Please check the examination details below before entering your candidate information

Candidate surname	Other names

Centre Number | Candidate Number

Pearson Edexcel International Advanced Level

Friday 12 January 2024

Morning (Time: 1 hour 45 minutes) | **Paper reference** | **WCH15/01**

Chemistry

International Advanced Level
UNIT 5: Transition Metals and Organic Nitrogen 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.*
- In 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.
- Try to answer every question.
- Check your answers if you have time at the end.

Turn over ▶

Pearson

SECTION A

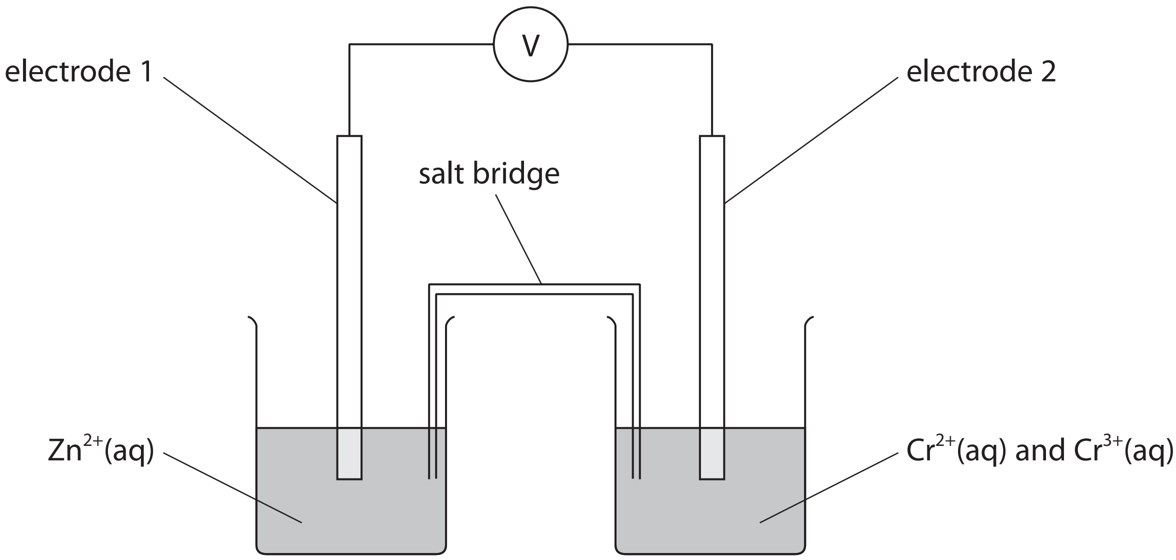
Answer ALL the questions in this section.

You should aim to spend no more than 20 minutes on this section.

For each question, select one answer from A to D and put a cross in the box ☒. If you change your mind, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 The apparatus can be used to measure $E^{\ominus}_{cell}$ for the reaction shown.

$$2Cr^{3+}(aq) + Zn(s) \rightarrow 2Cr^{2+}(aq) + Zn^{2+}(aq)$$



(a) Which electrodes are used for this cell?

(1)

		electrode 1	electrode 2
☒	**A**	platinum	platinum
☒	**B**	platinum	chromium
☒	**C**	zinc	chromium
☒	**D**	zinc	platinum

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P 7 3 4 5 7 R A 0 2 3 6

(b) A student wishes to measure the standard cell potential, $E^\ominus_{cell}$, of this cell. The right-hand cell requires Cr^{3+} and Cr^{2+} ions.

What mass of $Cr_2(SO_4)_3 \cdot 18H_2O$ must be dissolved in 1.00 dm^3 of deionised water to give the concentration of Cr^{3+} ions required to measure this $E^\ominus_{cell}$?

(1)

☒ **A** 52.0 g

☒ **B** 196 g

☒ **C** 358 g

☒ **D** 716 g

(c) What can be deduced from the fact that, for this reaction, $E^\ominus_{cell}$ is positive?

(1)

☒ **A** ΔS_{total} and ln K are positive

☒ **B** ΔS_{total} and ln K are negative

☒ **C** ΔS_{total} is positive and ln K is negative

☒ **D** ΔS_{total} is negative and ln K is positive

(Total for Question 1 = 3 marks)

Use this space for any rough working. Anything you write in this space will gain no credit.

2 The half-equations for a hydrogen-oxygen fuel cell in **alkaline** solution are shown.

$$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq) \qquad E^\ominus = -0.83\,V$$

$$\tfrac{1}{2}O_2(g) + H_2O(l) + 2e^- \rightarrow 2OH^-(aq) \qquad E^\ominus = +0.40\,V$$

(a) The equation for the overall cell reaction is

(1)

☒ **A** $3H_2O(l) + \tfrac{1}{2}O_2(g) \rightarrow H_2(g) + 4OH^-(aq)$

☒ **B** $H_2(g) + 4OH^-(aq) \rightarrow 3H_2O(l) + \tfrac{1}{2}O_2(g)$

☒ **C** $H_2(g) + \tfrac{1}{2}O_2(g) \rightarrow H_2O(l)$

☒ **D** $H_2O(l) \rightarrow H_2(g) + \tfrac{1}{2}O_2(g)$

(b) Calculate $E^\ominus_{cell}$ for the reaction occurring in the hydrogen-oxygen fuel cell, under alkaline conditions.

