1. This question is about compounds and ions of iron(II) and iron(III) that contain ethanedioate ions, $C_2O_4^{2-}$.

A student plans an investigation to find the number of waters of crystallisation, **x**, in a sample of hydrated iron(II) ethanedioate, $FeC_2O_4 \cdot \textbf{x}H_2O$.

The student decides to carry out a redox titration between solutions of iron(II) ethanedioate and potassium manganate(VII) in acidic conditions.

    i.   In the titration, both iron(II) ions and ethanedioate, $C_2O_4^{2-}$, ions are oxidised.

        Construct half-equations for the oxidation of iron(II) and ethanedioate ions.

        Oxidation of iron(II) ions

        Oxidation of ethanedioate ions

        [2]

    ii.   The student prepares a 250.0 cm³ solution of iron(II) ethanedioate by dissolving 1.295 g of $FeC_2O_4 \cdot \textbf{x}H_2O$, in dilute sulfuric acid.

        The student titrates 25.0 cm³ samples of this solution with 0.0200 mol dm⁻³ $KMnO_4$ in the burette. The student carries out a trial, followed by three further titrations.

        The diagrams show the initial burette readings and the final burette readings for the student's three further titrations.

All burette readings are measured to the nearest 0.05 cm³.

Complete the titration table.

	1	2	3
Final reading/ cm^3			
Initial reading/ cm^3			
Titre / cm^3			

[3]

iii.   The uncertainty in each burette reading is ±0.05 cm^3.

Calculate the percentage uncertainty for the titre in **Titration 1**.

percentage uncertainty = ... %**[1]**

iv.   In the titration, 5 mol of iron(II) ethanedioate reacts with 3 mol of manganate(VII) ions.

Analyse the student's results to find the number of waters of crystallisation, **x**, in the hydrated iron(II) ethanedioate, $FeC_2O_4 \cdot$**x**H_2O.

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Extra answer space if required.

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[6]

2. This question is about the chemistry of compounds containing phosphorus.

When phosphorus(V) chloride, PCl_5, and ammonium chloride are heated together, the compound $P_3N_3Cl_6$ is formed, together with HCl gas.

$P_3N_3Cl_6$ has a cyclic structure, like the Kekulé structure of benzene.

   i.   Write an equation for the reaction of PCl_5 and ammonium chloride to form $P_3N_3Cl_6$.

[1]

   ii.   Calculate the percentage by mass of P in $P_3N_3Cl_6$.

      Give your answer to **2** decimal places.

percentage by mass of P = ... % **[2]**

   iii.   Suggest **one** example of evidence that could show that $P_3N_3Cl_6$ has a Kekulé structure rather than a delocalised structure.

[1]

   iv.   In a molecule of $P_3N_3Cl_6$ all the N and Cl atoms are bonded to P atoms.
      Suggest a possible structure for a molecule of $P_3N_3Cl_6$.

[2]

3(a). Water is added to 10.0 cm^3 of 0.750 mol dm^{-3} HCl (aq) to produce 100 cm3 of diluted HCl (aq).

What is the pH of the diluted HCl (aq)?

Give your answer to **2** decimal places.

pH = ... **[1]**

(b). A student is provided with hydrated copper(II) nitrate, $Cu(NO_3)_2 \cdot 3H_2O$.

The student needs to prepare a standard solution of $Cu(NO_3)_2 \cdot 3H_2O$ with a concentration of 0.200 mol dm^{-3}. The student has access to usual laboratory apparatus and equipment.

Describe how the student would prepare 100.0 cm^3 of this solution, giving quantities, apparatus and method.

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[5]

4(a). Hydrogen gas is manufactured by the chemical industry from the reversible reaction of methane and steam, shown below.

$CH_4(g) + H_2O(g) \rightleftharpoons 3H_2(g) + CO(g)$ ΔH = +195 kJ mol^{-1}

Average bond enthalpies are shown in the table.

Bond	H−H	O−H	C=O
Average bond enthalpy / kJ mol^{-1}	+436	+464	+1077

    i.   Why do all average bond enthalpies have a positive value?

    _____

[1]

ii.   Determine the C−H bond enthalpy, in kJ mol⁻¹, using the information above.

C−H bond enthalpy = ... kJ mol⁻¹**[3]**

iii.   Hydrogen gas is being considered as a household fuel to replace methane.

The enthalpy change of formation, Δ_fH, for $H_2O(l)$ is −285.8 kJ mol⁻¹.

Determine the energy released when 60.0 m³ of hydrogen is used as a household fuel at RTP.

Give your answer to **3** significant figures and in **standard form**.

energy released = ... kJ **[2]**

(b). Compound **A** is a chloride of a Period 3 element.

A student carries out the 2 steps below to find the formula of compound **A**.

Step 1   The student adds 5.00×10^{-4} mol of compound **A** to water.
A colourless solution is formed.

Step 2   The colourless solution reacts with exactly 60.0 cm³ of 2.50×10^{-2} mol dm⁻³ $AgNO_3(aq)$ to form a
white precipitate.

i.   Write an ionic equation, with state symbols, for the reaction in **Step 2**.

---**[1]**

ii.   Determine the formula of compound **A**.

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

(c). Compound **B**, shown below, is an antiviral medicine
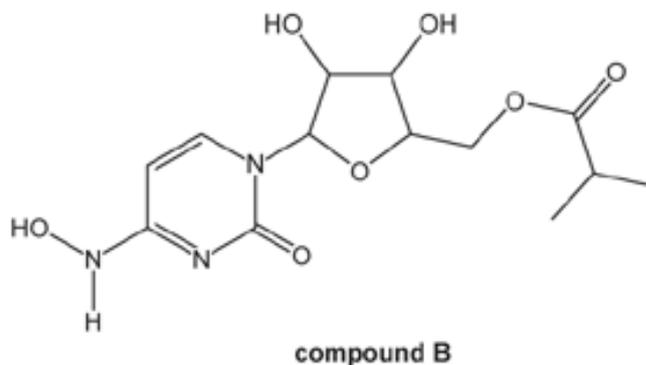
compound B

i.   What is the molecular formula of compound **B**

--**[1]**

ii.   How many chiral carbon atoms are there in one molecule of compound **B**?

--**[1]**

iii.   A research chemist synthesises two related compounds, compound **C** and compound **D**, from compound **B**.

- In compound **C**, the N atoms in compound **B** had been replaced by P atoms.
- In compound **D**, the O atoms in compound **B** had been replaced by S atoms.

What is the difference between the relative molecular masses of compound **C** and compound **D**?

difference = ... **[2]**

5. Oil of wintergreen is a liquid used in medicine to relieve muscle pain.

Compound **H** is a component in oil of wintergreen and can be synthesised from compound **G**, as shown below. The boiling point and density of compound **H** are stated.

Compound G

Compound H

boiling point = 222 °C
density = 1.174 g cm^{-3}
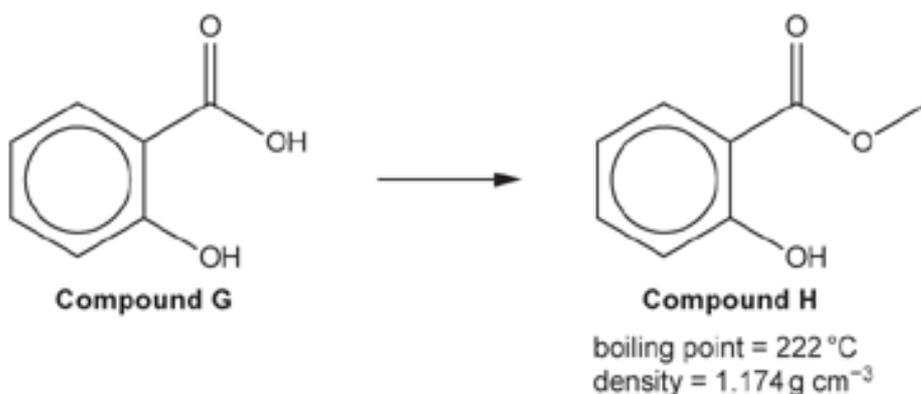
A student prepares a sample of compound **H** by the method below.

Step 1   Reflux 8.97 g of compound **G** for 30 minutes with an excess of methanol in the presence of a small amount of sulfuric acid as a catalyst.

Step 2   Add an excess of aqueous sodium carbonate, $Na_2CO_3(aq)$. Two layers are obtained.

Step 3   Purify the impure compound **H** that forms from the resulting mixture.

The student follows this method and obtains 5.32 g of pure compound **H**.

Calculate the percentage yield of compound **H**.

Give your answer to **three** significant figures.
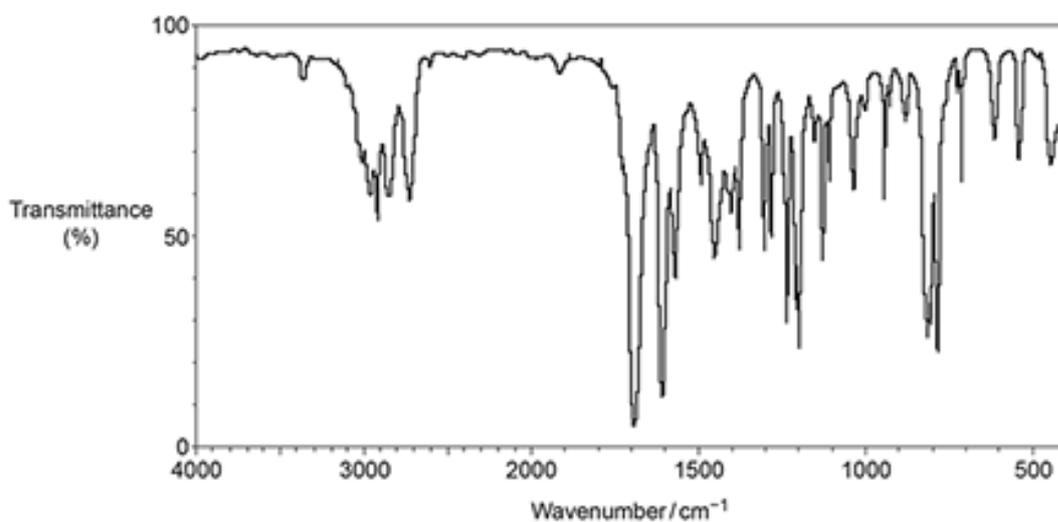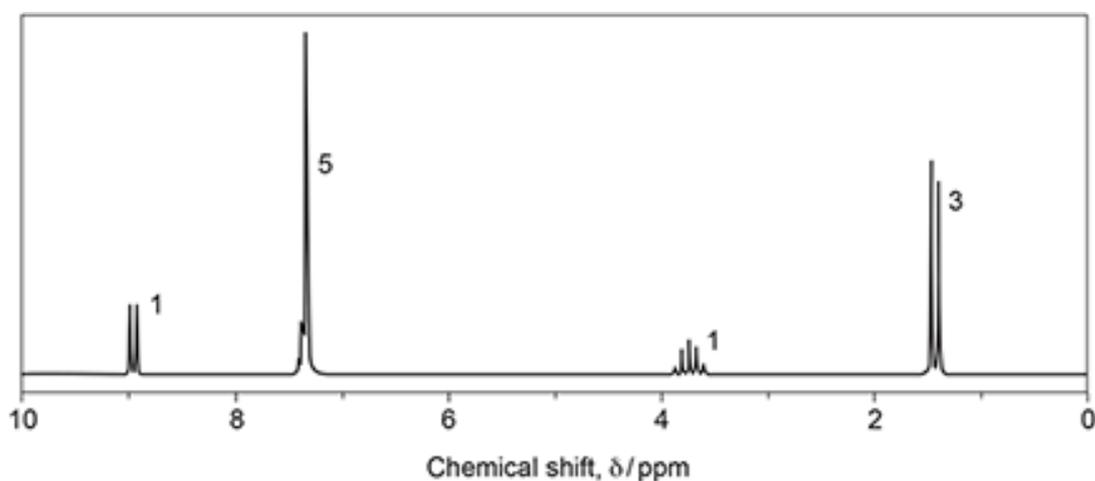
percentage yield = ... % **[3]**

