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 25 October 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 ▶

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 What is the electronic configuration of the chromium **atom**?

☐ **A** [Ar] $3d^4$ $4s^2$

☐ **B** [Ar] $3d^5$ $4s^1$

☐ **C** [Ar] $3d^6$

☐ **D** [Ar] $3d^1$ $4s^2$ $4p^3$

(Total for Question 1 = 1 mark)

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2 Which ion shows the typical property of transition metals by forming coloured complexes?

☐ **A** Cu^+

☐ **B** Ni^{2+}

☐ **C** Sc^{3+}

☐ **D** Zn^{2+}

(Total for Question 2 = 1 mark)

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3 The formula of a chromium compound is $[Cr(H_2O)_4Cl_2]^+Cl^-$.
The molar mass of the **compound** is 230.5 g mol^{-1}.

What is the percentage by mass of chlorine in the **complex ion**?

☐ **A** 18.2%

☐ **B** 30.8%

☐ **C** 36.4%

☐ **D** 46.2%

(Total for Question 3 = 1 mark)

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

4 The reaction between peroxodisulfate ions and iodide ions is shown.

$$S_2O_8^{2-} + 2I^- \rightarrow 2SO_4^{2-} + I_2$$

The reaction has a high activation energy but is catalysed by iron(II) ions.

(a) What is the best explanation for the high activation energy of this reaction?

(1)

☒ **A** the peroxodisulfate ion is a weak oxidising agent

☒ **B** the iodide ion is a weak reducing agent

☒ **C** peroxodisulfate ions and iodide ions are both negatively charged

☒ **D** the reaction involves three reactant ions

(b) Which property of iron(II) ions enables them to function as a catalyst for this reaction?

(1)

☒ **A** iron(II) ions can be easily reduced to metallic iron

☒ **B** iron(II) ions effectively adsorb the reactants

☒ **C** iron(II) ions can be easily oxidised and then reduced

☒ **D** iron(II) ions can be easily reduced and then oxidised

(Total for Question 4 = 2 marks)

---

5 Chromium(III) hydroxide, $Cr(OH)_3(H_2O)_3$, is amphoteric.

This means that chromium(III) hydroxide dissolves in

☒ **A** water

☒ **B** strong acid only

☒ **C** strong alkali only

☒ **D** strong acid and strong alkali

(Total for Question 5 = 1 mark)

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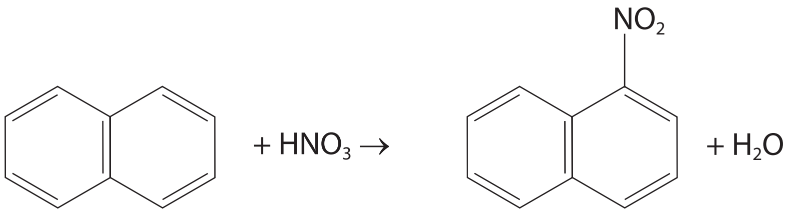
6 Naphthalene is an aromatic molecule with two aromatic rings joined together. It can be nitrated at position 1 as shown.



naphthalene
Molar mass = 128 g mol^{-1}

1-nitronaphthalene
Molar mass = 173 g mol^{-1}

(a) In an experiment, a 2.00 g sample of naphthalene was nitrated and produced 2.57 g of 1-nitronaphthalene.

What is the percentage yield of 1-nitronaphthalene?

(1)

☒ **A** 95.1%

☒ **B** 77.8%

☒ **C** 74.0%

☒ **D** 57.6%

(b) A student carrying out this experiment calculated the percentage yield of the reaction to be greater than 100%.

What is the **most likely** explanation for this result?

(1)

☒ **A** there was unreacted naphthalene present

☒ **B** the naphthalene was impure

☒ **C** the sample of 1-nitronaphthalene was damp

☒ **D** other isomers of 1-nitronaphthalene were produced

(Total for Question 6 = 2 marks)

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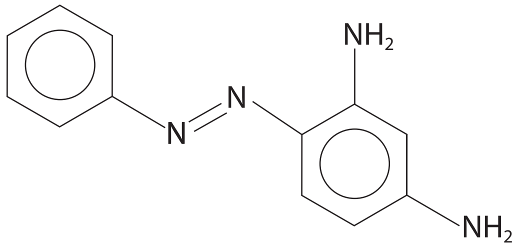
7 This question is about the azo dye, chrysoidine, which has the structure shown.



