Cambridge Assessment International Education

Cambridge International AS & A Level

CANDIDATE NAME	

CENTRE NUMBER		CANDIDATE NUMBER	

1342134629

CHEMISTRY **9701/41**

Paper 4 A Level Structured Questions **May/June 2025**

2 hours

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

INFORMATION

- The total mark for this paper is 100.
- The number of marks for each question or part question is shown in brackets [ ].
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

This document has **24** pages. Any blank pages are indicated.

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[Turn over

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1 Both calcium carbonate, $CaCO_3$, and barium carbonate, $BaCO_3$, decompose when heated to form the metal oxide and a gas.

(a) Write an equation for the thermal decomposition of $CaCO_3$.

.... [1]

(b) State which of $CaCO_3$ and $BaCO_3$ decomposes at a lower temperature.

Explain your answer.

The compound that decomposes at a lower temperature is ....

explanation ....

....

....

....

....

[2]

(c) Calcium oxide, CaO, reacts with water to form compound **A**.

Barium oxide, BaO, reacts with water to form compound **B**.

(i) Identify **A**.

.... [1]

(ii) Explain why **A** is less soluble than **B**.

....

....

....

....

....

.... [3]

[Total: 7]

2 Three experiments are carried out to investigate the reaction of nitrogen oxide, NO, with chlorine.

$$2NO + Cl_2 \rightarrow 2NOCl$$

The rate equation for this reaction is shown.

$$\text{rate} = k[NO]^2[Cl_2]$$

(a) Under the conditions used in experiments 1 and 2, the value of *k* is 26.4.

(i) The rate of the reaction is measured in $\text{mol dm}^{-3}\text{s}^{-1}$. State the units of *k*.

units of *k* = ... [1]

(ii) In experiment 1, the initial concentrations of NO and Cl_2 are equal.

The initial rate of the reaction in experiment 1 is $2.57 \times 10^{-6}\,\text{mol dm}^{-3}\text{s}^{-1}$.

Calculate the initial concentration of NO.

Show your working.

initial concentration of NO = ... mol dm^{-3} [2]

(iii) In experiment 2, the initial concentrations of NO and Cl_2 are both ten times greater than the initial concentrations used in experiment 1.

Calculate the initial rate of the reaction in experiment 2.

initial rate of reaction in experiment 2 = ... $\text{mol dm}^{-3}\text{s}^{-1}$ [1]

(b) Experiment 3 uses a large excess of NO.

The initial concentration of Cl_2 is $2.00 \times 10^{-4}\,mol\,dm^{-3}$.

(i) The graph of $[Cl_2]$ against time shows that the reaction has a constant half-life, $t_{½}$.

Explain this observation.

....

.... [1]

(ii) Under the conditions used in experiment 3, the value of the rate constant is 105.6.

Show that $t_{½}$ of $[Cl_2]$ is 6.56×10^{-3} s under these conditions.

[1]

(iii) Calculate the time taken, in s, for $[Cl_2]$ to fall to $1.25 \times 10^{-5}\,mol\,dm^{-3}$ in experiment 3.

time = ... s [1]

(c) Sulfur dioxide, SO_2, reacts very slowly with oxygen in the atmosphere, forming sulfur trioxide, SO_3. This reaction is much faster in the presence of NO.

Explain the role of NO in this process.

Include chemical equations in your answer.

....

....

....

.... [3]

[Total: 10]

3 **(a)** Chromium(III) hydroxide, $Cr(OH)_3$, is only slightly soluble in water. The value of the solubility product, K_{sp}, of $Cr(OH)_3$ is 1.0×10^{-33} at 298 K.

(i) Complete the expression for K_{sp} of $Cr(OH)_3$. Include the units.

K_{sp} =

units = ... [2]

(ii) Calculate the solubility, in $g\,dm^{-3}$, of $Cr(OH)_3$ in pure water at 298 K.

Show your working.

solubility = ... $g\,dm^{-3}$ [3]

(iii) $Cr(OH)_3$ is less soluble in $0.100\,mol\,dm^{-3}$ NaOH than it is in pure water.

Explain this observation.

....

.... [1]

(b) The value of the acid dissociation constant, K_a, of butanoic acid, $CH_3CH_2CH_2COOH$, is 1.51×10^{-5} at 298 K.

(i) Calculate the pH of $0.100\,mol\,dm^{-3}$ $CH_3CH_2CH_2COOH$ at 298 K.

Show your working.

pH = ... [2]

(ii) Calculate the pH of $0.100\,mol\,dm^{-3}$ NaOH at 298 K.

pH = ... [1]

(iii) 5.00 cm^3 of 0.100 $mol\,dm^{-3}$ NaOH is added to 10.00 cm^3 of 0.100 $mol\,dm^{-3}$ $CH_3CH_2CH_2COOH$.

Calculate the pH of the resulting solution.

Show your working.

pH = ... [2]

(c) 80.0 cm^3 of an aqueous solution containing 0.704 g of $CH_3CH_2CH_2COOH$ is shaken with 100 cm^3 of benzene, C_6H_6.

There is 0.556 g of $CH_3CH_2CH_2COOH$ in the 100 cm^3 of C_6H_6 at equilibrium.

Calculate the partition coefficient, K_{pc}, of $CH_3CH_2CH_2COOH$ between C_6H_6 and water.

