Please check the examination details below before entering your candidate information

Candidate surname	Other names
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Pearson Edexcel Level 3 GCE

Tuesday 10 June 2025

Morning (Time: 1 hour 45 minutes)

Paper reference **9CH0/01**

Chemistry

Advanced

PAPER 1: Advanced Inorganic and Physical Chemistry

You must have:
Scientific calculator, Data Booklet, ruler

Total Marks

Instructions

- Use **black** ink or ball-point pen.
- If pencil is used for diagrams/sketches/graphs it must be dark (HB or B).
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions.
- Answer the questions in the spaces provided
  – *there may be more space than you need.*

Information

- The total mark for this paper is 90.
- The marks for **each** question are shown in brackets
  – *use this as a guide as to how much time to spend on each question.*
- For the question marked with an **asterisk** (*), marks will be awarded for your ability to structure your answer logically, showing how the points that you make are related or follow on from each other where appropriate.
- A Periodic Table is printed on the back cover of this paper.

Advice

- Read each question carefully before you start to answer it.
- Show all your working in calculations and include units where appropriate.
- Check your answers if you have time at the end.

Turn over ▶

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Answer ALL questions.

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 The table shows data for the three stable isotopes of argon.

Isotope	Relative isotopic mass	Percentage abundance
^{36}Ar	35.97	0.337
^{38}Ar	37.96	0.063
^{40}Ar	39.96	99.600

(a) State what is meant by the term 'relative isotopic mass'.

(2)

The mass of an atom of an isotope (of an element),

relative to 1/12th of the mass of an atom of carbon-12.

(b) State what is meant by the term 'isotope'.
Illustrate your answer by referring to the numbers of sub-atomic particles in these isotopes of argon.

(2)

Isotopes are atoms of the same element with the same number of protons but

different numbers of neutrons.

All three isotopes have 18 protons (and 18 electrons), but ^{36}Ar has 18 neutrons, ^{38}Ar

has 20 neutrons and ^{40}Ar has 22 neutrons.

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(c) Calculate the relative atomic mass of argon.
Give your answer to **two** decimal places.

(2)

$$A_r = \frac{(35.97 \times 0.337) + (37.96 \times 0.063) + (39.96 \times 99.600)}{100}$$

$= 3994.529 \div 100 = 39.945$

$A_r = 39.95$

(Total for Question 1 = 6 marks)

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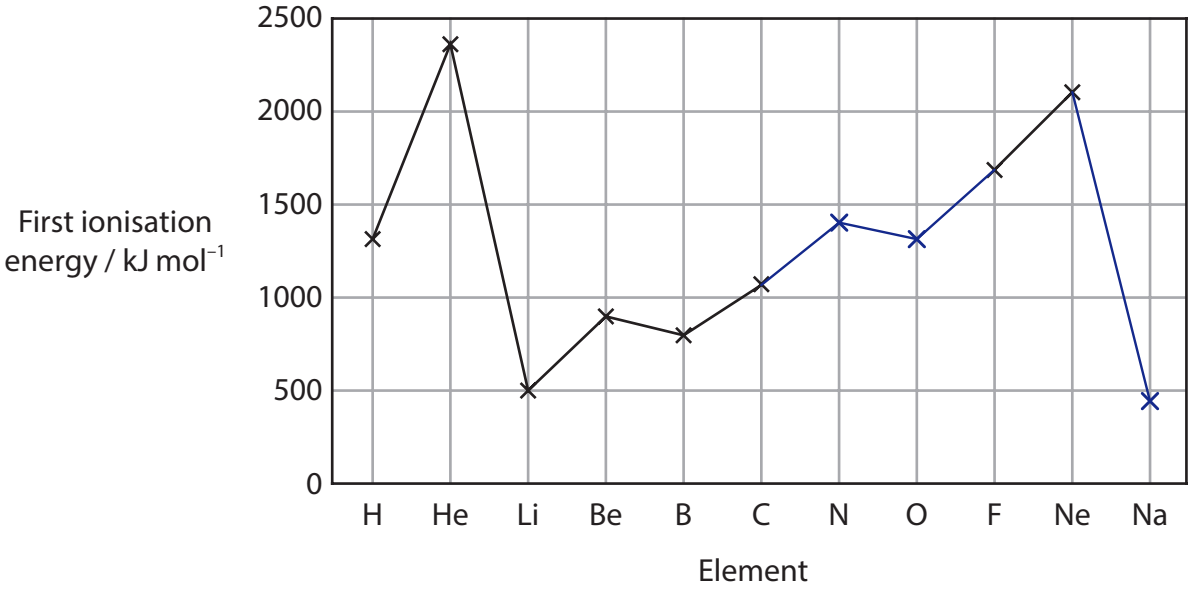
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2 This question is about some trends in properties of elements and compounds.

