Please check the examination details below before entering your candidate information

Candidate surname	Other names

Pearson Edexcel
International Advanced Level

Centre Number	Candidate Number

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

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.*
- The question labelled with an **asterisk** (*) is one 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 this question.*
- 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.
- Check your answers if you have time at the end.
- Good luck with your examination.

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 In which of the following pairs does the metal have **different** oxidation numbers?

☐ **A** CrO_4^{2-} and $Cr_2O_7^{2-}$

☐ **B** CrO_4^{2-} and CrO_3Cl^-

☐ **C** V_2O_5 and VO_4^{3-}

☐ **D** VO_2^+ and VO^{2+}

(Total for Question 1 = 1 mark)

---

2 This question is about the reaction

$$2Fe^{3+}(aq) + Ti(s) \rightarrow 2Fe^{2+}(aq) + Ti^{2+}(aq) \qquad E^\ominus_{cell} = +2.40\,V$$

(a) The electrode potential for the Fe^{3+}/Fe^{2+} electrode system is +0.77 V.

What is the electrode potential for the Ti^{2+}/Ti electrode system?

(1)

☐ **A** −3.17 V

☐ **B** −1.63 V

☐ **C** +1.63 V

☐ **D** +3.17 V

(b) What metals should be used for the electrodes in the cell for this reaction?

(1)

	Metals used for the electrode	
	Fe^{3+}/ Fe^{2+} electrode system	Ti^{2+}/ Ti electrode system
☒ **A**	iron	titanium
☒ **B**	iron	platinum
☒ **C**	platinum	titanium
☒ **D**	platinum	platinum

(c) The half-cell for the Fe^{3+}/ Fe^{2+} electrode system is prepared by mixing **equal** volumes of solutions of iron(II) sulfate, $FeSO_4$, and iron(III) sulfate, $Fe_2(SO_4)_3$.

What concentrations of the **original** solutions are needed for the resulting mixture to be standard?

(1)

	Concentration of the original solution	
	$FeSO_4$	$Fe_2(SO_4)_3$
☒ **A**	1 mol dm^{-3}	0.5 mol dm^{-3}
☒ **B**	1 mol dm^{-3}	1 mol dm^{-3}
☒ **C**	2 mol dm^{-3}	1 mol dm^{-3}
☒ **D**	2 mol dm^{-3}	2 mol dm^{-3}

(Total for Question 2 = 3 marks)

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

3 What is the electronic configuration of a chromium atom?

		3d					4s
☒ **A**	(Ar)	↑	↑	↑	↑	↑	↑
☒ **B**	(Ar)	↑	↑	↑	↑		↑↓
☒ **C**	(Ar)	↑↓	↑↓	↑			↑
☒ **D**	(Ar)	↑↓	↑	↑			↑↓

(Total for Question 3 = 1 mark)

4 A ligand must be an

☒ **A** electron-pair donor

☒ **B** electron-pair donor and negatively charged

☒ **C** electron-pair acceptor

☒ **D** electron-pair acceptor and negatively charged

(Total for Question 4 = 1 mark)

5 Diamminecopper(I) ions are **not** coloured because

☒ **A** the d orbitals in copper(I) cannot be split

☒ **B** the energy difference between the split d orbitals is outside the visible region of the spectrum

☒ **C** d—d transitions are not possible because the d orbitals are fully occupied

☒ **D** copper(I) complexes are readily oxidised

(Total for Question 5 = 1 mark)

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

6 Copper(II) ions form a complex with 1,2-diaminoethane (symbol 'en') with the formula $Cu(en)_3^{2+}$.

What type of ligand is 1,2-diaminoethane, and what is the coordination number of copper(II) in the complex?

	Type of ligand	Coordination number
☒ **A**	bidentate	3
☒ **B**	bidentate	6
☒ **C**	tridentate	3
☒ **D**	tridentate	6

(Total for Question 6 = 1 mark)

7 Aqueous sodium hydroxide was added to aqueous iron(II) sulfate and the mixture allowed to stand.

What would be observed?

	Observations	
	Immediately after adding sodium hydroxide	After standing
☒ **A**	brown precipitate	no change
☒ **B**	green precipitate	no change
☒ **C**	brown precipitate	precipitate turns green
☒ **D**	green precipitate	precipitate turns brown

(Total for Question 7 = 1 mark)

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

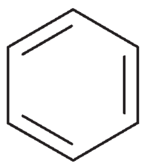
8 When aqueous ammonia is added to an aqueous solution of zinc sulfate, a white precipitate forms which dissolves in excess ammonia to give a colourless solution.