(1)

☒ **A** −1.23 V

☒ **B** −0.43 V

☒ **C** +0.43 V

☒ **D** +1.23 V

(Total for Question 2 = 2 marks)

Use this space for any rough working. Anything you write in this space will gain no credit.

3 Which successive ionisation energies (in $kJ\,mol^{-1}$) are most likely to be those of a transition element?

☒	**A**	578	1817	2745	11 578	14 831
☒	**B**	759	1561	2958	5290	7236
☒	**C**	789	1577	3232	4356	16 091
☒	**D**	801	2427	3660	25 026	32 828

(Total for Question 3 = 1 mark)

4 Which sequence shows the ions in order of increasing strength as a reducing agent?
Refer to your Data Booklet.

☒ **A** $V^{2+} < Fe^{2+} < Cr^{2+}$

☒ **B** $Cr^{2+} < Fe^{2+} < V^{2+}$

☒ **C** $Cr^{2+} < V^{2+} < Fe^{2+}$

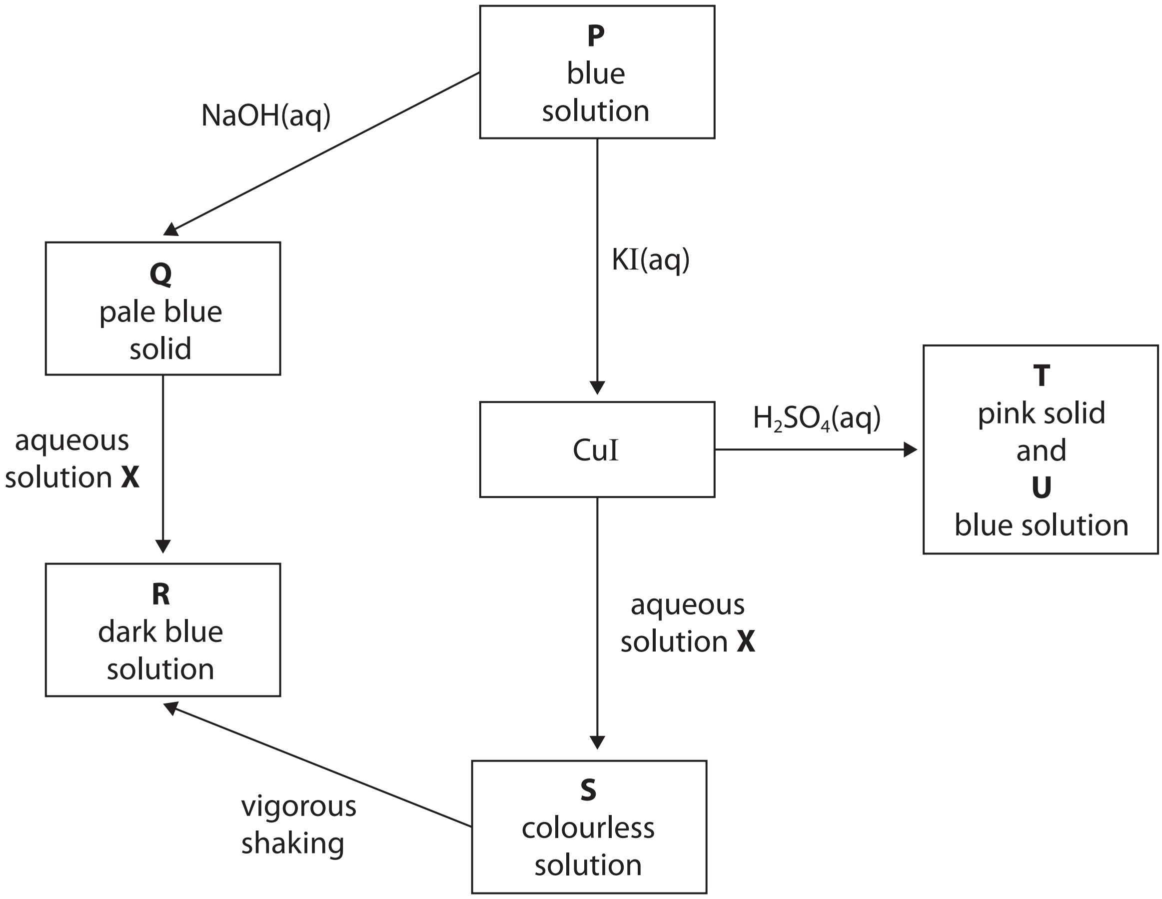
☒ **D** $Fe^{2+} < V^{2+} < Cr^{2+}$

(Total for Question 4 = 1 mark)

Use this space for any rough working. Anything you write in this space will gain no credit.

5 This question concerns the chemistry of copper.

In the reaction sequence, the substances P, Q, R, S, T and U contain copper in various oxidation states.



(a) What are the electronic structures of the three copper species?

