Please check the examination details below before entering your candidate information

Candidate surname	Other names
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Pearson Edexcel Level 3 GCE

Centre Number	Candidate Number

Time 1 hour 45 minutes

Paper reference **9CH0/01**

Chemistry

Advanced

PAPER 1: Advanced Inorganic and Physical Chemistry

Candidates must have: **Scientific calculator**
Data Booklet
Ruler

Total Marks

Instructions

- Use **black** ink or **black** ball-point pen.
- **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.*
- Show all your working in calculations and include units where appropriate.

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 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.
- Check your answers if you have time at the end.
- Good luck with your examination.

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 This is a question about atoms, isotopes and ions.

(a) Which of the following pairs of ions is isoelectronic?

(1)

☒ **A** N^{3-} and Cl^{-}

☒ **B** O^{2-} and S^{2-}

☒ **C** Na^{+} and K^{+}

☒ **D** Na^{+} and Mg^{2+}

(b) Which is a correct definition of relative isotopic mass?

(1)

☒ **A** the weighted mean mass of an atom of an element relative to one twelfth of the mass of an atom of the isotope carbon-12

☒ **B** the mass of one atom of an isotope relative to one twelfth of the mass of an atom of the isotope carbon-12

☒ **C** the weighted mean mass of an atom of an element relative to 12 g of the isotope carbon-12

☒ **D** the mass of one atom of an isotope relative to the mass of 12 g of the isotope carbon-12

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(c) The percentage composition of the two bromine isotopes in a sample is given in the table.

Isotope	Relative isotopic mass	Percentage abundance
bromine-79	78.918	50.52
bromine-81	80.916	49.48

Calculate the relative atomic mass of bromine in this sample.
Give your answer to two decimal places.

(2)

$A_r = [(50.52 \times 78.918) + (49.48 \times 80.916)] \div 100$

$A_r = 7990.66 \div 100 = 79.9066$

$A_r = 79.91$

(Total for Question 1 = 4 marks)

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2 Barium ions can be identified by their flame colour.

(a) Which of the following should be used for a flame test on barium carbonate?

(1)

☒ **A** iron wire and water

☒ **B** iron wire and concentrated hydrochloric acid

☒ **C** nichrome wire and water

☒ **D** nichrome wire and concentrated hydrochloric acid

(b) What colour do barium ions give in a flame test?

(1)

☒ **A** green

☒ **B** lilac

☒ **C** red

☒ **D** yellow

(c) A flame test was carried out on a mixture of barium chloride and magnesium chloride.

How does the presence of magnesium ions affect the appearance of the flame colour of barium ions?

(1)

☒ **A** the colour is more intense

☒ **B** a bright white colour completely masks the barium colour

☒ **C** there is no change

☒ **D** the barium colour is decreased by the white magnesium flame colour

(Total for Question 2 = 3 marks)

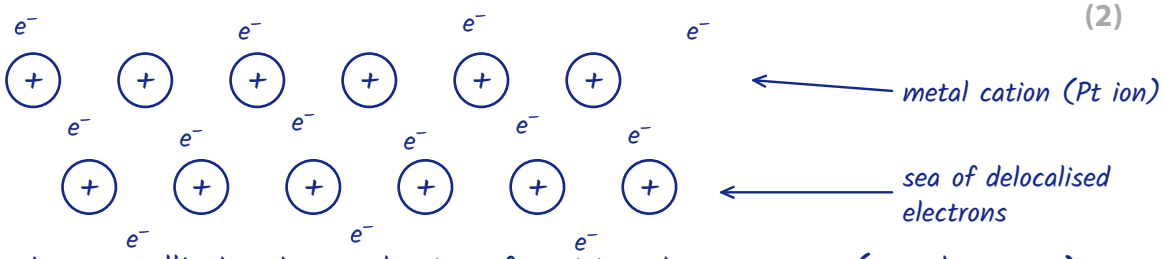
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3 This question is about catalytic converters.

(a) Catalytic converters contain metals such as platinum.

Describe the bonding in platinum.
You may include a diagram in your answer.

(2)



Platinum has metallic bonding: a lattice of positive platinum ions (metal cations) in a 'sea' of delocalised electrons.

The bonding is the strong electrostatic attraction between the metal cations and the delocalised electrons.

(b) A catalytic converter decreases the emissions of gases, such as carbon monoxide and nitrogen monoxide, from an internal combustion engine.

Describe the stages in a catalytic converter that result in this decrease.
No equations are required.