What types of reaction are occurring?

	Type of reaction	
	Formation of white precipitate	Formation of colourless solution
☒ **A**	deprotonation	ligand exchange
☒ **B**	deprotonation	deprotonation
☒ **C**	ligand exchange	deprotonation
☒ **D**	ligand exchange	ligand exchange

(Total for Question 8 = 1 mark)

9 Benzene is sometimes represented by a Kekulé structure.



Kekulé structure of benzene

If this were the **only** structure of benzene, what would be the total number of isomers of dichlorobenzene?

☒ **A** two

☒ **B** three

☒ **C** four

☒ **D** five

(Total for Question 9 = 1 mark)

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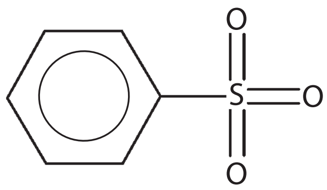
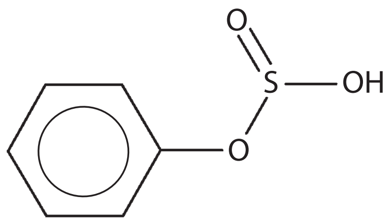
10 What is the product when benzene reacts with fuming sulfuric acid?

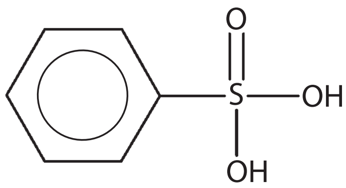
☒ **A**



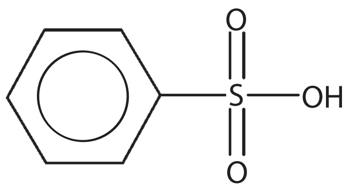
☒ **B**



☒ **C**



☒ **D**

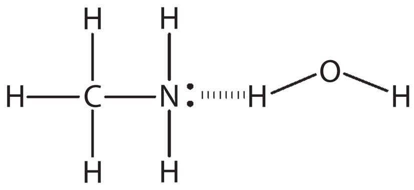


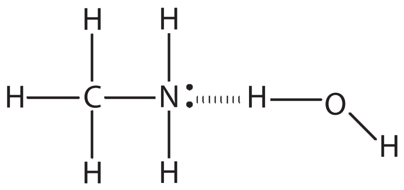
(Total for Question 10 = 1 mark)

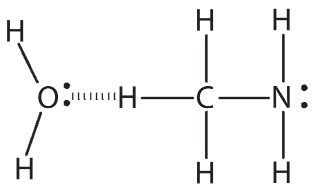
Use this space for any rough working. Anything you write in this space will gain no credit.

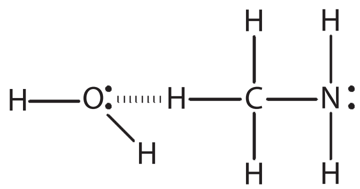
11 Hydrogen bonds are formed when methylamine dissolves in water.

Which structure best represents a hydrogen bond between methylamine and water?

☒ **A** 

☒ **B** 

☒ **C** 

☒ **D** 

(Total for Question 11 = 1 mark)

12 Which type of compound **cannot** be a monomer in the formation of polyamides?

☒ **A** amides

☒ **B** amino acids

☒ **C** diacyl chlorides

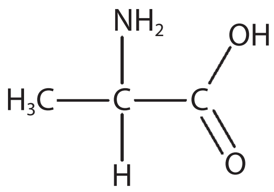
☒ **D** diamines

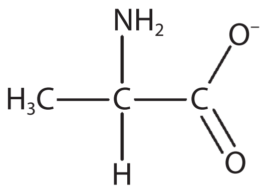
(Total for Question 12 = 1 mark)

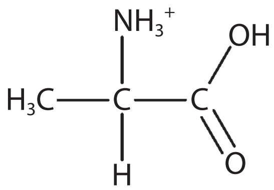
13 Alanine is an amino acid.

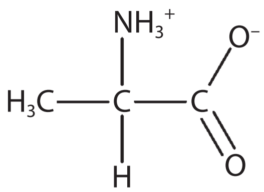
(a) Which structure best represents alanine at **high** pH?

(1)

☒ **A** 

☒ **B** 

☒ **C** 

☒ **D** 

(b) Alanine is a crystalline solid at room temperature.

What are the main forces broken when alanine melts?