6. Analysis of an unknown organic compound **J** produces the following results.

Elemental analysis by mass of compound J

C, 80.60%; H, 7.46%; O, 11.94%
Mass spectrum of compound J
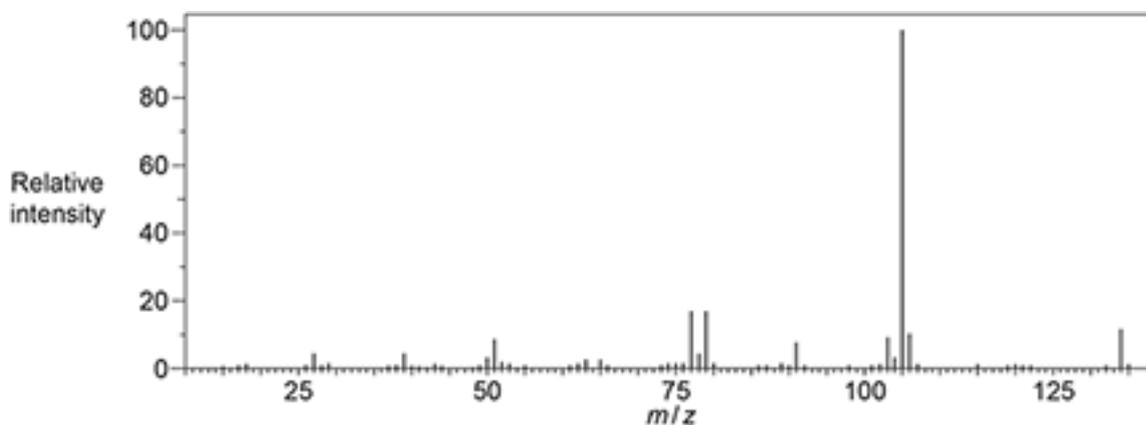
IR spectrum of compound J

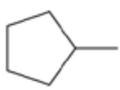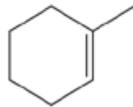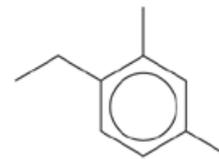## Proton NMR spectrum of compound J

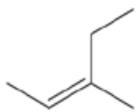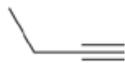
The numbers by the peaks are the relative peak areas.

Determine the structure of compound **J**, showing **all** your reasoning.

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[6]
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7. This question is about hydrocarbons.

The structures of hydrocarbons **A–E** are shown below.

A   **B**   **C**

D   **E**

Which hydrocarbons have the general formula C_nH_{2n}?

[1]
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8. 1.35 g of ethylamine gas, $CH_3CH_2NH_2$ (M_r = 45.0), is reacted with 20 cm³ of 2.0 mol dm⁻³ hydrochloric acid forming a solution of ethylammonium chloride.

$CH_3CH_2NH_2(g) + HCl(aq) \rightarrow CH_3CH_2NH_3^+(aq) + Cl^-(aq)$
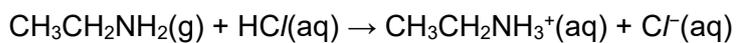
What is the concentration of ethylammonium chloride in mol dm⁻³?

A   0.03
B   0.67
C   1.50
D   2.00

Your answer   ☐   **[1]**

9. This question is about iron.

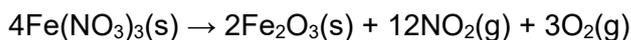The iron compound, $Fe(NO_3)_3$, decomposes when heated.
The equation for the decomposition of $Fe(NO_3)_3$ is shown below.

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

Molar mass of $Fe(NO_3)_3$ = 241.8 g mol^{-1}

4.836 g of $Fe(NO_3)_3$ is heated until it has completely decomposed.

Calculate the **total** volume of gas, in dm^3, produced at RTP.

total volume of gas = ... dm^3 **[3]**

10. This question is about the reactions of acids.

Ethanoic acid, CH_3COOH, is found in some descalers to soften hard water.

A student carries out a titration with a standard solution of sodium carbonate, Na_2CO_3, to determine the percentage composition by mass of CH_3COOH in a descaler.

The equation is shown below.

$2CH_3COOH + Na_2CO_3 \rightarrow 2CH_3COONa + CO_2 + H_2O$
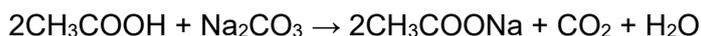
i.   The method is outlined below:

- Dissolve 6.50 g of the descaler in distilled water.
- Transfer the solution into a 250.0 cm^3 volumetric flask.
- Make up to the mark with distilled water and invert several times.
- Pipette 25.0 cm^3 of this solution into a conical flask and add a few drops of indicator.
- Titrate this solution with 0.200 mol dm^{-3} Na_2CO_3(aq), in the burette.

The student carries out a trial titration, followed by further titrations.

The results are shown in the table below.

The trial titration has been omitted.

Titration	1	2	3
Final reading/ cm^3	48.95	24.15	48.35
Initial reading/ cm^3	24.55	0.00	24.10
Titre / cm^3			

Complete the table by adding the titres.

[1]

ii.   Calculate the mean titre, to the nearest 0.05 cm^3, that the student should use for analysing these results.

mean titre = ... cm^3 **[1]**

iii.   Calculate the percentage composition by mass of CH_3COOH in the descaler.

Assume that CH_3COOH is the only acid in the descaler.

Give your answer to **3** significant figures.

percentage composition by mass = ... % **[5]**

11. A nitrogen oxide contains 36.84% of nitrogen by mass.

What is the empirical formula of the nitrogen oxide?

A   NO
B NO_2
C N_2O
D N_2O_3

Your answer ☐   **[1]**

12. Carbon monoxide reacts with oxygen to form carbon dioxide:

$2CO(g) + O_2(g) \rightarrow 2CO_2(g)$
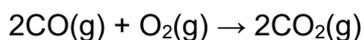
Which volumes of $CO(g)$ and $O_2(g)$ produce the largest volume of $CO_2(g)$?

All gas volumes are measured at RTP.

A   1.00 dm^3 CO and 4.00 dm^3 O_2
B   2.00 dm^3 CO and 3.00 dm^3 O_2
C   3.00 dm^3 CO and 2.00 dm^3 O_2
D   4.00 dm^3 CO and 1.00 dm$_3$ O_2

Your answer ☐   **[1]**

13. In the UK, water companies typically treat drinking water with chlorine gas at a concentration of 0.500 mg dm⁻³ or less.

Which statement about UK drinking water is correct?

A   Chlorine in drinking water can catalyse the breakdown of ozone.

B   Chlorine may form toxic chlorinated hydrocarbons.

C   Drinking water with a chlorine gas concentration of 0.500 mg dm⁻³ contains 2.12×10^{18} chlorine molecules in each dm³.

D   In hot weather, chlorine can vaporise from drinking water to cause global warming.

Your answer ☐   **[1]**

14. This question is about transition elements.

The flowchart shows some reactions of cobalt(II) chloride, $CoCl_2$.
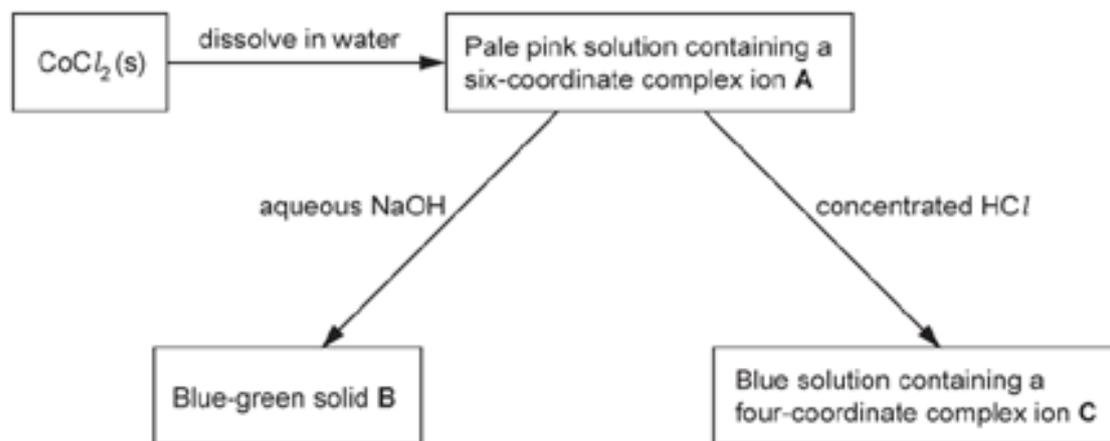
In **A**, **B** and **C**, cobalt has an oxidation number of +2.

i.   Suggest the formulae of **A**, **B** and **C**.

Complex ion **A**:   ....

Solid **B**:   ....

Complex ion **C**:   ....

                                                                                                              [3]

ii.   Cobalt (III) forms an octahedral complex ion **D**, which contains both ammonia and chloride ligands.

Complex ion **D** has a molar mass of 197.9 g mol⁻¹.

Determine the formula **and** charge of complex ion **D**.

_____

_____ **[2]**

15. A student titrates a 10.0 cm³ sample of ethanoic acid, CH_3COOH, against an aqueous solution of 0.0560 mol dm⁻³ $Ba(OH)_2$.

$$2CH_3COOH + Ba(OH)_2 \rightarrow Ba(CH_3COO)_2 + 2H_2O$$
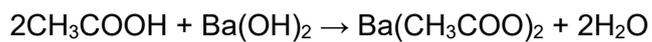
The student used a pH meter to measure the pH of the mixture after every addition of $Ba(OH)_2$ throughout the titration.