(a) The trend in the first ionisation energies for some of the first eleven elements is shown.

Complete the graph by including the points for nitrogen, oxygen, and sodium.

(3)



(b) Explain why the first ionisation energy of beryllium is higher than the first ionisation energy of both lithium and boron.

(4)

Beryllium has one more proton than lithium, so it has a higher nuclear charge.

In both atoms the outer electron is in the 2s orbital, so the shielding is similar and the outer electron is a similar distance from the nucleus. So more energy is needed to remove the outer electron from beryllium.

In boron the outer electron is in a 2p orbital (subshell), which is higher in energy than the 2s orbital in beryllium.

The effect of the extra proton in boron is outweighed by the increased shielding (from the inner 2s subshell), so less energy is needed to remove the outer electron from boron than from beryllium.

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(c) Write the equation for the **second** ionisation energy of beryllium.
Include state symbols.

(1)

$Be^+(g) \rightarrow Be^{2+}(g) + e^-$

(d) Which orbital is an electron removed from during the second ionisation of calcium?

(1)

- ☐ **A** 3s
- ☐ **B** 3p
- ☒ **C** 4s
- ☐ **D** 4p

(e) Which of these isoelectronic ions has the **largest** ionic radius?

(1)

- ☒ **A** S^{2-}
- ☐ **B** Cl^-
- ☐ **C** K^+
- ☐ **D** Ca^{2+}

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(f) Discuss the reasons for the differences between the boiling temperatures of the compounds in the table.
Refer to intermolecular forces in your answer.
Detailed descriptions of how these forces arise are not required.

(6)

Compound	Boiling temperature / K
water (H_2O)	373
hydrogen fluoride (HF)	293
hydrogen chloride (HCl)	188
hydrogen iodide (HI)	238

Hydrogen bonding is the strongest type of intermolecular force, so H_2O and HF have the highest boiling temperatures. There are hydrogen bonds between H_2O molecules and between HF molecules, and these need the most energy to overcome.

Water has a higher boiling temperature than HF because each H_2O molecule can form two hydrogen bonds (twice as many as HF), as the oxygen has two lone pairs and there are two H atoms. So more energy is needed to break the hydrogen bonds in water.

HCl and HI cannot form hydrogen bonds. There are permanent dipole-dipole forces between HCl molecules, because of the large electronegativity difference between H and Cl (as well as London forces).

HI has more electrons per molecule than HCl, so there are stronger London forces between HI molecules than between HCl molecules.

The increased London forces between HI molecules outweigh the permanent dipole forces between HCl molecules, so more energy is needed to overcome the intermolecular forces in HI and its boiling temperature is higher than that of HCl.

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(Total for Question 2 = 16 marks)

3 A student carried out an investigation to determine indirectly the enthalpy change for the thermal decomposition of calcium carbonate. The reaction equation is shown.

Reaction **1**: $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$ $\Delta_r H_1$

(a) State why the enthalpy change for the thermal decomposition of calcium carbonate cannot be determined directly.

(1)

Heat must be supplied, so the temperature change measured is not just due to the decomposition (and it is hard to tell when the reaction is complete).

(b) The student placed a known mass of calcium carbonate in a polystyrene cup. 30.0 cm^3 of hydrochloric acid of concentration 3.00 mol dm^{-3} was added. The mixture was stirred, and the highest temperature reached was recorded.

The equation for the reaction is shown.

Reaction **2**: $CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$

(i) Complete the missing data in the table for Reaction **2**.

