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)

Wednesday 22 June 2016 – Morning
Time: 1 hour 40 minutes

Paper Reference
WCH05/01

You must have: Data Booklet

Candidates may use a calculator.

Total Marks

Instructions

- Use **black** ink or 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 ▶

6/6/6/3/3/3/1/e2/

P 4 6 6 6 5 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 What are the oxidation states of vanadium in the ions shown?

	VO_2^+	VO^{2+}	VO_3^-
☒ **A**	+3	+2	+5
☒ **B**	+1	+2	−1
☒ **C**	+5	+4	+7
☒ **D**	+5	+4	+5

(Total for Question 1 = 1 mark)

2 The conditions of concentration and temperature required for the standard electrode potential of the hydrogen electrode to be exactly 0.0 V are

	Concentration	Temperature
☒ **A**	1 mol dm^{-3} H^+(aq)	273 K
☒ **B**	1 mol dm^{-3} H^+(aq)	298 K
☒ **C**	0.5 mol dm^{-3} H_2SO_4 (aq)	273 K
☒ **D**	0.5 mol dm^{-3} H_2SO_4 (aq)	298 K

(Total for Question 2 = 1 mark)

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

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

3 Excess potassium iodide solution is added to acidified potassium manganate(VII) solution. The reaction taking place is

$$2MnO_4^- + 16H^+ + 10I^- \rightarrow 2Mn^{2+} + 5I_2 + 8H_2O$$

The iodine produced is titrated, with sodium thiosulfate solution in the burette.

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

(a) The mole ratio of MnO_4^- to $S_2O_3^{2-}$ is

(1)

☒ **A** 1:2

☒ **B** 1:5

☒ **C** 2:5

☒ **D** 5:1

(b) The titration is carried out **without** starch indicator.

The colour change at the end point of the titration is

(1)

☒ **A** brown to yellow.

☒ **B** purple to colourless.

☒ **C** purple to brown.

☒ **D** yellow to colourless.

(Total for Question 3 = 2 marks)

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

4 Methanol can be used as the fuel in a fuel cell.

The half-equations for the reactions taking place in acidic conditions are

$CO_2 + 6H^+ + 6e^- \rightleftharpoons CH_3OH + H_2O$ half-equation **1**

$\frac{1}{2}O_2 + 2H^+ + 2e^- \rightleftharpoons H_2O$ half-equation **2**

The standard electrode potential of half-equation **1** is +0.02 V.

$E^\ominus_{cell}$ for the fuel cell is +1.21 V.

(a) The standard electrode potential of half-equation **2** is

(1)

☒ **A** +1.19 V

☒ **B** −1.19 V

☒ **C** +1.23 V

☒ **D** −1.23 V

(b) The half-equations for the reactions taking place in alkaline conditions are

$$CO_2 + 5H_2O + 6e^- \rightleftharpoons CH_3OH + 6OH^-$$

$$\frac{1}{2}O_2 + H_2O + 2e^- \rightleftharpoons 2OH^-$$

The value for $E^\ominus_{cell}$ in alkaline conditions is exactly the same as $E^\ominus_{cell}$ in acidic conditions. This is because the

(1)

☒ **A** acid and alkali are catalysts.

☒ **B** $E^\ominus$ values for the half-equations are the same.

☒ **C** temperature and pressure are the same.

☒ **D** overall reaction is the same.

(Total for Question 4 = 2 marks)

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

5 What are the shapes of the complexes $[CuCl_2]^-$ and $[Pt(NH_3)_2Cl_2]$?

	$[CuCl_2]^-$	$[Pt(NH_3)_2Cl_2]$
☒ **A**	V shaped	square planar
☒ **B**	V shaped	tetrahedral
☒ **C**	linear	square planar
☒ **D**	linear	tetrahedral

(Total for Question 5 = 1 mark)

6 An aqueous solution of copper(II) sulfate, containing $[Cu(H_2O)_6]^{2+}$ ions, is reacted with solutions containing other ligands.

The most stable complex ions will be produced when the water molecules are replaced by

☒ **A** ammonia molecules.

☒ **B** chloride ions.