The student's results are shown below.
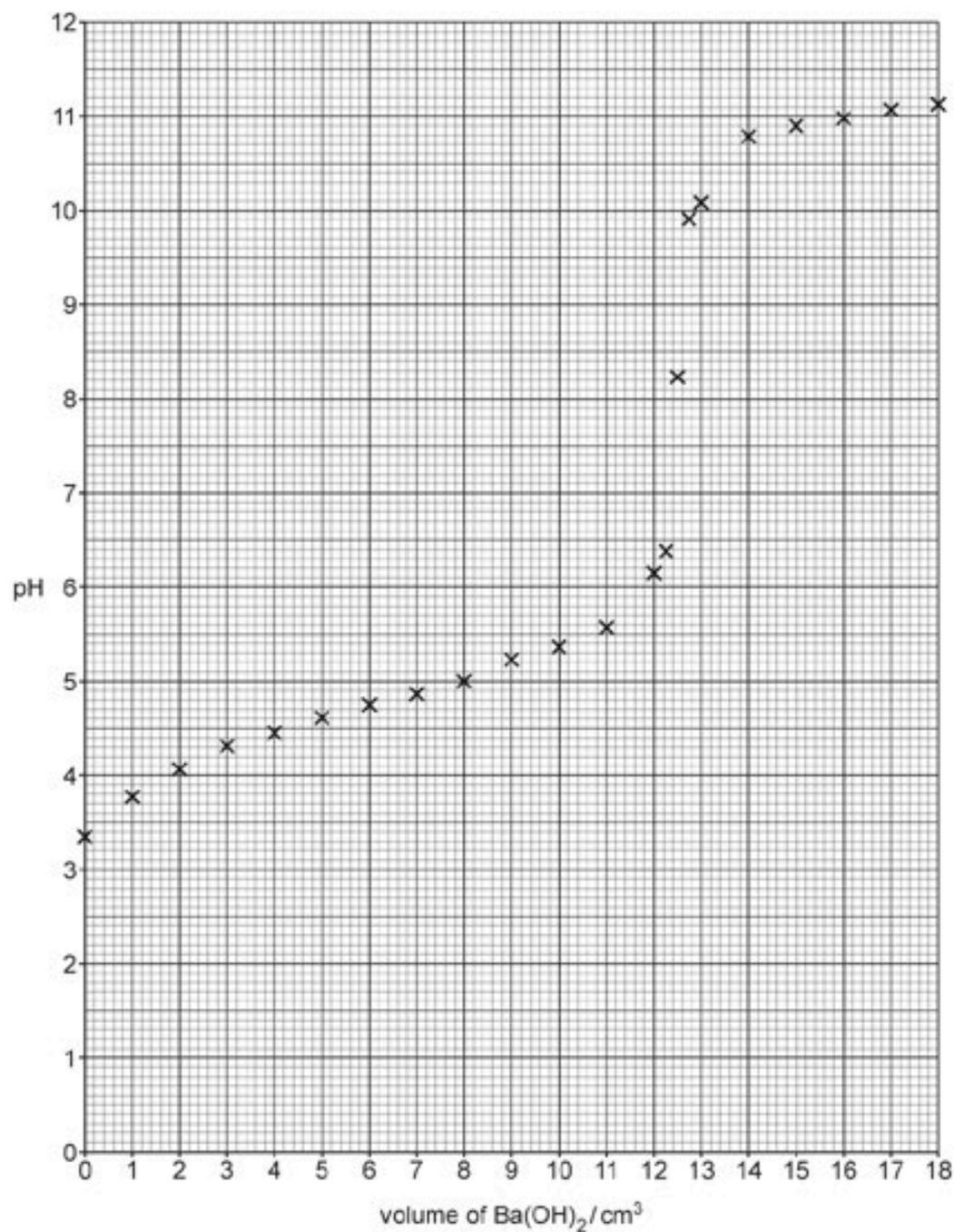
i.   Draw a best-fit curve on the graph and calculate the concentration of the CH_3COOH solution.

CH_3COOH concentration = ... mol dm^{-3} **[5]**

ii. The end point of the titration can also be found by observing the colour change of an indicator.

The pH ranges of some indicators are shown in the table.

Indicator	pH range
Malachite green	0.2 − 1.8
Bromophenol blue	2.8 − 4.6
Phenol red	6.8 − 8.4
Phenolphthalein	8.2 − 10.0

Identify the indicator in the table that would be suitable to observe the end point of the titration between CH_3COOH and $Ba(OH)_2$.

_____**[1]**

16. Potassium iodate tablets prevent the uptake of radioactive iodine in the human body following a nuclear accident.

The mass of potassium iodate(V), KIO_3, in a tablet can be determined by reaction with an aqueous solution of potassium iodide, KI, in the presence of acid.

$$IO_3^- + 5I^- + 6H^+ \rightarrow 3I_2 + 3H_2O$$
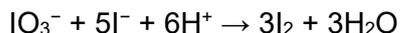
A chemist finds that two KIO_3 tablets react with exactly 26.2 cm³ 0.150 mol dm⁻³ KI.

Calculate the mass, in mg, of KIO_3 in **one** tablet.

Give your answer to the nearest whole number.

mass KIO_3 = ... mg **[4]**

17. The equation for the reaction of sulfuric acid with potassium hydroxide is shown below.

$$H_2SO_4(aq) + 2KOH(aq) \rightarrow K_2SO_4(aq) + 2H_2O(l)$$
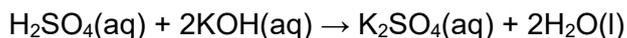
25 cm³ of 1.00 mol dm⁻³ H_2SO_4 is reacted with excess KOH.
The energy given out is 2.8 kJ.

What is the enthalpy change of neutralisation, in kJ mol⁻¹?

A   −56
B   −70
C   −112
D   −224

Your answer ☐ **[1]**

18. Which chemical process is the most sustainable in terms of the atom economy of the iron produced?

A $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$
B $Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$
C $2Fe_2O_3 \rightarrow 4Fe + 3O_2$
D $2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2$

Your answer ☐ **[1]**

19. Compound **X** is an organic compound with **two** functional groups.

Compound **X** has the percentage composition by mass:
C, 40.91%; H, 4.54%; O, 54.55%.

Compound **X** does **not** decolourise bromine water.

A scientist analyses compound **X** using mass spectrometry and infrared spectroscopy.

Mass spectrum of X

IR spectrum of X
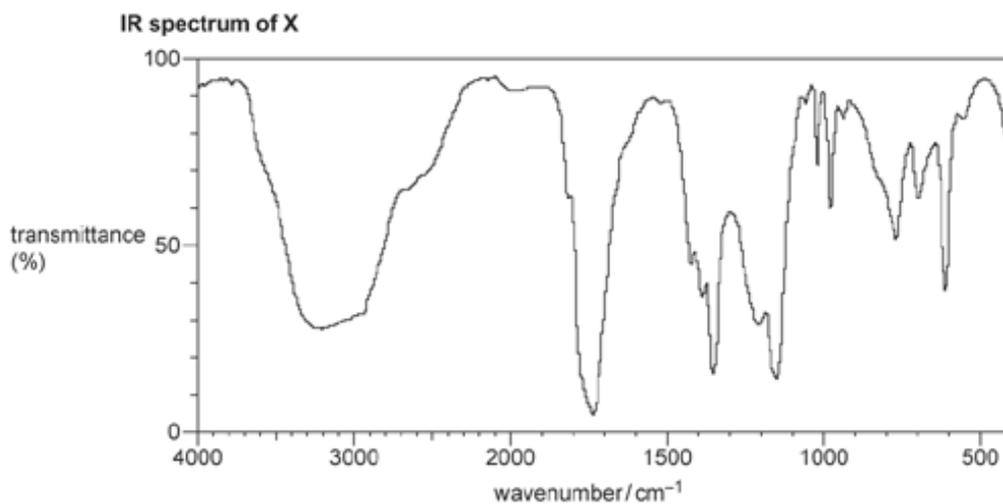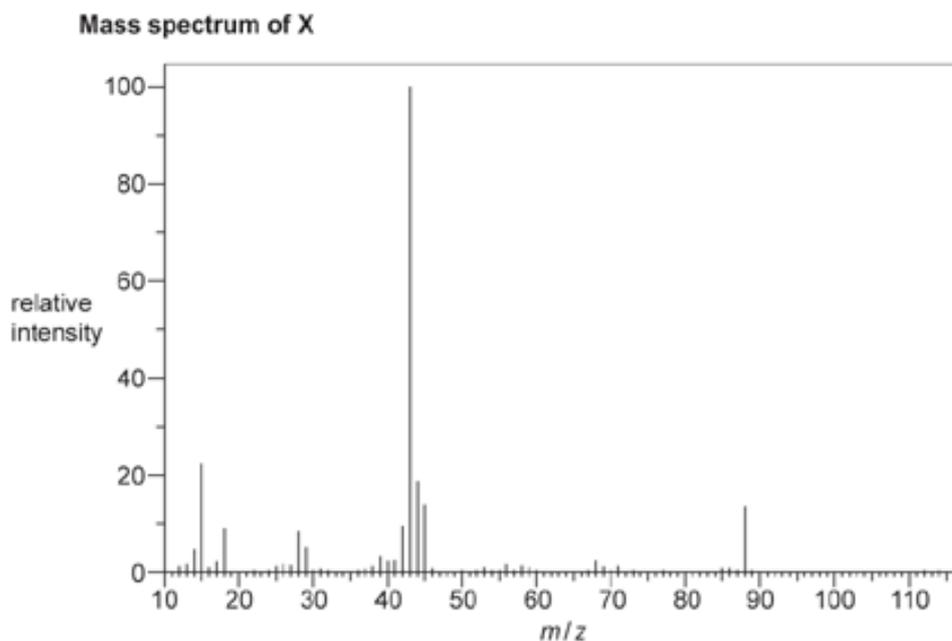
Use all the information to determine a possible structure of compound **X**.

In your answer, make it clear how your conclusions are linked to the evidence.

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_____

_____

_____**[6]**

20(a). Enthalpy changes of reaction can be determined by experiment.

A student carries out an experiment to determine the enthalpy change for the reaction between zinc and copper(II) nitrate solution.

$Zn(s) + Cu(NO_3)_2(aq) \rightarrow Zn(NO_3)_2(aq) + Cu(s)$ $\Delta_r H$ **Equation 3.1**

The student follows the method outlined below.

- Add 100 cm^3 of 0.500 mol dm^{-3} $Cu(NO_3)_2(aq)$ to a beaker.
- Measure the temperature of the solution.
- Add excess zinc to the beaker.
- Stir the mixture and record the maximum temperature.

The temperature of the solution changes from 19.5 °C to 38.1 °C.

Calculate $\Delta_r H$, in kJ mol^{-1}, for **equation 3.1.**

State any assumptions you have made in your calculation.

Suggest improvements for obtaining a more accurate value for $\Delta_r H$.

[6]

(b). The student modifies the experiment using 50 cm³ instead of 100 cm³ of 0.500 mol dm⁻³ copper(II) nitrate solution.

The value of $\Delta_r H$ for this modified experiment is the same as in **equation 3.1.**

Explain why.

_____

_____

_____

_____

_____

[2]

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21. Aqueous hydrogen peroxide, $H_2O_2(aq)$, gradually decomposes to produce water and oxygen.

$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$ ΔH=-196 kJ mol⁻¹   **Equation 4.1**
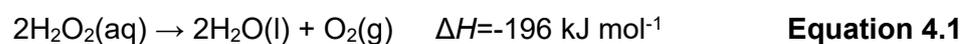
The rate of decomposition of H_2O_2 can be increased by adding a small amount of manganese(IV) oxide, MnO_2, which acts as a catalyst.

A student investigates the rate of decomposition of H_2O_2, on addition of MnO_2 catalyst, using a gas syringe.

100 cm³ gas syringe
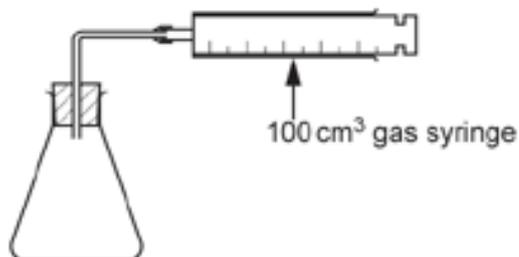
The student obtains the results shown in **graph 4.1.**
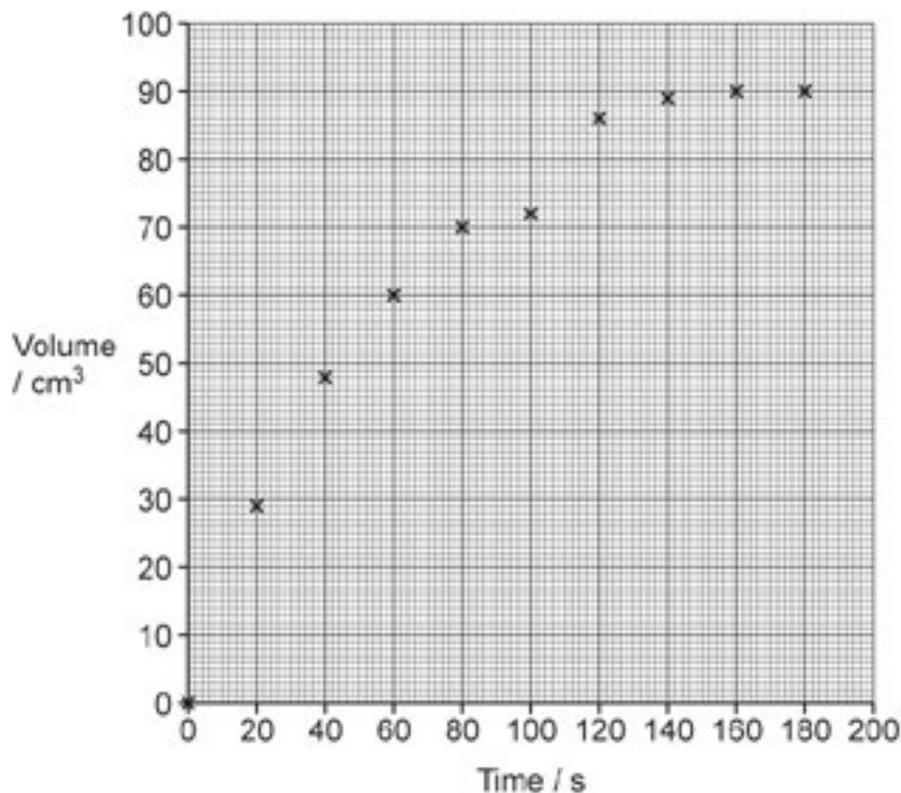
Graph 4.1

i.   On **graph 4.1**, draw a best-fit smooth curve of the results **and** circle the anomalous result.

