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 24 October 2025

Afternoon (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 ▶

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P 7 9 1 3 7 A 0 1 3 6

Pearson

SECTION A

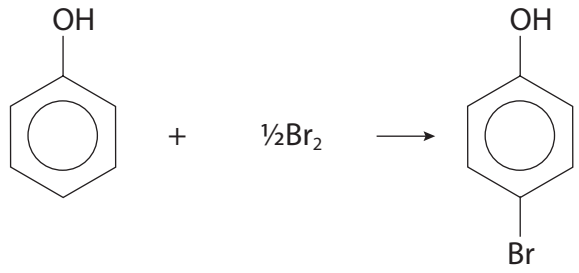
Answer ALL the questions in this section.

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

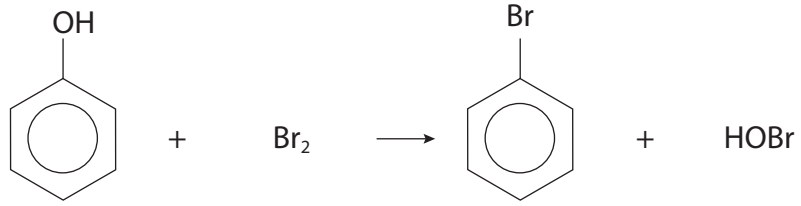
For each question, select one answer from A to D and put a cross in the box ☒. If you change your mind, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 Which is the equation for the reaction of phenol with bromine water?

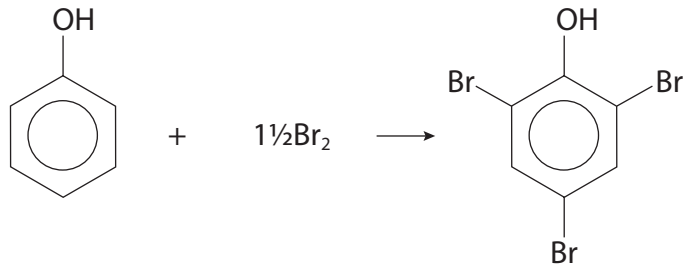
☒ **A**



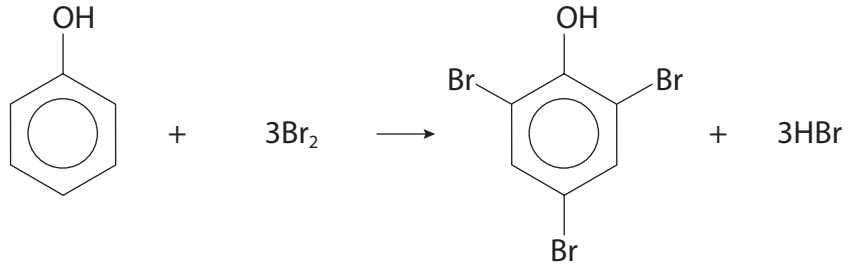
☒ **B**



☒ **C**



☒ **D**



(Total for Question 1 = 1 mark)

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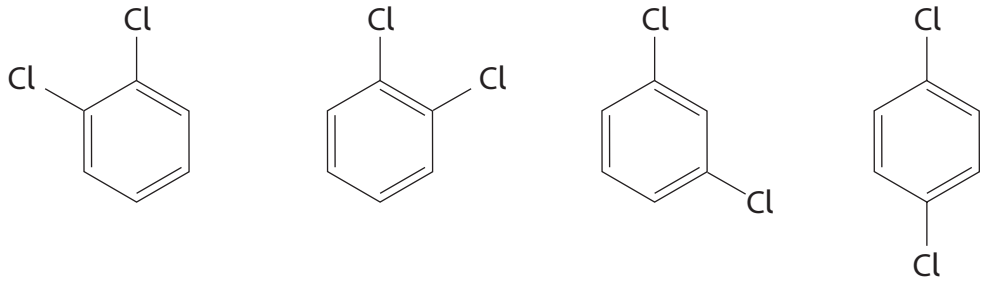
2 If benzene has the structure suggested by Kekulé, then there should be four isomers of dichlorobenzene as shown.



1 2 3 4

In the correct delocalised model of the benzene structure, there are only three isomers of dichlorobenzene.

Which two Kekulé isomers are actually the same?

☒ **A** 1 and 2

☒ **B** 1 and 4

☒ **C** 2 and 3

☒ **D** 3 and 4

(Total for Question 2 = 1 mark)

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

3 The delocalised model of the aromatic benzene structure involves the overlap of p orbitals to form π-bonds.

(a) Which describes this p orbital overlap to form π-bonds **only**?

(1)

- ☒ **A** head-on overlap which is in the plane of the ring
- ☒ **B** head-on overlap which is both above and below the plane of the ring
- ☒ **C** sideways overlap which is in the plane of the ring
- ☒ **D** sideways overlap which is both above and below the plane of the ring

(b) The delocalisation of the π-bonds in benzene results in various properties or characteristics which are different from those expected of Kekulé benzene.

Which property of benzene is **not** due to the delocalisation of the π-bonds?