(1)

		Cu	Cu^+	Cu^{2+}
☒	**A**	[Ar] $3d^9\ 4s^2$	[Ar] $3d^9\ 4s^1$	[Ar] $3d^9$
☒	**B**	[Ar] $3d^9\ 4s^2$	[Ar] $3d^8\ 4s^2$	[Ar] $3d^7\ 4s^2$
☒	**C**	[Ar] $3d^{10}\ 4s^1$	[Ar] $3d^9\ 4s^1$	[Ar] $3d^8\ 4s^1$
☒	**D**	[Ar] $3d^{10}\ 4s^1$	[Ar] $3d^{10}$	[Ar] $3d^9$

(b) Which rows show the substances with their correct oxidation states?

(1)

		Cu(0)	Cu(I)	Cu(II)
☒	**A**	S	U	P
☒	**B**	S	R	Q
☒	**C**	T	S	P
☒	**D**	T	U	Q

(c) Aqueous solution **X** contains

(1)

☒ **A** H_2SO_4

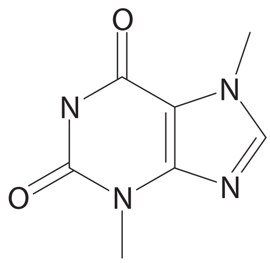
☒ **B** KI

☒ **C** NaOH

☒ **D** NH_3

(Total for Question 5 = 3 marks)

6 The diagram shows the skeletal structure of theobromine, which has a bitter taste and is found in chocolate and tea leaves.



Which of the functional groups listed is **not** present in the structure?

☒ **A** alkyl

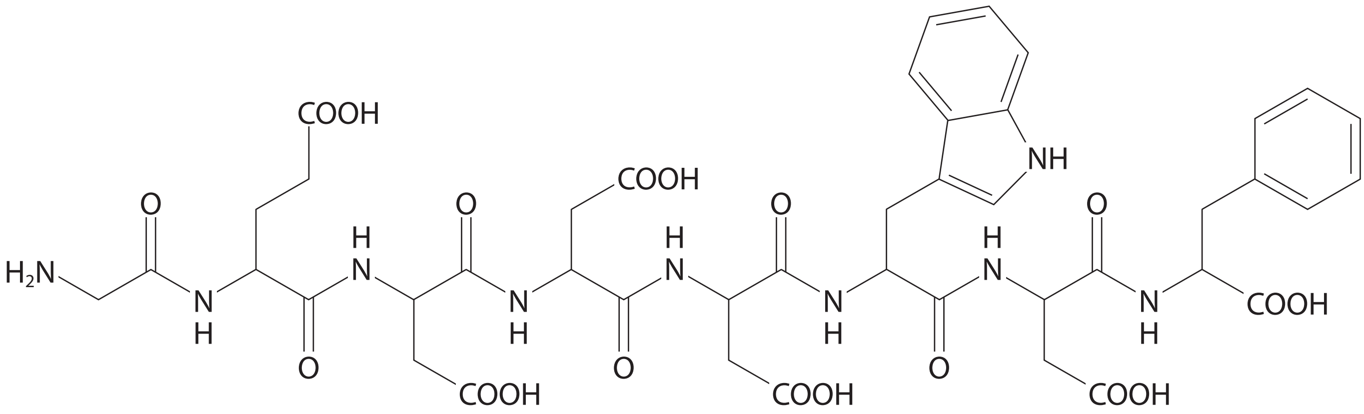
☒ **B** amide

☒ **C** amine

☒ **D** ketone

(Total for Question 6 = 1 mark)

7 Peptides are short chains of amino acids linked by peptide bonds.



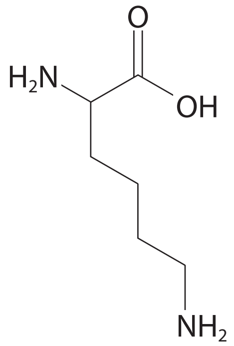
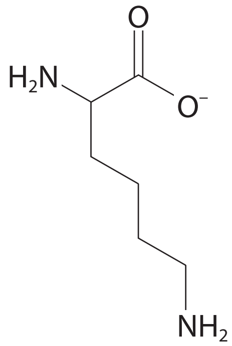
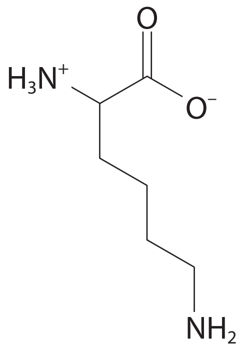
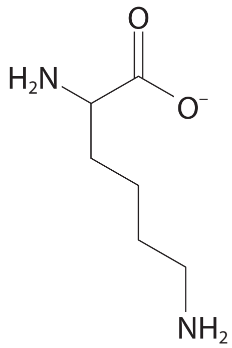
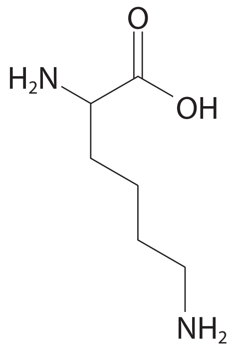
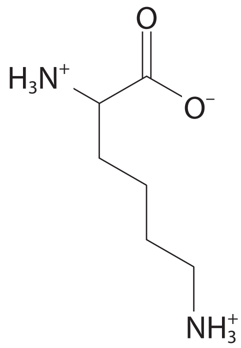
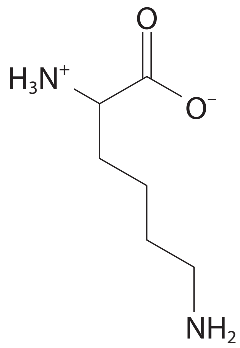
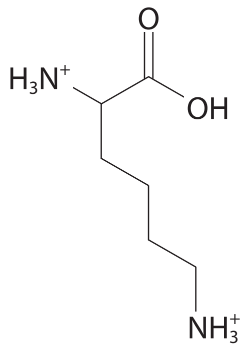
How many **different** types of amino acid have joined to form the octapeptide?