(a) In the production of chrysoidine, phenylamine is first reacted with nitrous acid.

Which equation shows the formation of nitrous acid from sodium nitrite?

(1)

☒ **A** $NaNO_2 + HCl \rightarrow HNO_2 + NaCl$

☒ **B** $NaNO_3 + HCl \rightarrow HNO_3 + NaCl$

☒ **C** $NaNO_3 + HCl \rightarrow HNO_2 + NaClO$

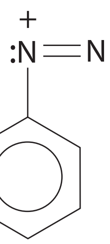
☒ **D** $NaNO_2 + HCl \rightarrow HNO_2 + Na + \frac{1}{2}Cl_2$

(b) The reaction of phenylamine with nitrous acid produces the benzenediazonium ion.

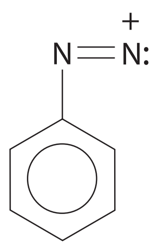
Which is the structure of the benzenediazonium ion?

(1)

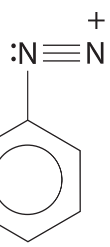
☒ **A**



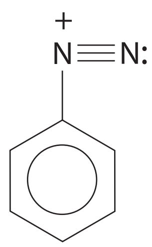
☒ **B**



☒ **C**



☒ **D**

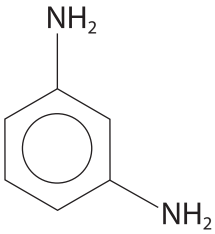


P 8 0 6 6 4 A 0 6 3 2

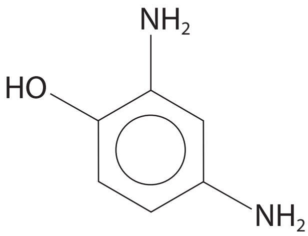
(c) Which reactant is required for the coupling reaction with the benzenediazonium ion to form chrysoidine?

(1)

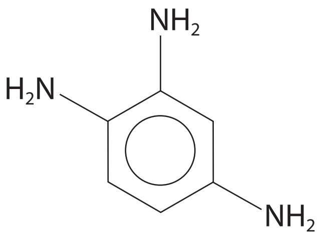
☒ **A**



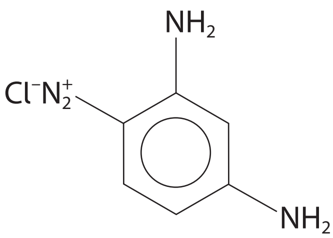
☒ **B**



☒ **C**



☒ **D**



(Total for Question 7 = 3 marks)

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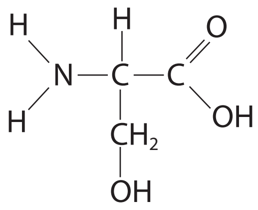
8 The amino acid serine has the structure shown.



(a) The IUPAC name for serine is

(1)

☒ **A** 2-amino-2-carboxyethanol

☒ **B** 2-amino-1-hydroxyethanoic acid

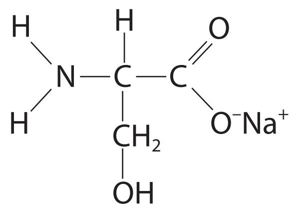
☒ **C** 2-amino-1-hydroxypropanoic acid

☒ **D** 2-amino-3-hydroxypropanoic acid

(b) Which is the organic product of the reaction between serine and sodium hydroxide solution?

(1)

☒ **A**



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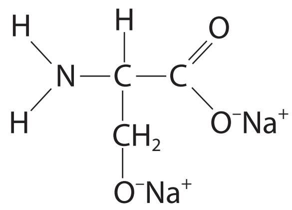
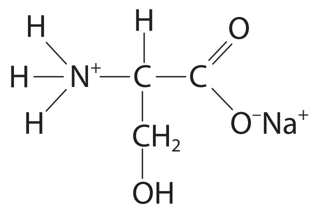
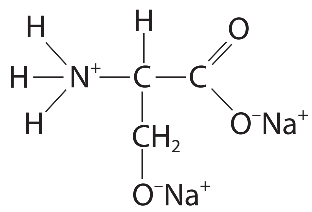