(3)

CO and NO molecules are adsorbed onto the surface of the catalyst (onto active sites on the platinum surface).

This weakens the bonds within the CO and NO molecules, so they react with each other on the catalyst surface to form CO_2 and N_2.

The product molecules, CO_2 and N_2, are then desorbed from the catalyst surface, freeing the surface for more reactant molecules.

(Total for Question 3 = 5 marks)

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4 Ionisation energies provide information about the number of electrons and the arrangement of the electrons in an atom of an element.

(a) A student's definition of first ionisation energy is shown.

> First ionisation energy is the energy released when one mole of gaseous atoms loses one mole of electrons to form one mole of gaseous 1+ ions.

There is one incorrect word in the student's definition.

Identify the word, giving the reason why this word is incorrect.

(2)

The incorrect word is 'released'.

Energy is required (absorbed) to overcome the electrostatic attraction between the nucleus and the electron, so removing an electron is endothermic.

(b) Write an equation for the **second** ionisation energy of oxygen.
Include state symbols.

(2)

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

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(c) A sodium atom has 11 protons whereas a potassium atom has 19 protons.

Explain why the first ionisation energy of sodium is greater than that of potassium.

(3)

The outer electron of a sodium atom is in the 3s sub-shell whereas in potassium it is in the 4s sub-shell, so the outer electron in sodium is closer to the nucleus (sodium atoms are smaller).

Sodium has fewer inner shells of electrons, so there is less shielding of the outer electron from the nucleus.

These factors outweigh the greater nuclear charge (more protons) of potassium, so the attraction between the nucleus and the outer electron is stronger in sodium and more energy is needed to remove it.

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(d) The successive ionisation energies for magnesium are given in the table.

Electron number removed	1	2	3	4	5	6	7	8	9	10	11	12
Ionisation energy / kJ mol^{-1}	738	1451	7733	10 541	13 629	17 995	21 704	25 657	31 644	35 463	169 996	189 371
Log (ionisation energy)	2.87	3.16	3.89	4.02	4.13	4.26	4.34	4.41	4.50	4.55	5.23	5.28

(i) Complete the table.

(1)

(ii) Give a reason why the logarithm of the ionisation energy, rather than just the ionisation energy, is used to plot a graph.

(1)

The range of ionisation energies (738 to 189 371 kJ mol^{-1}) is too large to fit on the graph axis; logarithms give a much smaller range of numbers, so all the values fit on the graph.

(iii) Give a reason why the successive ionisation energies increase.

(1)

