Write your name here

Surname	Other names

Pearson Edexcel
International
Advanced Level

Centre Number | | | | | |

Candidate Number | | | | |

Chemistry
Advanced
Unit 5: General Principles of Chemistry II – Transition Metals and Organic Nitrogen Chemistry (including synoptic assessment)

Monday 19 June 2017 – Morning
Time: 1 hour 40 minutes

Paper Reference
WCH05/01

Candidates must have: Data Booklet
Scientific calculator

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.*

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.*
- Questions labelled with an **asterisk** (*) are ones where the quality of your written communication will be assessed
  – *you should take particular care with your spelling, punctuation and grammar, as well as the clarity of expression, on these questions.*
- A Periodic Table is printed on the back cover of this paper.

Advice

- Read each question carefully before you start to answer it.
- Keep an eye on the time.
- Try to answer every question.
- Check your answers if you have time at the end.

Turn over ▶

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5/6/6/6/1/

P 4 8 3 8 7 A 0 1 3 2

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 of these elements is a transition metal?

☒ **A** scandium

☒ **B** tin

☒ **C** titanium

☒ **D** zinc

(Total for Question 1 = 1 mark)

2 Thallium(III) ions oxidise iodide ions to iodine.

$$2I^- \rightarrow I_2 + 2e^-$$

0.0012 mol of Tl^{3+} ions oxidised 0.0024 mol iodide ions.

What is the oxidation number of the thallium ions produced in this reaction?

☒ **A** +1

☒ **B** +2

☒ **C** +4

☒ **D** +5

(Total for Question 2 = 1 mark)

3 The $[Cu(H_2O)_6]^{2+}$ ion is blue because the water ligands split the 3d subshell and a 3d electron is promoted to a higher energy level

☒ **A** absorbing all but blue light as it drops back to its ground state.

☒ **B** emitting blue light as it drops back to its ground state.

☒ **C** absorbing all but blue light.

☒ **D** emitting all but blue light.

(Total for Question 3 = 1 mark)

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

4 Ammonium vanadate(V), NH_4VO_3, dissolves in aqueous sodium hydroxide solution releasing a colourless gas. The gas gives a pale blue precipitate with aqueous copper(II) sulfate.

What is the colourless gas?

☒ **A** H_2

☒ **B** N_2

☒ **C** NH_3

☒ **D** O_2

(Total for Question 4 = 1 mark)

5 25.0 cm^3 of a 0.0100 mol dm^{-3} solution of vanadium(II) ions is titrated with an acidified solution containing 0.0200 mol dm^{-3} manganate(VII) ions, MnO_4^-.

$$3MnO_4^- + 5V^{2+} + 4H^+ \rightarrow 3Mn^{2+} + 5VO_2^+ + 2H_2O$$

What volume, in cm^3, of this solution of manganate(VII) ions is needed for the reaction?

☒ **A** 7.5

☒ **B** 15.0

☒ **C** 20.8

☒ **D** 41.7

(Total for Question 5 = 1 mark)

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

6 Manganate(VII) ions, MnO_4^-, react with ethanedioate ions, $C_2O_4^{2-}$, in acid solution.

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

What is the **change** in oxidation number of each carbon atom in this reaction?

☒ **A** +1

☒ **B** +3

☒ **C** +4

☒ **D** +5

(Total for Question 6 = 1 mark)

7 The standard electrode potential for the $Ag^+(aq)|Ag(s)$ electrode is measured.

Which is the only suitable chemical for the solution in a salt bridge to connect the silver electrode to the standard hydrogen electrode?

☒ **A** potassium carbonate

☒ **B** potassium chloride

☒ **C** potassium iodide

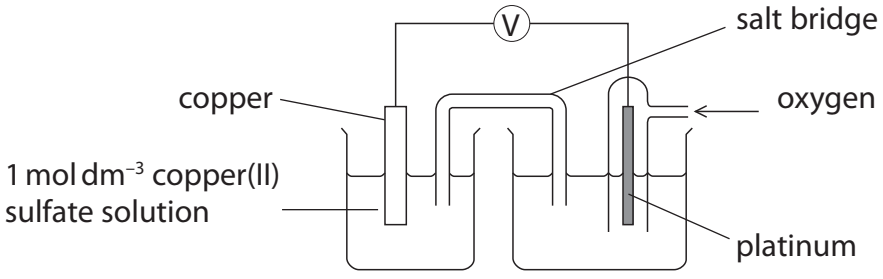
☒ **D** potassium nitrate

(Total for Question 7 = 1 mark)

8 The cell below was set up. Copper is the negative electrode.

The solution in the right-hand beaker contained a suitable electrolyte and phenolphthalein.