☒ **C**



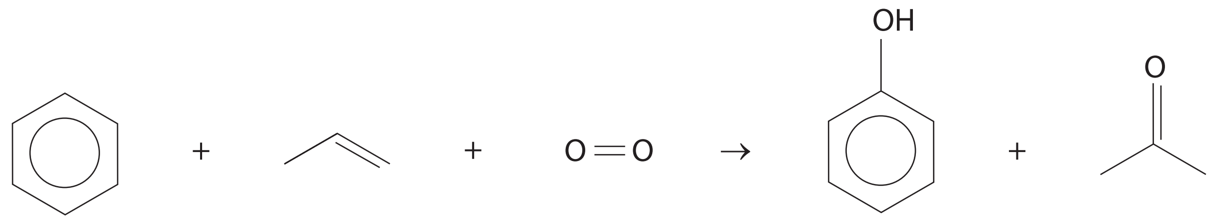
☒ **D**



(Total for Question 8 = 2 marks)

P 8 0 6 6 4 A 0 8 3 2

9 The cumene process is the main industrial method for making phenol.
The overall equation for this process is shown.



What is the atom economy by mass of the cumene process for making phenol?

- ☒ **A** 61%
- ☒ **B** 62%
- ☒ **C** 94%
- ☒ **D** 95%

(Total for Question 9 = 1 mark)

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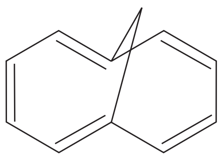
10 An aromatic compound with a ten-carbon ring has the structure shown.



(a) Evidence for the aromaticity of this compound is that the carbon-carbon bonds in the ten-carbon ring

(1)

- ☒ **A** alternate in length between single and double bonds
- ☒ **B** all have similar lengths
- ☒ **C** have no regular pattern of bond length
- ☒ **D** are all similar to the carbon-carbon double bond length

(b) The aromaticity is due to the formation of pi (π) bonds as a result of overlap of

(1)

- ☒ **A** s and p orbitals
- ☒ **B** p and d orbitals
- ☒ **C** p orbitals
- ☒ **D** d orbitals

(Total for Question 10 = 2 marks)

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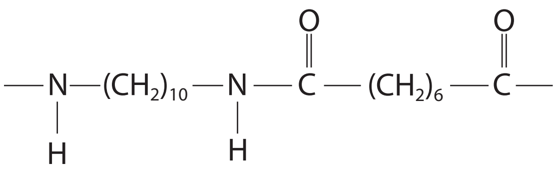
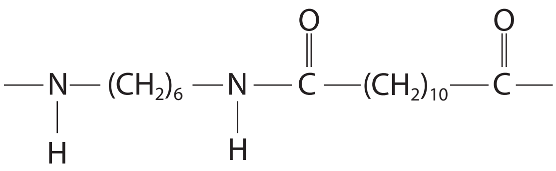
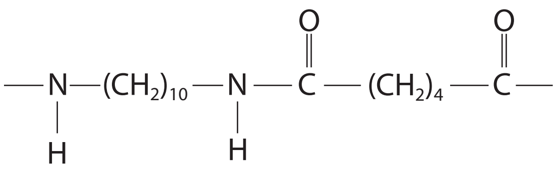
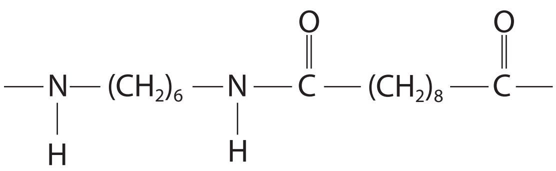
11 The polymer, nylon 6-10, is made from a six-carbon diamine and a ten-carbon dicarboxylic acid.

Which is the repeat unit of this nylon?

☒ **A** 

☒ **B** 

☒ **C** 

☒ **D** 

(Total for Question 11 = 1 mark)

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12 Car exhaust gases react on the surface of a catalytic converter.

$$2CO + 2NO \rightarrow 2CO_2 + N_2$$

Which interactions could **not** occur between the gases and the catalytic converter in this process?