☒ **C** EDTA ions.

☒ **D** 1,2-diaminoethane molecules.

(Total for Question 6 = 1 mark)

7 Zinc hydroxide reacts with acids to form $[Zn(H_2O)_6]^{2+}$ ions and with alkalis to form $[Zn(OH)_4]^{2-}$ ions.

From this information, it can be deduced that zinc hydroxide is

☒ **A** only acidic.

☒ **B** only basic.

☒ **C** amphoteric.

☒ **D** not acidic, basic or amphoteric.

(Total for Question 7 = 1 mark)

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

8 Acidified sodium potassium tartrate solution was mixed with hydrogen peroxide solution in a boiling tube.

When pink cobalt(II) chloride solution was added to the mixture, there was rapid effervescence as carbon dioxide was produced and the solution turned green.

$$C_4H_4O_6^{2-} + 5H_2O_2 + 2H^+ \rightarrow 4CO_2 + 8H_2O$$

After a few seconds, the effervescence stopped and the solution turned back to pink.

From these observations it can be deduced that the cobalt(II) ions are acting as

☒ **A** a catalyst.

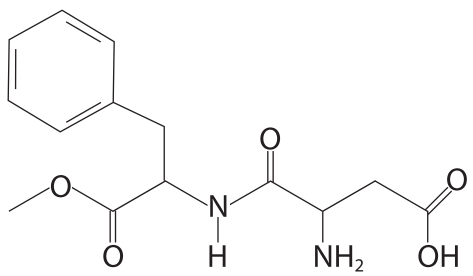
☒ **B** a dehydrating agent.

☒ **C** an oxidizing agent.

☒ **D** a reducing agent.

(Total for Question 8 = 1 mark)

9 The structure of aspartame, an artificial sweetener, is shown below.



The functional groups in a molecule of aspartame are

☒ **A** alkene, amine, carboxylic acid, ester and ketone.

☒ **B** alkene, amide, amine, carboxylic acid and ester.

☒ **C** amine, arene, carboxylic acid, ester and ketone.

☒ **D** amide, amine, arene, carboxylic acid and ester.

(Total for Question 9 = 1 mark)

10 How many compounds are there which have a benzene ring and the structural formula $C_6H_3(NO_2)_3$?

☒ **A** 3

☒ **B** 4

☒ **C** 5

☒ **D** 6

(Total for Question 10 = 1 mark)

11 When amines dissolve in water they form

☒ **A** a neutral solution.

☒ **B** an acidic solution.

☒ **C** an alkaline solution.

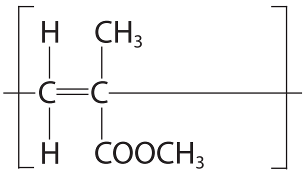
☒ **D** a zwitterion.

(Total for Question 11 = 1 mark)

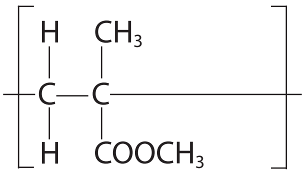
12 Methyl methacrylate has the structure $CH_2{=}C(CH_3)COOCH_3$.

The repeat unit for poly(methyl methacrylate) is

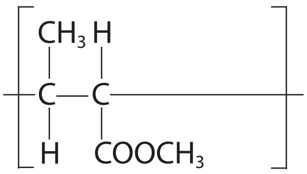
☒ **A**



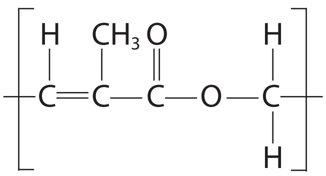
☒ **B**



☒ **C**



☒ **D**



(Total for Question 12 = 1 mark)

13 A mixture of amino acids is best separated and identified using

☒ **A** chromatography.

☒ **B** infrared spectroscopy.

☒ **C** mass spectrometry.

☒ **D** solvent extraction.