After some time, the solution in the right-hand beaker turned pink.



Which ionic half-equation shows the reaction at the oxygen electrode that caused the phenolphthalein to turn pink?

☒ **A** $\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$

☒ **B** $H_2O \rightarrow \frac{1}{2}O_2 + 2H^+ + 2e^-$

☒ **C** $\frac{1}{2}O_2 + H_2O + 2e^- \rightarrow 2OH^-$

☒ **D** $2OH^- \rightarrow \frac{1}{2}O_2 + H_2O + 2e^-$

(Total for Question 8 = 1 mark)

9 Use these electrode potentials to answer the following questions.

Electrode reaction	$E^{\ominus}$ /V
$Cr^{3+}(aq) + e^- \rightleftharpoons Cr^{2+}(aq)$	−0.41
$\frac{1}{2}I_2(aq) + e^- \rightleftharpoons I^-(aq)$	+0.54
$\frac{1}{2}Br_2(aq) + e^- \rightleftharpoons Br^-(aq)$	+1.09
$\frac{1}{2}Cr_2O_7^{2-}(aq) + 7H^+(aq) + 3e^- \rightleftharpoons Cr^{3+}(aq) + 3\frac{1}{2}H_2O(l)$	+1.33
$\frac{1}{2}Cl_2(aq) + e^- \rightleftharpoons Cl^-(aq)$	+1.36

(a) Which of these species is the strongest reducing agent?

(1)

☒ **A** $Cr^{2+}(aq)$

☒ **B** $Cr^{3+}(aq)$

☒ **C** $Cl^-(aq)$

☒ **D** $Cl_2(aq)$

(b) Which halogen(s) would oxidise chromium(II) to chromium(III) but **not** to chromium(VI) under standard conditions?

(1)

☒ **A** $Br_2(aq)$ only

☒ **B** $I_2(aq)$ only

☒ **C** $Br_2(aq)$ and $Cl_2(aq)$ only

☒ **D** $I_2(aq)$ and $Br_2(aq)$ only

(Total for Question 9 = 2 marks)

10 The information about benzene **not** provided by X-ray diffraction is that

☒ **A** all C—C—C bond angles are the same.

☒ **B** all C—C bond lengths are the same.

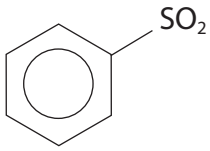
☒ **C** all C—C bond energies are the same.

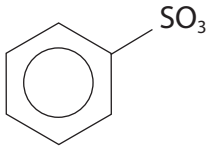
☒ **D** the molecule is planar.

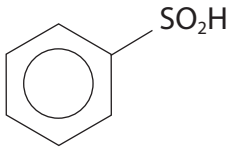
(Total for Question 10 = 1 mark)

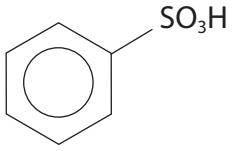
Use this space for any rough working. Anything you write in this space will gain no credit.

11 The formula of the organic product of the reaction between benzene and fuming sulfuric acid is

☒ **A** 

☒ **B** 

☒ **C** 

☒ **D** 

(Total for Question 11 = 1 mark)

12 Benzene is nitrated using a mixture of concentrated nitric and sulfuric acids.

In this reaction, the concentrated sulfuric acid acts as

☒ **A** an acid and catalyst.

☒ **B** an acid and nucleophile.

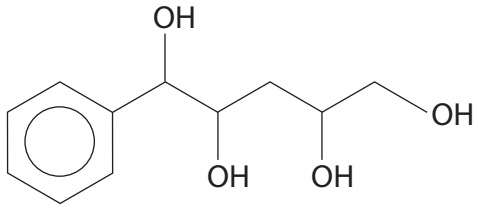
☒ **C** a base and catalyst.

☒ **D** a base and electrophile.

(Total for Question 12 = 1 mark)

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

13 How many chiral carbon atoms are there in the following structure?



☒ **A** 2

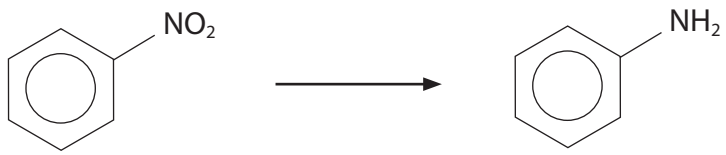
☒ **B** 3

☒ **C** 4

☒ **D** 5

(Total for Question 13 = 1 mark)