- ☒ **A** 4
- ☒ **B** 5
- ☒ **C** 6
- ☒ **D** 8

(Total for Question 7 = 1 mark)

Use this space for any rough working. Anything you write in this space will gain no credit.

8 Which shows the structure of the amino acid lysine as a solid, and in solution at high pH?

<table>
<tr><th></th><th></th><th>Solid</th><th>High pH solution</th></tr>
<tr><td>☒</td><td>A</td><td></td><td></td></tr>
<tr><td>☒</td><td>B</td><td></td><td></td></tr>
<tr><td>☒</td><td>C</td><td></td><td></td></tr>
<tr><td>☒</td><td>D</td><td></td><td></td></tr>
</table>

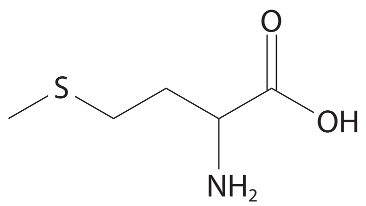
(Total for Question 8 = 1 mark)

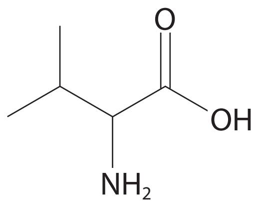
Turn over ▶

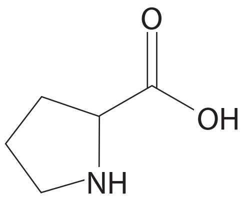
9 A dipeptide has the molecular formula $C_7H_{12}N_2O_3$.

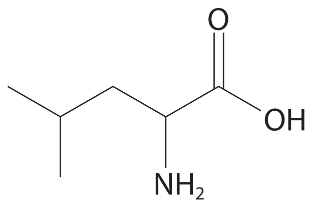
The dipeptide is hydrolysed to form two amino acids. One of the amino acids produced does not have a chiral centre.

What is the structure of the other amino acid which does have a chiral centre?

☒ **A** 

☒ **B** 

☒ **C** 

☒ **D** 

(Total for Question 9 = 1 mark)

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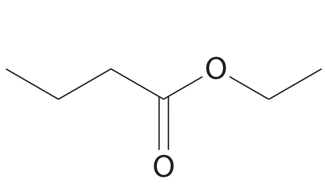
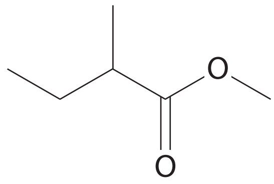
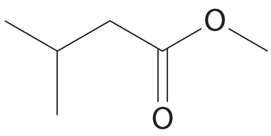
10 The aroma of strawberries is due to a number of volatile compounds, including the four isomeric esters shown.



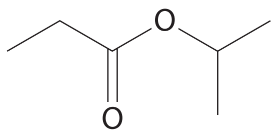
ester **P**



ester **Q**



ester **R**



ester **S**

(a) Which of the esters have five peaks in their ^{13}C NMR spectrum?

(1)

☒ **A** **P** only

☒ **B** **Q** and **R** only

☒ **C** **R** and **S** only

☒ **D** **Q**, **R** and **S** only

(b) Which of the esters will **not** have a doublet in its high resolution proton NMR spectrum?

(1)

☒ **A** **P**

☒ **B** **Q**

☒ **C** **R**

☒ **D** **S**

(c) Which of the esters could rotate the plane of plane-polarised monochromatic light?

(1)

☒ **A** **Q** only

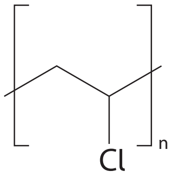
☒ **B** **Q** and **R**

☒ **C** **Q**, **R** and **S**

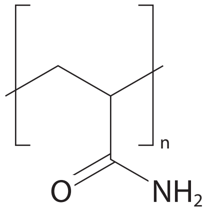
☒ **D** **R** and **S**

(Total for Question 10 = 3 marks)

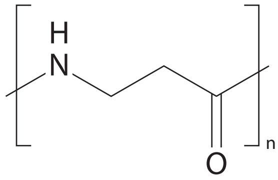
11 The formulae of three synthetic polymers, **X**, **Y** and **Z**, are shown.



X



Y



Z

Which are made by addition polymerisation reactions?

☒ **A** **X**, **Y** and **Z**

☒ **B** **X** and **Y**

☒ **C** **X** and **Z**

☒ **D** **Y** and **Z**

(Total for Question 11 = 1 mark)

Use this space for any rough working. Anything you write in this space will gain no credit.

12 Sodium thiosulfate can be used to determine the concentration of an iodine solution by titration using starch indicator.

(a) 5.00 g of sodium thiosulfate was dissolved in deionised water and the solution made up to 250.0 cm^3 in a volumetric flask.

The volumetric flask has an uncertainty of ± 0.25 cm^3.

