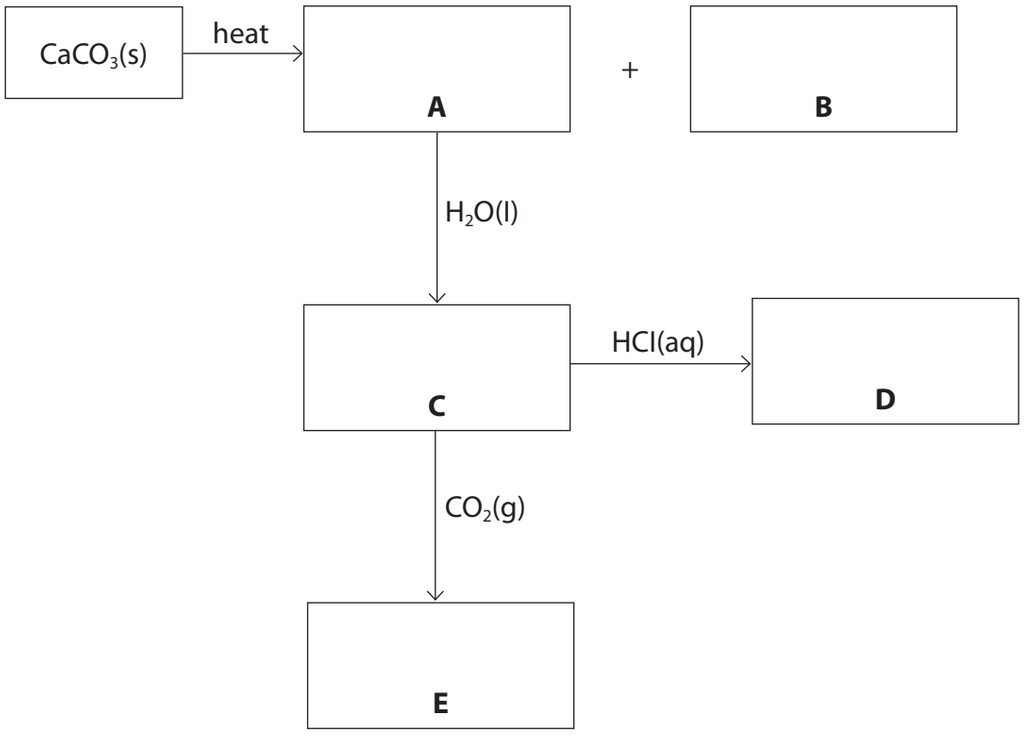
Answer ALL questions.

Write your answers in the spaces provided.

Some questions must be answered with a cross in a box ☒.
If you change your mind about an answer, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 This question is about the chemistry of the Group 2 elements and their compounds.

(a) The flow chart shows some reactions involving calcium compounds.



Identify the substances **A** to **E** by writing their formulae and state symbols in the boxes.

(5)

(b) Explain how the thermal stability of magnesium carbonate compares with that of calcium carbonate.

(4)

(Total for Question 1 = 9 marks)

2 Aqueous silver nitrate is used as a test for halide ions. A student decides to carry out this test on a solution of magnesium chloride. The bottle of solid magnesium chloride shows the formula $MgCl_2.6H_2O$.

(a) The student dissolves a small amount of $MgCl_2.6H_2O$ in water and adds aqueous silver nitrate, $AgNO_3(aq)$, to the solution.

(i) Calculate the molar mass of $MgCl_2.6H_2O$

(1)

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

(ii) State what the student would see after adding the aqueous silver nitrate.

(1)

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(iii) Write an ionic equation for this reaction. Include state symbols.

(1)

(b) Using aqueous silver nitrate, it is sometimes difficult to distinguish between chloride, bromide and iodide ions.

Describe how aqueous ammonia can be used to distinguish between these three ions.

(3)

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(Total for Question 2 = 6 marks)

3 This question is about bonding, structure and shapes of molecules.

(a) Which solid structure consists of particles held together by London forces only?

(1)

- ☒ **A** 2-aminoethanoic acid
- ☒ **B** copper
- ☒ **C** iodine
- ☒ **D** silicon(IV) oxide

(b) Ionic oxides and giant covalent oxides are used in the manufacture of fibreglass. Which oxide is **not** a constituent of fibreglass?

(1)

- ☒ **A** Al_2O_3
- ☒ **B** MgO
- ☒ **C** P_4O_{10}
- ☒ **D** SiO_2

(c) Which statement describes a phenomenon that can be explained by the existence of intermolecular hydrogen bonding?