14 A sample of phenylamine was prepared from 2.46 g of nitrobenzene. The yield of phenylamine was 70.0% by mass.



nitrobenzene
$M_r = 123$

phenylamine
$M_r = 93$

The mass of phenylamine produced is

☒ **A** 0.014 g

☒ **B** 1.302 g

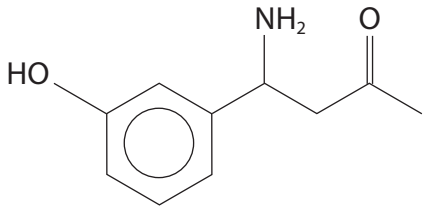
☒ **C** 1.722 g

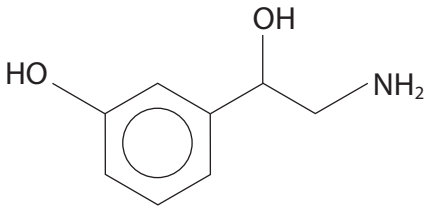
☒ **D** 2.277 g

(Total for Question 14 = 1 mark)

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

15 Which reagent can be used to distinguish between these two compounds?



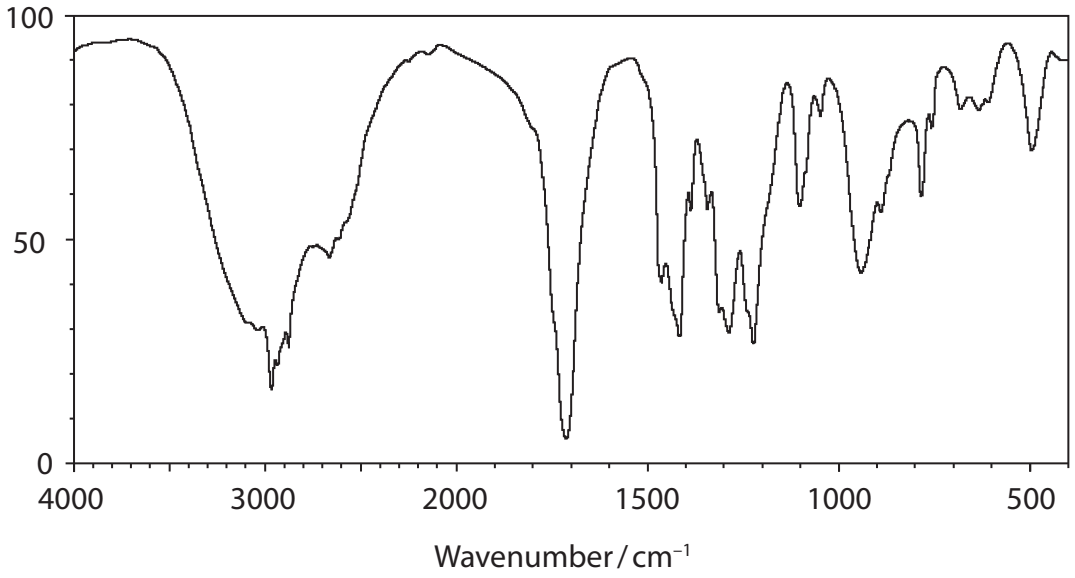


- ☒ **A** Bromine water
- ☒ **B** Copper(II) sulfate solution
- ☒ **C** Iodine in alkali
- ☒ **D** Tollens' reagent

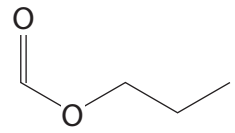
(Total for Question 15 = 1 mark)

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

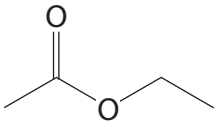
16 Which compound would give the infrared spectrum shown?



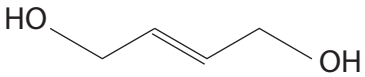
☒ **A**



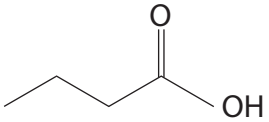
☒ **B**



☒ **C**



☒ **D**



(Total for Question 16 = 1 mark)

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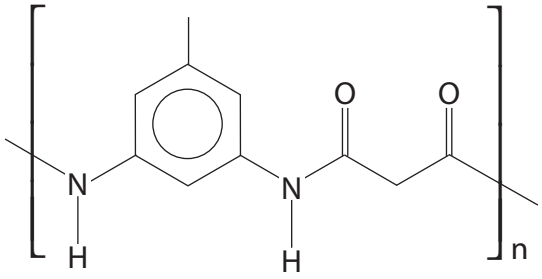
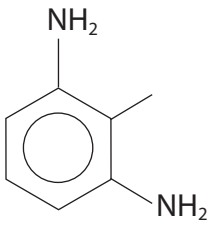
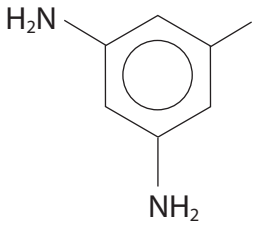
17 Which isomer reacts with propanedioyl dichloride to form the polymer shown?