(1)

☒ **A** London forces

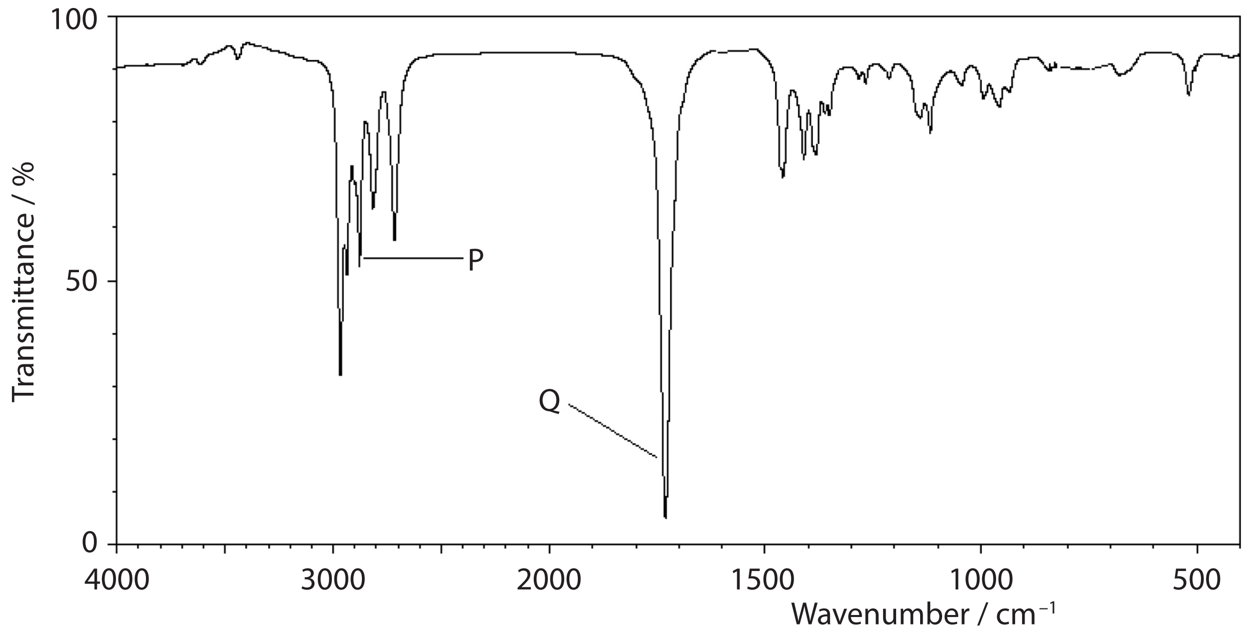
☒ **B** hydrogen bonds

☒ **C** covalent bonds

☒ **D** ionic bonds

(Total for Question 13 = 2 marks)

14 An aliphatic organic compound has the infrared spectrum shown.



What are the bond stretches responsible for the peaks **P** and **Q** in the spectrum?

	P	**Q**
☒ **A**	O—H carboxylic acid	C═O carboxylic acid
☒ **B**	O—H carboxylic acid	C═O aldehyde
☒ **C**	C—H aldehyde	C═O carboxylic acid
☒ **D**	C—H aldehyde	C═O aldehyde

(Total for Question 14 = 1 mark)

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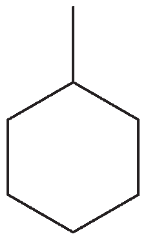
15 How many peaks are there in the carbon-13 (^{13}C) NMR spectrum of methylcyclohexane?



methylcyclohexane

☒ **A** one

☒ **B** three

☒ **C** five

☒ **D** seven

(Total for Question 15 = 1 mark)

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16 In the **high** resolution proton NMR spectrum of propan-2-ol, $CH_3CHOHCH_3$ there are

☒ **A** one singlet, one doublet and a heptet

☒ **B** one singlet, two doublets and a heptet

☒ **C** two singlets and two triplets

☒ **D** three singlets and a quartet

(Total for Question 16 = 1 mark)

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

17 What is the minimum volume of oxygen gas, measured at room temperature and pressure, required for the complete combustion of 9.2 g of $C_3H_8O_3$ (M_r = 92)?