What is the minimum uncertainty of the balance required to match the uncertainty of the volumetric flask?

Assume two weighings are needed.

(1)

☒ **A** ± 0.0025 g

☒ **B** ± 0.005 g

☒ **C** ± 0.01 g

☒ **D** ± 0.05 g

(b) The titration was carried out with sodium thiosulfate in the burette and starch was added just before the end-point.

What would be the colour of the solution in the conical flask at the end-point?

(1)

☒ **A** blue-black

☒ **B** brown

☒ **C** colourless

☒ **D** yellow

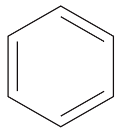
(Total for Question 12 = 2 marks)

TOTAL FOR SECTION A = 20 MARKS

SECTION B

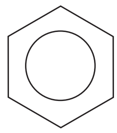
Answer ALL the questions. Write your answers in the spaces provided.

13 In 1865, Friedrich August Kekulé suggested a structure for benzene which consisted of alternating single and double carbon–carbon bonds.



Kekulé structure

However, modern analytical techniques indicate a structure in which the electrons are delocalised.



delocalised structure

(a) Explain how the results of X-ray diffraction experiments on benzene suggest a delocalised structure rather than the Kekulé structure.

(2)

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(b) The compound 1,2-dichlorobenzene exists as only one structure.
Explain how this supports the delocalised structure of benzene rather than the Kekulé structure.

(2)

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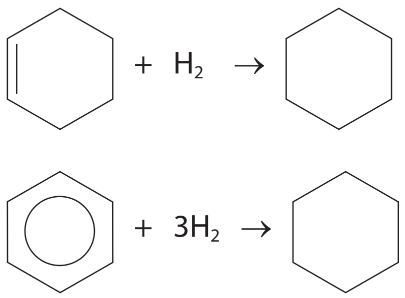
(c) State how the enthalpy changes of hydrogenation for cyclohexene and benzene provide evidence for the delocalised structure.



$\Delta H = -118\ \mathrm{kJ\,mol^{-1}}$

$\Delta H = -205\ \mathrm{kJ\,mol^{-1}}$

(1)

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(d) Describe the structure of benzene in terms of the atomic orbitals involved, the bonds formed and the delocalised electrons.

(3)

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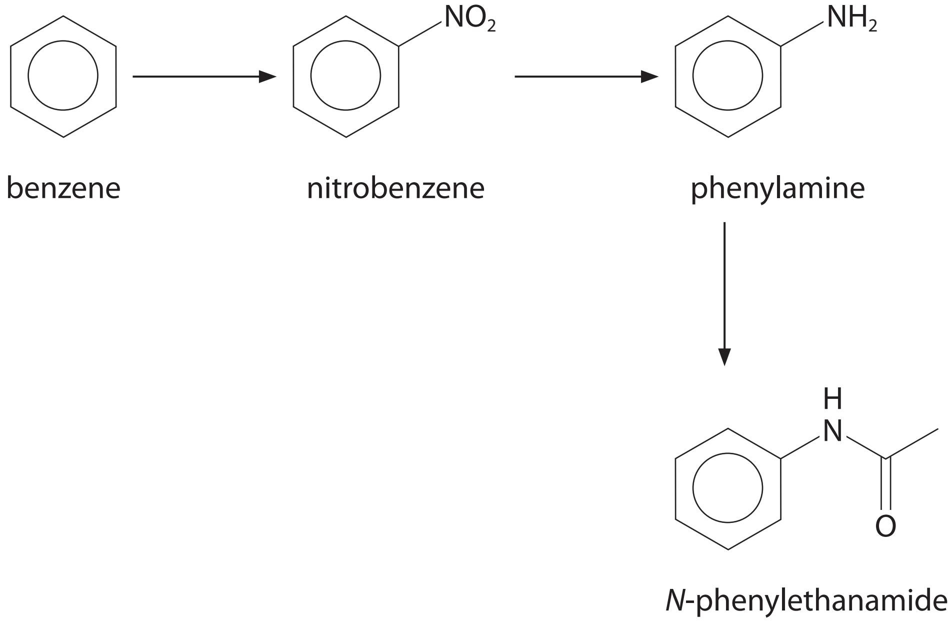
(Total for Question 13 = 8 marks)

14 *N*-phenylethanamide, historically used as a painkiller, can be synthesised from benzene as shown.



(a) Concentrated nitric acid reacts with a second reagent to produce an electrophile. This electrophile reacts with benzene to form nitrobenzene.

(i) Identify, by name or formula, the second reagent and the electrophile.

(2)

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(ii) Draw the mechanism for the reaction between the electrophile and benzene to form nitrobenzene.

(3)

(b) (i) Identify, by name or formula, the reagent(s) required to convert nitrobenzene into phenylamine.

(1)

....

(ii) State the type of reaction occurring during this step.

(1)

....

*(c) In the final step of the synthesis, phenylamine reacts with either ethanoyl chloride or ethanoic anhydride.

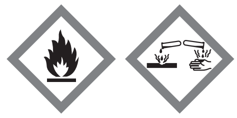
phenylamine + ethanoyl chloride → *N*-phenylethanamide + hydrogen chloride

phenylamine + ethanoic anhydride → *N*-phenylethanamide + ethanoic acid

Ethanoyl chloride is considerably more reactive than ethanoic anhydride.