(1)

Measurement	Value
Mass of weighing boat with calcium carbonate / g	4.30
Mass of weighing boat after emptying out calcium carbonate / g	0.20
Mass of calcium carbonate used / g	*4.10*
Temperature at the start / °C	19.0
Highest temperature / °C	*24.5*
Temperature change / °C	5.5

(ii) 0.041 mol of $CaCO_3(s)$ was used in the experiment.

Show, by calculation, that the hydrochloric acid is in excess for Reaction **2**.

(2)

mol HCl = 3.00 × 30.0 ÷ 1000 = 0.0900 mol

mol HCl needed = 2 × 0.041 = 0.082 mol

0.0900 mol > 0.082 mol, so the hydrochloric acid is in excess

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(iii) Calculate the enthalpy change, $\Delta_r H_2$, for Reaction **2** in kJ mol^{-1}.
Include a sign in your answer.

[Assume the specific heat capacity of the solution = 4.18 J g^{-1} °C^{-1}
and the mass of the solution = 30 g]

(3)

$Q = mc\Delta T = 30 \times 4.18 \times 5.5 = 689.7\ J = 0.6897\ kJ$

$\Delta_r H_2 = -0.6897 \div 0.041$

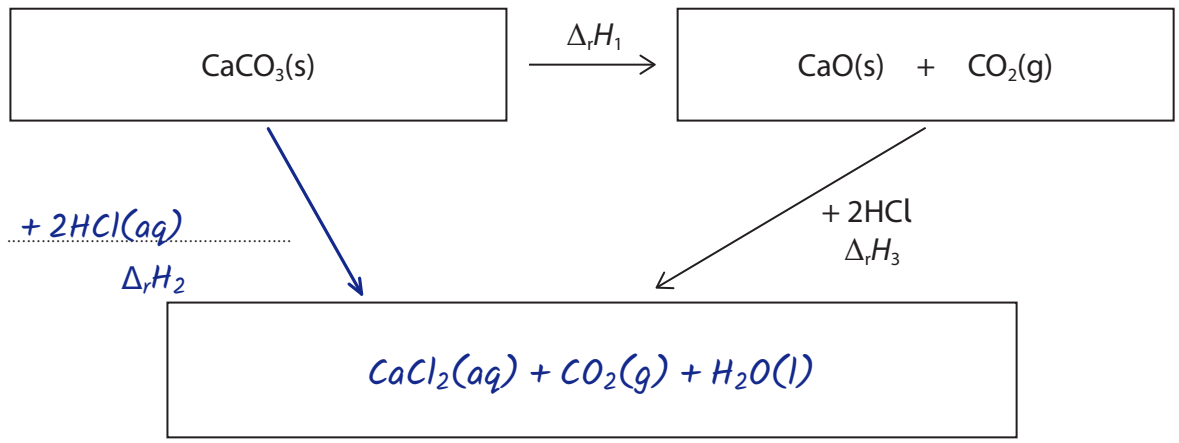
$\Delta_r H_2 = -16.8\ kJ\ mol^{-1}$

(iv) The student carried out a similar procedure with calcium oxide.
The enthalpy change, $\Delta_r H_3$, calculated for Reaction **3** was −176.3 kJ mol^{-1}.

Reaction **3**: $CaO(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l)$

Complete the enthalpy cycle.
Include the correct substances with state symbols in the lower box.
Add an appropriately labelled arrow.

(2)



(v) Calculate a value for the enthalpy change $\Delta_r H_1$ for the thermal decomposition of calcium carbonate by using your cycle.

(1)

$\Delta_r H_1 = \Delta_r H_2 - \Delta_r H_3 = -16.8 - (-176.3)$

$\Delta_r H_1 = +159.5\ kJ\ mol^{-1}$

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(c) A data book value for the thermal decomposition of calcium carbonate, $\Delta_r H^{\ominus}$ (Reaction **1**), under standard conditions is +178.2 kJ mol^{-1}.

(i) Deduce the feasibility of the thermal decomposition of calcium carbonate at 298 K using the data in the table.