(1)

- ☒ **A** the boiling temperatures of the alkanes increase with increasing relative molecular mass
- ☒ **B** hydrogen bromide has a higher boiling temperature than hydrogen chloride
- ☒ **C** CH_3COCH_3 has a higher boiling temperature than $CH_3CH_2CH_2CH_3$
- ☒ **D** ice has a lower density than water at 0 °C

(d) (i) Which of these pairs of molecules have similar shapes?

(1)

☒ **A** $AlCl_3$ and BCl_3

☒ **B** $AlCl_3$ and PCl_3

☒ **C** BCl_3 and NH_3

☒ **D** $BeCl_2$ and H_2O

(ii) The chlorine atom in chlorine trifluoride, ClF_3, is surrounded by three bonding pairs of electrons and two lone pairs of electrons.

Draw two possible shapes for the ClF_3 molecule, showing the positions of the lone pairs of electrons.

(2)

Shape 1

Shape 2

(iii) Explain, using the electron pair repulsion theory, which of the two shapes is more likely to be the correct shape of the ClF_3 molecule.

(2)

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(Total for Question 3 = 8 marks)

4 Chlorine compounds take part in many redox reactions.

(a) State, in terms of electron transfer, what is meant by the term oxidising agent.

(1)

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(b) Chlorine dioxide gas, ClO_2, is used to whiten flour.
It is unstable and hence is prepared in situ by the reaction:

$$2ClO_3^-(aq) + SO_2(g) + H^+(aq) \rightarrow 2ClO_2(g) + HSO_4^-(aq)$$

Explain, using oxidation numbers, which species is acting as the oxidising agent in this reaction.

(2)

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(c) Chlorine dioxide reacts in alkaline solution to form a mixture of ClO_2^- and ClO_3^- ions.

(i) Write an equation for this reaction. State symbols are not required.

(2)

(ii) Give the reason why this reaction is disproportionation.

(1)

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(Total for Question 4 = 6 marks)

5 Magnesium and strontium are elements in Group 2 of the Periodic Table. The first three ionisation energies of magnesium and strontium are shown in the table.

Element	Ionisation energy / kJ mol^{-1}		
	First	Second	Third
magnesium	738	1451	7733
strontium	550	1064	4210

(a) (i) Explain why the first ionisation energy of magnesium is larger than that of strontium.

(2)

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(ii) Explain why the second ionisation energy of magnesium is larger than its first ionisation energy.

(2)

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(iii) Explain why the third ionisation energy of magnesium is **significantly** larger than its second ionisation energy.

(2)

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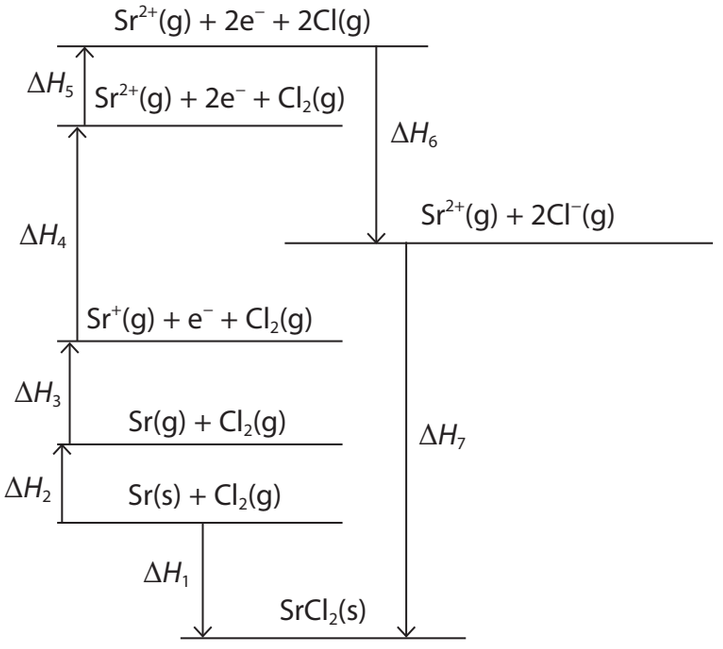
(b) The diagram shows the Born-Haber cycle for the formation of strontium chloride from its elements.



The table gives the values of enthalpy changes ΔH_1 through to ΔH_6.

Enthalpy change	ΔH_1	ΔH_2	ΔH_3	ΔH_4	ΔH_5	ΔH_6
Value / kJ mol^{-1}	– 828	+ 164	+ 548	+ 1060	+ 242	– 728

(i) Give the names of the enthalpy changes represented by ΔH_1 and ΔH_2.

(2)

ΔH_1 .....

ΔH_2 .....

(ii) Write an expression linking all the enthalpy changes listed in the Born-Haber cycle and use it to calculate a value for ΔH_7.