(Total for Question 13 = 1 mark)

14 Lysine is an amino acid and its structure is shown below.

$H_2NCHCOOH$
|
$(CH_2)_3$
|
CH_2NH_2

In a solution at pH 1.0, lysine will exist as

☒ **A** $H_3\overset{+}{N}CHCOO^-$
|
$(CH_2)_3$
|
$CH_2\overset{+}{N}H_3$

☒ **B** $H_3\overset{+}{N}CHCOOH$
|
$(CH_2)_3$
|
$CH_2\overset{+}{N}H_3$

☒ **C** $H_2NCHCOO^-$
|
$(CH_2)_3$
|
CH_2NH_2

☒ **D** $H_3\overset{+}{N}CHCOO^-$
|
$(CH_2)_3$
|
CH_2NH_2

(Total for Question 14 = 1 mark)

15 How many different peaks due to hydrogen atoms would you expect to see in a **low** resolution proton nmr spectrum of 2,2-dimethylpropanal?

☒ **A** 2

☒ **B** 3

☒ **C** 4

☒ **D** 10

(Total for Question 15 = 1 mark)

16 One reason for using steam distillation, rather than fractional distillation, to separate a liquid from a mixture is because the liquid

☒ **A** decomposes below its boiling temperature.

☒ **B** has a boiling temperature of 100 °C.

☒ **C** is flammable.

☒ **D** is soluble in water.

(Total for Question 16 = 1 mark)

17 Complete combustion of a hydrocarbon produced 1.76 g of carbon dioxide and 0.720 g of water.

The molecular formula of a hydrocarbon which is consistent with these data is

☒ **A** C_2H_6.

☒ **B** C_3H_8.

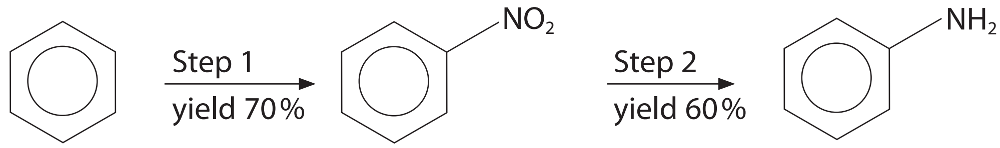
☒ **C** C_4H_8.

☒ **D** C_6H_6.

(Total for Question 17 = 1 mark)

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

18 Phenylamine can be produced from benzene by the reaction sequence below.



benzene
$M_r = 78$

phenylamine
$M_r = 93$

The mass of phenylamine, to 2 decimal places, produced from 3.90 g of benzene is

- ☒ **A** 1.95 g.
- ☒ **B** 2.79 g.
- ☒ **C** 3.26 g.
- ☒ **D** 4.65 g.

(Total for Question 18 = 1 mark)

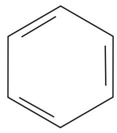
TOTAL FOR SECTION A = 20 MARKS

SECTION B

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

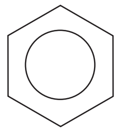
19 This question is about benzene and some of its compounds.

*(a) In 1865, Kekulé suggested that the benzene molecule was a six-membered carbon ring with alternate double and single bonds.



However, this suggestion did not fully explain the structure and stability of benzene.

State and explain **three** different types of evidence that led to this structure of benzene being rejected, in favour of benzene with a ring of delocalised electrons.



(3)

....

....

....

....

....

....

....

....

....

....

....

....

(b) Benzene reacts with a mixture of concentrated nitric acid and concentrated sulfuric acid to form nitrobenzene.

(i) Give the mechanism for this reaction, including an equation for the formation of the electrophile.

(4)

(ii) The preparation of nitrobenzene is usually carried out between 50 °C and 60 °C.

Explain why the temperature used should not be higher or lower.

(2)

....

....

....

....

(c) Benzene reacts with pure bromine when heated under reflux in the presence of a Friedel-Crafts catalyst. Phenol reacts with bromine water at room temperature.

(i) Write the equation for the reaction between phenol and **excess** bromine water.

(2)

*(ii) Explain why phenol reacts with bromine under much milder conditions than those required for the reaction between benzene and bromine.

(2)

....

....

....