[2]

ii. Use your graph to determine the rate of reaction, in cm^3 s^{-1}, at 50 s.

Show your working below and on the graph.

rate = ... cm^3 s^{-1} **[2]**

iii. The student uses 50.0 cm^3 of H_2O_2 in the experiment. **Equation 4.1** shows the reaction that takes place.
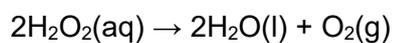
$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$ **Equation 4.1**

Calculate the concentration of H_2O_2, in mol dm^{-3}, required to produce 90 cm^3 of $O_2(g)$ at RTP.

concentration = ... mol dm^{-3} **[3]**

22. A student heats 11.50 g of hydrated zinc sulfate, $ZnSO_4 \cdot 7H_2O$, to remove all the water of crystallisation.

Calculate the mass of anhydrous zinc sulfate that should be obtained.

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

23. The reaction between calcium and hydrochloric acid is a redox reaction.
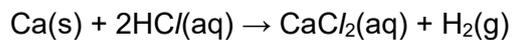
$Ca(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2(g)$ **Equation 2.1**

   i.   Explain, in terms of electron transfer, why the reaction shown in **equation 2.1** is a redox reaction.

_____

_____

_____

[2]

   ii.   A student plans to add 0.0100 mol of Ca to 120 cm^3 of 0.100 mol dm^{-3} HCl (aq).

When the student carries out this reaction, they are surprised that all the calcium reacts, despite being in excess of the HCl(aq).

- Show by calculation that calcium is in excess of the HCl(aq).
- Suggest a reason for this unexpected result.

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[3]

24. Three reactions involving sulfuric acid are shown below.

Reaction 1
Dilute sulfuric acid is reacted with nickel(II) hydroxide to form a green solution.

The solvent is allowed to evaporate leaving hydrated crystals of compound **D**, with the percentage composition by mass: Ni, 22.33%; S, 12.20%; O, 60.87%; H, 4.60%.

Reaction 2
Concentrated sulfuric acid is reacted with hydrogen bromide, HBr, to form three products:

- an element which exists as diatomic molecules
- a gaseous compound **E**
- a liquid.

At RTP, 1.00 dm^3 of compound **E** has a mass of 2.67 g.

Reaction 3
Concentrated sulfuric acid acts as a catalyst when 2-hydroxypropanoic acid reacts to form compound **F** (M_r = 144).

In this reaction, 2 mol of 2-hydroxypropanoic acid forms 1 mol of compound **F** and 2 mol of water.

Identify compounds **D**, **E** and **F** and construct equations for the reactions.

Show structures for any organic compounds.

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____ **[6]**

25. This question is about the first 36 elements in the periodic table:

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr

From these 36 elements **only**, write the symbol for the element(s) that fit each description.

The element with an average atomic mass of 1.244×10^{-22} g.

.... **[1]**

26(a). Tutton's salts are 'double salts' with the formula $\mathbf{X}_2\mathbf{Y}(\mathbf{Z}O_4)_2 \cdot 6H_2O$.

A Tutton's salt contains two cations: $\mathbf{X}^+$ and $\mathbf{Y}^{2+}$.

- $\mathbf{X}^+$ can be an ion of the Group 1 elements K, Rb, Cs or Fr, or an ammonium ion.
- $\mathbf{Y}^{2+}$ can be a 2+ ion of magnesium or an ion of most of the transition elements in Period 4.
- $\mathbf{Z}$ can be S or Cr.

$(NH_4)_2Cu(SO_4)_2 \cdot 6H_2O$ is an example of a Tutton's salt.

A student prepares a sample of the Tutton's salt, $(NH_4)_2Cu(SO_4)_2 \cdot 6H_2O$ using the method shown below.

Step 1	Dissolve 0.025 mol of ammonium sulfate and 0.025 mol of hydrated copper(II) sulfate, $CuSO_4 \cdot 5H_2O$, in water and make up to 50 cm³.
Step 2	Boil the resulting mixture for 2 minutes and allow to cool.
Step 3	Allow the solvent to evaporate slowly. Pale blue crystals of the Tutton's salt form.

i.   What masses are needed of ammonium sulfate and $CuSO_4 \cdot 5H_2O$?

mass of ammonium sulfate .... g

mass of $CuSO_4 \cdot 5H_2O$ .... g

[2]

ii.   In **Step 3**, why does the student allow the solvent to evaporate and **not** boil off all the solvent in **Step 2**?

....

....

....**[1]**

(b). The student dissolves their Tutton's salt in water. A pale blue solution forms.

The student carries out two tests on this aqueous solution.

i.   The student adds an excess of aqueous ammonia to their aqueous solution of Tutton's salt. A deep blue solution forms.

The complex ion responsible for the deep blue solution has a molar mass of 167.5 g mol^{-1}.

Suggest the formula of this complex ion.

....**[1]**

ii.   The student adds NaOH(aq) to the aqueous solution of Tutton's salt and warms the mixture.

A precipitate and a gas are formed.

Write the formulae of the precipitate and gas and suggest a test that could confirm the identity of the gas.

Formula of precipitate _____

Formula of gas _____

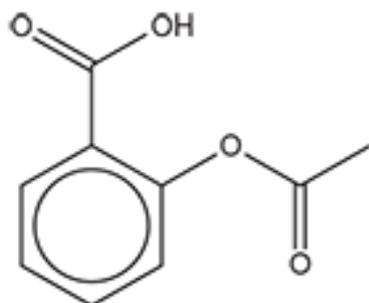Test to confirm the identity of the gas _____

....**[3]**

iii.   How could the student carry out a test-tube test to confirm the anion in the Tutton's salt?

_____

_____

_____

[2]

27. Aspirin tablets are used for pain relief.

The structure of aspirin is shown below.

Aspirin

A student uses the reaction of aspirin with cold NaOH(aq) to determine the mass of aspirin in **one** tablet.

In this reaction, 1 mol of aspirin reacts with 1 mol of cold NaOH(aq).

The student's method is outlined below.

Step 1   The student reacts **three** aspirin tablets with 100 cm³ of 0.500 mol dm⁻³ NaOH(aq).
             The NaOH is in excess. A colourless solution forms.

Step 2   The colourless solution from **Step 1** is made up to 250.0 cm³ with distilled water.

Step 3   A 25.00 cm³ sample of the diluted solution from **Step 2** is titrated with 0.200 mol dm⁻³ HC*l* (aq) in
             the burette.

The HC*l* (aq) reacts with excess NaOH(aq) that remains in **Step 1**:

NaOH(aq) + HC*l* (aq) NaC*l* (aq) + H₂O(l)
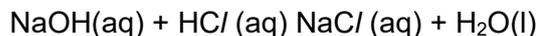
The student repeats the titration to obtain concordant (consistent) titres.

Titration results
The trial titre has been omitted.

The burette readings have been read to the nearest 0.05 cm^3.

	1	2	3
Final reading / cm^3	23.10	45.40	27.40
Initial reading / cm^3	0.00	23.10	5.00

Analysis of results
From the results, the student can determine the following.

1. The amount, in mol, of excess NaOH(aq) that remains after the reaction of aspirin with NaOH(aq).
2. The amount, in mol, of NaOH(aq) that reacted with the aspirin.

Use the results to determine the mass, in mg, of aspirin in **one** aspirin tablet.

mass of aspirin in **one** tablet = ... mg **[6]**

28(a). This question is about oxides of nitrogen.

An investigation is carried out on the equilibrium system shown below.

$2NO_2(g) \rightleftharpoons N_2O_4(g)$ $\Delta H = -57.4$ kJ mol^{-1}

   i.   A sealed flask containing 6.00 moles of $NO_2(g)$ is heated to a constant temperature and allowed to reach equilibrium.

       The equilibrium mixture contains 5.40 mol of $NO_2(g)$, and the total pressure is 5.00 atm.

       Determine the value of K_p and give your answer to **3** significant figures.

       Include an expression for K_p and the units of K_p in your answer.

K_p = ... units ....**[5]**

  ii.   The sealed flask in **(a)(i)** is then heated to a higher temperature at an increased pressure. The system is allowed to reach equilibrium again.

       Explain why it is difficult to predict how these changes in reaction conditions affect the amount of $N_2O_4(g)$ formed at equilibrium.

       _____

       _____

       _____

       _____

       _____

       _____

[3]

(b). N_2O_4 reacts fully with oxygen to form a different oxide of nitrogen, oxide **A**, as the only product.

Oxide **A** is collected and cooled to 75.0 °C at a pressure of 101 kPa.

Under these conditions, oxide **A** is a gas that occupies a volume of 74.0 cm³ and has a mass of 0.280 g.

Calculate the molar mass of oxide **A** and suggest its molecular formula.

molar mass = ... g mol⁻¹
molecular formula = ...

[5]

29(a). This question is about acids and bases.

Table 20.1 shows the ionic product, K_w, of water at 25 °C and 40 °C.

Table 20.1

Temperature / °C	K_w / mol² dm⁻⁶
25	1.00×10^{-14}
40	2.92×10^{-14}

i. Calculate the pH of water at 40 °C.

   Give your answer to **2** decimal places.

pH = ... **[2]**

ii. **Table 20.1** shows different K_w values at 25 °C and at 40 °C. A student suggests that water is neutral at these temperatures.

   Explain why this student is correct.

   _____

   _____

   [1]

(b). A student reacts strontium metal with water to make a 250.0 cm^3 solution of aqueous strontium hydroxide, $Sr(OH)_2$. The solution contains 0.145 g of strontium hydroxide.

- Write an equation for the reaction of strontium with water.

  Calculate the pH of this 250.0 cm^3 solution of strontium hydroxide at 40 °C.

- You should refer back to **Table 20.1** at the start of **(a)**.

  Give your answer to **2** decimal places.

Equation _____

Calculation

pH = ... **[5]**

(c). Butanoic acid, $CH_3CH_2CH_2COOH$, is a weak monobasic acid.

i.   Explain what is meant by the term **monobasic acid**.

_____

_____**[1]**

ii. A buffer solution is prepared by dissolving 3.39g of potassium hydroxide in 250 cm^3 of 0.376 mol dm^{-3} butanoic acid.

This buffer solution has a pH of 5.07 at 25 °C.

Calculate the acid dissociation constant, K_a, of butanoic acid at 25°C.

Assume that the volume of the solution remains constant at 250 cm^3 when the potassium hydroxide is dissolved.

K_a = ... mol dm^{-3} **[4]**

30(a). Some grass fertilisers contain compounds of iron.

During heavy rain, a fertiliser is washed into a nearby river causing the water to be polluted with a mixture of iron(II) and iron(III) ions.

A student determines the concentration of iron(II) ions in a sample of river water by titration with potassium manganate(VII).