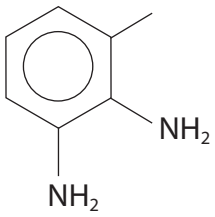
☒ **A**



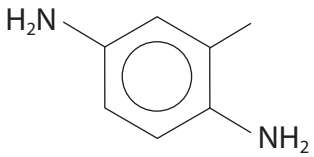
☒ **B**



☒ **C**



☒ **D**



(Total for Question 17 = 1 mark)

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

18 Benzaldehyde, C_6H_5CHO, reacts with an aqueous solution of potassium hydroxide. During this reaction, the benzaldehyde is both oxidised and reduced.

The organic products of this reaction are

☒ **A** C_6H_5COOH and $C_6H_5CH_2OH$

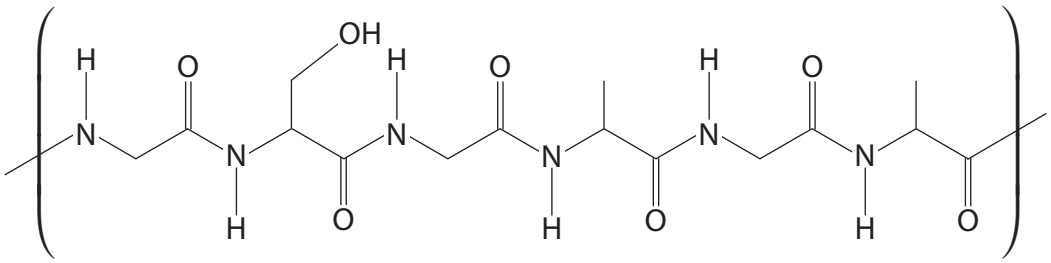
☒ **B** C_6H_5COOH and $C_6H_5CH_2O^-K^+$

☒ **C** $C_6H_5COO^-K^+$ and $C_6H_5CH_2OH$

☒ **D** $C_6H_5COO^-K^+$ and $C_6H_5CH_2O^-K^+$

(Total for Question 18 = 1 mark)

19 Fibroin is one of the proteins in silk. Part of the structure of fibroin is shown.



How many **different** amino acids have combined to form this part of the structure?

☒ **A** 2

☒ **B** 3

☒ **C** 4

☒ **D** 6

(Total for Question 19 = 1 mark)

TOTAL FOR SECTION A = 20 MARKS

SECTION B

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

20 Chromium forms many different complex ions.

(a) State and explain the shape of the $[CrCl_4]^-$ complex ion.

(2)

Shape .....

Explanation

.....

.....

.....

.....

(b) When a small amount of aqueous sodium hydroxide is added to a solution of chromium(III) ions, $[Cr(H_2O)_6]^{3+}(aq)$, a green precipitate forms.

This precipitate dissolves in excess aqueous sodium hydroxide.

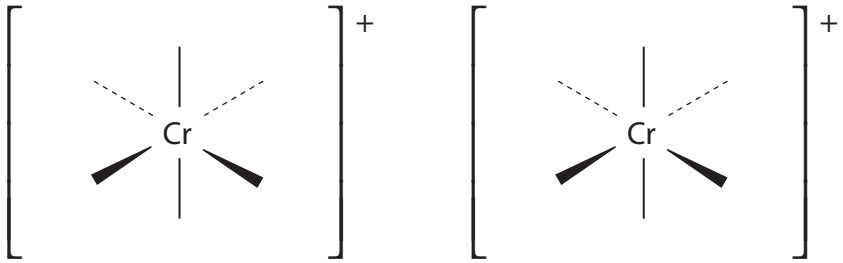
Write the ionic equations for these two reactions. Include state symbols.