(1)

- ☒ **A** the enthalpy of hydrogenation is less exothermic than the value calculated for the Kekulé structure
- ☒ **B** the carbon–carbon bond lengths are all the same
- ☒ **C** the carbon–hydrogen bond lengths are all the same
- ☒ **D** all the carbon–carbon bonds give the same infrared stretching vibration peaks

(Total for Question 3 = 2 marks)

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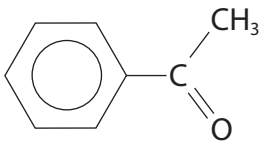
4 Benzene undergoes electrophilic substitution in the presence of a catalyst to form phenylethanone. The structure of phenylethanone is shown.



(a) Which reagent is used to react with benzene to form phenylethanone?

(1)

☒ **A** CH_3COOH

☒ **B** CH_3COCH_3

☒ **C** CH_3COCl

☒ **D** CH_3CONH_2

(b) Which compound is **not** a catalyst that can be used to form the electrophile for this reaction?

(1)

☒ **A** $AlCl_3$

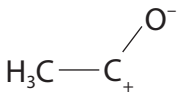
☒ **B** $FeBr_3$

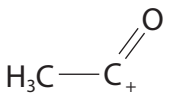
☒ **C** $FeCl_3$

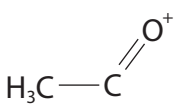
☒ **D** PCl_5

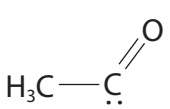
(c) Which is the electrophile for this reaction?

(1)

☒ **A** 

☒ **B** 

☒ **C** 

☒ **D** 

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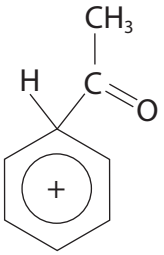
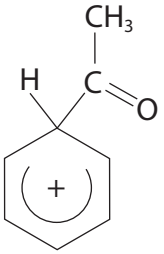
(d) Which is the structure of the intermediate in this reaction?

(1)

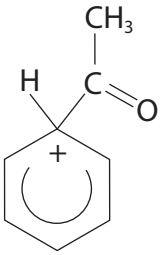
☒ **A**



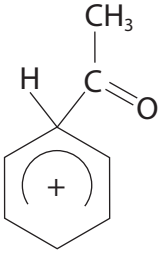
☒ **B**



☒ **C**



☒ **D**



(Total for Question 4 = 4 marks)

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5 $E^{\ominus}_{cell}$ is related to other thermodynamic functions for a reaction.

(a) The relationship between $E^{\ominus}_{cell}$ and the total entropy change is shown.

$$E^{\ominus}_{cell} = \frac{T\Delta S_{total}}{nF}$$

[Data: F is the Faraday constant, 96 500 C mol^{-1}
n is the number of electrons transferred
T is the temperature in kelvin]

$$Zn(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g) \qquad E^{\ominus}_{cell} = +0.76\,V \text{ at } 25\,^{\circ}C$$

What is the **numerical** value for the total entropy change for this reaction?

(1)

☒ **A** 246

☒ **B** 492

☒ **C** 2934

☒ **D** 5867

(b) The relationship between $E^{\ominus}_{cell}$ and the equilibrium constant is shown.

$$\ln K = \frac{nFE^{\ominus}_{cell}}{RT}$$

[Data: R is the gas constant, 8.31 J mol^{-1} K^{-1}]

$$2Fe^{3+}(aq) + 2I^-(aq) \rightleftharpoons 2Fe^{2+}(aq) + I_2(aq) \qquad E^{\ominus}_{cell} = +0.23\,V \text{ at } 298\,K$$

What is the **numerical** value of the equilibrium constant for this reaction?

(1)

☒ **A** 6.1×10^7

☒ **B** 7.8×10^3

☒ **C** 17.9

☒ **D** 8.96

(Total for Question 5 = 2 marks)

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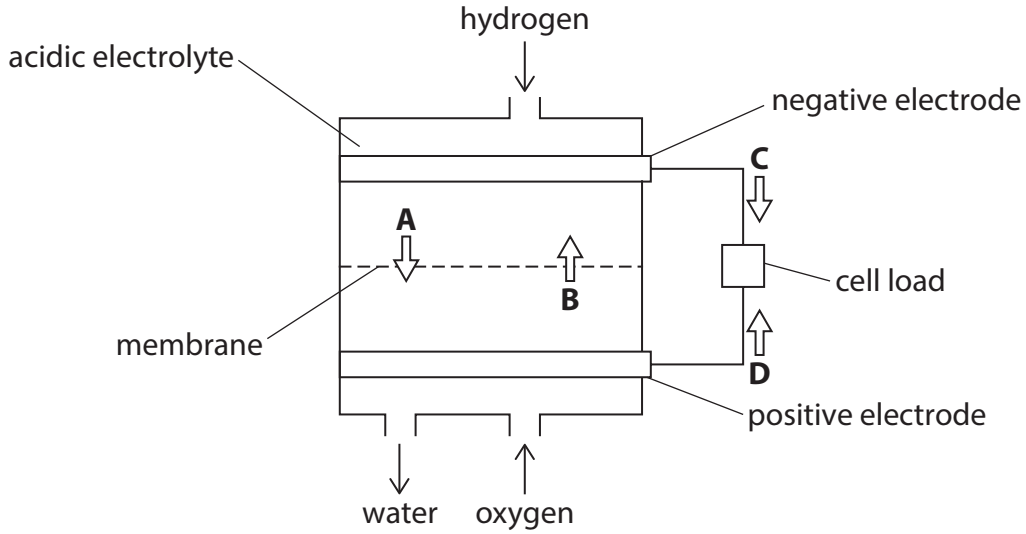
6 The hydrogen-oxygen fuel cell can have an acidic or an alkaline electrolyte.