(3)

Compound	Entropy / J K^{-1} mol^{-1}
calcium carbonate, $CaCO_3(s)$	92.9
calcium oxide, CaO(s)	39.7
carbon dioxide, $CO_2(g)$	213.6

$\Delta S_{system} = (39.7 + 213.6) - 92.9 = +160.4$ J K^{-1} mol^{-1}

$\Delta G = \Delta H - T\Delta S_{system} = 178.2 - (298 \times 0.1604)$

$\Delta G = +130.4$ kJ mol^{-1}

ΔG is positive (> 0), so the decomposition is not feasible at 298 K.

(ii) Calculate the **minimum** temperature, in **°C**, at which thermal decomposition would occur.
Give your answer to 3 significant figures.

(2)

For feasibility $\Delta G = 0$, so $T = \Delta H \div \Delta S_{system}$

$T = 178.2 \div 0.1604 = 1111$ K

$1111 - 273 = 838$ °C

Minimum temperature = 838 °C

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(d) Explain why magnesium carbonate undergoes thermal decomposition at a **lower** temperature than calcium carbonate.

(3)

Mg^{2+} has a smaller ionic radius than Ca^{2+} (with the same charge), so Mg^{2+} has a greater charge density.

So Mg^{2+} polarises the carbonate ion, CO_3^{2-}, more (it distorts the anion's electron cloud more).

This weakens the C–O bonds within the carbonate ion more in $MgCO_3$, so less energy is needed to break them and magnesium carbonate decomposes at a lower temperature.

(Total for Question 3 = 18 marks)

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4 Ethanol is made industrially by the reaction of ethene and steam.
The equation is shown.

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g) \qquad \Delta H = -45.0\,kJ\,mol^{-1}$$

The catalyst used is phosphoric acid, H_3PO_4, which is bound to a solid silicon dioxide support.

90.0 mol of ethene and 54.0 mol of steam are mixed in a sealed reactor at 500 K. At equilibrium, the total pressure is 60.0 atm and 5% of the ethene has been converted into ethanol.

(a) Calculate the value of K_p at this temperature.
Include the expression for K_p and units as appropriate.

(5)

Ethene converted = 5% × 90.0 = 4.5 mol

At equilibrium: C_2H_4 = 90.0 − 4.5 = 85.5 mol

H_2O = 54.0 − 4.5 = 49.5 mol C_2H_5OH = 4.5 mol

Total moles = 85.5 + 49.5 + 4.5 = 139.5 mol

Mole fractions: C_2H_4 = 85.5 ÷ 139.5 = 0.6129

H_2O = 49.5 ÷ 139.5 = 0.3548 C_2H_5OH = 4.5 ÷ 139.5 = 0.0323

Partial pressures: $p(C_2H_4)$ = 0.6129 × 60.0 = 36.77 atm

$p(H_2O)$ = 0.3548 × 60.0 = 21.29 atm

$p(C_2H_5OH)$ = 0.0323 × 60.0 = 1.94 atm

$$K_p = \frac{p(C_2H_5OH)}{p(C_2H_4) \times p(H_2O)}$$

$$K_p = \frac{1.94}{36.77 \times 21.29} = 0.00247$$

$$K_p = 2.47 \times 10^{-3}\ atm^{-1}$$

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(b) (i) It is proposed to increase the pressure in the reactor to 70.0 atm.

Explain the effect this change would have on the yield of ethanol by referring to the equilibrium.

(2)

The yield of ethanol would increase.

The position of equilibrium shifts to the right (forward direction), as there are fewer moles of gas on the right-hand side (2 mol of gas on the left, 1 mol on the right).

(ii) Which of these factors would change the value of K_p?

(1)

- ☒ **A** using a different catalyst
- ☒ **B** increasing the pressure
- ☒ **C** decreasing the temperature
- ☒ **D** increasing the volume of the reaction vessel

(Total for Question 4 = 8 marks)

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5 This question is about acids and bases.

(a) The reaction of nitric acid with water can be represented by the equation shown.

$$HNO_3(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + NO_3^-(aq)$$

Which is a conjugate acid–base pair for the reaction?

(1)

		Acid	Conjugate base
☒	**A**	HNO_3	H_2O
☒	**B**	NO_3^-	HNO_3
☒	**C**	H_3O^+	H_2O
☒	**D**	H_2O	H_3O^+

(b) State the expression that defines the pH of a solution.