25.0 cm^3 portions of river water are acidified with dilute sulfuric acid. Each portion is titrated with 0.00250 mol dm^{-3} potassium manganate(VII) until a colour change is seen.

$MnO_4^{-}(aq) + 8H^+(aq) + 5Fe^{2+}(aq) \rightarrow Mn^{2+}(aq) + 4H_2O(l) + 5Fe^{3+}(aq)$
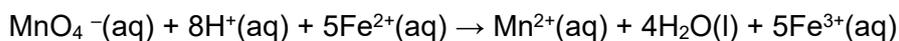
i. State the colour change seen at the end point of the titration.

from .... to ....

[1]

ii.   The student's titration results are shown in the table below.
       The trial titre has been omitted.

	1	2	3
Final volume / cm³	12.65	25.60	38.35
Initial volume / cm³	0.00	12.65	25.60
Titre volume / cm³	....	....	....

Complete the table above and calculate the mean titre that the student should use to determine the concentration of iron(II) ions in the river water.

mean titre = ... cm³ **[2]**

iii.   Determine the concentration, in mol dm⁻³, of iron(II) ions in the river water.

concentration = ... mol dm⁻³ **[3]**

(b). The student modifies the experiment in **(a)** to determine the combined concentration of iron(II) and iron(III) ions in the river water.

The student's method is shown below.

Step 1 Add excess zinc to a 250.0 cm³ sample of river water and warm gently.

Step 2 Cool the solution and remove excess zinc by filtration.

Step 3 Acidify 25.0 cm³ portions of the filtrate from **Step 2**. Then titrate each portion with 0.00250 mol dm⁻³ potassium manganate(VII) until a colour change is seen.

The table below shows information about three redox systems.

Redox system	Half-equation	$E^\ominus$ / V
1	$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	−0.76
2	$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
3	$MnO_4{}^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$	+1.51

Use the information in the table above to explain the reasons for **Step 1** and **Step 2**.

Reason(s) for **Step 1** _____

_____

_____

_____

Reason(s) for **Step 2** _____

_____

_____

[4]

31. This question is about enthalpy changes of reactions involving hydrocarbons.

A student determines the enthalpy change of combustion, $\Delta_c H$, of heptane, C_7H_{16}, using the method outlined below.

- Add 150 g of water to a beaker and measure its temperature.
- Weigh a spirit burner containing heptane and use it to heat the water.
- Extinguish the flame and record the maximum temperature reached by the water.
- Reweigh the spirit burner.

The temperature of the water increased by 10.5 °C.

The spirit burner decreased in mass by 0.133 g.

Use the student's results to determine the enthalpy change of combustion of heptane, $\Delta_c H$ (C_7H_{16}), in kJ mol^{-1}.

$\Delta_c H$ (C_7H_{16}) = ... kJ mol^{-1} **[3]**

32. Which sample contains the greatest number of molecules?

A   35.0 g of C_2H_2
B   45.0 g of C_2H_6
C   60.0 g of C_4H_{10}
D   100.0 g of C_6H_6

Your answer ☐   **[1]**

33. 0.688 g of an oxide of manganese is reduced by hydrogen gas to form manganese metal and 0.235 g of water.

What is the formula of the oxide of manganese?

A   MnO
B MnO_2
C Mn_2O_3
D Mn_3O_4

Your answer ☐   **[1]**

34. How many hydrogen atoms are in 2.50 g of pharmacolite, $CaHAsO_4 \cdot 2H_2O$ (M_r = 216.0)?

A 6.97×10^{21}
B 2.09×10^{22}
C 2.79×10^{22}
D 3.48×10^{22}

Your answer ▢   **[1]**

35. 40.0 cm³ of 0.200 mol dm⁻³ HCl is added to 60.0 cm³ of 0.100 mol dm⁻³ NaOH.

What is the concentration of the resulting solution?

A   0.0200 mol dm⁻³ HC*l* and 0.0200 mol dm⁻³ NaC*l*
B   0.0200 mol dm⁻³ HC*l* and 0.0400 mol dm⁻³ NaC*l*
C   0.0200 mol dm⁻³ HC*l* and 0.0600 mol dm⁻³ NaC*l*
D   0.0600 mol dm⁻³ HC*l* and 0.0200 mol dm⁻³ NaC*l*

Your answer ▢   **[1]**

36. This question is about reactions involving acids.

A student carries out an investigation to identify an unknown Group 1 metal **M**.

- The student reacts 2.62 g of the Group 1 metal, **M**, with water.
  A solution of the alkali, **M**OH(aq), is formed.
- The student makes this solution of **M**OH(aq) up to 250.0 cm³ with water.
- The student pipettes 25.0 cm³ of this **M**OH(aq) solution into a conical flask.
- The student titrates this 25.0 cm³ volume of **M**OH(aq) with 0.165 mol dm⁻³ H_2SO_4(aq).

The equation is shown below.

2**M**OH(aq) + H_2SO_4(aq) → **M**$_2SO_4$(aq) + $2H_2O$(l)
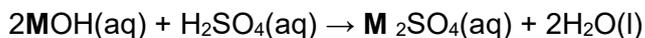
i.   Name the type of flask that the student should use to make up the 250.0 cm³ solution of **M**OH(aq).

.... flask   **[1]**

ii. The student takes burette readings to the nearest 0.05 cm^3.

The student's readings are shown in the table.

The rough titre has been omitted.

Complete the table below.

Final reading / cm^3	20.25	40.85	25.85
Initial reading / cm^3	0.00	20.25	5.50
Titre / cm^3	....	....	....

[1]

iii. Calculate the mean titre of H$_2$SO$_4$, to the nearest 0.05 cm^3, that the student should use to analyse the results.

mean titre = ... cm^3 **[1]**

iv. Calculate the amount, in mol, of **M**OH in 25.0 cm^3 of solution and determine the identity of the Group 1 metal **M**.

metal **M** = ... **[4]**

37. Magnesium nitrate, $Mg(NO_3)_2$, decomposes when heated:

$Mg(NO_3)_2(s) \rightarrow MgO(s) + 2NO_2(g) + \frac{1}{2}O_2(g)$
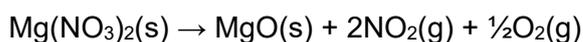
0.00250 mol of $Mg(NO_3)_2$ is decomposed.

What is the volume of gas produced, measured at RTP?

A   30 cm³
B   60 cm³
C   120 cm³
D   150 cm³

Your answer ☐   **[1]**

38. Zinc reacts with aqueous silver nitrate, as shown in the equation:

$Zn(s) + 2AgNO_3(aq) \rightarrow 2Ag(s) + Zn(NO_3)_2(aq)$
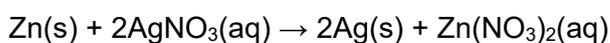
0.10 g of zinc is added to 15 cm³ of 0.25 mol dm⁻³ aqueous silver nitrate.

What is the mass of silver metal that would be formed?

A   0.16 g
B   0.20 g
C   0.33 g
D   0.40 g

Your answer ☐   **[1]**

39. 15.00 cm³ of 18.0 mol dm⁻³ concentrated hydrochloric acid is diluted with water to prepare 250 cm³ of dilute hydrochloric acid.

What is the concentration, in mol dm⁻³, of the dilute hydrochloric acid?

A   0.0675
B   0.270
C   0.300
D   1.08

Your answer ☐   **[1]**

40. A hydrocarbon contains 85.71% carbon by mass.

What is the empirical formula of the hydrocarbon?

A   CH
B CH_2
C CH_4
D C_2H_4

Your answer [ ]   **[1]**

41. Hydrogen can be prepared industrially by the reaction of methane with steam.
The equation is shown below.

$CH_4(g) + 2H_2O(g) \rightarrow 4H_2(g) + CO_2(g)$
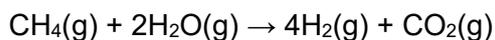
What is the atom economy of hydrogen for this process?

A   3.8%
B   4.3%
C   15.4%
D   17.4%

Your answer [ ]   **[1]**

42. How many oxygen atoms are in 120.2 g of SiO_2?

A 3.01×10^{23}
B 1.20×10^{24}
C 2.41×10^{24}
D 3.61×10^{24}

Your answer [ ]   **[1]**

43. This question is about aromatic compounds containing the –COOH and –OH functional groups.

PAS, shown below, is an antibiotic used to treat several diseases including tuberculosis (TB).

PAS
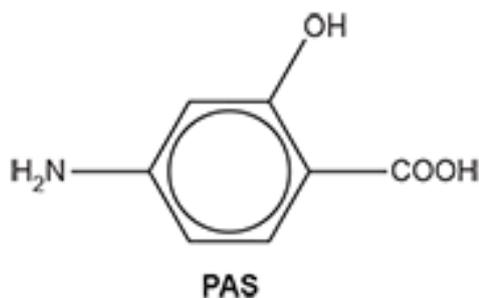
i. A student predicts that PAS could polymerise to form a polymer containing **both** ester and amide linkages.

Draw a section of this polymer.

The section should contain **one** amide and **one** ester linkage, which should be displayed.

[3]

ii. For the treatment of TB, the maximum daily dosage of PAS that should be prescribed is 300 mg per kg of body mass.

A child weighs 20.0 kg.

Calculate the number of PAS molecules in the maximum daily dosage of PAS for this child.

number of PAS molecules = ...

[3]

44. 2-methylpentane reacts with bromine by radical substitution.

2-methylpentane

A mixture of organic products is formed, including 3-bromo-2-methylpentane, and compounds **A** and **B**.

i.   Complete the table below to show the mechanism for the formation of 3-bromo-2-methylpentane and **three** possible equations for termination.

In your equations, use **structural or skeletal formulae** and 'dots' (•) for the position of radicals.

Initiation	Equation: ....
	Conditions: ....
Propagation	$\longrightarrow$
	$\longrightarrow$
Termination	$\longrightarrow$
	$\longrightarrow$
	$\longrightarrow$

[6]

ii.   Organic compound **A** is formed by the substitution of **all** 14 H atoms in 2-methylpentane by Br atoms.

Write the equation, using **molecular formulae**, for the formation of compound **A** from 2-methylpentane.

[2]

iii. Organic compound **B** is formed by the substitution of **some** of the 14 H atoms in 2-methylpentane by Br atoms.

0.8649 g of compound **B** is heated until it is vaporised.

Under the conditions used:

*   compound **B** has a volume of 72.0 cm^3
*   the molar gas volume is 40.0 dm^3 mol^{-1}.

Determine a possible molecular formula of compound **B**.

molecular formula = ... **[3]**

45. 1,3-dinitrobenzene is a solid at room temperature.

A chemist prepares 1,3-dinitrobenzene as outlined below.

Step 1 12.5 cm³ of nitrobenzene (density = 1.20 g cm⁻³) is refluxed with concentrated nitric acid in the presence of concentrated sulfuric acid as a catalyst.

Step 2 The mixture is cooled. Impure crystals of 1,3-dinitrobenzene appear.

Step 3 The impure crystals are purified to obtain pure 1,3-dinitrobenzene.

The chemist obtains 15.0 g of pure 1,3-dinitrobenzene.

Determine the percentage yield of 1,3-dinitrobenzene.

Give your answer to **3** significant figures.

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

46. An unknown organic compound is analysed.

The results are shown below.