(2)

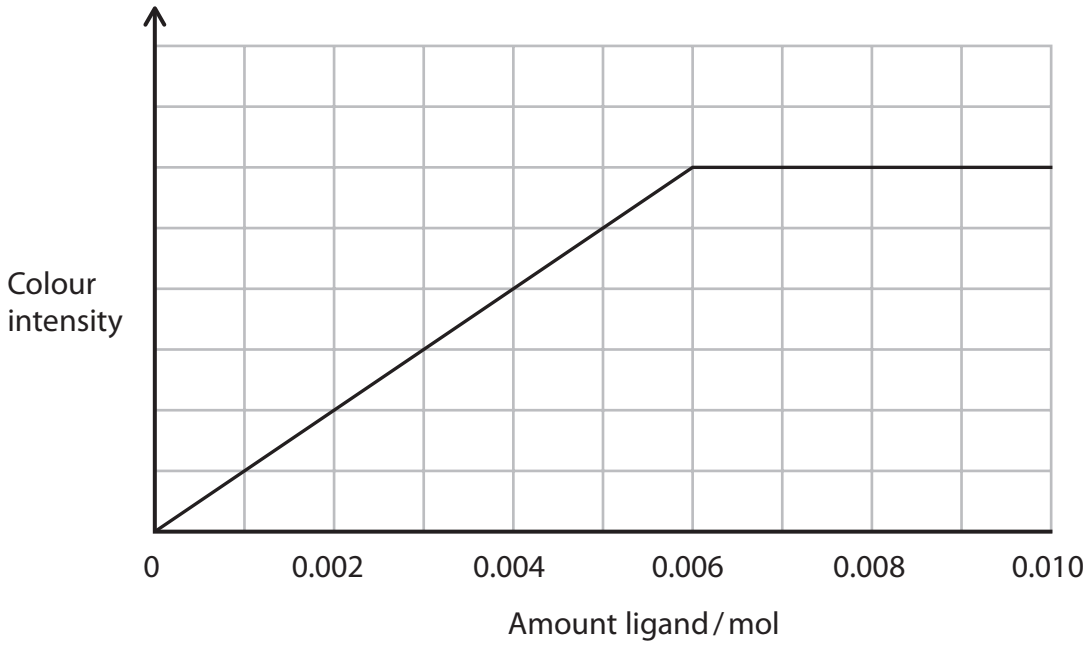
(c) The complex ion $[Cr(NH_3)_4Cl_2]^+$ is octahedral and exists as two isomers.

Complete the diagrams to show these two isomers.

(2)



(d) The diagram shows how the colour intensity of an aqueous solution containing 0.001 mol of chromium(III) ions varies with increasing amounts of cyanide ions, CN^-.

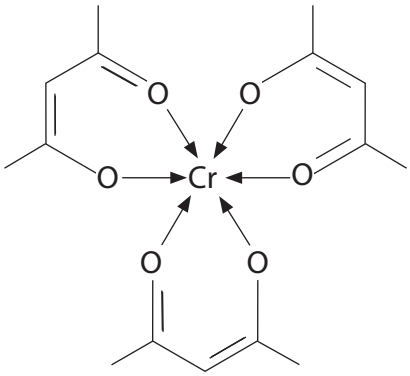


Chromium(III) ions form a complex ion with EDTA with a greater colour intensity than the complex ion formed with cyanide ions.

Sketch on the above axes the result you would expect to obtain if increasing amounts of EDTA were used instead of CN^-.

(2)

(e) Chromium(III) ions form a **neutral** complex with the bidentate ligand commonly known as 'acac'.
The structure of the chromium(III) complex $Cr(acac)_3$ is



Draw the structure of the bidentate ligand 'acac'.

(1)

(Total for Question 20 = 9 marks)

21 The –OH group is present in alcohols and phenols.

(a) Phenol, C_6H_5OH, is used as a starting material to make polymers, explosives and drugs.

(i) State what is **seen** when phenol reacts with excess bromine water.

(1)

.....

.....

(ii) Write the equation for the reaction between phenol and excess bromine water. State symbols are not required.

(2)

*(iii) Benzene only reacts with bromine in the presence of a Friedel-Crafts catalyst. Explain why bromine reacts much more readily with phenol than with benzene.

(2)

.....

.....

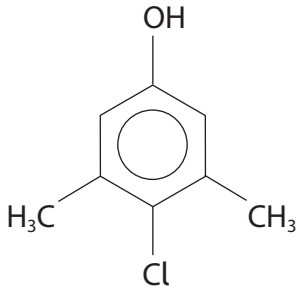
.....

.....

.....

.....

(iv) Compound **P** is a powerful antiseptic.



Give the systematic name of compound **P**.

(1)

*(b) Phenol is more acidic than aliphatic alcohols, such as ethanol, but less acidic than carboxylic acids. It reacts with sodium hydroxide but not with sodium carbonate.

2.5 g of a mixture of phenol and benzoic acid, C_6H_5COOH, was added to excess sodium carbonate solution, Na_2CO_3. 185 cm^3 of carbon dioxide was produced.