☒ **A** covalent bonds

☒ **B** hydrogen bonds

☒ **C** London forces

☒ **D** permanent dipole-induced dipole forces

(Total for Question 12 = 1 mark)

13 Which pair of equations shows the most likely mechanism for vanadium(V) oxide acting as a catalyst in the contact process?

☒ **A** $V_2O_5 + \frac{1}{2}O_2 \rightarrow V_2O_6$ then $V_2O_6 + SO_2 \rightarrow V_2O_5 + SO_3$

☒ **B** $V_2O_5 + SO_2 \rightarrow V_2O + 1\frac{1}{2}O_2 + SO_3$ then $V_2O + 2O_2 \rightarrow V_2O_5$

☒ **C** $V_2O_5 + \frac{1}{2}O_2 \rightarrow 2VO_3$ then $2VO_3 + SO_2 \rightarrow V_2O_5 + SO_3$

☒ **D** $V_2O_5 + SO_2 \rightarrow V_2O_4 + SO_3$ then $V_2O_4 + \frac{1}{2}O_2 \rightarrow V_2O_5$

(Total for Question 13 = 1 mark)

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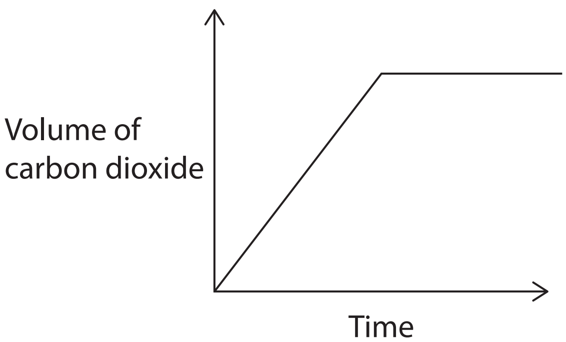
14 The formation of carbon dioxide from the reaction between manganate(VII) ions and ethanedioate ions is autocatalysed by manganese(II) ions.

The equation for this reaction is shown.

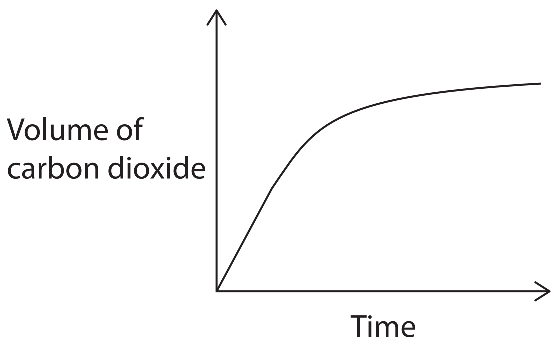
$$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \rightarrow 10CO_2 + 2Mn^{2+} + 8H_2O$$

Which graph for the complete reaction shows the autocatalysis of this reaction by the manganese(II) ions?

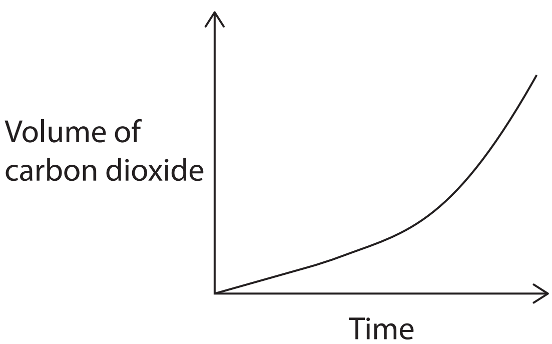
☒ **A**



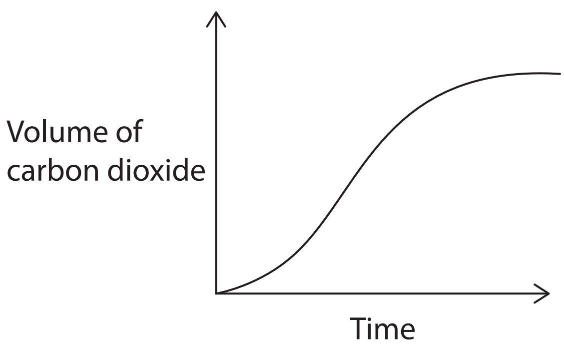
☒ **B**



☒ **C**



☒ **D**



(Total for Question 14 = 1 mark)

TOTAL FOR SECTION A = 20 MARKS

SECTION B

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

15 This question is about butylamine, $C_4H_9NH_2$.

The boiling temperature of butylamine is 78°C, which is much higher than alkanes of similar molar mass.