Hazard symbols for reactants and products are shown.

Compound	Hazards
phenylamine	
ethanoic anhydride	
ethanoyl chloride	

Compound	Hazards
N-phenylethanamide	
ethanoic acid	
hydrogen chloride	

Assess the advantages and disadvantages of the use of ethanoic anhydride rather than ethanoyl chloride for this reaction.

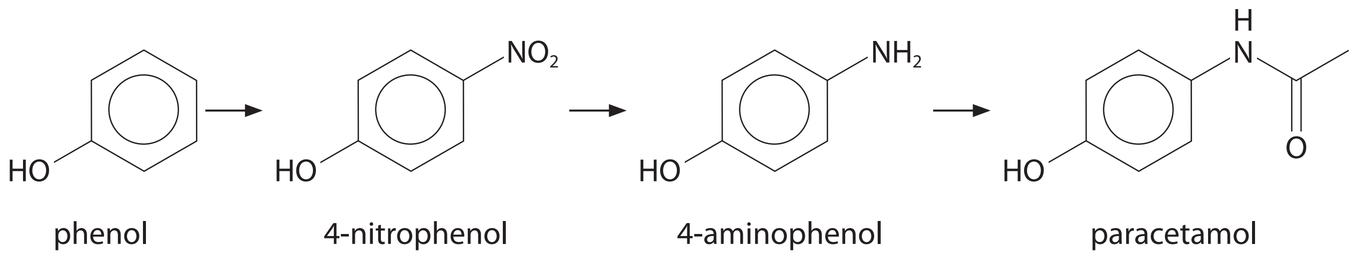
Consider the hazards associated with the reactants and products, and the atom economy of each reaction.

(6)

(d) The overall yield for the synthesis of *N*-phenylethanamide from benzene was found to be 35.2%.
Calculate the minimum volume of benzene, in cm^3, required to make 10.0 g of *N*-phenylethanamide.
[Density of benzene = 0.879 g cm^{-3}]

(4)

(e) Another painkiller, paracetamol, can be synthesised from phenol in a similar sequence. Phenol is nitrated by dilute nitric acid.



Explain why the nitration of phenol requires much milder conditions than the formation of nitrobenzene.

(2)

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(Total for Question 14 = 19 marks)

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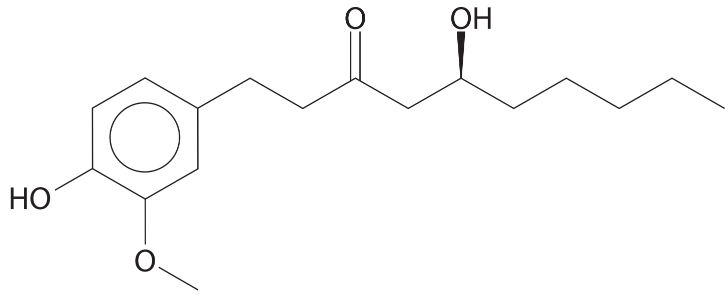
15 (a) Gingerol is a compound found in fresh ginger that activates spice receptors on the tongue, giving raw ginger a hot taste.
The skeletal formula of gingerol is shown.



gingerol

(i) Give the molecular formula of gingerol.

(1)

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(ii) The OH group is shown attached to the carbon chain by a wedge-shaped bond.
Suggest why the bond between the carbon chain and the OH group is shown as a wedge.

(2)

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(b) Cooking fresh ginger converts gingerol into zingerone, which is less pungent and has a sweeter flavour.

Zingerone can be formed in a four-step synthesis from coniferyl alcohol. Step **2** in the synthesis involves a Grignard Reagent, while Steps **1**, **3** and **4** are redox reactions.

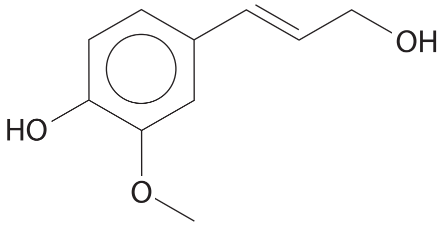
The synthesis is shown with the structures of the intermediate compounds incomplete.

Complete this four-step synthesis of zingerone from coniferyl alcohol.

Include in your answer completed structures of the intermediate compounds and the reagents and conditions required.

(7)

Step **1**



coniferyl alcohol

Reagents and conditions

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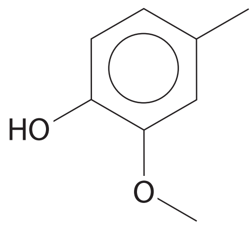

intermediate 1

Step **2**

intermediate 1

Reagents and conditions

....

....

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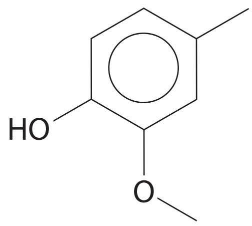


intermediate 2

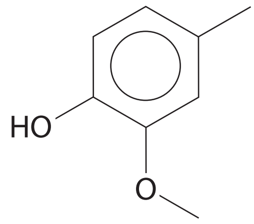
Step **3**

Reagents and conditions

....

....

intermediate 2 →



intermediate 3

Step **4**

Reagents and conditions

....