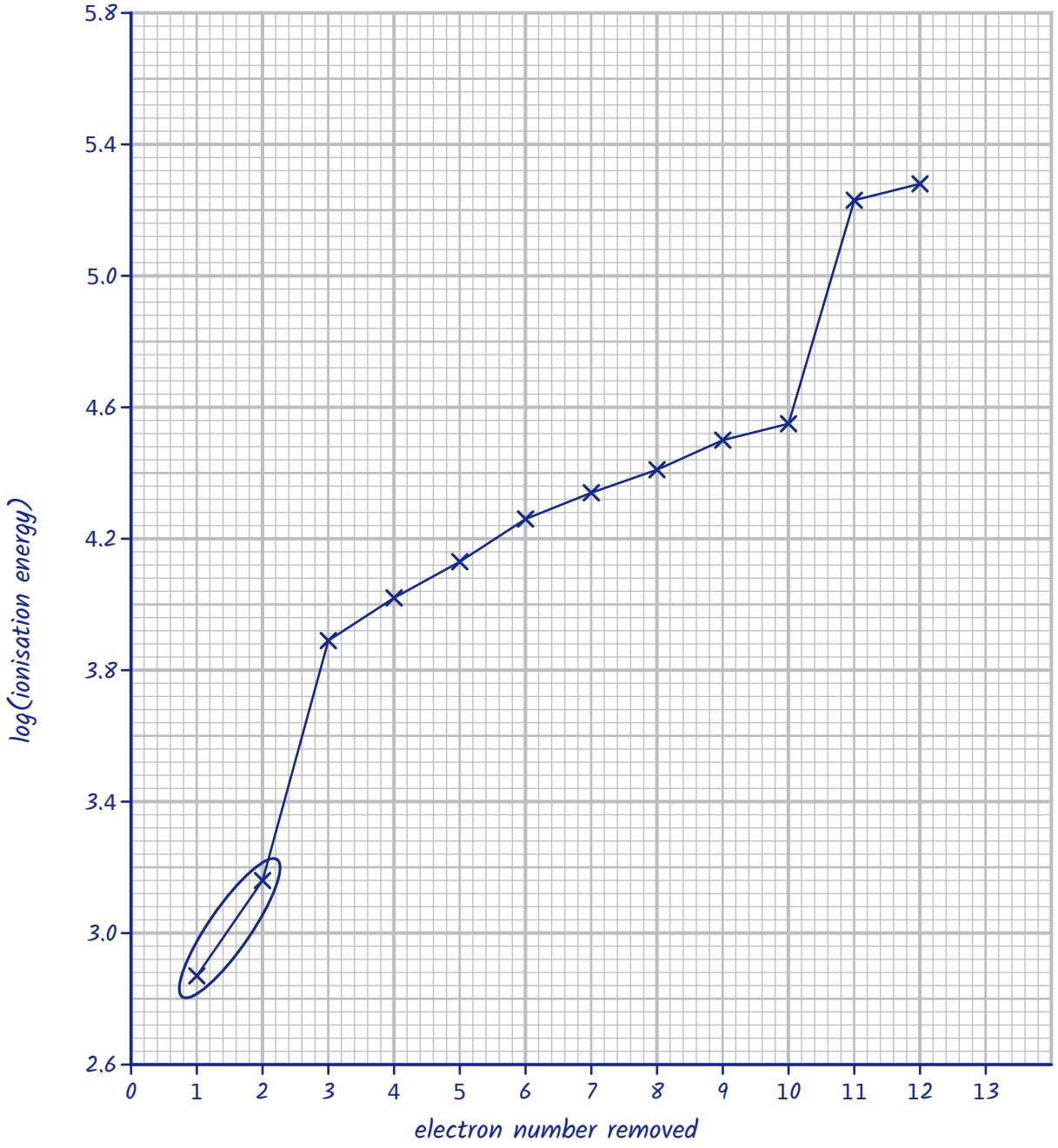
Each electron is removed from an increasingly positive ion: the same number of protons is attracting a decreasing number of electrons, so there is less electron-electron repulsion.

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(iv) Plot the graph of log(ionisation energy) against electron number removed.

Join the individual points using straight lines.

(3)



(v) Identify on the graph, using a circle, the points that represent the removal of the electrons in the **outermost** energy level of magnesium.

(1)

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(e) Estimate a value for the first ionisation energy of oxygen given the data in the table.

(1)

Element	First ionisation energy / kJ mol^{-1}
carbon	1086
nitrogen	1402
oxygen	1310

(Total for Question 4 = 15 marks)

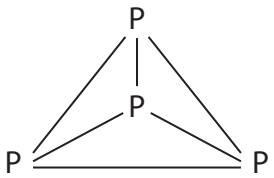
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5 The halogens are elements in Group 7 of the Periodic Table.

(a) Chlorine compounds have many uses, including water treatment.

(i) Chlorine and phosphorus (P_4) can react to form phosphorus(V) chloride.

The structure of a molecule of phosphorus is



Some mean bond enthalpy values are shown in the table.

Bond	Mean bond enthalpy / kJ mol^{-1}
P—P	+198
Cl—Cl	+243
P—Cl	+326

Calculate the enthalpy change for the reaction between chlorine and phosphorus to form phosphorus(V) chloride.

$$10Cl_2 + P_4 \rightarrow 4PCl_5$$

(3)

Bonds broken: 6 P–P + 10 Cl–Cl = (6 × 198) + (10 × 243) = 3618 kJ mol^{-1}

Bonds made: 20 P–Cl = 20 × 326 = 6520 kJ mol^{-1}

ΔH = bonds broken − bonds made = 3618 − 6520

ΔH = −2902 kJ mol^{-1}

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(ii) Give a reason why bond enthalpy values are always positive.

(1)

Breaking a bond always requires energy (bond breaking is endothermic), and bond enthalpy is the energy needed to break one mole of the bond, so the values are always positive.

(b) Sodium chlorate(I) is a bleaching agent.

(i) Sodium chlorate(I) can be made by the reaction of chlorine with sodium hydroxide.

Show, by using oxidation numbers, that this reaction is disproportionation.

$$2NaOH + Cl_2 \rightarrow NaClO + NaCl + H_2O$$

(2)

Oxidation numbers of Cl: $Cl_2 = 0$, $NaClO = +1$, $NaCl = -1$

Chlorine is oxidised from 0 to +1 (in NaClO) and reduced from 0 to −1 (in NaCl).