(a) Butylamine is miscible with water. Draw a labelled diagram to show one of the intermolecular interactions between a butylamine molecule and a molecule of water.
Include relevant lone pairs and dipoles.

(2)

(b) Butylamine has a fishy, ammonia-like smell. The exposure limit or safety level in the atmosphere for butylamine is $15\,mg\,m^{-3}$.
Calculate the maximum number of butylamine molecules that are allowed per cubic metre.
[Avogadro constant, $L = 6.02 \times 10^{23}\,mol^{-1}$]

(2)

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(c) Butylamine reacts with ethanoyl chloride to form *N*-butylethanamide.
Write an equation for this reaction using **displayed** formulae.

(2)

(d) Explain why butylamine is a stronger base than ammonia.

(3)

(Total for Question 15 = 9 marks)

16 Iron is generally prescribed when a person is suffering from anaemia. Many people find it easier to take medicine in liquid form rather than solid tablets.

An iron solution, advertised for this purpose, contains iron as Fe^{2+}.
An adult is advised to take 90.0 mg of iron daily.

A 25.0 cm^3 sample of the solution was made up to 100.0 cm^3 using sulfuric acid and deionised water.
25.0 cm^3 samples of the diluted iron(II) solution were titrated with a 0.0125 mol dm^{-3} potassium manganate(VII) solution.
The mean titre was 16.20 cm^3.

The reaction is shown.

$$MnO_4^- + 8H^+ + 5Fe^{2+} \rightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$$

Calculate the volume of iron solution required to obtain a 90.0 mg dose of iron.
Give your answer to an appropriate number of significant figures.

Volume required by an adult to obtain a 90.0 mg dose .... cm^3

(Total for Question 16 = 6 marks)

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17 This question is about electrochemical cells.

*(a) Describe how you would carry out an experiment to determine the standard electrode potential of the electrode system shown.

$$Co^{2+}(aq) + 2e^- \rightleftharpoons Co(s)$$

Assume that you have access to the equipment and chemicals that you need, describing their use in your answer.
You may include a labelled diagram.

(6)

(b) Acidified potassium dichromate(VI) is an oxidising agent.
The acid commonly used is sulfuric acid.

Explain, using reference to the electrode potentials shown, why **concentrated** hydrochloric acid should **not** be used to acidify potassium dichromate(VI).

Electrode system	$E^{\ominus}$ / V
$Cr_2O_7^{2-} + 14H^+ + 6e^- \rightleftharpoons 2Cr^{3+} + 7H_2O$	+1.33
$Cl_2 + 2e^- \rightleftharpoons 2Cl^-$	+1.36

(3)

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(c) The cell diagram for an electrochemical cell is shown.

$$Ag(s) \mid Ag^+(aq) \parallel [VO_2^+(aq) + 2H^+(aq)], [VO^{2+}(aq) + H_2O(l)] \mid Pt(s)$$

Write the **reduction** half-equation for this electrochemical cell.
State symbols are not required.

(1)

(d) The Direct Methanol Fuel Cell (DMFC) uses methanol and oxygen to generate electricity. When the cell operates, the methanol reacts with water at one electrode to produce carbon dioxide and hydrogen ions.
At the other electrode the oxygen reacts with hydrogen ions to form water.

(i) Write the oxidation half-equation for this fuel cell.
State symbols are not required.

(1)

(ii) Write the overall equation for this fuel cell.
State symbols are not required.

(1)

(iii) The reduction half-cell in the DMFC has a standard electrode potential $E^{\ominus} = +1.23\,V$.
When the solution concentration changes, the electrode potential changes so that $E = +1.20$ V.
The relationship between these values is given by the equation

$$E = E^{\ominus} + 4.277 \times 10^{-3} \ln \mathbf{X}$$

where **X** is the concentration of the solution in $mol\,dm^{-3}$.

Calculate the value of **X** in the non-standard half-cell.