Addition of 2,4-DNP
No visible change

Elemental analysis by mass
C, 66.63%; H, 11.18%; O, 22.19%

Mass spectrum
Molecular ion peak at m / z = 144.0

IR spectrum
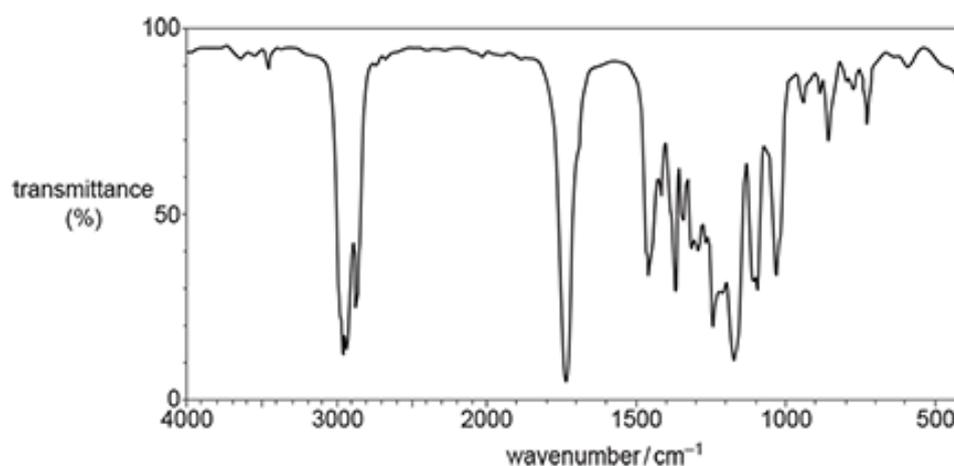
Proton NMR spectrum
The numbers by each peak are the relative peak areas.

Use the information to identify the organic compound.

Show **all** your reasoning.

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

[6]

47. Oxymetazoline, shown below, is used as a decongestant in the treatment of colds.

Oxymetazoline

How many H atoms are in one molecule of oxymetazoline?

A   23
B   24
C   25
D   26

Your answer   ☐   **[1]**

48. For complete combustion, 0.100 mol of an alkane requires 22.8 dm^3 of O$_2$, measured at RTP.

Which alkane has undergone complete combustion?

A　　pentane

B　　hexane

C　　heptane

D　　octane

Your answer ☐　　　　　　　　　　　　　　　　　　　　**[1]**

49. This question is about halogens and halogen compounds.

Seawater contains very small quantities of dissolved iodide ions.

The concentration of potassium iodide, KI, in seawater is 0.150 g dm^{-3}.

Iodine can be extracted by bubbling chlorine gas through seawater.

Explain why chlorine is more reactive than iodine and determine the volume, in dm^3, of seawater that is needed to manufacture 1.00 tonne of iodine, I$_2$.

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

[6]

50. This question is about titanium (atomic number 22) and its compounds.

An ore of titanium contains impure TiO_2.

Titanium is manufactured from TiO_2 in a two-stage process.

Stage 1 $TiO_2 + 2C + 2Cl_2 \rightarrow TiCl_4 + 2CO$ **Reaction 1.1**
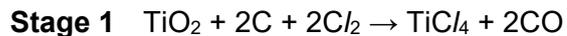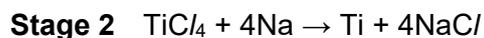
Stage 2 $TiCl_4 + 4Na \rightarrow Ti + 4NaCl$ **Reaction 1.2**

   i.   The common name for TiO_2 is titanium dioxide.

   What is the systematic name of TiO_2?

--**[1]**

   ii.   In **Reaction 1.2**, the percentage yield of titanium from $TiCl_4$ is 72.0%.

   Calculate the minimum mass, in kg, of sodium that is needed to produce 1.00 kg of titanium.

   Give your answer to **3** significant figures.

mass of sodium = ... kg **[4]**

   iii.   **Reaction 1.2** produces a mixture of titanium and sodium chloride.

   Suggest how titanium could be separated from this mixture at room temperature.

   Explain your answer.

--**[2]**

51. This question is about some elements in Period 3 and compounds they form.

A student has a 5.00 g mixture of sodium chloride, $NaCl$(s), and barium nitrate, $Ba(NO_3)_2$(s).

The student also has a solution of sodium sulfate, Na_2SO_4(aq).

The student uses the method below to determine the percentage by mass of $NaCl$(s) in the mixture.

Step 1   Dissolve the 5.00g mixture in distilled water.
Step 2   Add an excess of Na_2SO_4(aq) to the solution. A precipitate of barium sulfate forms.
Step 3   Filter off the precipitate, wash with water, and dry.
Step 4   Weigh the dried precipitate.

The molar mass of barium sulfate is 233.4 g mol^{-1}.

   i.   Write an equation for the formation of barium sulfate in **step 2**.

         Include state symbols.

_____**[2]**

   ii.   The student obtains 3.28 g of precipitate.

         Calculate the percentage by mass of $NaCl$(s) in the 5.00 g mixture.

         Give your answer to **3** significant figures.

                                    percentage by mass of $NaCl$ (s) = ... % **[4]**

   iii. The student changes the method in **2(b)**.

         In **step 2**, the student adds an excess of silver nitrate solution, $AgNO_3$(aq), instead of Na_2SO_4(aq).

         Explain whether this change would allow the student to determine the percentage by mass of $NaCl$(s) in the mixture.

         _____

         _____

         _____

_____**[2]**

52. Information about 1-bromobutane and butan-1-ol is shown in the table.

Compound	Melting point /°C	Boiling point / °C	Density / g cm^{-3}
1-bromobutane	-113	102	1.268
butan-1-ol	-90	118	0.810

A student prepares a sample of 1-bromobutane by refluxing 9.25 g of butan-1-ol with sodium bromide and sulfuric acid.

After reflux, the reaction mixture is purified.

The student obtains 6.10 cm^3 of pure 1-bromobutane.

* Draw a diagram to show how the student would have carried out the reflux and calculate the percentage yield of 1-bromobutane that the student obtains.

Describe how the student could have obtained pure 1-bromobutane from the reaction mixture obtained after reflux.

_____

_____

_____

_____

_____

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_____**[6]**
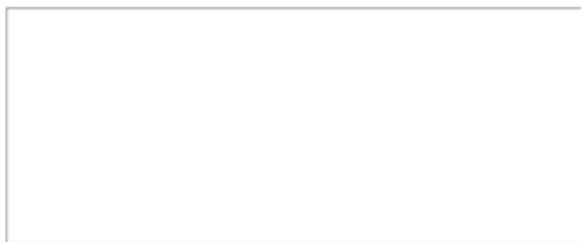
53(a). This question is about compounds that contain the carboxylic acid functional group.

A polymer is formed from 400 molecules of 2-aminopropanoic acid.

    i.   Draw **one** repeat unit of this polymer.

[1]

    ii.   What is the relative molecular mass, M_r, of the polymer?

M_r = ... **[2]**

(b). * A student intends to synthesise compound **I**.

Compound I

Plan a synthesis to prepare 9.36 g of compound **I** starting from 2-chloropropanoic acid, $CH_3CHClCOOH$. The overall percentage yield of compound **I** from 2-chloropropanoic acid is 64%.

In your answer, include starting mass of 2-chloropropanoic acid, reagents, conditions and equations where appropriate.

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Additional answer space if required.

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[6]

54. Which process has the highest atom economy for preparing ethene, C_2H_4?

In each process, assume that ethene is the only product that is used.

A $C_{10}H_{22} \rightarrow 3C_2H_4 + C_4H_{10}$
B $C_6H_{14} \rightarrow 2C_2H_4 + C_2H_6$
C $C_2H_5Cl \rightarrow C_2H_4 + HCl$
D $C_2H_5OH \rightarrow C_2H_4 + H_2O$

Your answer   ☐   **[1]**

55. Complete combustion of 0.050 mol of an alkane produces 5.40g of H_2O.

What is the molecular formula of the alkane?

A C_2H_6
B C_3H_8
C C_4H_{10}
D C_5H_{12}

Your answer   ☐   **[1]**

56. The structure of the painkiller, paracetamol, is shown below.
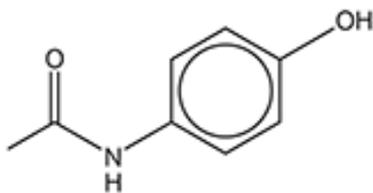
paracetamol

A tablet contains 3.31×10^{-3} mol of paracetamol.

What is the mass of paracetamol in the tablet?

A   493 mg
B   497 mg
C   500 mg
D   506 mg

Your answer ☐   **[1]**

57. The compound below reacts with hydrogen gas to form a saturated compound.

What is the volume of hydrogen, measured at room temperature and pressure, that reacts with 0.0500 mol of the compound?

A   2.40 dm³
B   3.60 dm³
C   4.80 dm³
D   6.00 dm³

Your answer ☐   **[1]**

58. This question is about an analysis of an unknown organic **Compound X**.

Some properties of **Compound X** are shown in the table.

Molecular formula	Functional groups	Chirality
$C_xH_yF_6O$	C–F C–O–C	1 chiral carbon

At a pressure of 1.07×10^5 Pa at 30 °C, 1.327 g of **Compound X** is a gas with a volume of 186 cm^3.

Determine the molar mass of **Compound X** and its molecular formula.

Draw a possible structure for a molecule of **Compound X**.

molar mass .... gmol $^{-1}$

molecular formula ....

Structure of Compound X

[6]
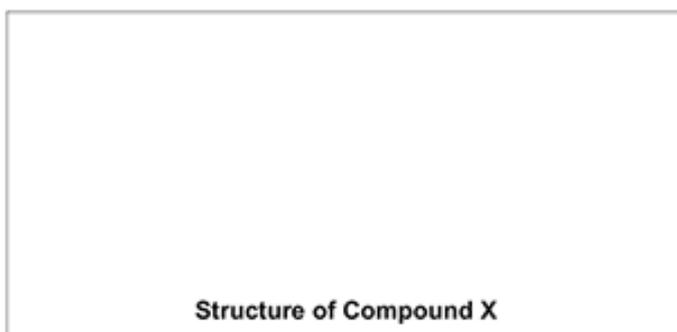
59. This question is about atomic structure and formulae.

Substance **A** is a hydrated salt with the following percentage composition by mass:

Zn, 21.99%; H, 4.04%; N, 9.41%; O, 64.56%.

- Determine the empirical formula of **A**.
- Write the formula of **A** showing the water of crystallisation.

empirical formula: ....

formula showing water of crystallisation: ....

[3]

60. This question is about halogens and practical tests

A student is supplied with aqueous solutions of ionic compounds **B** and **C**.

Compound **B** is a chloride, bromide or iodide of a Group 1 element.

Compound **C** is a chloride, bromide or iodide of a Group 2 element.

The molar masses of **B** and **C** are both in the range 100–115 g mol^{-1}.

Use this information and test-tube tests to show how the student could identify the halide present in **B** and **C** and the formulae of **B** and **C**.

Explain your reasoning.

In your answer, include observations, colours and equations.

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[5]

61. This question is about enthalpy changes and reaction rates.

Aqueous barium hydroxide, $Ba(OH)_2(aq)$, reacts with dilute nitric acid, $HNO_3(aq)$, as in **Equation 25.1**.

$Ba(OH)_2(aq) + 2HNO_3(aq) \rightarrow Ba(NO_3)_2(aq) + 2H_2O(l)$ **Equation 25.1**

A student carries out an experiment to determine the enthalpy change of this reaction, $\Delta_r H$.

The student measures out:

• 25.0 cm^3 of 2.00 mol dm^{-3} $Ba(OH)_2(aq)$ and

• 50.0 cm^3 of 2.00 mol dm^{-3} $HNO_3(aq)$.

The temperature of each solution is the same.

The student mixes both solutions in a polystyrene cup, stirs the mixture and records the maximum temperature.

Temperature readings

Initial temperature	= 20.5 °C
Maximum temperature	= 39.0 °C

i.   Calculate $\Delta_r H$, in kJ mol^{-1}, for the reaction shown in **Equation 25.1**.
     Give your answer to **3** significant figures.
     Assume that the density and specific heat capacity, *c*, of the solutions are the same as for water.