(a) A diagram with an **acidic** electrolyte is shown.



Which arrow shows the direction of electron flow?

(1)

- ☒ **A** arrow **A**
- ☒ **B** arrow **B**
- ☒ **C** arrow **C**
- ☒ **D** arrow **D**

(b) In a hydrogen-oxygen fuel cell with an **alkaline** electrolyte, the reduction half-equation is shown.

$$\tfrac{1}{2}O_2(g) + H_2O(l) + 2e^- \rightleftharpoons 2OH^-(aq)$$

The overall equation is shown.

$$\tfrac{1}{2}O_2(g) + H_2(g) \rightleftharpoons H_2O(l)$$

What is the oxidation half-equation for this fuel cell?

(1)

- ☒ **A** $H_2(g) + 2OH^-(aq) \rightleftharpoons 2H_2O(l) + 2e^-$
- ☒ **B** $2OH^-(aq) \rightleftharpoons H_2(g) + O_2(g) + 2e^-$
- ☒ **C** $H_2O(l) + 2OH^-(aq) \rightleftharpoons 2H_2(g) + 1\tfrac{1}{2}O_2(g) + 2e^-$
- ☒ **D** $H_2(g) \rightleftharpoons 2H^+(aq) + 2e^-$

(c) It has been reported that in a typical hydrogen fuel cell, each kilogram of fuel produces nine kilograms of water.

What is the percentage yield of water?

(1)

- ☒ **A** 11%
- ☒ **B** 25%
- ☒ **C** 50%
- ☒ **D** 100%

(Total for Question 6 = 3 marks)

7 Which *d*-block elements of Period 3 do **not** follow the periodic pattern in the electronic configuration of their atoms?

- ☒ **A** chromium and copper
- ☒ **B** chromium and manganese
- ☒ **C** scandium and copper
- ☒ **D** scandium and zinc

(Total for Question 7 = 1 mark)

8 Which is the **best** description of the type of reaction which occurs when carbon monoxide binds to oxyhaemoglobin?

- ☒ **A** deprotonation
- ☒ **B** ligand addition
- ☒ **C** ligand exchange
- ☒ **D** reduction

(Total for Question 8 = 1 mark)

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9 This question is about polymers.

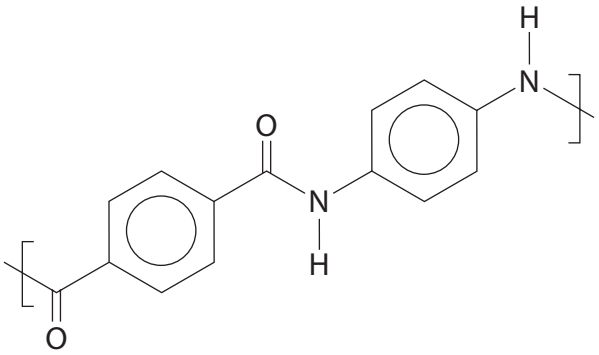
(a) Molecule **X** reacts by both electrophilic substitution and electrophilic addition. It does not react with carbonates or with water.

What type(s) of polymerisation, if any, can molecule **X** undergo?

(1)

- ☒ **A** addition only
- ☒ **B** condensation only
- ☒ **C** addition and condensation
- ☒ **D** does not polymerise

(b) Kevlar is a polyamide and has the repeat unit shown.



What is the percentage by mass of carbon in the repeat unit?

(1)

- ☒ **A** 67.3 %
- ☒ **B** 69.4 %
- ☒ **C** 70.0 %
- ☒ **D** 70.6 %

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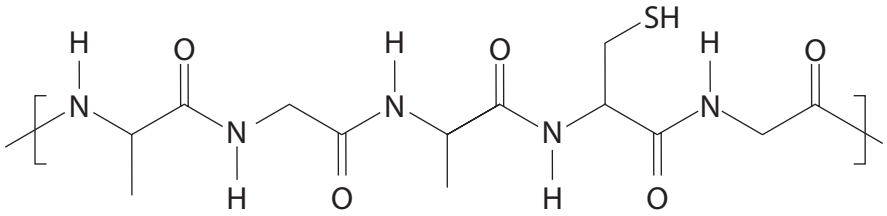
(c) The repeat unit of a polypeptide is shown.