The same element is simultaneously oxidised and reduced, so it is disproportionation.

(ii) A different bleaching agent can be made by the reaction of chlorine with sodium hydroxide under different conditions.

Balance this equation.

$$\underline{6}\ NaOH + \underline{3}\ Cl_2 \rightarrow NaClO_3 + \underline{5}\ NaCl + \underline{3}\ H_2O$$

(1)

(iii) What conditions are required for the reaction in (b)(ii)?

(1)

- ☐ **A** cold and dilute alkali
- ☐ **B** cold and concentrated alkali
- ☒ **C** hot alkali
- ☐ **D** excess chlorine

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(c) The halogens can be identified by their colour in an organic solvent such as hexane or cyclohexane.

Which sequence of colours is correct for chlorine, bromine and iodine dissolved in an organic solvent?

(1)

	Chlorine	Bromine	Iodine
☒ **A**	orange	red-brown	black
☒ **B**	pale green	orange	black
☒ **C**	orange	red-brown	purple
☒ **D**	pale green	orange	purple

(d) Halide ions can be identified by their reaction with silver nitrate.

(i) Write the **ionic** equation for the reaction between aqueous solutions of sodium iodide and silver nitrate.
Include state symbols.

(2)

$Ag^+(aq) + I^-(aq) \rightarrow AgI(s)$

(ii) A solution containing 0.010 mol of a halide ion was reacted with excess silver nitrate and produced 1.88 g of precipitate.

Identify the halide ion.
Justify your answer.

(2)

$M(precipitate) = 1.88 \div 0.010 = 188\ g\ mol^{-1}$

$188 - 107.9\ (Ag) = 80.1$, which is the A_r of bromine

(0.010 mol AgCl = 1.43 g, AgBr = 1.88 g, AgI = 2.35 g)

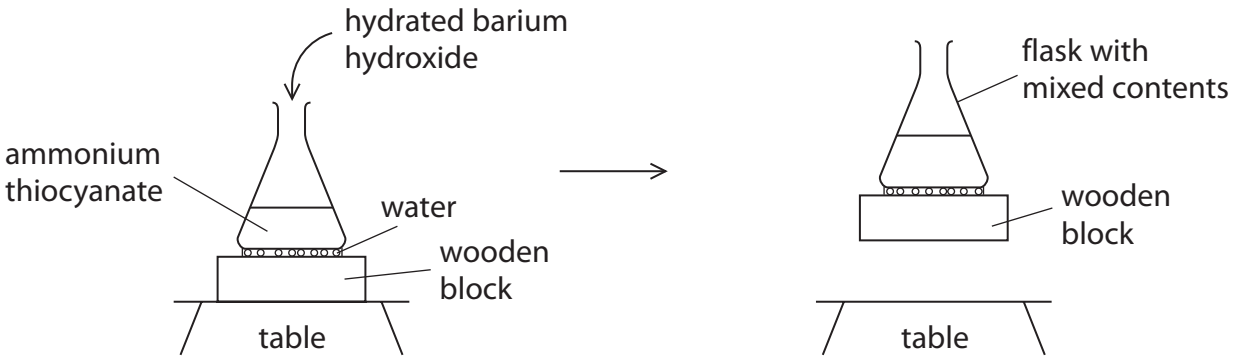
The halide ion is bromide, Br^-, as the precipitate is AgBr.

(Total for Question 5 = 13 marks)

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6 This question is about entropy.

(a) Some hydrated barium hydroxide is added to ammonium thiocyanate in a flask which is placed on a few drops of water on a wooden block. After the addition, the contents are stirred and then the flask can be lifted up with the wooden block attached, as shown.



The equation for the reaction is

$$Ba(OH)_2.8H_2O(s) + 2NH_4SCN(s) \rightarrow Ba(SCN)_2(aq) + 2NH_3(g) + 10H_2O(l)$$

(i) Give **two** reasons why you would expect $\Delta S^{\ominus}_{system}$ to be positive.

(2)

The number of moles (particles) increases, from 3 moles of reactants to 13 moles of products.

Solids react to form a solution, a gas and a liquid, which are more disordered (more ways of arranging the particles and their energy).

(ii) Explain why the wooden block is lifted up by the flask.

(2)

The reaction is endothermic, so it absorbs heat energy from the surroundings, including the water under the flask.