$\Delta_r H$ = ... kJ mol^{-1} **[4]**

ii. The student looked back at **Equation 25.1** and noticed that the reaction was a neutralisation.
     The student concluded that $\Delta_r H$ is the enthalpy change of neutralisation.
     Explain why the student's conclusion is **incorrect** and determine the correct value for the enthalpy
     change of neutralisation.

     _____

     _____

     _____

     _____

enthalpy change of neutralisation = ... kJ mol ^{1} **[2]**

62. This question is about haloalkanes.

A bromoalkane **D** is a liquid at room temperature and pressure but can easily be vaporised. When vaporised, 0.330g of **D** produces 74.0 cm^3 of gas at 1.01×10^5 Pa and 100 °C. Determine the molar mass and molecular formula of bromoalkane **D**.

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

[5]

63. A sample of lead(II) sulfate (M = 303.3 g mol^{-1}) is decomposed by heat, as shown in the equation below.

$2PbSO_4(s) \rightarrow 2PbSO_3(s) + O_2(g)$

The reaction forms 2.40 g of $O_2(g)$.

What is the mass of lead(II) sulfate that has been heated? Assume a 100% yield.

A   22.7g
B   30.3g
C   45.5g
D   60.7g

Your answer   ☐   **[1]**

64. What is the number of **ions** in 4.00 mol of magnesium chloride, $MgCl_2$?

A 1.81×10^{24}
B 2.41×10^{24}
C 4.82×10^{24}
D 7.22×10^{24}

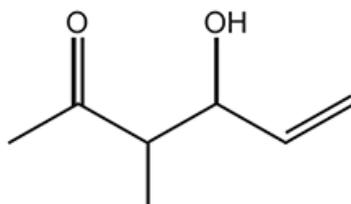Your answer ☐   **[1]**

65. Which volume of 18.0 mol dm^{-3} hydrochloric acid should be diluted to 250.0 cm^3 to prepare a 0.450 mol dm^{-3} solution of hydrochloric acid?

A 4.50 cm^3
B 6.25 cm^3
C 10.0 cm^3
D 32.4 cm^3

Your answer ☐   **[1]**

66. What is the number of hydrogen atoms in **one** molecule of the compound below?

A   8
B   10
C   12
D   14

Your answer ☐   **[1]**

67. Complete combustion of an alkane forms 30 cm^3 of carbon dioxide and 40 cm^3 of water vapour, under the same conditions of temperature and pressure.
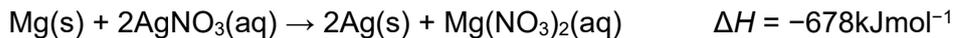
Which alkane has undergone complete combustion?

A   butane
B   ethane
C   heptane
D   propane

Your answer ☐   **[1]**

68. This question is about energy changes.

Magnesium reacts with aqueous silver nitrate, $AgNO_3(aq)$ as shown below.

$Mg(s) + 2AgNO_3(aq) \rightarrow 2Ag(s) + Mg(NO_3)_2(aq)$ $\Delta H = -678kJmol^{-1}$

A student adds an excess of magnesium to 100.0 cm^3 of 0.400 mol dm^{-3} $AgNO_3(aq)$.

The initial temperature is 20.0°C.

   i.   Determine the maximum temperature reached in this reaction.

       Give your answer to **3** significant figures.

       Assume that the specific heat capacity and density of the solution are the same as for water, and that there are no heat losses.

maximum temperature reached = ... °C **[4]**

  ii.   The student wants to repeat the experiment, but there is not enough $AgNO_3(aq)$ left to use another 100.0 cm^3 portion.

       The student decides to modify the method by adding an excess of magnesium to 50.0 cm^3 of 0.400 mol $dm^{-3}AgNO_3(aq)$.

       Predict, with reasons, how this modification would affect the maximum temperature reached. Assume that there are no heat losses.

[1]

69. The graph shows the first ionisation energies for elements from helium, He, to boron, B, in the periodic table.
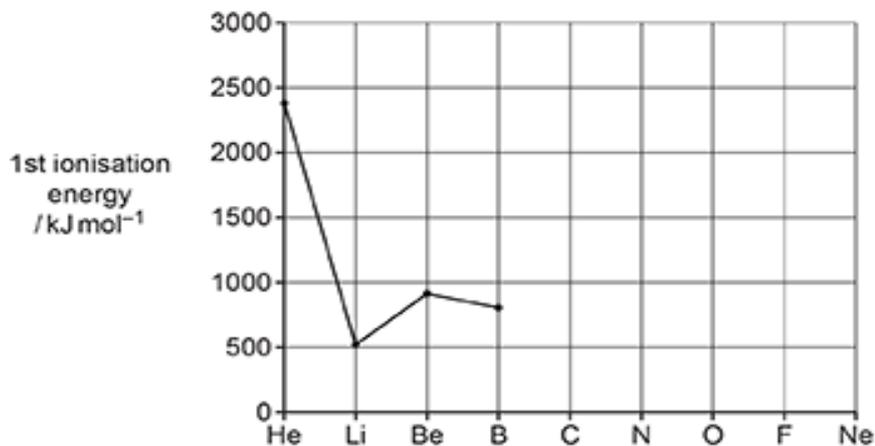
Estimate the energy required to form **one** Li$^+$(g) ion from one Li(g) atom.

Give your answer in kJ, in standard form, and to **two** significant figures.

energy = ... kJ **[1]**

70(a). This question is about acids and buffer solutions.

Succinic acid, $HOOC(CH_2)_2COOH$, is a weak dibasic acid that is used in tablet form in health supplements.

A student plans to determine the mass of succinic acid in one tablet of a succinic acid health supplement.

The student carries out a titration with potassium hydroxide.

The end point occurs when both acidic protons in succinic acid have been replaced as shown in **Equation 19.1**.

$HOOC(CH_2)_2COOH + 2KOH \rightarrow KOOC(CH_2)_2COOK + 2H_2O$ **Equation 19.1**

The student uses the following method.

Stage 1	The student crushes four tablets of the health supplement and dissolves the powdered tablets in distilled water.
Stage 2	The student makes up the solution from **Stage 1** to 250.0 cm^3 in a volumetric flask.
Stage 3	The student titrates 10.0 cm^3 portions of the solution obtained in **Stage 2** with 0.0600 mol dm^{-3} potassium hydroxide, using phenolphthalein as the indicator.

The student carries out a trial titration, followed by three further titrations.
The results are shown below.

Titration	Trial	1	2	3
Final burette reading/cm^3	25.25	23.75	25.35	25.75
Initial burette reading/cm^3	2.50	1.30	2.65	3.20
Titre/cm^3				

i.   Complete the table and calculate the mean titre that the student should use for analysing the results.

mean titre = ... cm^3 **[2]**

ii.   Use the student's results and **Equation 19.1** to calculate the mass, in mg, of succinic acid in **one** tablet of the health supplement.

Give you answer to **3** significant figures.

mass = ... mg **[5]**

(b). Glycolic acid, $HOCH_2COOH$, ($pK_a = 3.83$) is a weak monobasic acid used in some skincare products.

A buffer solution is prepared by adding 60.0 cm^3 of 0.750 mol dm^{-3} glycolic acid to 40.0 cm^3 of 0.625 mol dm^{-3} potassium hydroxide, KOH.

   i.   Explain why a buffer solution is formed.

[1]

   ii.   Calculate the pH of the buffer solution that has been prepared.

      Give your answer to **2** decimal places.

pH = ... **[4]**

   iii.   A small amount of aqueous ammonia, $NH_3(aq)$, is added to the buffer solution.

      Explain, in terms of equilibrium, how the buffer solution would respond to the added $NH_3(aq)$.

[2]

71. This question is about equilibria involving hydrogen.

* Hydrogen is used industrially to manufacture ammonia.

The equilibrium is shown below.

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ $\Delta H = -92kJ\ mol^{-1}$ **Equilibrium 20.1**

1.20 mol $N_2(g)$ is mixed with 3.60 mol $H_2(g)$ in a 8.00 dm³ container.

The mixture is heated to 550 °C with an iron catalyst and allowed to reach equilibrium.

The equilibrium mixture contains 0.160 mol of NH_3.

Determine the equilibrium constant K_c for **Equilibrium 20.1**, and explain why the operational conditions used by industry may be different from those required for a maximum equilibrium yield of ammonia.

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[6]

72(a). This question is about the reactions of Group 2 metals and their compounds.

A sample of barium oxide is added to distilled water at 25 °C.
A colourless solution forms containing barium hydroxide, $Ba(OH)_2$.

The solution is made up to 250.0 cm^3 with distilled water.
The pH of this solution is 13.12.

  i.   Determine the mass of barium oxide that was used.

        Give your answer to **3** significant figures.

mass of barium oxide = ... g **[5]**

  ii.   10 cm^3 of dilute sulfuric acid is added to 10 cm^3 of the colourless solution of $Ba(OH)_2$. Write an ionic
        equation, including state symbols, for the reaction.

        [1]

(b). Limestone and huntite are two calcium minerals.

  i.   A typical sample of limestone contains 95.0% by mass of calcium carbonate, $CaCO_3$. Fertiliser **Z**,
        $Ca_5NH_4(NO_3)_{11} \cdot 10H_2O$ (M_r = 1080.5 g mol^{-1}) can be made from limestone. Calculate the mass, in g, of
        limestone needed to make 1.50 kg of fertiliser **Z**.

        Give your answer to **3** significant figures.

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

  ii.   Huntite is a carbonate mineral with the chemical formula $Mg_3Ca(CO_3)_4$.

        Huntite reacts with dilute hydrochloric acid to produce bubbles of a gas and a colourless solution.

        Construct the equation for the reaction. Include state symbols.

        [2]

73. * This question is about copper and copper compounds.

Experiment 1

Hydrochloric acid, HC*l*(aq), is added to an aqueous solution containing $[Cu(H_2O)_6]^{2+}$ complex ions.

A yellow-green solution forms containing complex ion **B**.

Experiment 2

A piece of copper metal is heated with concentrated sulfuric acid.

A reaction takes place forming a pale blue solution **C** and 45 cm^3 of a gas **D**, measured at RTP. The mass of gas **D** is 0.12 g.

Experiment 3

An excess of copper(II) oxide is heated with dilute nitric acid. The resulting mixture is filtered. The filtrate is a blue solution **E**.
Aqueous potassium iodide, KI(aq), is added to the blue solution **E**.
A white precipitate F and a brown solution **G** form.

Determine the formulae of **B–G**.
Construct equations for the reactions taking place, include any changes in oxidation number, and show your working where appropriate.

[6]

74. 20 cm^3 of nitrogen gas reacts with 10 cm^3 of oxygen gas to form 20 cm^3 of a gaseous product. Which equation is the most likely for the reaction?

A $N_2(g) + O_2(g) \rightarrow 2NO(g)$
B $N_2(g) + 2O_2(g) \rightarrow N_2O_4(g)$
C $2N_2(g) + O_2(g) \rightarrow 2N_2O(g)$
D $2N_2(g) + 2O_2(g) \rightarrow 4NO(g)$

Your answer   ☐   **[1]**

75. 0.541 g of an element **X** is reacted with oxygen to form 0.790 g of the oxide **X**$_2$**O**$_3$.

What is the element **X**?

A   Al
B   Cr
C   Ga
D   Sc

Your answer   ☐   **[1]**

76. Hydrogen peroxide, H_2O_2, can be oxidised by manganate(VII) ions under acid conditions as shown below.

$2MnO_4^-(aq) + 5H_2O_2(aq) + 6H^+(aq) \rightarrow 2Mn^{2+}(aq) + 5O_2(g) + 8H_2O(l)$
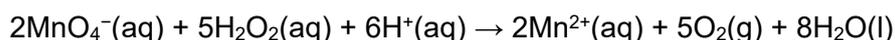
In a titration, 25.00 cm^3 of a disinfectant containing hydrogen peroxide reacts with 22.00 cm^3 of 0.125 mol dm^{-3} $KMnO_4(aq)$.