(1)

$pH = -\log_{10}[H^+(aq)]$

(c) What is the concentration of $OH^-(aq)$ ions, in mol dm^{-3}, in a solution of $Ba(OH)_2(aq)$ with pH = 9.50 at 298 K?

(1)

☒ **A** 3.16×10^{-10}

☒ **B** 3.16×10^{-5}

☒ **C** 6.32×10^{-5}

☒ **D** 3.16×10^{4}

(Total for Question 5 = 3 marks)

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6 This question is about transition metals.

(a) (i) Which pair of electronic configurations is correct?

(1)

		Cr	Cr^{3+}
☒	**A**	[Ar] $3d^4 4s^2$	[Ar] $3d^1 4s^2$
☒	**B**	[Ar] $3d^5 4s^1$	[Ar] $3d^1 4s^2$
☒	**C**	[Ar] $3d^4 4s^2$	[Ar] $3d^3$
☒	**D**	[Ar] $3d^5 4s^1$	[Ar] $3d^3$

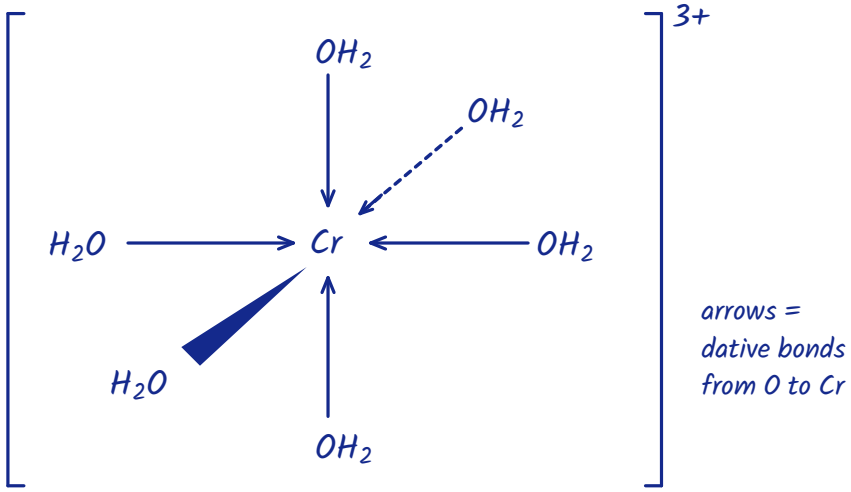
(ii) State why chromium is classified as a transition metal.

(1)

It forms a stable ion (Cr^{3+}) with an incompletely filled d-subshell (d-orbitals).

(b) (i) Draw the structure of the complex ion, $[Cr(H_2O)_6]^{3+}(aq)$, showing clearly its 3-dimensional shape, and the bonds between the chromium ion and the water ligands.

(2)



(ii) Name the **shape** of the $[Cr(H_2O)_6]^{3+}(aq)$ complex ion.

(1)

octahedral

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(c) Write **two ionic** equations which demonstrate the amphoteric nature of chromium(III) hydroxide $[Cr(OH)_3(H_2O)_3]$.
Include state symbols.

(3)

$[Cr(OH)_3(H_2O)_3](s) + 3H^+(aq) \rightarrow [Cr(H_2O)_6]^{3+}(aq)$

$[Cr(OH)_3(H_2O)_3](s) + 3OH^-(aq) \rightarrow [Cr(OH)_6]^{3-}(aq) + 3H_2O(l)$

(d) Name the type of reaction that occurs when chromium(III) hydroxide reacts with excess aqueous ammonia.

(1)

ligand exchange (ligand substitution)

(e) (i) Explain why aqueous solutions of $[Cr(H_2O)_6]^{3+}$ are coloured.

(4)

When the six water ligands bond to the Cr^{3+} ion, the d-orbitals split into two groups with different energies (higher and lower energy levels).

Electrons in the lower energy d-orbitals absorb energy from visible light (photons of a specific frequency) and are promoted (excited) to the higher energy d-orbitals, a d-d transition.