(1)

(Total for Question 17 = 13 marks)

18 This question is about coloured transition metal complex ions.

(a) The $[Fe(H_2O)_6]^{2+}$ complex ion is green and the $[Fe(H_2O)_6]^{3+}$ complex ion is yellow.

(i) Explain why the $[Fe(H_2O)_6]^{2+}$ complex ion is coloured.

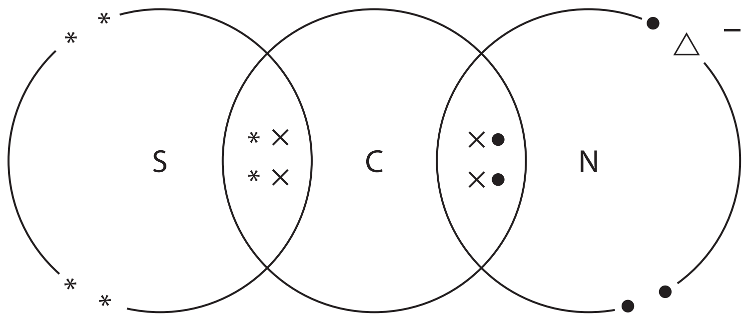
(3)

(ii) Explain why the two iron complex ions are different colours.

(2)

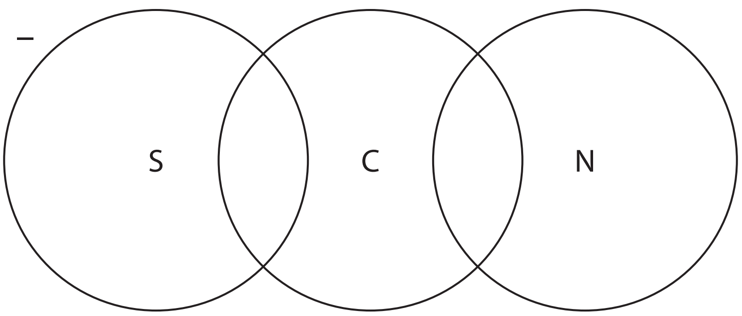
(b) The thiocyanate ion, SCN^-, forms a 'blood-red' coloured complex ion with iron(III) ions.

(i) The dot-and-cross diagram for the thiocyanate ion can be drawn in more than one way. For example, the negative charge can be on the nitrogen atom as shown.



Complete the alternative dot-and-cross diagram of the thiocyanate ion where the negative charge is on the sulfur atom.
Use (●) for the nitrogen electrons, (×) for the carbon electrons, (∗) for the sulfur electrons and (△) for the extra electron.

(2)



(ii) 12.8 cm^3 of 0.05 mol dm^{-3} iron(III) chloride solution reacted with 8.0 cm^3 of 0.08 mol dm^{-3} ammonium thiocyanate to form a complex ion.
Deduce the formula of the **octahedral** complex ion that iron(III) ions form with thiocyanate ions in aqueous solution.
You **must** show your working.

(3)

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Formula ....

(c) Colorimetry was used to determine the concentration of a solution of copper(II) sulfate.
Six solutions of copper(II) sulfate of known concentration were prepared and their absorbance at a wavelength of 635 nm measured. The results are shown.

Concentration of $CuSO_4$(aq) / mol dm^{-3}	0.00	0.10	0.20	0.30	0.40	0.50
Absorbance at 635 nm	0.00	0.28	0.55	0.83	1.10	1.38

(i) Plot a graph of absorbance against concentration using the data in the table.

(3)

(ii) 50.0 cm^3 of a solution of copper(II) sulfate of unknown concentration was pipetted into a 250.0 cm^3 volumetric flask and the volume made up to the mark with deionised water.
The absorbance at a wavelength of 635 nm for this diluted copper(II) sulfate solution was 0.72.

Determine the concentration of the **original** copper(II) sulfate solution.
You **must** show your working on the graph.

(2)

(iii) Give **one** possible reason why any concentrations of copper(II) sulfate determined from the graph of values over 0.50 mol dm^{-3} are uncertain.

(1)

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(d) The complex ion formed from cobalt(III) ions and ethane-1,2-diamine is a yellow-orange colour.
The equation for the formation of this complex ion is shown.

$$[Co(H_2O)_6]^{3+} + 3H_2NCH_2CH_2NH_2 \rightarrow [Co(H_2NCH_2CH_2NH_2)_3]^{3+} + 6H_2O$$

(i) Give a reason, by referring to the equation, why the formation of the diamine complex from the aqueous complex ion is thermodynamically favoured.