How many **different** amino acids are in this repeat unit?

(1)

☒ **A** 2

☒ **B** 3

☒ **C** 4

☒ **D** 5

(d) Why do polyamides melt at higher temperatures than polyalkenes of similar molar mass?

(1)

☒ **A** the amide bond is stronger than the carbon-carbon bond

☒ **B** there are hydrogen bonds between the chains

☒ **C** there are stronger London forces between the chains

☒ **D** the polyalkene monomers are less stable

(Total for Question 9 = 4 marks)

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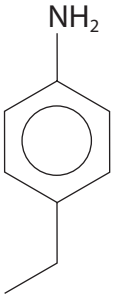
10 Which would **not** be formed from the reaction of phenylamine with chloroethane?

☒ **A**



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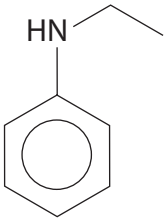

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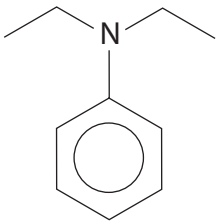
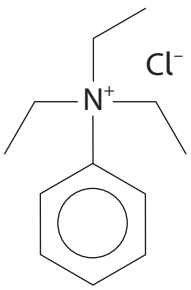


☒ **D**



(Total for Question 10 = 1 mark)

TOTAL FOR SECTION A = 20 MARKS

SECTION B

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

11 This question is about experimental techniques used to determine information about organic compounds.

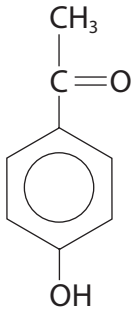
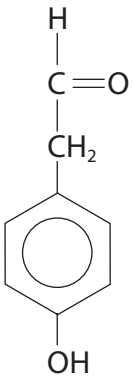
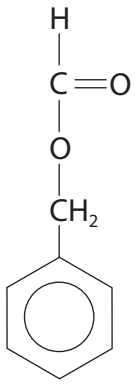
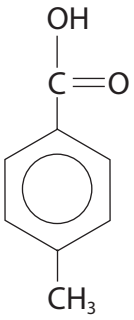
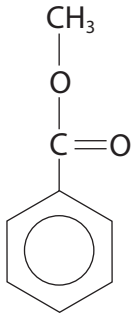
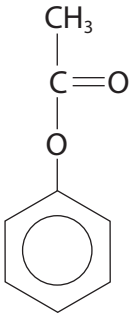
(a) Compound **J** contains carbon, hydrogen and oxygen only.

Complete combustion of 2.25 g of **J** produces 4.95 g of carbon dioxide and 0.90 g of water.

Determine the empirical formula of **J**.

(4)

(b) The molecules shown all have the molecular formula $C_8H_8O_2$.

 **K**	 **L**
 **M**	 **N**
 **O**	 **P**

(i) Identify the bond and the wavenumber ranges in the infrared spectra of **K** and **L** that could be used to distinguish between them.
Use your Data Booklet.

(2)

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(ii) Mass spectrometry may be used to distinguish **M** and **N**.

Suggest, for each molecule, the formula of one ion, which would distinguish **M** and **N**.
These ions should be formed by a single fragmentation.
Include the *m/z* value for each peak.

(2)

M fragment ion .....

N fragment ion .....

(iii) Both **O** and **P** have a singlet peak with a relative area of three in their high resolution proton NMR spectra.

Explain how this peak can be used to distinguish between these two molecules.
Refer to information in your Data Booklet in your answer.

(2)

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.....

.....

.....

(iv) Only one of **K**, **L**, **M**, **N**, **O** and **P** undergoes acid hydrolysis to form methanoic acid.

Write the equation for this hydrolysis to show which molecule this is.

(1)

(Total for Question 11 = 11 marks)

12 This question is about transition elements.

*(a) "*The shapes of transition metal complex ions depend on the metal ion and on the size of the ligands*."

Discuss this statement by referring to complex ions of copper with coordination numbers four and six.
You should include one specific example of each coordination number, drawing three-dimensional diagrams, indicating the bond angles and stating the type of bonding involved.

(6)

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(b) Vanadium forms compounds in a variety of oxidation states.

(i) Identify the **metal** that can reduce the dioxovanadium(V) ion, VO_2^+, to the oxovanadium(IV) ion, VO^{2+}, but **no further**.
Justify your answer with reference to the relevant $E^{\ominus}_{cell}$ values determined from the standard electrode potentials in the Data Booklet.

(3)

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(ii) During the contact process to make sulfuric acid, vanadium(V) oxide is used as a catalyst in the oxidation of sulfur dioxide to sulfur trioxide.

Describe, with the aid of equations, how changes in the oxidation states of vanadium enable it to act as a catalyst.

(2)

.....

.....

(c) Platinum is one of the transition metals used in catalytic converters to decrease the release of carbon monoxide from internal combustion engines.

Describe how the platinum acts as a heterogeneous catalyst in this process.

(2)

(d) Manganese(II) ions act as an autocatalyst in the reaction shown.