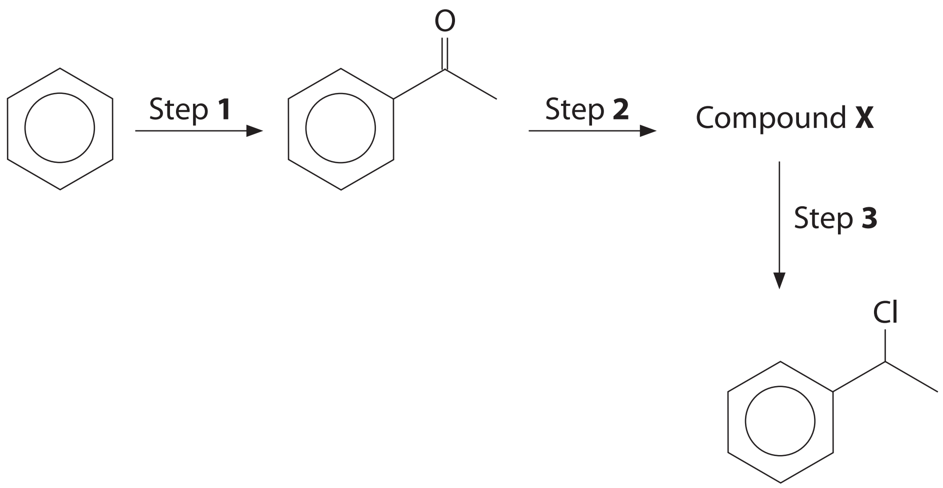
....

....

....

(d) 1-chloro-1-phenylethane is found in some fruits, such as apples, and is used to make fragrances.

It can be synthesised from benzene in three steps.



1-chloro-1-phenylethane

(i) Identify, by name or formula, the reagent and catalyst used in Step **1**.

(2)

....

....

(ii) Draw the structure for Compound **X**.

(1)

(iii) Identify, by name or formula, the reagent used in Step **2**.

(1)

....

(iv) Identify, by name or formula, the reagent used in Step **3**.

(1)

....

(Total for Question 19 = 18 marks)

BLANK PAGE

20 Manganese exists in different oxidation states which can be interconverted, using suitable oxidizing and reducing agents.

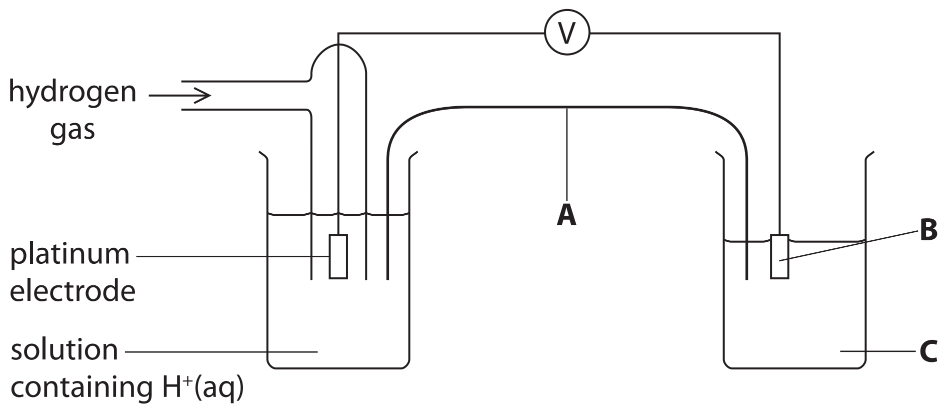
(a) Use relevant standard electrode potential values, from page 17 of the Data Booklet, to complete the table below in which two $E^\ominus$ values are missing.

(1)

Half-equation	$E^\ominus$ / V
$MnO_4^-(aq) + e^- \rightleftharpoons MnO_4^{2-}(aq)$	
$MnO_4^{2-}(aq) + 2H_2O(l) + 2e^- \rightleftharpoons MnO_2(s) + 4OH^-(aq)$	
$Mn^{3+}(aq) + e^- \rightleftharpoons Mn^{2+}(aq)$	+1.49
$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightleftharpoons Mn^{2+}(aq) + 4H_2O(l)$	+1.51
$BiO_3^-(aq) + 6H^+(aq) + 2e^- \rightleftharpoons Bi^{3+}(aq) + 3H_2O(l)$	+1.60
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77

(b) The apparatus below is used to measure the standard electrode potential of

$$Mn^{3+}(aq) + e^- \rightleftharpoons Mn^{2+}(aq)$$



Identify, by name or formula, the substances needed in the salt bridge and the right-hand half-cell to measure the standard electrode potential.