(1)

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(ii) Explain, by reference to the structure of ethane-1,2-diamine, why it is a bidentate ligand.

(2)

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(iii) Explain how the H—N—H bond angles would be expected to change in ethane-1,2-diamine when the complex ion is formed.

(3)

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(Total for Question 18 = 22 marks)

TOTAL FOR SECTION B = 50 MARKS

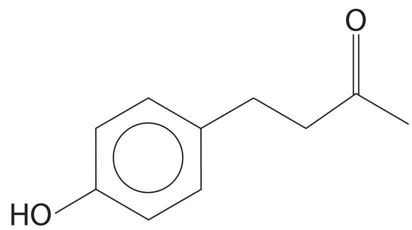
SECTION C

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

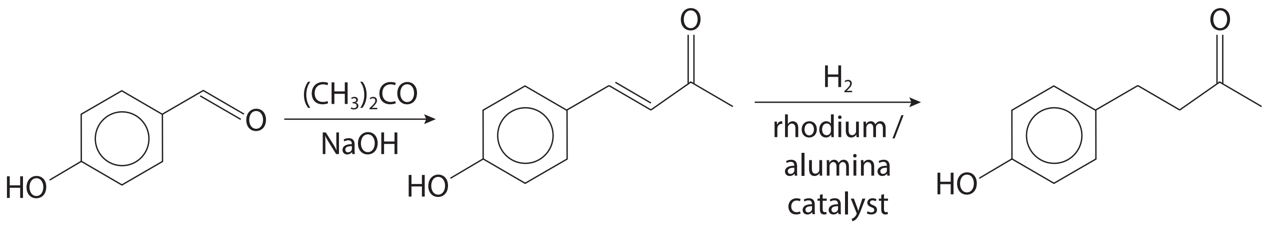
19

Raspberry ketone

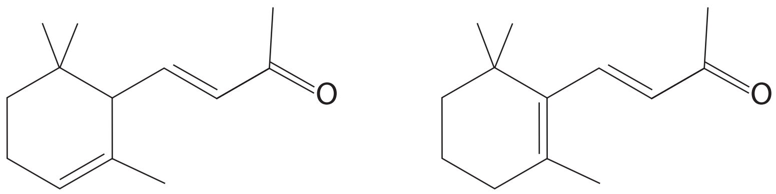
Over two hundred different compounds contribute to the smell of raspberries, including the one known as *raspberry ketone*.



Raspberry ketone is also found in other fruits such as cranberries and blackberries. It can be extracted from fruit but it is present in a very low percentage and so it is prepared industrially by a variety of methods.
The two-step method shown gives a 99% yield.



Two other compounds which contribute to the characteristic smell of raspberries are shown.

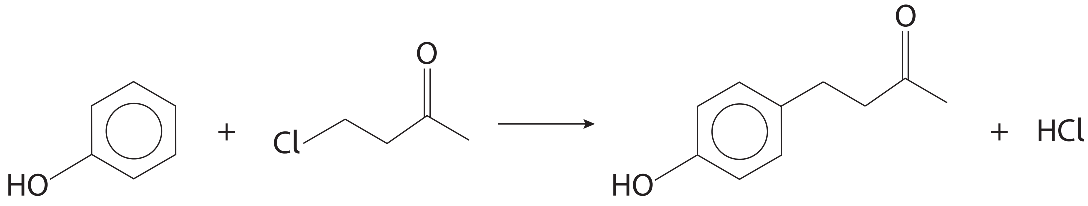


α-ionone β-ionone

(a) Give the **empirical** formula of the *raspberry ketone*.

(1)

(b) *Raspberry ketone* can be synthesised in the laboratory from phenol using a Friedel–Crafts reaction. The overall reaction is shown.



(i) Draw the mechanism for this reaction, using appropriate curly arrows. Include equations showing the formation of the electrophile and the regeneration of the catalyst at the end of the reaction.

(5)

(ii) Give a reason why the yield of the *raspberry ketone* by this method is **not** high.