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

(i) In the first step of the two-step catalytic sequence, manganese(II) ions reduce the manganate(VII) ions to manganese(III) ions.

Step **1** $8Mn^{2+} + 2MnO_4^- + 16H^+ \rightarrow 10Mn^{3+} + 8H_2O$

Deduce the second step of the reaction.

(1)

(ii) Explain **all** the changes in rate of the reaction as the reaction proceeds.

(2)

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(e) The iron(III) to iron(II) standard electrode potential is +0.77 V when measured in an electrochemical cell with a standard hydrogen electrode.

Draw a labelled diagram of the apparatus that you would use to measure this standard electrode potential.
Include the chemicals and the conditions required.

(6)

(Total for Question 12 = 22 marks)

13 Redox reactions occur widely in inorganic chemistry and involve a variety of compounds.

(a) Potassium manganate(VII) solutions, $KMnO_4(aq)$, are frequently used in redox titrations.

(i) Pyrolusite is one of the ores which is used industrially to produce potassium manganate(VII). It contains manganese(IV) oxide.
One method of extraction initially treats the ore with potassium hydroxide which produces potassium manganate(VI), as shown in the equation.

$$2MnO_2 + 4KOH + O_2 \rightarrow 2K_2MnO_4 + 2H_2O$$

The second step involves the reaction with carbon dioxide as shown.

$$3K_2MnO_4 + 2CO_2 \rightarrow 2KMnO_4 + MnO_2 + 2K_2CO_3$$

One tonne (1×10^6 g) of ore yielded 0.342 tonnes of potassium manganate(VII).

Calculate the percentage by mass of manganese in this pyrolusite sample. Assume that all of the manganese in the ore is manganese(IV) oxide.

(3)

(ii) One of the advantages of using potassium manganate(VII) in a titration is that it is self-indicating.

State why potassium manganate(VII) is self-indicating.

(1)

.....

.....

.....

(b) The Winkler method is used to measure the amount of dissolved oxygen in freshwater and involves a number of steps, which include a redox titration.

Step **1** $MnSO_4$ is added to the water sample and then made alkaline with sodium hydroxide. The reaction shown occurs.

$$2Mn^{2+}(aq) + 4OH^-(aq) + O_2(aq) \rightarrow 2MnO_2(s) + 2H_2O(l)$$

Step **2** Acidified potassium iodide is added, which results in the liberation of iodine as shown.

$$MnO_2(s) + 2I^-(aq) + 4H^+(aq) \rightarrow Mn^{2+}(aq) + I_2(aq) + 2H_2O(l)$$

Step **3** Sodium thiosulfate is then used to determine the amount of iodine present by titration using a starch indicator.

$$I_2(aq) + 2S_2O_3^{2-}(aq) \rightarrow S_4O_6^{2-}(aq) + 2I^-(aq)$$

Several 100.0 cm^3 water samples were analysed using this method and the mean titre was 11.45 cm^3 of a 0.0100 mol dm^{-3} sodium thiosulfate solution.

Calculate the dissolved oxygen content, in **mg dm^{-3}**, of the water sample.

(5)

(c) Sodium dichromate(VI), $Na_2Cr_2O_7(aq)$, is another solution that is often used in redox titrations.

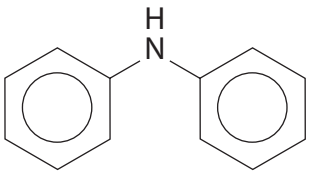
(i) The dichromate(VI) ions are in equilibrium with chromate(VI) ions as shown.

$$Cr_2O_7^{2-} + H_2O \rightleftharpoons 2CrO_4^{2-} + 2H^+$$

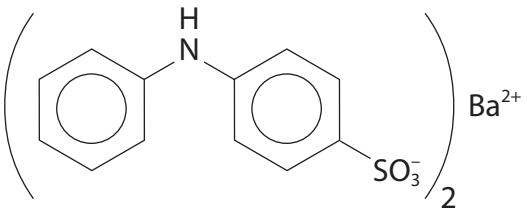
Explain the effect on the equilibrium position if the solution is made alkaline and not acidic.

(2)

(ii) Diphenylamine and barium diphenylaminesulfonate are used as indicators in sodium dichromate(VI) titrations.
Their structures are shown.



diphenylamine



barium diphenylaminesulfonate

Give a possible explanation why barium diphenylaminesulfonate is preferred as an indicator in aqueous solutions.