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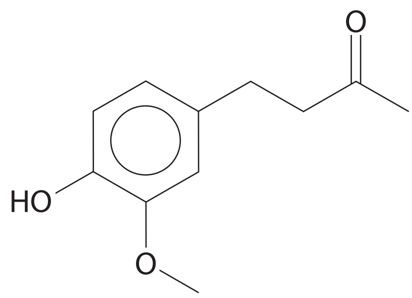
intermediate 3 →



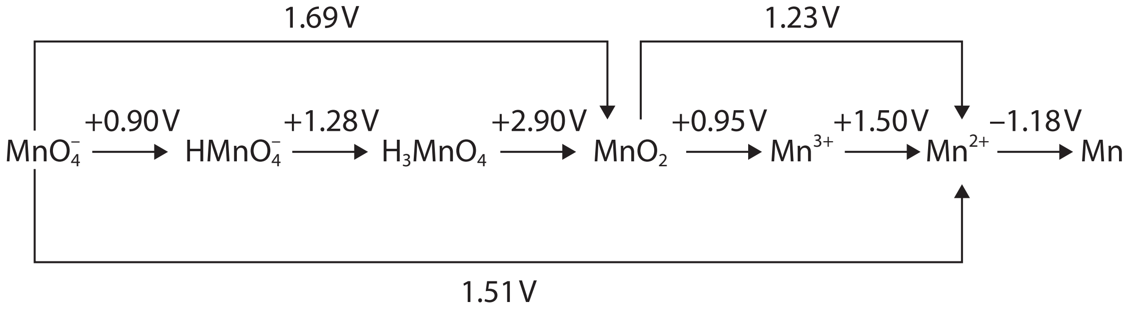
zingerone

(Total for Question 15 = 10 marks)

16 A Latimer diagram for a chemical element is a summary of the standard electrode potential data for that element.

In a Latimer diagram, the form of the element with the highest oxidation state is on the left, with successively lower oxidation states to the right.

A Latimer diagram for manganese at pH = 0 is shown.



The diagram shows that the standard electrode potential for the reduction of MnO_4^- to MnO_2, in acidic conditions, is +1.69 V.

$$MnO_4^- + 4H^+ + 3e^- \rightleftharpoons MnO_2 + 2H_2O \qquad E^\ominus = +1.69\,V$$

(a) (i) Justify the assignment of the oxidation state of +5 to manganese in H_3MnO_4 using oxidation numbers.

(1)

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(ii) Write an equation for the reaction of H_3MnO_4 in acidic solution to give ions containing manganese(VI) and manganese(IV).
Use the Latimer diagram to obtain the formulae of the ions produced.
State symbols are not required.

(2)

P 7 3 4 5 7 R A 0 2 6 3 6

(iii) Deduce whether or not this disproportionation reaction is thermodynamically feasible by calculating $E^{\ominus}$ for the reaction.

(2)

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DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

(b) Before use in titration experiments, potassium manganate(VII) solutions must be standardised. One method uses ethanedioate ions to find the exact concentration of the manganate(VII) ions.

$250.0\,cm^3$ of a standard solution contained 1.915 g of sodium ethanedioate, $Na_2C_2O_4$.

A potassium manganate(VII) solution of approximately $0.02\,mol\,dm^{-3}$ was standardised using this solution.
Excess sulfuric acid was added to $25.0\,cm^3$ portions of the potassium manganate(VII) solution which were titrated with the sodium ethanedioate solution.

The mean titre was $22.95\,cm^3$.

The relevant ionic half-equations are shown.

$$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$$

$$C_2O_4^{2-} \rightarrow 2CO_2 + 2e^-$$

(i) State the colour change at the end-point of the titration.

(1)

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(ii) Calculate the accurate concentration of the potassium manganate(VII), in $mol\,dm^{-3}$, giving your answer to an appropriate number of significant figures.

(4)

(iii) A second titration carried out without the addition of sulfuric acid resulted in the formation of a brown suspension.
Explain how the value of the mean titre would be affected, if at all, by the reaction that forms this suspension.
Use the Data Booklet as a source of information.
There is no need to calculate E_{cell} values.

(3)

(Total for Question 16 = 13 marks)

TOTAL FOR SECTION B = 50 MARKS

SECTION C

Answer ALL the questions. Write your answers in the spaces provided.

17 Transition metal compounds can show a number of different types of isomerism. Hydration isomerism is where different numbers of water molecules act as ligands. The name chromium(III) chloride is given to several chemical compounds with the formula $CrCl_3{\cdot}xH_2O$, including a number of hydration isomers.

(a) Anhydrous chromium(III) chloride, $CrCl_3$, is a violet solid which can react with water to produce three isomers.

$[Cr(H_2O)_6]^{3+}3Cl^-$ is violet.

$[Cr(H_2O)_5Cl]^{2+}2Cl^-{\cdot}H_2O$ is pale green.

$[Cr(H_2O)_4Cl_2]^+Cl^-{\cdot}2H_2O$ is dark green.

(i) Explain why the three isomers have different colours.