So the temperature falls below 0 °C and the water freezes, sticking the wooden block to the flask.

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(b) What is the standard molar entropy change, $\Delta S^{\ominus}_{system}$, in $J\,K^{-1}\,mol^{-1}$, for the reaction shown?

$$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$$

Substance	Standard molar entropy, $S^{\ominus}$ / $J\,K^{-1}\,mol^{-1}$
Mg(s)	32.7
$O_2(g)$	205.0
MgO(s)	26.9

(1)

☒ **A** +210.8

☒ **B** –210.8

☒ **C** +216.6

☒ **D** –216.6

(Total for Question 6 = 5 marks)

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7 This question is about acids and buffer solutions.

(a) Ethanoic acid, CH_3COOH, is a monobasic acid.

$$CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H_3O^+$$

Give a reason why only the proton from the carboxylic acid group, and not from the methyl group, is donated to a water molecule.

(1)

The O–H bond is polar because oxygen is much more electronegative than hydrogen, whereas the C–H bond has little polarity (C and H have similar electronegativities). Also the carboxylate ion formed is stabilised by delocalisation of its negative charge, but losing H^+ from the methyl group would give an unstabilised carbanion.

(b) The reaction of ammonia with water can be represented by

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

Which is the acid-conjugate base pair?

(1)

	Acid	Conjugate base
☒ **A**	NH_3	OH^-
☒ **B**	NH_3	NH_4^+
☒ **C**	H_2O	OH^-
☒ **D**	H_2O	NH_4^+

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(c) A commercial nitric acid solution, $HNO_3(aq)$, has a concentration of 15.9 mol dm^{-3}. A 15.0 cm^3 sample was made up to 100 cm^3 by adding deionised water.

Calculate the pH of this diluted solution.

(2)

$[HNO_3] = 15.9 \times 15.0 \div 100 = 2.385$ mol dm^{-3}

HNO_3 is a strong acid, so $[H^+] = 2.385$ mol dm^{-3}

$pH = -\log(2.385) = -0.38$

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(d) Propanoic acid is a weak acid.

(i) Calculate the pH of a 0.100 mol dm^{-3} solution of propanoic acid at 298 K. Give your answer to an appropriate number of significant figures.

[$K_a = 1.35 \times 10^{-5}$ mol dm^{-3} at 298 K]

(3)

$K_a = [H^+][C_2H_5COO^-] \div [C_2H_5COOH] = [H^+]^2 \div [C_2H_5COOH]$

$[H^+] = \sqrt{(1.35 \times 10^{-5} \times 0.100)} = \sqrt{(1.35 \times 10^{-6})}$

$[H^+] = 1.16 \times 10^{-3}$ mol dm^{-3}

$pH = -\log(1.16 \times 10^{-3}) = 2.93$

(ii) State **two** assumptions that you made in the calculation in d(i).

(2)

The equilibrium concentration of propanoic acid equals its initial concentration, 0.100 mol dm^{-3} (the dissociation of the acid is negligible).

$[H^+] = [C_2H_5COO^-]$, i.e. all the H^+ ions come from the acid and the H^+ from the ionisation of water is negligible.

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(e) A buffer solution was made using 20.0 cm^3 of a butanoic acid solution, of concentration 0.100 mol dm^{-3} and 30.0 cm^3 of sodium butanoate solution, of concentration 0.305 mol dm^{-3}.

[$K_a = 1.52 \times 10^{-5}$ mol dm^{-3} at 298K]

(i) Calculate the pH of this buffer solution at 298 K.

(4)

Total volume = 20.0 + 30.0 = 50.0 cm^3

[acid] = 0.100 × 20.0 ÷ 50.0 = 0.0400 mol dm^{-3}

[salt] = 0.305 × 30.0 ÷ 50.0 = 0.183 mol dm^{-3}

$[H^+] = K_a \times [acid] \div [salt] = 1.52 \times 10^{-5} \times 0.0400 \div 0.183$

$[H^+] = 3.32 \times 10^{-6}$ mol dm^{-3}

$pH = -\log(3.32 \times 10^{-6}) = 5.48$

(ii) Explain why the pH of the buffer solution hardly changes when a few drops of sodium hydroxide solution are added to it.
Include an equation or equations in your answer.
Use C_3H_7COOH as the formula for butanoic acid.

(2)

$C_3H_7COOH + OH^- \rightarrow C_3H_7COO^- + H_2O$

The added OH^- ions are removed by reacting with the large reservoir of undissociated butanoic acid.