(2)

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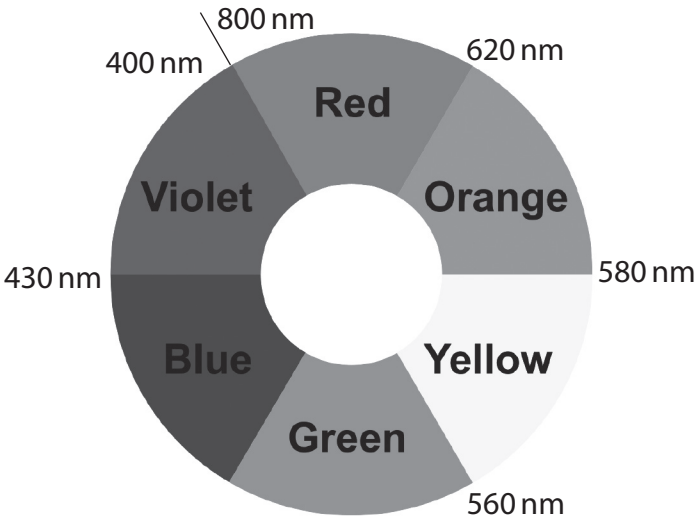
(d) Cerium(IV) ammonium sulfate is another solution used in redox titrations.
It is reduced from yellow Ce^{4+} to colourless Ce^{3+}. The origin of the colour is similar to that in transition metal complexes but involves different orbitals.

(i) The colours in the visible spectrum and their approximate wavelengths are shown in the diagram, which is known as the 'colour wheel'. It shows that a complex ion with a blue colour absorbs orange-coloured light.



(Source: PAL)

Deduce the colour and approximate wavelength of light that is **absorbed** by the Ce^{4+} ion.
Justify your answer by referring to the colour wheel **and** the origin of the colour.

(3)

(ii) Give a possible reason why the Ce^{3+} ion is colourless.

(1)

(Total for Question 13 = 17 marks)

TOTAL FOR SECTION B = 50 MARKS

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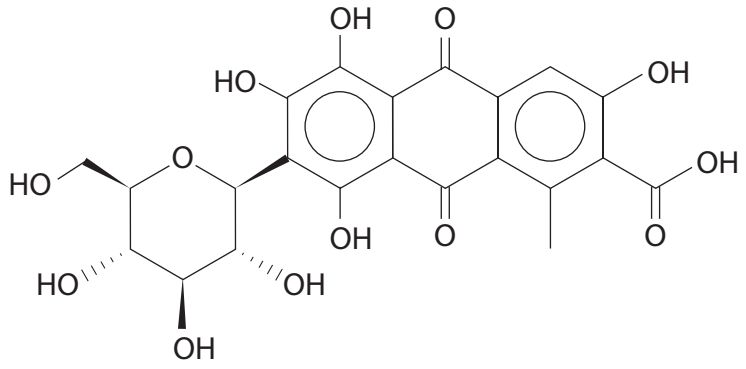
SECTION C

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

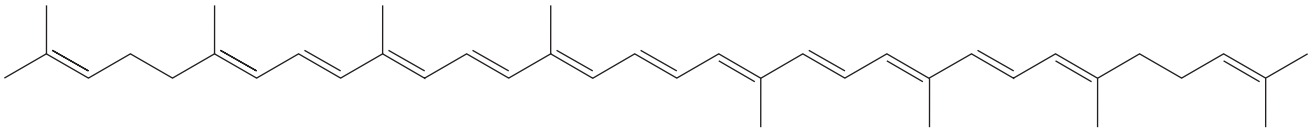
14

Red dyes and red colouring compounds

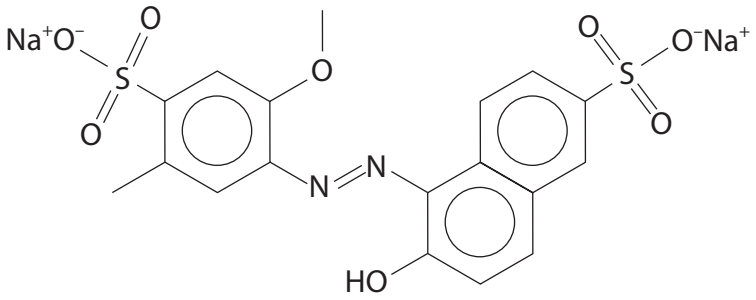
Carmine is a red pigment used to colour products such as food, textiles and paints.
It is produced from carminic acid, which is extracted from insects.
Carminic acid has the structure shown.



Lycopene is another naturally occurring pigment which is present in many red fruits, including tomatoes. It has been used in preference to carmine because it is plant-based. It has the structure shown.



Allura Red AC is a red food dye which is used in products such as yoghurts, sweets and ice creams.
Approximately 18 million kilograms of this dye are sold per year worldwide.



(a) 70 000 insects are required to produce 450 g of carminic acid.

Calculate the approximate number of carminic acid molecules in each insect.

