stoves. Butane reacts with oxygen as in the equation below:

$$C_4H_{10}(g) + 6.5O_2(g) \rightarrow 4CO_2(g) + 5H_2O(l)$$

i. The use of portable heaters in enclosed spaces can result in potential dangers if incomplete combustion takes place.
Explain the potential danger of incomplete combustion.

[1]

ii. A portable heater is lit to heat a room.
The heater burns 600 g of butane and consumes 1.50 m^3 of O_2, measured at room temperature and pressure.
Determine whether this portable heater is safe to use.
Show **all** your working.

conclusion, with reason: _____

[3]

(b). Alkane **X** can be used as a fuel.
Complete combustion of 0.0117 mol of **X** produces 2.00×10^{-3} m^3 of carbon dioxide gas, measured at 24.0 °C and 101 kPa.
Determine the molecular formula of **X**.
Show **all** your working.

molecular formula of **X** = …… **[4]**

27. This question looks at groups in the periodic table.

Calcium and strontium are Group 2 metals. They both react with water.
A chemist reacts 0.200 g of strontium with 250 cm^3 water, leaving a colourless solution containing strontium ions. The volume remains at 250 cm^3.

i. Write an equation for the reaction between strontium and water.

Include state symbols.

[1]

ii. Calculate the concentration, in mol dm^{-3}, of strontium ions in the resulting solution.

concentration of strontium ions = ……mol dm^{-3} **[2]**

iii. A student plans to carry out this experiment using 0.200 g of calcium instead of 0.200 g of strontium.
Predict the difference, if any, between the volume of gas produced by calcium and strontium.
Explain your reasoning and include a calculation in your answer.

[3]

28(a). Calculate the number of europium atoms in 0.0019 g of europium.

Give your answer **in standard form** to an **appropriate** number of significant figures.

= …… atoms **[2]**

(b). Europium reacts with dilute sulfuric acid, forming a solution of europium sulfate and hydrogen gas.

A chemist reacts 0.608 g of europium with an excess of $H_2SO_4(aq)$ and collects 144 cm^3 of hydrogen gas at room temperature and pressure.

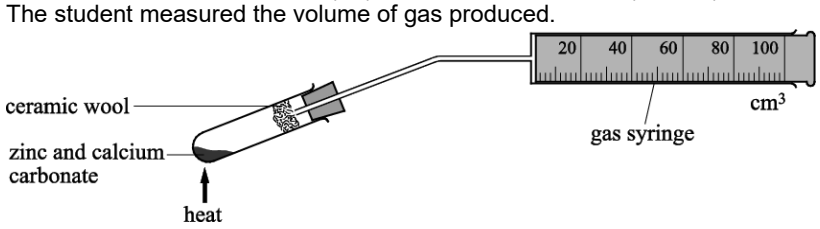
Analyse the chemist's results to write the overall equation for the reaction between europium and sulfuric acid.

Show **all** your working.

equation:

[6]

29. A student carried out the reaction of zinc (Zn) and calcium carbonate ($CaCO_3$) in a fume cupboard. The student measured the volume of gas produced.



A mixture containing 0.27 g of powdered zinc and 0.38 g of powdered $CaCO_3$ was heated strongly for two minutes. The volume of gas collected in the 100 cm^3 syringe was then measured. The experiment was then repeated.

i. Calculate the maximum volume of carbon monoxide, measured at room temperature and pressure, that could be produced by heating this mixture of Zn and $CaCO_3$.

Show **all** your working.

volume of carbon monoxide = ... cm^3 **[2]**

ii. The student did **not** obtain the volume of gas predicted in **(i)** using this procedure.

Apart from further repeats, suggest **two** improvements to the practical procedure that would allow the student to obtain a more accurate result.

[2]

END OF QUESTION PAPER