There is a large excess of acid and salt compared with the OH^- added, so the ratio [acid] : [salt] hardly changes, so $[H^+]$ and the pH stay almost constant.

(Total for Question 7 = 15 marks)

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8 Transition metals form complex ions.

(a) Complex ions have a central metal ion surrounded by ligands.

(i) Give a reason why the ammonium ion cannot act as a ligand.

(1)

The ammonium ion, NH_4^+, has no lone pair of electrons to form a dative (coordinate) bond to the metal ion.

(ii) Explain why the complex ions $[Co(NH_3)_6]^{2+}$ and $[Co(H_2O)_6]^{2+}$ are coloured and have different colours.

(4)

The ligands cause the 3d orbitals of the Co^{2+} ion to split into two different energy levels.

Electrons are promoted from the lower to the higher energy d orbitals by absorbing photons of visible light of a particular frequency.

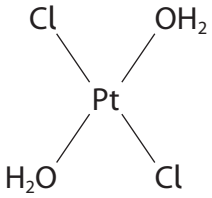
The frequencies of light that are not absorbed are transmitted (or reflected), and this is the colour seen, so both ions are coloured.

The size of the energy gap depends on the ligand: NH_3 and H_2O split the d orbitals by different amounts, so different frequencies (wavelengths) of light are absorbed and the two complexes have different colours.

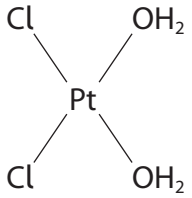
(b) Which of these complexes is used in the treatment of cancer?

(1)

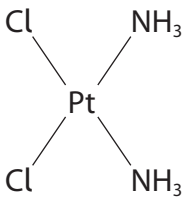
☒ **A**



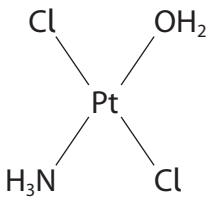
☒ **B**



☒ **C**



☒ **D**



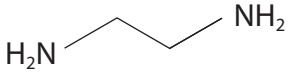
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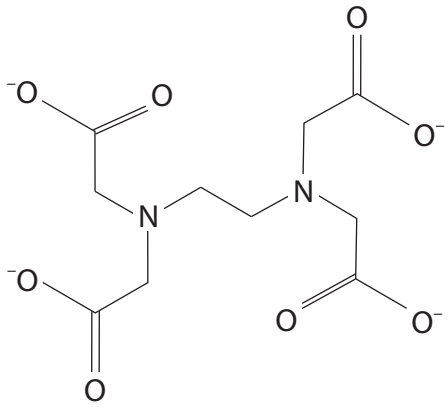
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(c) Compare and contrast the complex ions formed by cobalt(III) ions with the ligand ethane-1,2-diamine and with the ligand $EDTA^{4-}$.

Ignore any difference in colour.



ethane-1,2-diamine



$EDTA^{4-}$

(4)

Similarities: both ligands form dative covalent bonds to the Co^{3+} ion by donating lone pairs of electrons; both complexes have a coordination number of 6 and are octahedral.

Differences: ethane-1,2-diamine is bidentate, so three ligands bond to each Co^{3+} ion (ratio 1 : 3), but $EDTA^{4-}$ is hexadentate, so only one ligand bonds (ratio 1 : 1).

The ethane-1,2-diamine complex is a positive ion (cation), as the ligand is neutral, whereas the EDTA complex is a negative ion (anion).

The EDTA complex is more stable, because there is a greater increase in entropy when it forms (more particles are released).

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(d) Hydrated chromium(III) chloride, $CrCl_3.6H_2O$, dissolves in water to form a number of different complex ions containing both chloride and water ligands.

The general formula of these complex ions is $[Cr(H_2O)_x(Cl)_y]^{(3-y)+}$

In an experiment, 0.10 mol of a complex reacted with excess silver nitrate solution to produce 0.20 mol of silver chloride.

Chloride ions which are ligands within the complex do not react with silver nitrate.

Deduce the formula of this chromium(III) complex ion. Justify your answer.

(2)

0.10 mol of complex gives 0.20 mol AgCl, so there are 2 mol of free Cl^- ions per mole of complex.

So the complex ion has a 2+ charge: 3 − y = 2, so y = 1 and x = 5

Two moles of chloride ions are free in solution (they react with silver nitrate), so one mole of chloride ions must be a ligand within the complex.