The remaining light is transmitted (or reflected), so we see the complementary colour to the light absorbed.

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(ii) Give the reason why the solutions of $[Cr(H_2O)_6]^{3+}$ and $[CrCl_4]^-$ are **different** colours.

(1)

The ligands (and the coordination number) are different, so the energy gap (splitting, ΔE) between the d-orbitals is different and a different frequency of light is absorbed.

(f) The standard electrode potentials for two half-cell reactions are shown.

$CrO_4^{2-}(aq) + 4H_2O(l) + 3e^- \rightleftharpoons Cr(OH)_3(s) + 5OH^-(aq)$ $\quad E^\ominus = -0.13\,V$

$H_2O_2(aq) + 2e^- \rightleftharpoons 2OH^-(aq)$ $\quad E^\ominus = +0.88\,V$

(i) Write the overall equation for the reaction of chromium(III) hydroxide with hydrogen peroxide in alkaline conditions to form chromate(VI) ions.
State symbols are not required.

(2)

$2Cr(OH)_3 + 10OH^- \rightarrow 2CrO_4^{2-} + 8H_2O + 6e^-$

$3H_2O_2 + 6e^- \rightarrow 6OH^-$

$2Cr(OH)_3 + 3H_2O_2 + 4OH^- \rightarrow 2CrO_4^{2-} + 8H_2O$

(ii) Calculate the $E^\ominus_{cell}$ for this reaction.
Include a reason whether or not the reaction is thermodynamically feasible.

(2)

$E^\ominus_{cell} = E^\ominus(reduced) - E^\ominus(oxidised) = +0.88 - (-0.13)$

$E^\ominus_{cell} = +1.01\,V$

$E^\ominus_{cell}$ is positive (> 0), so the reaction is thermodynamically feasible.

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(iii) Which is a correct statement about $E^{\ominus}_{cell}$?

(1)

☒ **A** $E^{\ominus}_{cell}$ is directly proportional to ln K

☒ **B** $E^{\ominus}_{cell}$ is directly proportional to ΔS_{system}

☒ **C** $E^{\ominus}_{cell}$ is directly proportional to ln ΔS_{total}

☒ **D** $E^{\ominus}_{cell}$ is directly proportional to K

(Total for Question 6 = 19 marks)

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7 This question is about lattice energy.

(a) Which statement defines the lattice energy of an ionic solid?

(1)

- ☐ **A** the energy absorbed when 1 mol of an ionic substance is formed from its gaseous ions
- ☐ **B** the energy change when 1 mol of an ionic substance is formed from its elements in their standard states
- ☒ **C** the energy change when 1 mol of an ionic substance is formed from its gaseous ions
- ☐ **D** the energy absorbed when 1 mol of an ionic substance is formed from its elements in their standard states

(b) Which substance has the lattice energy with the most exothermic value?

(1)

- ☒ **A** NaCl
- ☐ **B** NaI
- ☐ **C** KCl
- ☐ **D** KI

(c) Which ionic solid would have the greatest difference between the theoretical and experimental lattice energies?

(1)

- ☐ **A** NaCl
- ☒ **B** NaI
- ☐ **C** KCl
- ☐ **D** KI

(Total for Question 7 = 3 marks)

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***8** Compare and contrast the mechanisms of the catalysts in the table.
Illustrate your answer with equations that demonstrate the redox reactions involved.

(6)

Catalyst	Catalysed reaction
$V_2O_5(s)$	$SO_2(g) + \frac{1}{2}O_2(g) \rightarrow SO_3(g)$
$Fe^{2+}(aq)$	$S_2O_8^{2-}(aq) + 2I^-(aq) \rightarrow I_2(aq) + 2SO_4^{2-}(aq)$

Both catalysts increase the rate of reaction by providing an alternative pathway (route) with a lower activation energy.

In both, the catalyst changes oxidation number and then returns to its original oxidation number, so it is regenerated at the end.

However, V_2O_5 is a heterogeneous catalyst, as it is a solid while the reactants are gases (different phase), whereas Fe^{2+} is a homogeneous catalyst, as it is in the same (aqueous) phase as the reactants.