[Molar volume of gas at room temperature and pressure = 24.0 $dm^3\ mol^{-1}$]

☒ **A** 4.8 dm^3

☒ **B** 8.4 dm^3

☒ **C** 12.0 dm^3

☒ **D** 16.8 dm^3

(Total for Question 17 = 1 mark)

TOTAL FOR SECTION A = 20 MARKS

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SECTION B

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

18 This question is about manganese compounds. Some data are given below.

	Electrode reaction	$E^\ominus$ / V
1	$MnO_4^- + e^- \rightleftharpoons MnO_4^{2-}$	+0.56
2	$MnO_4^{2-} + 2H_2O + 2e^- \rightleftharpoons MnO_2 + 4OH^-$	+0.59
3	$Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$	+0.77
4	$MnO_2 + 4H^+ + 2e^- \rightleftharpoons Mn^{2+} + 2H_2O$	+1.23
5	$MnO_4^- + 8H^+ + 5e^- \rightleftharpoons Mn^{2+} + 4H_2O$	+1.51
6	$MnO_4^- + 4H^+ + 3e^- \rightleftharpoons MnO_2 + 2H_2O$	+1.70
7	$MnO_4^{2-} + 4H^+ + 2e^- \rightleftharpoons MnO_2 + 2H_2O$	+2.26

(a) (i) Write the ionic equation for the disproportionation of manganate(VI) ions, MnO_4^{2-}, in **acidic** conditions, using relevant half-equations from the table.
State symbols are not required.

(2)

(ii) Calculate $E^\ominus_{cell}$ for the disproportionation of manganate(VI) ions in **acidic** conditions, stating whether or not the reaction is thermodynamically feasible.

(2)

(iii) Using the standard electrode potentials in the table, assess the thermodynamic feasibility of preparing manganate(VI) by reacting manganate(VII) and manganese(IV) oxide in **alkaline** conditions.

(4)

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(b) Steel is an alloy of iron and carbon. A group of students determined the iron content of a sample of steel wire by a titration method.

A known mass of the wire was dissolved in dilute sulfuric acid and the resulting solution made up to 250.0 cm^3 with more dilute sulfuric acid and mixed thoroughly.

$$Fe + H_2SO_4 \rightarrow FeSO_4 + H_2$$

25.0 cm^3 samples of the resulting solution were titrated with 0.0195 mol dm^{-3} potassium manganate(VII) solution.

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

(1)

....

(ii) One student used 1.53 g of the wire (weighed directly on the balance pan) and obtained a mean titre of 27.35 cm^3.

Using half-equations 3 and 5 from the table, calculate the percentage of iron in the steel wire. Give your answer to **three** significant figures.

(5)

(iii) A second student carried out the same experiment but used distilled water to make up the solution in the volumetric flask.
A brown suspension formed during the titration.
Explain how, if at all, the titre value would be affected by this student's error.

(3)

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(c) The uncertainties of the apparatus used in the experiment in (b) are shown.

Apparatus	Value measured	Uncertainty on each reading	Percentage uncertainty on value measured / %
Balance	1.53 g	±0.005 g	0.65
Burette	27.35 cm^3	±0.05 cm^3	
Pipette	25.0 cm^3	±0.06 cm^3	
Volumetric flask	250.0 cm^3	±0.3 cm^3	

(i) Complete the table.

(2)

(ii) A third student obtained a value of 95.863% for the proportion of iron in the wire. State whether or not this student has given their answer to an appropriate number of significant figures. Justify your answer in terms of the **total** percentage uncertainty of the experiment.

(2)

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19 This question is about the investigation of an organic compound **X**.
X is a liquid at room temperature and pressure, which turns damp red litmus paper blue.

(a) (i) Name the functional group present in **X**.

(1)

....

(ii) When 0.493 g of **X** was vaporised, 157 cm^3 of dry air was displaced, measured at 15°C and 103 000 Pa.

Calculate the molar mass of **X**, using the ideal gas equation.
You **must** show your working.

(4)

(b) **X** reacted vigorously with ethanoyl chloride forming steamy fumes and a white solid **Y**.

(i) Identify the steamy fumes, by name or formula.

(1)

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....

(ii) Suggest the functional group present in **Y**.