The other five positions (coordination number 6) are occupied by water ligands, so the complex ion is $[Cr(H_2O)_5Cl]^{2+}$.

(Total for Question 8 = 12 marks)

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9 This question is about lattice energies.

(a) The table shows the theoretical and experimental lattice energy values of two compounds.

Compound	Theoretical lattice energy / kJ mol^{-1}	Experimental lattice energy / kJ mol^{-1}
magnesium iodide	–1944	–2327
barium iodide	–1831	–1877

(i) State what can be deduced by the close similarity of the lattice energy values for barium iodide.

(1)

Barium iodide is (almost) 100% ionic: the bonding has negligible covalent character, so it fits the ionic model.

(ii) Explain why there is a significant difference in the lattice energy values for magnesium iodide.

(4)

The magnesium ion, Mg^{2+}, is small and has a 2+ charge, so it has a high charge density.

The iodide ion, I^-, is large (it has a large ionic radius), so its electron cloud is easily distorted.

So the Mg^{2+} ion polarises the iodide ion, distorting the electron cloud of the I^- ion towards the Mg^{2+} ion.

So the bonding in magnesium iodide has partial covalent character. The theoretical value assumes 100% ionic bonding, so the experimental lattice energy is more exothermic than the theoretical value.

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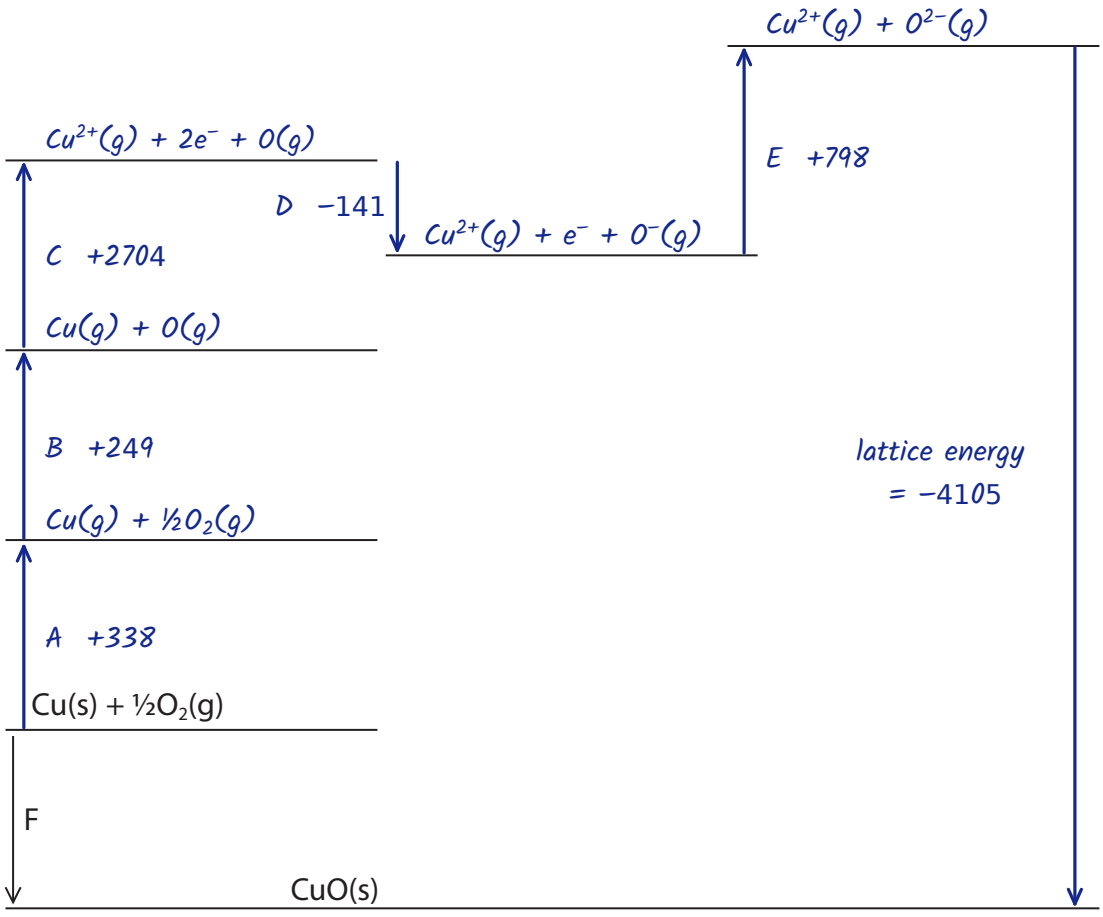
(b) Data for the Born-Haber cycle for copper(II) oxide are given in the table.