(3)

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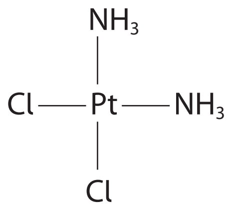
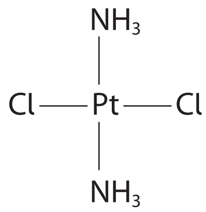
(ii) You are provided with three equimolar solutions of the three isomers.
Suggest how you would quantitatively determine the relative numbers of free chloride ions in the three isomers using the standard test for a chloride ion.

(5)

(b) Complexes can exhibit both cis-trans and optical isomerism. The cis- and trans-isomers of diamminedichloroplatinum(II) are commonly known as *cis*-platin and *trans*-platin.

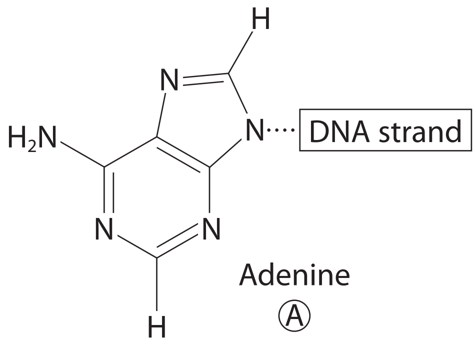


cis-platin

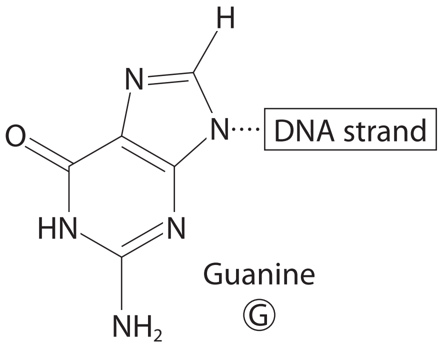


trans-platin

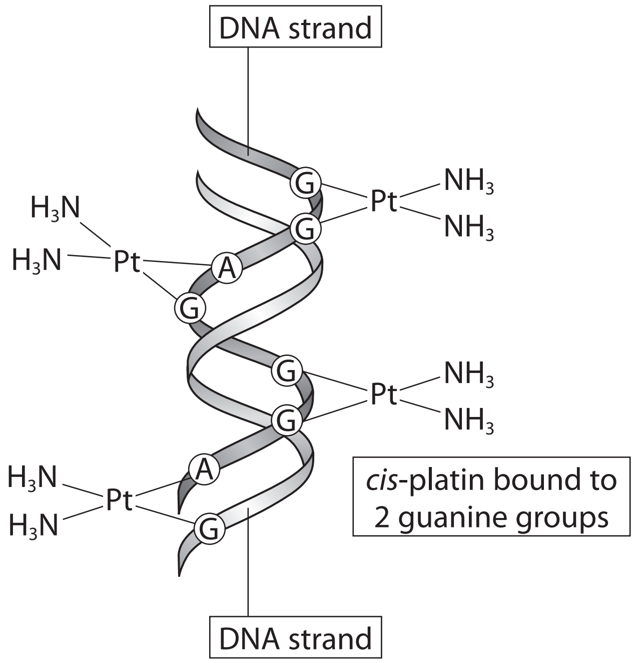
In chemotherapy medication, *cis*-platin is used to treat a number of cancers including testicular cancer and breast cancer, while *trans*-platin has no beneficial effect against cancer. The cis-isomer is effective because it binds with the deoxyribonucleic acid (DNA) molecules in a cancerous cell through adenine and guanine groups. This interferes with the replication of the cell and results in its destruction.



Adenine Ⓐ



Guanine Ⓖ



This works in three steps.

Step **1** Slow substitution of one chloride ligand by a water.

Step **2** This water ligand is easily displaced by guanine or adenine in the DNA strand.

Step **3** Finally the second chloride ligand is displaced by a different guanine or adenine from a different part of the strand.

(i) Write the balanced equation for Step **1**.
State symbols are not required.

(1)

(ii) Describe how guanine and adenine can bind to the platinum ion.

(1)

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(iii) *trans*-Platin binds to DNA.
Suggest why this does not damage the DNA.

(2)

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(c) Reinecke's salt has the formula $NH_4[Cr(SCN)_x(NH_3)_y] \cdot zH_2O$. The anion exists as a trans-isomer.
It contains 14.67% chromium, 36.23% sulfur, 4.51% oxygen and 27.65% nitrogen by mass.

(i) Calculate the values x, y and z in Reinecke's salt.
You **must** show your working.

(3)

(ii) Draw a diagram of the **anion** of Reinecke's salt showing its three-dimensional shape.

(2)

(d) (i) Explain why the tetrahedral complex $[Co(NH_3)ClBrI]$ exists as two optical isomers.

(2)

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(ii) Complete the diagram showing the **two** optical isomers of the tetrahedral complex.

(1)

(Total for Question 17 = 20 marks)

TOTAL FOR SECTION C = 20 MARKS
TOTAL FOR PAPER = 90 MARKS

The Periodic Table of Elements

Key

relative atomic mass **atomic symbol** name atomic (proton) number

1	2											3	4	5	6	7	0 (8)
							1.0 **H** hydrogen 1										*(18)* 4.0 **He** helium 2
(1)	*(2)*											*(13)*	*(14)*	*(15)*	*(16)*	*(17)*	
6.9 **Li** lithium 3	9.0 **Be** beryllium 4											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