(1)

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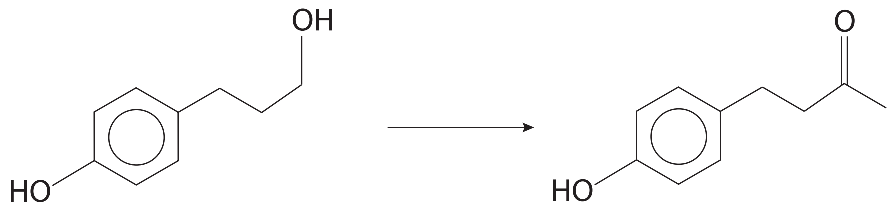
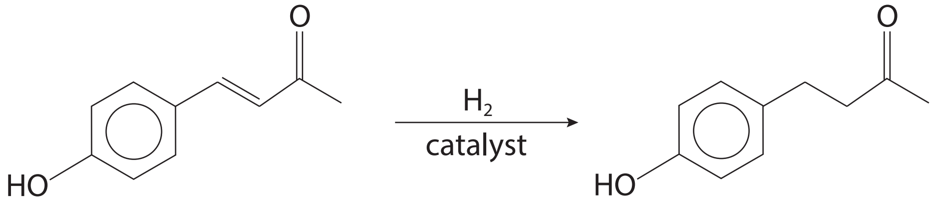
(c) *Raspberry ketone* can also be synthesised in the laboratory using a Grignard reagent via a multi-step process. The overall reaction is shown.



Devise this multi-step synthesis.
Give the reagents and conditions for each step in the synthesis, including the formation of the Grignard reagent and the structures of the intermediates.

(7)

(d) The second step of the industrial preparation of the *raspberry ketone* involves the reduction shown.



Suggest why the choice of reducing agent is particularly important in this reaction.

(1)

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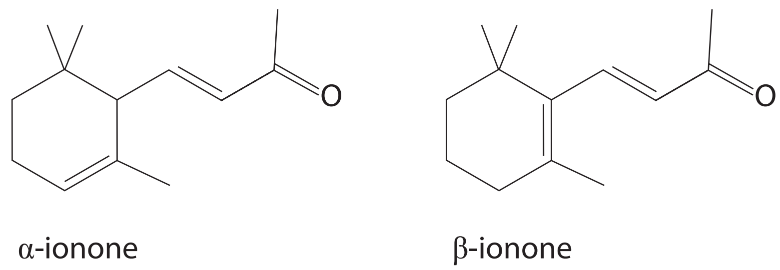
(e) The α-ionone and β-ionone molecules are structural isomers.



(i) Compare and contrast the **stereoisomerism** of these two molecules. On the structures, circle any features of the molecules that give rise to stereoisomerism.

(3)

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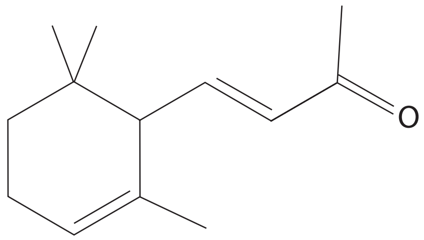
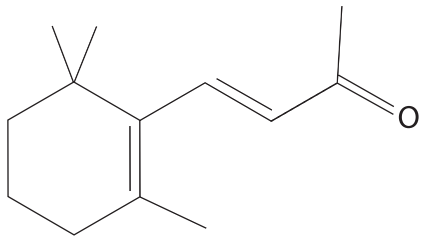
(ii) Identify with an asterisk (*) the carbon atom environment in α-ionone which would be expected to produce a peak with a **quartet** splitting pattern in a high resolution proton NMR spectrum.

(1)



α-ionone

(iii) Predict the number of peaks in the carbon-13 NMR spectrum of β-ionone, which has the molecular formula $C_{13}H_{20}O$.
Justify your answer.



β-ionone

(1)

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(Total for Question 19 = 20 marks)

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

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The Periodic Table of Elements

Key

relative atomic mass
atomic symbol
name
atomic (proton) number

1 (1)	2 (2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	3 (13)	4 (14)	5 (15)	6 (16)	7 (17)	0 (8) (18)
							1.0 **H** hydrogen 1										4.0 **He** helium 2
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											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

Series														
* 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