With V_2O_5, SO_2 and O_2 adsorb onto the catalyst surface, bonds in the reactants weaken and break, and the product SO_3 then desorbs.

V_2O_5 oxidises SO_2 and is reduced from V(+5) to V(+4):

$V_2O_5(s) + SO_2(g) \rightarrow V_2O_4(s) + SO_3(g)$

V_2O_4 is then oxidised back to V_2O_5 by oxygen:

$V_2O_4(s) + \frac{1}{2}O_2(g) \rightarrow V_2O_5(s)$

Without a catalyst, $S_2O_8^{2-}$ and I^- react slowly because both are negative ions and repel each other. The positive Fe^{2+} ions attract the negative $S_2O_8^{2-}$ ions.

Fe^{2+} is oxidised to Fe^{3+} by the peroxodisulfate ions:

$S_2O_8^{2-}(aq) + 2Fe^{2+}(aq) \rightarrow 2Fe^{3+}(aq) + 2SO_4^{2-}(aq)$

The positive Fe^{3+} ions then attract and oxidise the negative I^- ions, so Fe^{3+} is reduced back to Fe^{2+}:

$2Fe^{3+}(aq) + 2I^-(aq) \rightarrow I_2(aq) + 2Fe^{2+}(aq)$

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So in both cases the overall reaction happens in two redox steps and the catalyst is not used up.

(Total for Question 8 = 6 marks)

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9 Some hand sanitisers contain hydrogen peroxide (H_2O_2) as an active ingredient. The World Health Organization recommends that the concentration of H_2O_2 is between 3.0% and 6.0% by mass.

A higher concentration results in the hand sanitiser being caustic.
A lower concentration means the sanitiser would not be effective.

A sample of a colourless hand sanitiser of density 0.82 g cm^{-3} was analysed.

10.00 cm^3 of the sanitiser was dissolved in deionised water to give a total volume of 250.0 cm^3. An acidified solution of potassium manganate(VII) with a concentration of 0.0200 mol dm^{-3} was titrated against a 25.00 cm^3 sample of the diluted hand sanitiser solution.

(a) The results of four titrations are shown in the table.

Complete the table by calculating the missing values.

(1)

Titration number	1	2	3	4
Final burette reading / cm^3	15.90	24.00	15.30	25.00
Initial burette reading / cm^3	0.00	8.45	0.05	9.35
Titre / cm^3	15.90	15.55	15.25	15.65

(b) The mean titre was calculated to be 15.60 cm^3.

State how this value was determined.

(1)

It is the mean of the concordant titres, titres 2 and 4:

$(15.55 + 15.65) \div 2 = 15.60\ cm^3$

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(c) The ionic equation for the titration reaction is shown.

$$2MnO_4^- + 5H_2O_2 + 6H^+ \rightarrow 2Mn^{2+} + 5O_2 + 8H_2O$$

State the colour change that would be seen in the **flask** at the end-point of this titration.

(2)

From *colourless* to *(pale) pink*

(d) Deduce by calculation whether the concentration of hydrogen peroxide in the hand sanitiser is within World Health Organization guidelines.

(5)

mol MnO_4^- = 0.0200 × 15.60 ÷ 1000 = 3.12×10^{-4} mol

mol H_2O_2 in 25.00 cm^3 = 3.12×10^{-4} × 5/2 = 7.80×10^{-4} mol

mol H_2O_2 in 250.0 cm^3 (= in 10.00 cm^3 of sanitiser)

= $7.80 \times 10^{-4} \times 10 = 7.80 \times 10^{-3}$ mol

mass H_2O_2 = $7.80 \times 10^{-3} \times 34.0$ = 0.2652 g

mass of 10.00 cm^3 sanitiser = 10.00 × 0.82 = 8.2 g

% by mass of H_2O_2 = 0.2652 ÷ 8.2 × 100 = 3.23 %

3.23 % is between 3.0 % and 6.0 %, so it is within the World Health Organization guidelines.

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(e) The uncertainty in the pipette volume is ± 0.04 cm^3. The uncertainty in each burette reading is ± 0.05 cm^3.

Calculate the percentage uncertainties for the pipette volume of 25.00 cm^3 and the burette volume of 15.55 cm^3 for titre 2.