What is the concentration of H_2O_2, in mol dm^{-3}, in the disinfectant?

Assume that KMnO4 only reacts with H_2O_2 in the disinfectant.

A   0.0440
B   0.110
C   0.275
D   0.550

Your answer   ☐   **[1]**

77. The mass of 4 molecules of a substance is 2.125×10^{-22} g.

What is the possible formula of the substance?

A CH_4
B O_2
C SO_2
D I_2

Your answer ☐   **[1]**

78(a). 2-Bromobutane, $CH_3CH_2CHBrCH_3$, can be prepared by several different methods.

The relative molecular mass, M_r, of 2-bromobutane is 136.9.

2-Bromobutane can be prepared by reacting butane with bromine (**Reaction 5.1**).
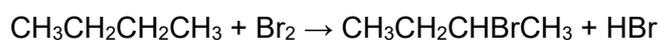
$CH_3CH_2CH_2CH_3 + Br_2 \rightarrow CH_3CH_2CHBrCH_3 + HBr$ **Reaction 5.1**

The reaction is initiated by the formation of bromine radicals from bromine.

   i.   State the conditions for the formation of bromine radicals from bromine.

_____**[1]**

   ii.   Write two equations for the propagation steps in the mechanism for **Reaction 5.1**.

         Use structural formulae for organic species and dots (·) for unpaired electrons on radicals.

   $CH_3CH_2CH_2CH_3$ + ... → .... + ...

   .... + ... → .... + ...
                                                                                                    [2]

   iii.   The yield of $CH_3CH_2CHBrCH_3$ is only 30%.

         Suggest **two** reasons why the yield of $CH_3CH_2CHBrCH_3$ is so low.

   1

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   2

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                                                                                                    [2]

(b). 2-Bromobutane can also be prepared by reacting but-2-ene, $CH_3CH=CHCH_3$, with hydrogen bromide, HBr (**Reaction 5.2**).

$CH_3CH=CHCH_3 + HBr \rightarrow CH_3CH_2CHBrCH_3$ **Reaction 5.2**

Explain, in terms of atom economy, why **Reaction 5.2** is more sustainable than **Reaction 5.1**.

Include calculations to justify your answer.

_____

_____

---**[2]**

(c). 2-Bromobutane can be prepared by reacting butan-2-ol, $CH_3CH_2CHOHCH_3$, with sodium bromide and sulfuric acid (**Reaction 5.3**).

$CH_3CH_2CHOHCH_3 + H^+ + Br^- \rightarrow CH_3CH_2CHBrCH_3 + H_2O$ **Reaction 5.3**
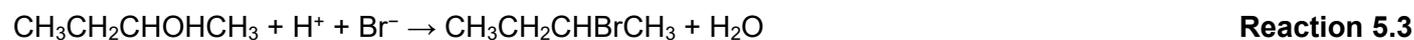
2-Bromobutane is a liquid with a boiling point of 91 °C and does not mix with water.

   i.   A student plans to prepare 10.0 g of 2-bromobutane using **Reaction 5.3**.

        The percentage yield is 67.0%.

        Calculate the mass of $CH_3CH_2CHOHCH_3$ needed for this preparation.

        Give your answer to **3** significant figures.

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

ii. The student mixes butan-2-ol, sodium bromide and sulfuric acid in a pear-shaped flask, and refluxes the mixture.

   After 1 hour, the mixture in the flask has separated into two layers: an aqueous layer and an organic layer.

   Describe the procedures the student would need to carry out to obtain a pure, dry sample of 2-bromobutane from this mixture.

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   [3]

79(a). Lime is a citrus fruit containing citric acid, $C_6H_8O_7$.

A student carries out a titration to determine the mass of citric acid in a lime.
The student follows the method below:

- Squeeze the juice out of two limes.
- Transfer the juice into a 250.0cm³ volumetric flask and make up to the mark with distilled water.
- Pipette 25.0cm³ of the diluted lime juice into a conical flask and add a few drops of phenolphthalein indicator.
- Titrate this solution with 0.800 mol dm⁻³ NaOH(aq).

The student carries out a trial titration, followed by three further titrations.

The diagram shows the burette readings for the three further titrations.
Each reading is measured to the nearest 0.05 cm³.

i.   Record the student's burette readings in the table below.

Calculate the mean titre, to the nearest 0.05 cm^3, that the student should use to analyse the results.

	Titration 1	Titration 2	Titration 3
Final reading/cm^3			
Initial reading/cm^3			
Titre/cm^3			

mean titre .... cm^3 **[4]**

ii.   Citric acid, $C_6H_8O_7$, is neutralised by NaOH as shown in the equation below.

$C_6H_8O_7 + 3NaOH \rightarrow Na_3C_6H_5O_7 + 3H_2O$
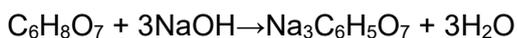
Calculate the mass, in g, of citric acid in **one** lime.

Assume that citric acid (M_r = 192.0) is the only acid in lime juice.

mass of citric acid in one lime = ... g **[5]**

(b). The student's teacher thinks that there is an unnecessary safety risk in using a sodium hydroxide concentration of 0.800 mol dm^{-3} for the titration.

Suggest how the student could modify the method using a sodium hydroxide concentration of 0.200 mol dm^{-3} instead of 0.800 mol dm^{-3}.

The student should aim to have the same titre as in the original method.

Justify your answer

_____

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_____**[2]**

80. Internal combustion engines have historically used fuels obtained from crude oil as a source of power.

The environmental effects of fossil fuel use can be reduced by blending petrol with biofuels such as ethanol.

A fuel is being developed using a 1:1 molar ratio of octane and ethanol.

i. Write the equation for the complete combustion of this fuel.

---**[1]**

ii. Calculate the energy released, in kJ, by the complete combustion of 8.00 kg of this fuel.
$\Delta_c H(C_8H_{18})$ = -5470 kJ mol^{-1} ; $\Delta_c H(C_2H_5OH)$ = -1367 kJ mol^{-1}.

energy released = ... kJ **[3]**

81. A student carries out an investigation on vitamin C, $C_6H_8O_6$.

The label on a carton of orange juice lists the mass of vitamin C, in mg, in a typical serving of 150 cm^3.

The student carries out an investigation to check the vitamin C content in the orange juice.

Vitamin C can be oxidised by iodine:

$C_6H_8O_6(aq) + I_2(aq) \rightarrow C_6H_6O_6(aq) + 2I^-(aq) + 2H^+(aq)$
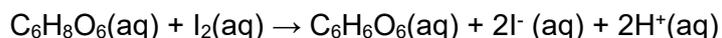
The student dilutes 150 cm^3 of the orange juice with water to 250.0 cm^3 in a volumetric flask.

The student then titrates 25.0 cm^3 volume of this solution with 9.60 × 10^{-4} mol dm^{-3} iodine solution, $I_2(aq)$.

The mean titre of $I_2(aq)$ is 22.50 cm^3.

Determine the mass, in mg, of vitamin C in a 150 cm^3 serving of the orange juice.

mass of vitamin C in the 150 cm^3 serving of orange juice = ... mg **[4]**

82. This question is about redox reactions.

'Calcium hypochlorite', Ca(C/O)$_2$, is an ionic compound used in 'bleaching powder'.

The *Cl* O$^-$ ion in Ca(C/O)$_2$ is the active ingredient that kills bacteria.

Calcium hypochlorite is prepared by reacting chlorine gas with calcium hydroxide.
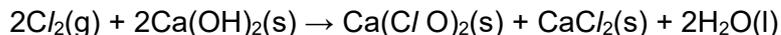
$2Cl_2(g) + 2Ca(OH)_2(s) \rightarrow Ca(ClO)_2(s) + CaCl_2(s) + 2H_2O(l)$ **Equation 2.1**

   i.   420 dm^3 of chlorine, measured at RTP, is reacted with an excess of Ca(OH)$_2$.

The solid products are dissolved in water to form 4.00 m^3 of solution.

Calculate the concentration of Ca(C/O)$_2$(aq) in this solution, in mol dm^{-3}.

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

concentration = ... mol dm $^{-3}$ **[3]**

   ii.   Calcium hypochlorite, Ca(C/O)$_2$, is heated. The Ca(C/O)$_2$ decomposes to form CaC/$_2$ and Ca(C/O$_3$)$_2$. This is a disproportionation reaction.
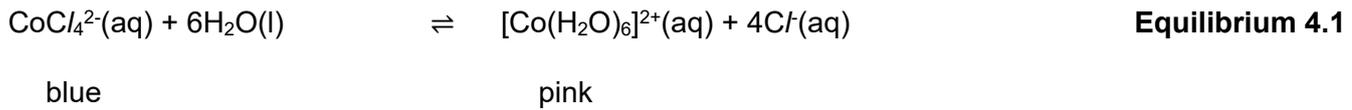
Write an equation for this decomposition and explain, using oxidation numbers, why this is a disproportionation reaction.

equation _____

_____

explanation _____

_____

_____

_____

_____**[3]**

83. Two students plan to investigate **Equilibrium 4.1**, shown below.

CoCl₄²⁻(aq) + 6H₂O(l) $\rightleftharpoons$ [Co(H₂O)₆]²⁺(aq) + 4Cl⁻(aq)   **Equilibrium 4.1**

   blue   pink

The students investigate how addition of aqueous silver nitrate, AgNO₃(aq), affects the equilibrium position in **Equilibrium 4.1**.

The graph shows the changes in the equilibrium concentrations of CoCl₄ ²⁻, Cl⁻ and [Co(H₂O)₆]²⁺ after addition of the AgNO₃(aq).

The AgNO₃(aq) is added at time = t_1
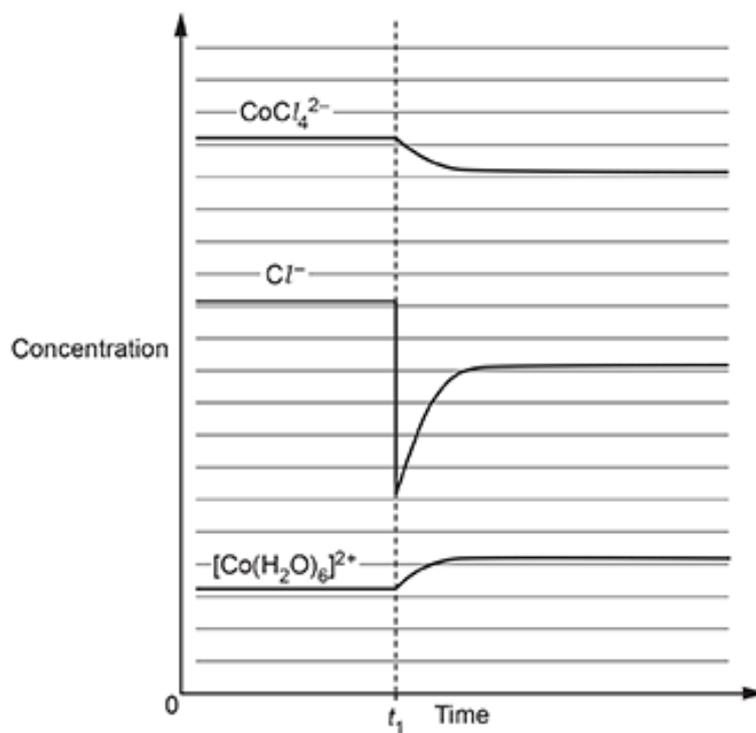
i.   Explain why the Cl⁻ concentration drops sharply at time = t_1.

_____

_____

_____**[1]**

ii.   Explain the changes in concentration of $CoCl_4{}^{2-}$, Cl^- and $[Co(H_2O)_6]^{2+}$ after time = t_1.
      Refer to **Equilibrium 4.1** in your answer.

[3]

END OF QUESTION PAPER