The measurement is made at 298 K and 1 atm. State the other essential condition for solution **C**.

(4)

A Salt bridge containing a solution of ....

B Electrode made of ....

C Solution containing ....

Essential condition ....

(c) Manganate(VII) ions, MnO_4^-, can be made by oxidizing manganese(II) ions with bismuthate(V) ions, BiO_3^-, in acid solution.

(i) Use the information in (a) to write the overall ionic equation for this reaction. State symbols are not required.

(2)

(ii) Hence calculate $E^{\ominus}_{cell}$ for this reaction. Include a sign and units in your answer.

(1)

*(d) Iron(II) ions in solution are oxidized by the air to iron(III) ions.

The amounts of iron(II) and iron(III) ions in solution can be found by using titrations with acidified potassium manganate(VII) which only reacts with the iron(II) ions.

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

- 25.0 cm^3 portions of a solution **A**, containing a mixture of iron(II) and iron(III) ions, were acidified and titrated with potassium manganate(VII) solution of concentration 0.0195 mol dm^{-3}.
- The mean titre was 16.80 cm^3.
- About 150 cm^3 of solution **A** was reacted with excess zinc, which reduced the iron(III) ions to iron(II) ions. The excess zinc was filtered off.
- 25.0 cm^3 portions of this reduced solution, which contained iron(II) ions but no iron(III) ions were acidified and titrated with potassium manganate(VII) solution of concentration 0.0195 mol dm^{-3}.
- The mean titre was 18.20 cm^3.

Calculate the **mass** of iron(II) ions and **the mass of** iron(III) ions in 500 cm^3 of the original solution **A**.

(5)

(Total for Question 20 = 13 marks)

21 Chromium is in the d-block of the Periodic Table and it is a transition metal.

(a) Scandium is also in the d-block of the Periodic Table but it is not a transition metal.

Explain, by giving any relevant electronic configurations, why scandium is **not** a transition metal.

(3)

....

....

....

....

....

....

(b) When a few drops of aqueous ammonia are added to an aqueous solution of chromium(III) ions, a green precipitate of chromium(III) hydroxide is formed.

Complete the ionic equation for this reaction. State symbols are not required.

(2)

$[Cr(H_2O)_6]^{3+}$ + ... NH_3 →

(c) Explain, in terms of oxidation numbers of chromium, whether or not each of these two reactions are redox.

$Cr_2O_7^{2-} + 14H^+ + 6Fe^{2+} \rightarrow 2Cr^{3+} + 7H_2O + 6Fe^{3+}$ **Reaction 1**

$2CrO_4^{2-} + 2H^+ \rightarrow Cr_2O_7^{2-} + H_2O$ **Reaction 2**

(2)

....

....

....

....

....

....

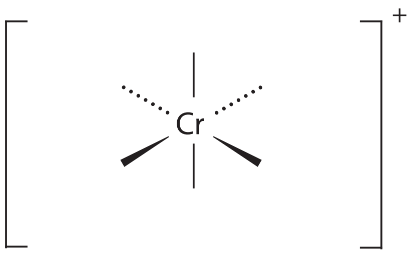
(d) Chromium(III) chloride can exist in aqueous solution as three possible complex ions with different numbers of free chloride ions.

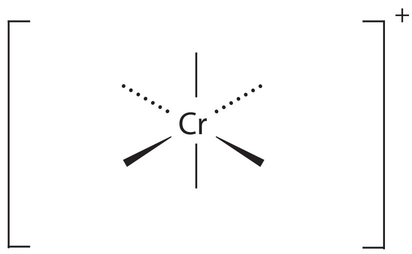
	Complex ion	Free chloride ions
X	$[Cr(H_2O)_6]^{3+}$	$3Cl^-$
Y	$[CrCl(H_2O)_5]^{2+}$	$2Cl^-$
Z	$[CrCl_2(H_2O)_4]^+$	Cl^-

(i) There are two possible structures for complex ion **Z**.