(2)

pipette: 0.04 ÷ 25.00 × 100 = ± 0.16 %

burette: (2 × 0.05) ÷ 15.55 × 100 = ± 0.643 %

(Total for Question 9 = 11 marks)

TOTAL FOR PAPER = 90 MARKS

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The Periodic Table of Elements

1	2											3	4	5	6	7	0 (8)
							1.0 H hydrogen 1										(18) 4.0 He helium 2
(1)	(2)		Key									(13)	(14)	(15)	(16)	(17)	
6.9 Li lithium 3	9.0 Be beryllium 4		relative atomic mass atomic symbol name atomic (proton) number									10.8 B boron 5	12.0 C carbon 6	14.0 N nitrogen 7	16.0 O oxygen 8	19.0 F fluorine 9	20.2 Ne neon 10
23.0 Na sodium 11	24.3 Mg magnesium 12	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	27.0 Al aluminium 13	28.1 Si silicon 14	31.0 P phosphorus 15	32.1 S sulfur 16	35.5 Cl chlorine 17	39.9 Ar argon 18
39.1 K potassium 19	40.1 Ca calcium 20	45.0 Sc scandium 21	47.9 Ti titanium 22	50.9 V vanadium 23	52.0 Cr chromium 24	54.9 Mn manganese 25	55.8 Fe iron 26	58.9 Co cobalt 27	58.7 Ni nickel 28	63.5 Cu copper 29	65.4 Zn zinc 30	69.7 Ga gallium 31	72.6 Ge germanium 32	74.9 As arsenic 33	79.0 Se selenium 34	79.9 Br bromine 35	83.8 Kr krypton 36
85.5 Rb rubidium 37	87.6 Sr strontium 38	88.9 Y yttrium 39	91.2 Zr zirconium 40	92.9 Nb niobium 41	95.9 Mo molybdenum 42	[98] Tc technetium 43	101.1 Ru ruthenium 44	102.9 Rh rhodium 45	106.4 Pd palladium 46	107.9 Ag silver 47	112.4 Cd cadmium 48	114.8 In indium 49	118.7 Sn tin 50	121.8 Sb antimony 51	127.6 Te tellurium 52	126.9 I iodine 53	131.3 Xe xenon 54
132.9 Cs caesium 55	137.3 Ba barium 56	138.9 La* lanthanum 57	178.5 Hf hafnium 72	180.9 Ta tantalum 73	183.8 W tungsten 74	186.2 Re rhenium 75	190.2 Os osmium 76	192.2 Ir iridium 77	195.1 Pt platinum 78	197.0 Au gold 79	200.6 Hg mercury 80	204.4 Tl thallium 81	207.2 Pb lead 82	209.0 Bi bismuth 83	[209] Po polonium 84	[210] At astatine 85	[222] Rn radon 86
[223] Fr francium 87	[226] Ra radium 88	[227] Ac* actinium 89	[261] Rf rutherfordium 104	[262] Db dubnium 105	[266] Sg seaborgium 106	[264] Bh bohrium 107	[277] Hs hassium 108	[268] Mt meitnerium 109	[271] Ds darmstadtium 110	[272] Rg roentgenium 111							

Elements with atomic numbers 112-116 have been reported but not fully authenticated

* Lanthanide series	140 Ce cerium 58	141 Pr praseodymium 59	144 Nd neodymium 60	[147] Pm promethium 61	150 Sm samarium 62	152 Eu europium 63	157 Gd gadolinium 64	159 Tb terbium 65	163 Dy dysprosium 66	165 Ho holmium 67	167 Er erbium 68	169 Tm thulium 69	173 Yb ytterbium 70	175 Lu lutetium 71
* Actinide series	232 Th thorium 90	[231] Pa protactinium 91	238 U uranium 92	[237] Np neptunium 93	[242] Pu plutonium 94	[243] Am americium 95	[247] Cm curium 96	[245] Bk berkelium 97	[251] Cf californium 98	[254] Es einsteinium 99	[253] Fm fermium 100	[256] Md mendelevium 101	[254] No nobelium 102	[257] Lr lawrencium 103

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