(2)

(c) Why is the lattice energy of magnesium chloride more exothermic than that of strontium chloride?

(1)

☒ **A** there are more cation-to-anion interactions in magnesium chloride

☒ **B** the inter-ionic distance is smaller in magnesium chloride

☒ **C** magnesium chloride has less covalent character

☒ **D** the magnesium ion has a greater charge than the strontium ion

(Total for Question 5 = 11 marks)

6 Iron is a transition element that forms a number of ions with the iron in different oxidation states.

(a) What is the electronic configuration of the iron cation that can form the complex ion $[Fe(CN)_6]^{4-}$?

(1)

☒ **A** [Ar] $3d^4 4s^2$

☒ **B** [Ar] $3d^5 4s^0$

☒ **C** [Ar] $3d^6 4s^0$

☒ **D** [Ar] $3d^6 4s^2$

(b) Iron forms a ferrate ion of formula FeO_4^{2-}.

(i) What is the oxidation number of the iron in FeO_4^{2-}?

(1)

☒ **A** + 2

☒ **B** + 3

☒ **C** + 4

☒ **D** + 6

(ii) Deduce, using the data shown, whether ferrate ions are stable in acidic conditions.

Write an overall ionic equation for any reaction that takes place.
State symbols are not required.

$$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons 2H_2O(l) \qquad E^{\ominus} = +1.23\,V$$

$$FeO_4^{2-}(aq) + 8H^+(aq) + 3e^- \rightleftharpoons Fe^{3+}(aq) + 4H_2O(l) \qquad E^{\ominus} = +2.20\,V$$

(4)

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(c) A complex ion contains one Fe^{3+} ion, four ammonia molecules and two chloride ions.

(i) Give the formula of this ion.

(1)

(ii) This complex ion exhibits *cis* -*trans* isomerism.
Draw diagrams to show the structure of both the *cis*- and the *trans*-isomer.
Label each isomer.

(2)

(d) The salt $K_3Fe(CN)_6$ can be prepared by oxidising $K_4Fe(CN)_6$.
The relevant standard electrode (redox) potential is:

$$[Fe(CN)_6]^{3-}(aq) + e^- \rightleftharpoons [Fe(CN)_6]^{4-}(aq) \qquad E^{\ominus} = +0.36\ V$$

Which species will oxidise $K_4Fe(CN)_6$ to $K_3Fe(CN)_6$?
You may find it helpful to refer to the Data booklet.

(1)

☒ **A** Ag(s)

☒ **B** $Cl_2(g)$

☒ **C** $Cu^{2+}(aq)$

☒ **D** $Fe^{2+}(aq)$

(Total for Question 6 = 10 marks)

7 The propulsion system of a torpedo is powered by sulfur hexafluoride, SF_6, in an exothermic reaction with solid lithium.

The equation for the reaction of sulfur hexafluoride with lithium is:

$$SF_6(g) + 8Li(s) \rightarrow Li_2S(s) + 6LiF(s) \qquad \Delta_r H^{\ominus} = -2\,934 \text{ kJ mol}^{-1}$$

(a) Calculate the mass of lithium needed to react with 398 kg of sulfur hexafluoride. Give your answer to an appropriate number of significant figures.

[Molar masses: SF_6 = 146.1 g mol^{-1}; Li = 6.90 g mol^{-1}]

(3)

Mass of lithium needed = ... kg

(b) The table gives the standard molar entropies, $S^{\ominus}$, at 298 K, of $SF_6(g)$, Li(s), $Li_2S(s)$ and LiF(s).

	SF_6(g)	**Li(s)**	**Li_2S(s)**	**LiF(s)**
$S^{\ominus}$ / J K^{-1} mol^{-1}	+292	+29.1	+63.0	+35.6

Calculate the standard total entropy change, $\Delta S^{\ominus}_{total}$, at 298 K, for the reaction between sulfur hexafluoride and lithium. Include units in your final answer.

(4)

$\Delta S^{\ominus}_{total}$ = ...

(c) The reaction between sulfur hexafluoride and lithium is started using a fuse.
Justify the need for a fuse, in view of your answer to part (b).

(2)

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(Total for Question 7 = 9 marks)

8 The table gives the value of the acid dissociation constant, K_a, for three acids.

Acid	Formula	K_a / mol dm^{-3}
methanoic acid	HCOOH	1.60×10^{-4}
phenol	C_6H_5OH	1.28×10^{-10}
chloric(III) acid	$HClO_2$	1.00×10^{-2}

(a) What information about an acid is supplied by its K_a value alone?