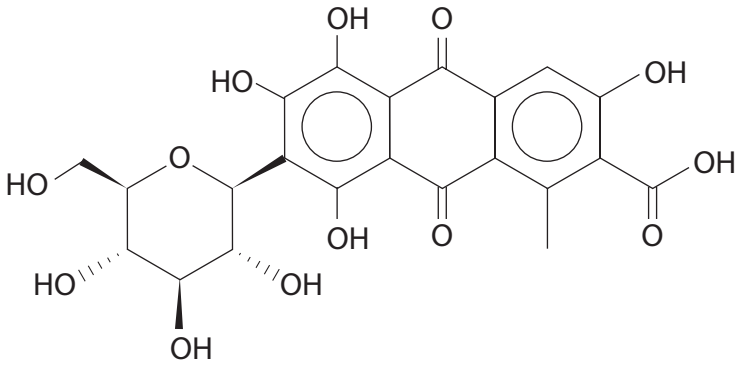
[Data: M_r carminic acid = 492]

(3)

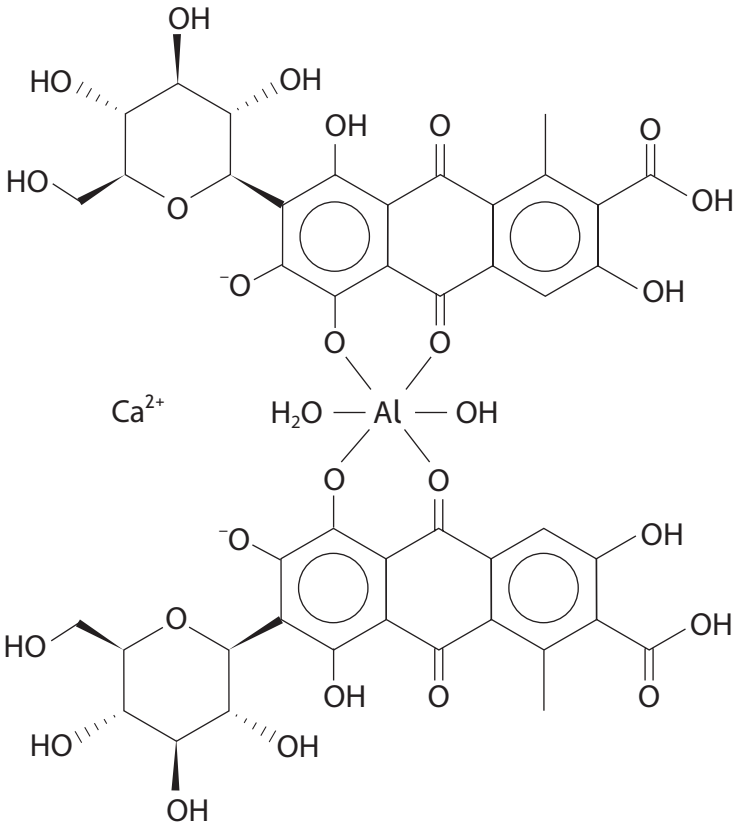
(b) The colour of carmine depends on the pH. This is because five groups in carminic acid can act as proton donors. As well as the hydrogen of the carboxylic acid group, the hydrogens of the phenol functional groups can also be donated.

Label, using circles, the **five** protons that can be removed from carminic acid.

(2)



(c) The textile industry increases the stability of the carminic acid red colour by forming a complex ion with aluminium ions, Al^{3+}.
A proposed structure for this complex is shown.



State and justify the type of ligand that carminic acid is in this complex.

(2)

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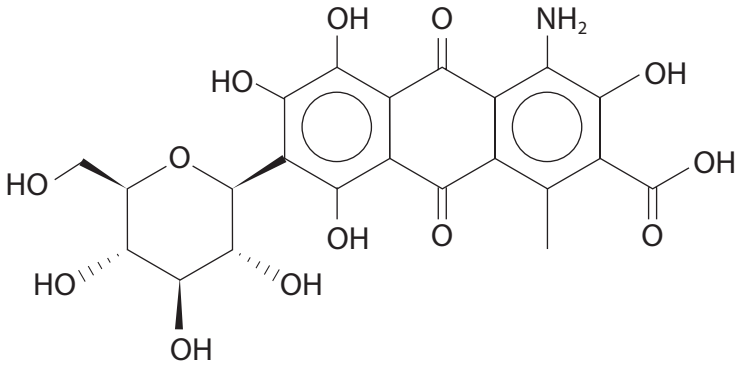
(d) The food industry has developed a derivative of carminic acid which is more stable. Carminic acid is boiled in ammonia for several hours to form the structure shown, which can form a zwitterion.



Explain how this carminic acid derivative can be a zwitterion.

(2)