Complete the diagrams below to show the two possible structures for complex ion **Z**.

(2)





(ii) Name the type of bond between the ligands and the chromium(III) ion and explain how it is formed.

(2)

....

....

....

....

(iii) The formula of the complex ion present in the solution is found by adding aqueous silver nitrate to the solution. This only reacts with the free chloride ions to form a precipitate of silver chloride.

$$Ag^{+}(aq) + Cl^{-}(aq) \rightarrow AgCl(s)$$

The precipitate is then filtered, washed, dried and weighed.

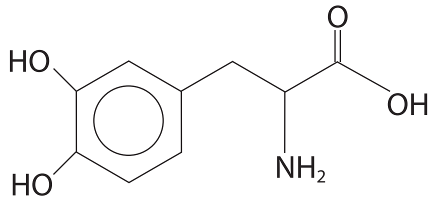
In an experiment, 0.012 mol of one of the forms of chromium(III) chloride was used and 3.44 g of silver chloride was formed.

Deduce the formula of the complex ion. You must show your working.

(3)

(Total for Question 21 = 14 marks)

22 The drug 3,4-dihydroxyphenylalanine, *L*-DOPA, is used in the treatment of Parkinson's disease.



(a) Give the molecular formula for *L*-DOPA.

(1)

....

(b) Suggest the organic product of the reaction between *L*-DOPA and **excess** ethanoyl chloride.

(1)

(c) Give a chemical reaction and its result that can be used to show the presence of the carboxylic acid group in *L*-DOPA.

(2)

....

....

....

....

(d) Molecules of *L*-DOPA can polymerize to form a polyamide by condensation.

Draw two repeat units of the polyamide formed from *L*-DOPA.

(2)

(Total for Question 22 = 6 marks)

TOTAL FOR SECTION B = 51 MARKS

SECTION C

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

23

Coloured substances

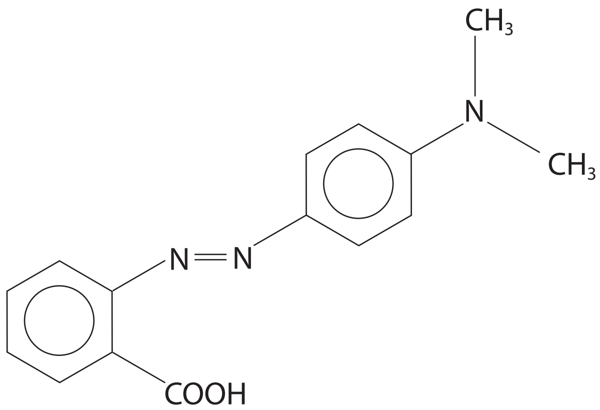
Coloured substances, both natural and synthetic, have long been of interest to the human race. For example, there are over 130 minerals that have been used as gemstones.

The corundum minerals, which include rubies and sapphires, are mainly aluminium oxide. Rubies have some of the aluminium ions replaced by chromium(III) ions and they range in colour from pink to deep red. Sapphires occur in many different colours including blue, yellow, purple, orange and green.

Diamond is an allotrope of carbon. It is the hardest naturally occurring substance. Diamonds are often colourless but the presence of nitrogen atoms in natural diamonds gives them a brown or yellow colour, whilst the presence of boron gives them a blue colour.

Dyes and pigments have been developed as colouring materials. Dyes are applied as a solution, whilst pigments are solids that are ground into a fine powder and made into a suspension with a suitable liquid.

Methyl red is an azo dye and is used as an indicator. Its structure is



Prussian Blue, $Fe_4[Fe(CN)_6]_3$, (discovered in 1704) is a deep blue colour and was one of the first synthetic pigments. It is used as a pigment in paints.

Colour can arise in many different ways; for example, the colours seen in flame tests and in transition metal compounds.

DO NOT WRITE IN THIS AREA

(a) (i) Explain why complex ions containing chromium(III) ions are coloured.