(1)

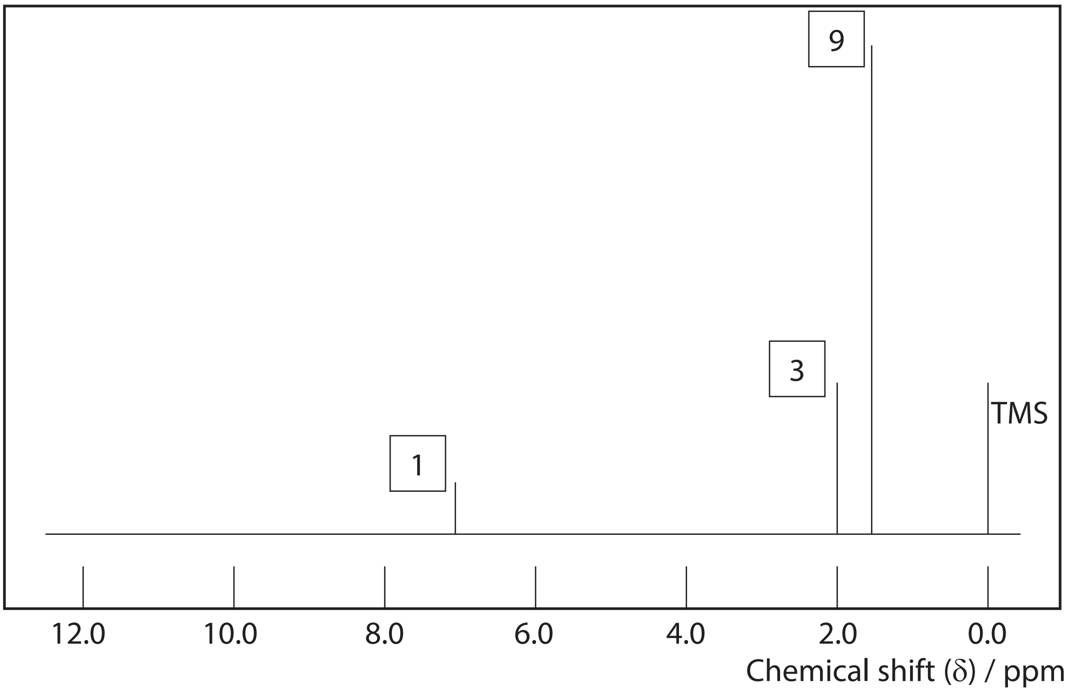
....

(iii) Analysis of **Y** showed that its composition by mass was 62.6% carbon; 11.3% hydrogen; 12.2% nitrogen; 13.9% oxygen.

Determine the empirical formula of **Y**. You **must** show your working.

(3)

*(c) A simplified **high** resolution proton NMR spectrum of **Y** is shown.
The relative peak areas are given near each peak.



Deduce the structure of **Y**, using the NMR spectrum and the other information in the question.

(6)

(d) Draw the structure of compound **X**.

(1)

(Total for Question 19 = 17 marks)

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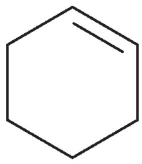
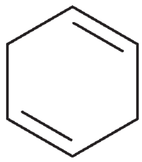
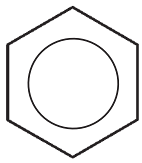
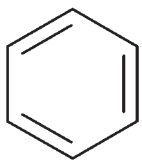
20 This question is about benzene and some related compounds.

(a) Some standard enthalpies of combustion are shown.

Compound	Structure	Standard enthalpy of combustion, $\Delta_c H^{\ominus}$ / kJ mol^{-1}
cyclohexene		−3752
cyclohexa-1,4-diene		−3584
benzene		−3267

(i) Using the standard enthalpies of combustion of cyclohexene and cyclohexa-1,4-diene, calculate a value for the enthalpy of combustion of the theoretical compound 'cyclohexa-1,3,5-triene'.

(2)



cyclohexa-1,3,5-triene

(ii) Explain the difference between the enthalpy of combustion of 'cyclohexa-1,3,5-triene' calculated in (a)(i) and the enthalpy of combustion of benzene given in the table.

(3)

(b) Bromine reacts with cyclohexene to form 1,2-dibromocyclohexane, and with benzene to form bromobenzene.

Compare and contrast these reactions, considering the type and mechanism of each reaction and the conditions required.

You are **not** required to draw the mechanisms of the reactions.

(4)

(c) Bromine also reacts with phenol.

(i) Identify, by name or formula, the organic product when phenol reacts with **excess** bromine.

(1)

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(ii) Explain why bromine reacts much faster with phenol than with benzene.

(2)

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(Total for Question 20 = 12 marks)

TOTAL FOR SECTION B = 50 MARKS

SECTION C

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

21

Iron Chemistry

Iron is a typical transition metal. Due to the similar energies of the 3d and 4s electrons, iron forms compounds in a number of oxidation states. Iron(II) and iron(III) are the most common oxidation states, and iron(III) is the most stable.

Iron ions form many complexes, including that in haemoglobin which is responsible for oxygen transport in the blood of most vertebrates. The haemoglobin-iron complex with oxygen is responsible for the red colour of blood.