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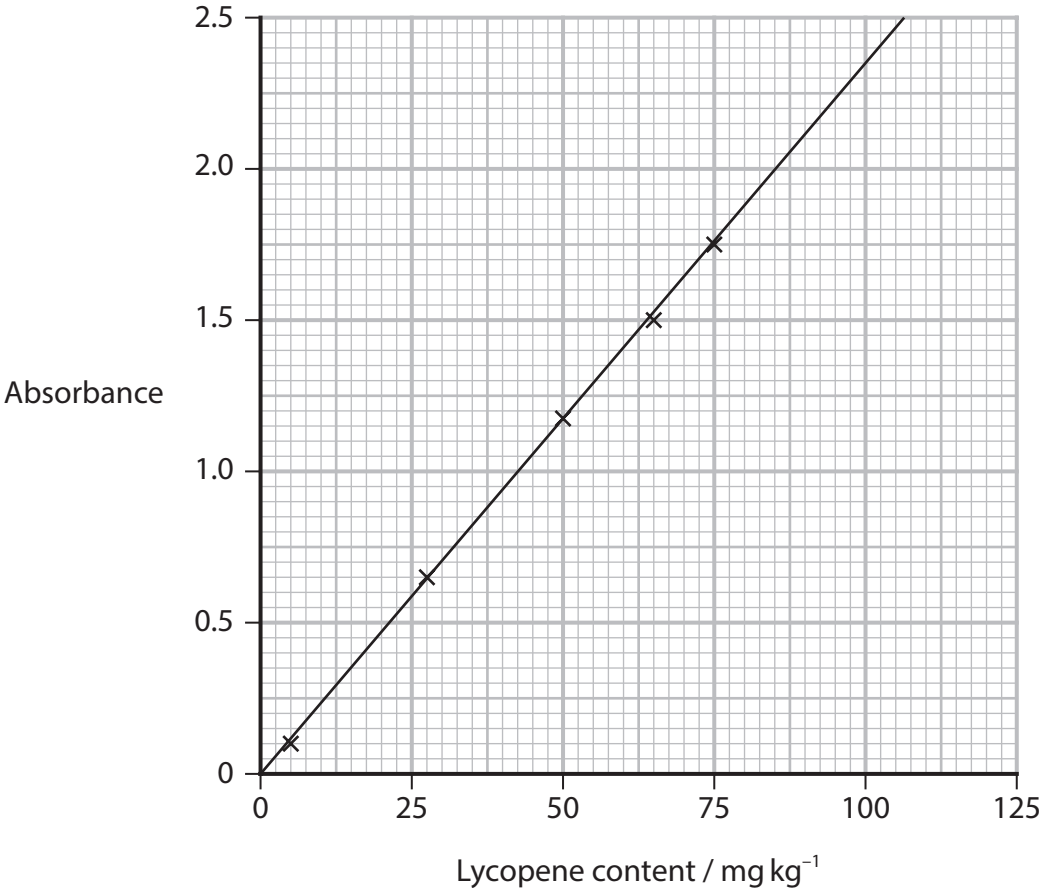
(e) The content of lycopene in tomato products is measured in mg of lycopene per kilogram of tomato product.
This lycopene content can be determined by colorimetry.
Solvent extraction was used to remove the lycopene from a number of tomato products and then the absorbance of these solutions was measured at a wavelength of 560 nm.
The calibration graph shown was produced by recording the absorbance of known concentrations of lycopene.



(i) Determine the concentration of lycopene if the absorbance of the solution is 2.0. Give your answer in parts per million (ppm).

(1)

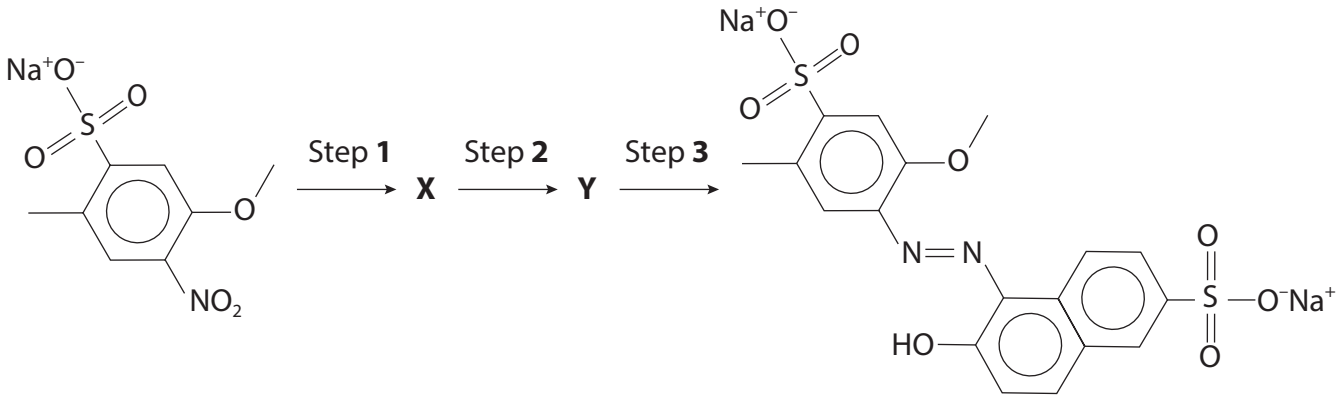
(ii) Explain, with reference to the range of the data shown in the graph, why the lycopene content determined in (e)(i) may or may not be valid.

(2)

(iii) Explain the meaning of the term 'solvent extraction'.

(2)

(f) Allura Red AC is an azo dye which can be synthesised using the pathway shown.



Give the reagents and conditions for each step in the synthesis, including the structures of the intermediate compounds **X** and **Y**.

(6)

(Total for Question 14 = 20 marks)

TOTAL FOR SECTION C = 20 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)											(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							

Key: relative atomic mass / **atomic symbol** / name / atomic (proton) number

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