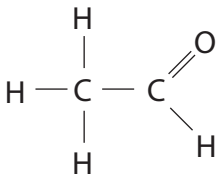
$$2C_6H_5COOH + Na_2CO_3 \rightarrow 2C_6H_5COONa + H_2O + CO_2$$

Calculate the percentage by mass of phenol in the mixture.

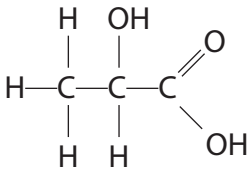
(The volume of 1 mol of gas under the conditions of the experiment is 24 000 cm^3)

(4)

(c) Lactic acid (2-hydroxypropanoic acid) is used as a flavouring. It may be prepared from ethanal.



ethanal



lactic acid

(i) Devise a two-step synthesis to produce lactic acid from ethanal. Include the reagents and conditions for each step, and the structure of the intermediate compound.

(3)

(ii) State the number of peaks in the **low** resolution proton nmr spectrum of lactic acid.

(1)

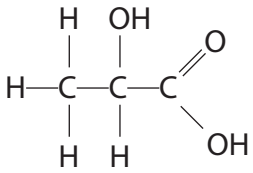
(iii) The hydrogen of the alcohol group in lactic acid produces a single peak in the proton nmr spectrum.

Give the chemical shift you would expect for this peak.

(1)

(iv) Two molecules of lactic acid react to form one molecule of a cyclic di-ester.

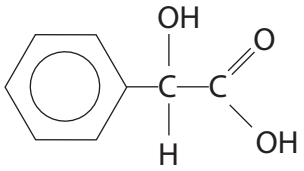
The structure of lactic acid is shown below



Draw the structure of the cyclic di-ester.

(1)

(d) 2-hydroxy-2-phenylethanoic acid is more commonly known as mandelic acid. It has antibacterial properties.



(i) Mandelic acid is made when 2-chloro-2-phenylethanoic acid reacts with hydroxide ions.

Draw the S_N1 mechanism for this reaction.

(3)

*(ii) Explain why the mandelic acid, produced by the S_N1 mechanism from a single optical isomer of 2-chloro-2-phenylethanoic acid, is **not** optically active.

(3)

(iii) An impure sample of mandelic acid can be recrystallised using methanol as the solvent.

The steps of the recrystallisation are summarised below. In the spaces provided, explain the purpose of each step, referring particularly to any words in **bold** type.

(5)

Step 1 The sample was dissolved in the **minimum** amount of hot methanol.

Step 2 The **hot** solution was **filtered**.

Step 3 The filtrate was cooled in an **ice bath**.

Step 4 The mixture was **filtered** using suction filtration.

(Total for Question 21 = 27 marks)

22 This question is about some metals and their compounds.

(a) Potassium and copper form ions with a single positive charge. Some information about these metals is given in the table.

	Potassium	Copper
Electronic configuration	$[Ar]4s^1$	$[Ar]3d^{10}4s^1$
Metallic radius / nm	0.235	0.128

(i) Most transition metals in Period 4 have two electrons in the 4s orbital of their atoms. State why copper atoms have one electron in their 4s orbitals.

(1)

(ii) Copper atoms have more electrons than potassium atoms. Explain why the metallic radius of copper is smaller than that of potassium.

(1)

(b) The standard electrode potential of the copper(II) / copper half-cell is $E^{\ominus} = +0.34$ V.

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

The effect of changing the concentration of the ions is calculated using the equation

$$E = E^{\ominus} + \frac{RT}{96\,500 \times n} \ln [Cu^{2+}(aq)]$$

where n is the number of electrons in the half-equation, T is the temperature in kelvin and R is the gas constant.

Calculate the electrode potential of the half-cell at 298 K when the concentration of copper(II) ions is 0.100 mol dm^{-3}.

[Gas constant, $R = 8.31$ J mol^{-1} K^{-1}]

(2)

(c) An aqueous solution of copper(II) ions reacts with excess iodide ions to form a white precipitate of copper(I) iodide.

$$2Cu^{2+}(aq) + 4I^{-}(aq) \rightarrow 2CuI(s) + I_2(aq)$$

(i) The relevant standard electrode potentials are given.

$$Cu^{2+}(aq) + e^{-} \rightleftharpoons Cu^{+}(aq) \quad E^{\ominus} = +0.15\,V$$

$$I_2(aq) + 2e^{-} \rightleftharpoons 2I^{-}(aq) \quad E^{\ominus} = +0.54\,V$$

Calculate the value for $E^{\ominus}_{cell}$ for the reaction between copper(II) ions and iodide ions and suggest why the reaction takes place.