Iron(III) ions may be detected in solution by the addition of thioglycolic acid ($HSCH_2COOH$). All the water ligands of the iron(III) ion are replaced giving a complex with an intense red colour which can be detected in very low concentrations.

The complexes of iron(II) and iron(III) usually have a coordination number of six and are octahedral but the chloro complexes have a coordination number of four and are tetrahedral.

Iron and its compounds can act as catalysts. The element catalyses the Haber process, acting as a typical heterogeneous catalyst. However, the compounds and complexes of iron are usually homogeneous catalysts.

(a) Explain, in terms of electronic structure, why iron(III) compounds are more stable than iron(II) compounds.

(2)

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(b) The third ionisation energy of iron is 2958 kJ mol^{-1}.

(i) Write the equation for the third ionisation energy of iron. Include state symbols.

(1)

(ii) Explain how **stable** iron(III) ions can be formed from iron(II) ions in aqueous solution. Refer to the relevant energy changes of these ions only.

(3)

(c) Invertebrates use a copper complex, haemocyanin, to transport oxygen. Blue oxyhaemocyanin gives invertebrate blood its characteristic colour.

Explain why oxyhaemocyanin and oxyhaemoglobin have different colours.

(3)

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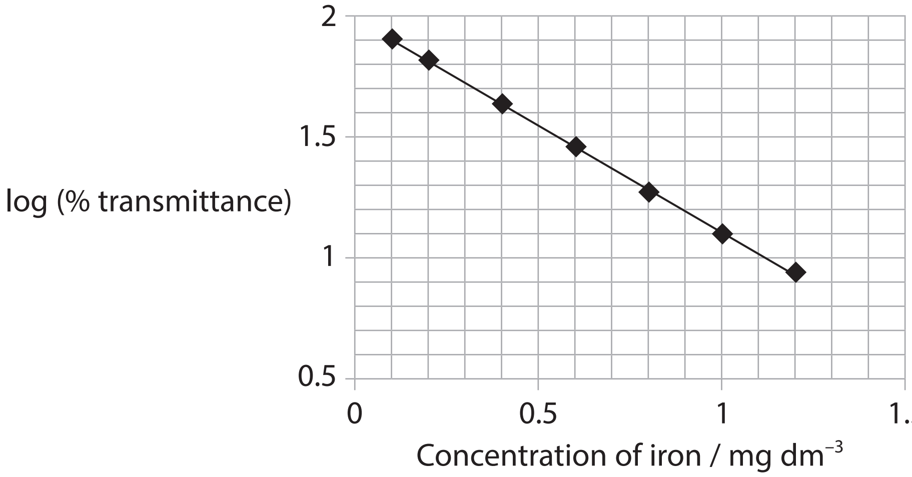
(d) The presence of iron in sodium carbonate can affect its properties; the higher the quality of the sodium carbonate, the lower the proportion of iron.

The proportion of iron in a laboratory grade anhydrous sodium carbonate was listed as less than 20 ppm by mass.

In an experiment to check this specification, 20 g of the sodium carbonate was dissolved in sulfuric acid, and thioglycolic acid added in excess to form the iron(III) thioglycolic acid complex, $Fe(HSCH_2COOH)_3^{3+}$. The solution was made up to 500 cm^3 in a volumetric flask and thoroughly mixed.

Colorimeter calibration graph



The transmittance of the resulting solution was determined using a colorimeter and found to be 39.8 %.

(i) Using the calibration graph, determine whether or not the iron concentration in this sample of sodium carbonate meets the stated specification.

(4)

(ii) Suggest what type of ligand thioglycolic acid is in the iron(III) thioglycolic acid complex. Justify your answer.

(2)

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(e) Iodide ions are oxidised to iodine by peroxodisulfate ions.

$$2I^{-}(aq) \quad + \quad S_2O_8^{2-}(aq) \quad \rightarrow \quad I_2(aq) \quad + \quad 2SO_4^{2-}(aq)$$

Iron(II) ions act as a homogeneous catalyst for this reaction.

(i) State why the catalyst is described as 'homogeneous'.

(1)

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(ii) Write two equations to show how iron(II) ions catalyse this oxidation. State symbols are not required.

(2)

(iii) Suggest how iron(II) ions lower the activation energy of this reaction.

(1)

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(f) Give a possible reason why the chloro complexes of iron ions have a coordination number of four rather than six.

(1)

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(Total for Question 21 = 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

* 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