(4)

....

....

....

....

....

....

....

....

....

....

(ii) Sapphires have the same type of structure as rubies.

Suggest why sapphires and rubies have different colours.

(1)

....

....

*(b) Carbon exists as diamond and graphite. Explain, in terms of structure and bonding, why diamond is much harder than graphite.

(3)

....

....

....

....

....

....

....

....

(c) (i) The standard enthalpy changes of combustion for diamond and graphite are shown below.

$$C(diamond) + O_2(g) \rightarrow CO_2(g) \quad \Delta H_c^\ominus = -395.4 \text{ kJ mol}^{-1}$$

$$C(graphite) + O_2(g) \rightarrow CO_2(g) \quad \Delta H_c^\ominus = -393.5 \text{ kJ mol}^{-1}$$

Calculate the enthalpy change for the conversion of diamond to graphite. Use your answer to draw an enthalpy level diagram for the combustion of diamond and graphite.

(2)

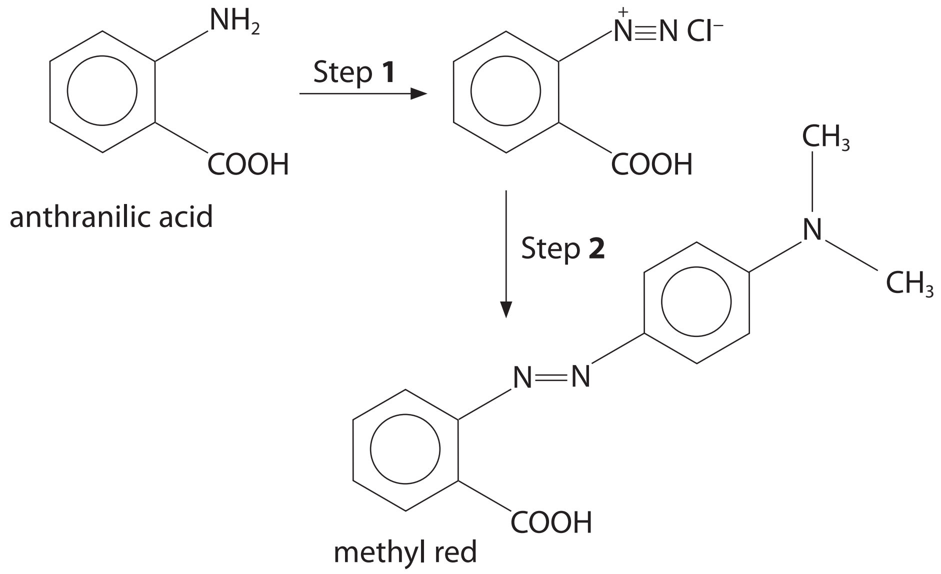
(ii) Explain which factor, other than enthalpy change, must be considered to show which allotrope is thermodynamically more stable.

(1)

....

....

(d) The indicator methyl red, can be formed in two steps, starting from anthranilic acid.



(i) State the reagents and condition needed for Step **1**.

(2)

....

....

(ii) Step **2** involves a reaction which is similar to the reaction of diazonium ions with phenol. Suggest the structure of the organic compound which reacts with the diazonium ion in Step **2** to form methyl red.

(1)

(iii) Use information from page 19 of the Data Booklet to suggest the type of acid-alkali titration for which methyl red indicator would be most suitable. Justify your answer.

(2)

(e) Prussian Blue contains the $[Fe(CN)_6]^{4-}$ ion.

(i) The $[Fe(CN)_6]^{4-}$ ion is formed when aqueous potassium cyanide is added to an aqueous solution containing Fe^{2+} ions.

Write the equation and state the type of reaction taking place when $[Fe(CN)_6]^{4-}$ is formed in this way.

(2)

Type of reaction ....

(ii) State the oxidation number of the iron ions shown in bold in $\mathbf{Fe}_4[Fe(CN)_6]_3$

(1)

(Total for Question 23 = 19 marks)

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

BLANK PAGE

BLANK PAGE

BLANK PAGE

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

* 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