(3)

(ii) Many coins are made of alloys containing copper and other metals.

A coin was treated with concentrated nitric acid to convert all the copper atoms into copper(II) ions. The solution was neutralised, made up to 1.00 dm^3 and mixed thoroughly. Excess potassium iodide was added to 25.0 cm^3 portions of this solution and the liberated iodine was titrated with sodium thiosulfate solution of concentration 0.150 mol dm^{-3}.

The mean titre was 10.90 cm^3.

The equations for the reactions are

$$2Cu^{2+}(aq) + 4I^{-}(aq) \rightarrow 2CuI(s) + I_2(aq)$$

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

Calculate the mass of copper in the coin.
Give your answer to **three** significant figures.

(4)

(d) Silver and gold are below copper in the Periodic Table.

(i) The standard electrode potential values involving silver ions are given.

$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$ $\quad E^{\ominus} = +0.80\,V$

$Ag^{2+}(aq) + e^- \rightleftharpoons Ag^+(aq)$ $\quad E^{\ominus} = +1.98\,V$

Write the equation for the reaction involving these species that is thermodynamically feasible under standard conditions. Explain whether or not this reaction is a disproportionation.

(2)

(ii) Chloroauric acid, $HAuCl_4$, is used in the production of gold nanoparticles. It is formed when gold reacts with aqua regia, a mixture of concentrated nitric and hydrochloric acids.

$$Au + HNO_3 + 4HCl \rightleftharpoons HAuCl_4 + NO + 2H_2O$$

Explain, in terms of oxidation numbers, why this is a redox reaction.

(2)

(Total for Question 22 = 15 marks)

TOTAL FOR SECTION B = 51 MARKS

SECTION C

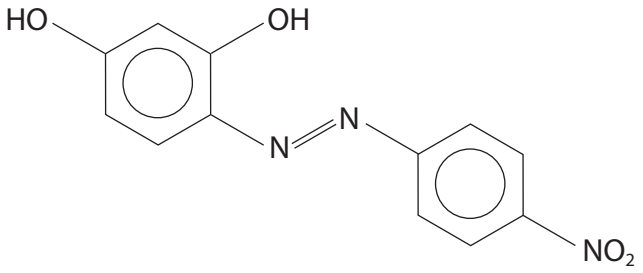
Answer ALL the questions. Write your answers in the spaces provided.

23

Organic Nitrogen Compounds

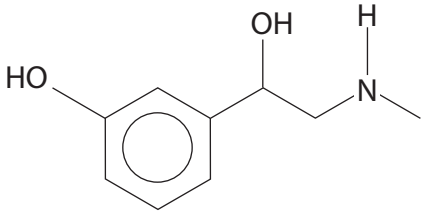
Nitrogen is present in many organic compounds, including amines, amides and nitriles. Many useful products are made from these compounds.

Amines are used to make dyes, drugs and polymers. Phenylamine and other aromatic amines are used to manufacture azo dyes such as azo violet.



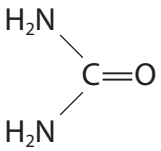
azo violet

The drug phenylephrine is used as a decongestant.



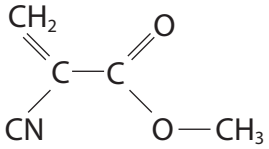
phenylephrine

Urea is a white crystalline solid which is soluble in water. It is used as a fertiliser as well as in the manufacture of biuret (used to test for compounds containing a peptide linkage) and of drugs such as barbiturates.