(1)

☒ **A** the concentration of the acid

☒ **B** the extent of dissociation into ions of the acid

☒ **C** the hydrogen ion concentration of the acid

☒ **D** the pH of the acid

(b) When aqueous solutions of chloric(III) acid and methanoic acid are mixed together, an acid-base reaction takes place.

$$HClO_2(aq) + HCOOH(aq) \rightleftharpoons ClO_2^-(aq) + HCOOH_2^+(aq)$$

....

(i) Label one acid-base conjugate pair as **acid 1** and **base 1**.
Label the other acid-base conjugate pair as **acid 2** and **base 2**.

(1)

(ii) Explain, with the aid of an equation, the acid-base reaction that takes place when methanoic acid is mixed with phenol.

(2)

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(c) (i) Give the expression for pH.

(1)

(ii) Calculate the pH of 0.0540 mol dm^{-3} hydrochloric acid, HCl(aq), and of 0.0540 mol dm^{-3} methanoic acid, HCOOH(aq).
Give your answers to two decimal places.

(4)

*(iii) An excess of magnesium was added to 100 cm^3 of 0.0540 mol dm^{-3} HCl(aq).
The same mass of magnesium, from the same sample, was added to 100 cm^3 of 0.0540 mol dm^{-3} HCOOH(aq).

Both reactions were carried out at the same temperature.
Compare and contrast the total volume of hydrogen evolved, and the rate at which it will be evolved, in the two reactions.

(6)

(Total for Question 8 = 15 marks)

9 Sulfur dioxide and oxygen react together to form sulfur trioxide in a reversible reaction that can reach a position of equilibrium. The equation for the reaction is:

$$SO_2(g) + \tfrac{1}{2}O_2(g) \rightleftharpoons SO_3(g) \qquad \Delta_r H^{\ominus} = -98.0 \text{ kJ mol}^{-1}$$

The numerical value of the equilibrium constant, K_p, for this reaction at 298 K is 2.00×10^{12}.

(a) The expression for K_p for this reaction is

(1)

☒ **A** $\dfrac{p^2_{SO_3}}{p^2_{SO_2} \cdot p_{O_2}}$

☒ **B** $\dfrac{p_{SO_3}}{p_{SO_2} \cdot p^{\frac{1}{2}}_{O_2}}$

☒ **C** $\dfrac{p^2_{SO_2} \cdot p_{O_2}}{p^2_{SO_3}}$

☒ **D** $\dfrac{p_{SO_2} \cdot p^{\frac{1}{2}}_{O_2}}{p_{SO_3}}$

(b) State what the value of K_p suggests about the relative amounts of the components in the equilibrium mixture at 298 K.

(1)

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(c) Explain, in terms of K_p, how an increase in temperature will affect the yield of sulfur trioxide in the equilibrium mixture.

(2)

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(d) Calculate the value for $\Delta_r G^{\ominus}$ at 298 K using the equation $\Delta_r G^{\ominus} = -RT \ln K_p$.
Hence confirm the thermodynamic feasibility of the reaction at this temperature.

(2)

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(e) Give a reason why, in industry, the reaction is carried out at a temperature of 687 K.

(1)

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(Total for Question 9 = 7 marks)

10 Sulfur dioxide is used as a preservative in wine. It kills bacteria and helps to prevent premature oxidation of the alcohol. However, if the concentration of the sulfur dioxide is too high, the taste and smell of the wine are adversely affected. The European Wine Regulations fix the maximum concentration for sweet white wine at 400 mg dm^{-3}.

The concentration of sulfur dioxide in a sample of wine can be determined by the Ripper method, which makes use of a technique known as back-titration.

Sulfur dioxide and iodine react in aqueous solution according to the equation:

$$SO_2(aq) + I_2(aq) + 2H_2O(l) \rightarrow H_2SO_4(aq) + 2HI(aq)$$

A 10.0 cm^3 sample of sweet white wine is treated with 10.0 cm^3 of 0.00500 mol dm^{-3} (an excess) of iodine solution.

After the reaction with sulfur dioxide is complete, the remaining iodine is titrated with 0.00100 mol dm^{-3} sodium thiosulfate, using a suitable indicator.

38.70 cm^3 of the sodium thiosulfate solution is required.

(a) Name a suitable indicator for this titration and state the colour change observed at the end-point.

(2)

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(b) Complete the ionic equation for the reaction between sodium thiosulfate and iodine. State symbols are not required.

(1)

$$2S_2O_3^{2-} + I_2 \rightarrow \text{.....} + \text{.....}$$

(c) Use the data provided to deduce whether this sweet white wine may be sold within the European Union.

(6)

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(Total for Question 10 = 9 marks)

TOTAL FOR PAPER = 90 MARKS