Label	Energy change	Value / kJ mol^{-1}
A	standard enthalpy change of atomisation of copper	+338
B	standard enthalpy change of atomisation of oxygen	+249
C	sum of first and second ionisation energies of copper	+2704
D	first electron affinity of oxygen	−141
E	second electron affinity of oxygen	+798
F	standard enthalpy change of formation of copper(II) oxide	−157

(i) Complete the diagram of the Born-Haber cycle for copper(II) oxide.

Include labels of enthalpy changes with arrows indicating the direction of change, and the respective species with state symbols.

(4)



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(ii) Calculate the lattice energy of copper(II) oxide.

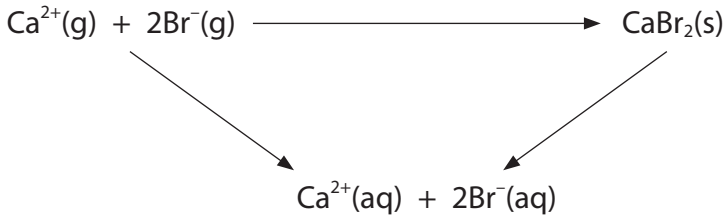
(1)

$LE = F - (A + B + C + D + E)$

$LE = -157 - (338 + 249 + 2704 - 141 + 798)$

$LE = -157 - 3948 = -4105\ kJ\ mol^{-1}$

(c) A different energy cycle can be used to calculate lattice energy.



Enthalpy change	Value / kJ mol^{-1}
enthalpy change of solution of $CaBr_2$	–73
enthalpy change of hydration of Ca^{2+}	–1577
enthalpy change of hydration of Br^-	–336

Calculate the lattice energy of calcium bromide.

(2)

Hess's law: $LE + \Delta_{sol}H = \Delta_{hyd}H(Ca^{2+}) + 2\Delta_{hyd}H(Br^-)$

$LE = -1577 + (2 \times -336) - (-73)$

$LE = -2176\ kJ\ mol^{-1}$

(Total for Question 9 = 12 marks)

*10 A student wrote:

> Whether or not a reaction occurs depends only on the thermodynamic feasibility calculated using
>
> $$\Delta G = \Delta H - T\Delta S_{system}$$

Discuss this statement.

Include reference to:

- changes in the values and signs of the terms in the equation for both endothermic and exothermic reactions
- circumstances where a reaction that is predicted to be thermodynamically feasible may not occur in practice.

(6)

For a reaction to be thermodynamically feasible, ΔG must be negative (or zero).

For an exothermic reaction ΔH is negative. If ΔS_{system} is positive, the $-T\Delta S_{system}$ term is also negative, so ΔG is always negative and the reaction is feasible at all temperatures.

If an exothermic reaction has a negative ΔS_{system}, the $-T\Delta S_{system}$ term is positive, so the reaction is only feasible when the magnitude of ΔH is greater than the magnitude of $T\Delta S_{system}$, i.e. at lower temperatures. As T increases, $T\Delta S_{system}$ gets larger until ΔG becomes positive.

For an endothermic reaction ΔH is positive. If ΔS_{system} is positive, the reaction is only feasible when the magnitude of $T\Delta S_{system}$ is greater than ΔH, so it becomes feasible above a certain temperature ($T = \Delta H \div \Delta S_{system}$).

If ΔH is positive and ΔS_{system} is negative, both terms make ΔG positive, so the reaction is never feasible at any temperature.

However, the statement is not correct, because ΔG only shows whether a reaction is thermodynamically feasible, not whether it actually takes place. A feasible reaction may not occur in practice for kinetic reasons: if the activation energy is very high, the rate is so slow that no reaction is seen, for example diamond turning into graphite, or a mixture of hydrogen and oxygen that does not react until a spark is

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applied.

A physical barrier can also stop a feasible reaction, for example the protective oxide layer on aluminium stops it reacting with water or air.

So whether a reaction occurs depends on both thermodynamic feasibility (ΔG) and kinetic factors (the activation energy).

(Total for Question 10 = 6 marks)

TOTAL FOR PAPER = 90 MARKS

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The Periodic Table of Elements

1	2											3	4	5	6	7	0 (8) (18)
							1.0 H hydrogen 1										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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