urea

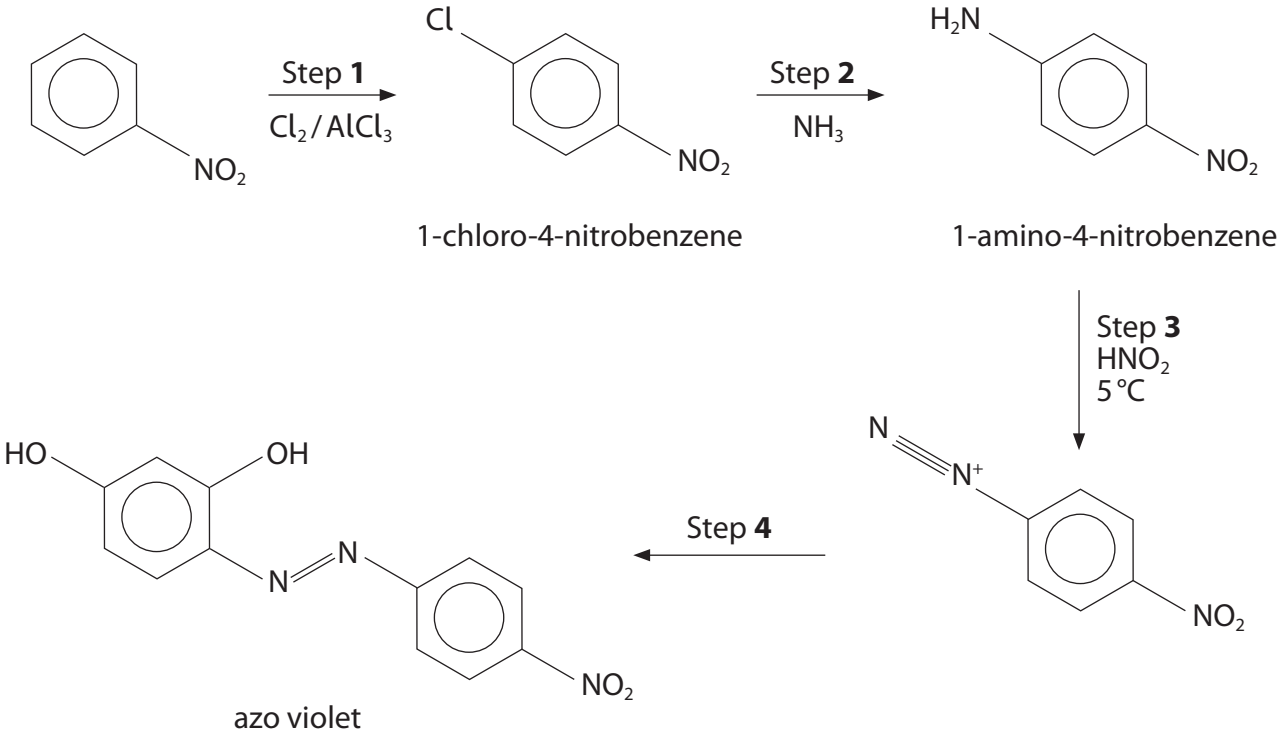
Methyl 2-cyanopropenoate is the main component of superglue.



methyl 2-cyanopropenoate

It polymerises rapidly in the presence of water.

(a) Azo violet is synthesised from nitrobenzene in four steps.



(i) Give the mechanism for the formation of 1-chloro-4-nitrobenzene from nitrobenzene. Include an equation to show the formation of the electrophile.

(4)

(ii) Draw the structure of the organic species needed for Step **4**.

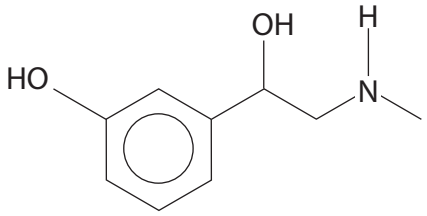
(1)

(iii) Give the molecular formula for azo violet.

(1)

(b) Draw the structure of the product formed when phenylephrine reacts with **excess** ethanoyl chloride.

(2)



phenylephrine

(c) (i) Suggest, with the aid of a diagram, why urea, $(H_2N)_2CO$, is soluble in water.

(3)

.....

.....

.....

.....

(ii) Urea is made by reacting ammonia and carbon dioxide at 200 °C and 200 atm pressure.

Write the equation for this reaction. State symbols are not required.

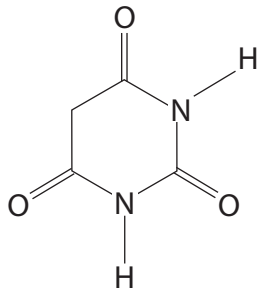
(1)

(iii) Biuret is formed when urea is heated above its melting temperature. A molecule of biuret is made when two molecules of urea react together with the loss of ammonia.

Suggest the **displayed** formula of a molecule of biuret.

(1)

(iv) Barbiturate drugs are derivatives of barbituric acid.



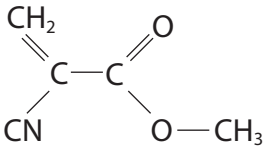
barbituric acid

Barbituric acid is formed from urea and a dicarboxylic acid in a condensation reaction.

Draw the **skeletal** formula of the dicarboxylic acid.

(1)

(d) (i) **Name** the functional groups present in methyl 2-cyanopropenoate.



(2)

.....

(ii) Methyl 2-cyanopropenoate polymerises.

Name the type of polymerisation and draw **two** repeat units of the polymer.

(3)

Type .....

(Total for Question 23 = 19 marks)

TOTAL FOR SECTION C = 19 MARKS
TOTAL FOR PAPER = 90 MARKS

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