Show your working.

K_{pc} = ... [2]

[Total: 13]

4 Table 4.1 gives the enthalpy changes of hydration, ΔH_{hyd}, of three ions, F^-, K^+ and Ca^{2+}.

Table 4.1

ion	ΔH_{hyd} / kJ mol^{-1}
F^-	–506
K^+	–322
Ca^{2+}	–1650

(a) **(i)** Define enthalpy change of hydration.

....

....

.... [1]

(ii) Explain the relative magnitudes of the enthalpy changes of hydration of K^+ and Ca^{2+}.

....

....

....

.... [2]

(iii) Define lattice energy.

....

.... [1]

(iv) The lattice energy, ΔH_{latt}, of calcium fluoride, CaF_2, is –2602 kJ mol^{-1}.

Calculate the enthalpy change of solution, ΔH_{sol}, in kJ mol^{-1}, of CaF_2.

ΔH_{sol} of CaF_2 = ... kJ mol^{-1} [2]

(b) The formation of CaF_2 at 298 K is shown.

$$Ca(s) + F_2(g) \rightarrow CaF_2(s) \qquad \Delta H^{\ominus} = -1214\,kJ\,mol^{-1}$$
$$\Delta G^{\ominus} = -1162\,kJ\,mol^{-1}$$

Calculate the entropy change, $\Delta S^{\ominus}$, in $J\,K^{-1}\,mol^{-1}$, for this reaction.

$\Delta S^{\ominus}$ = ... $J\,K^{-1}\,mol^{-1}$ [2]

[Total: 8]

5 Copper is a transition element.

(a) **(i)** Complete the electronic configurations of a Cu^+ ion and a Cu^{2+} ion.

Cu^+ ion: [Ar] ....

Cu^{2+} ion: [Ar] ....

[1]

(ii) Explain why transition elements have variable oxidation states.

....

.... [1]

(b) Aqueous copper(II) sulfate, $CuSO_4$, contains the $[Cu(H_2O)_6]^{2+}$ complex ion.

(i) A few drops of $NH_3(aq)$ are added to $CuSO_4(aq)$.

Describe any observations made.

.... [1]

(ii) Write an equation for the reaction taking place.

.... [1]

(c) **(i)** An **excess** of $NH_3(aq)$ is added to $CuSO_4(aq)$.

Describe any further observations made.

.... [1]

(ii) Write an equation for the reaction taking place.

.... [1]

(iii) State the name for the type of reaction taking place.

.... [1]

(d) Copper metal can be oxidised by acidified $KMnO_4$. The relevant half-equations and their standard electrode potentials, $E^\ominus$, are shown.

$$Cu^{2+} + 2e^- \rightleftharpoons Cu \qquad E^\ominus = +0.34\,V$$

$$MnO_4^- + 8H^+ + 5e^- \rightleftharpoons Mn^{2+} + 4H_2O \qquad E^\ominus = +1.52\,V$$

(i) A MnO_4^-/Mn^{2+} electrode is constructed using 0.0020 mol dm^{-3} MnO_4^-, 1.0 mol dm^{-3} Mn^{2+} and 1.0 mol dm^{-3} H^+. The temperature used is 298 K.

Use the Nernst equation to show that the E value for this MnO_4^-/Mn^{2+} electrode is +1.49 V.

[2]

(ii) An electrochemical cell is constructed using a standard Cu^{2+}/Cu electrode and the MnO_4^-/Mn^{2+} electrode described in **(d)(i)**.

Calculate the value of E_{cell}.

E_{cell} = ... V [1]

(iii) Write an equation for the reaction taking place in the electrochemical cell described in **(d)(ii)**.

.... [1]

(iv) Complete the sentences for the electrochemical cell described in **(d)(ii)**.

The .... electrode is the negative electrode. Electrons flow from the

.... electrode to the .... electrode when the cell is in use.
[1]

(e) A solution containing $[Cu(H_2O)_6]^{2+}$ is electrolysed for 5.00 hours using a constant electric current. 0.764 g of copper metal is formed at the cathode. No other reduction reaction takes place.

Calculate the electric current, in A, used. Give your answer to **three** significant figures.

current = ... A [3]

[Total: 15]

6 **(a)** Iron forms complex ions with the monodentate ligand, CN^-.

(i) Complex ion **A** contains one Fe^{3+} ion and six CN^- ligands.

Complex ion **B** contains one Fe^{2+} ion and six CN^- ligands.

State the formulae of these two complex ions. Include the overall charge of each complex ion.

complex ion **A** ....

complex ion **B** ....

[1]

(ii) Explain why a solution containing complex ion **A** and a solution containing complex ion **B** are different colours.

....

....

.... [2]

(iii) In complex ion **A**, the carbon atom of each CN^- ligand bonds to the Fe^{3+} ion.

State the type of bonding involved.

.... [1]

(b) Complex ions have different geometries.

Complex ion **A** is octahedral.

Ag^+ ions form a linear complex with ammonia.

Ni atoms form a tetrahedral complex with carbon monoxide molecules. The carbon atom in the monodentate carbon monoxide ligand bonds to the nickel atom.

Pd^{2+} ions form a square planar complex with chloride ions.

Complete Fig. 6.1 to show the geometry of each of these four ions, using three-dimensional bonds where necessary. Label **one** bond angle on each complex ion.

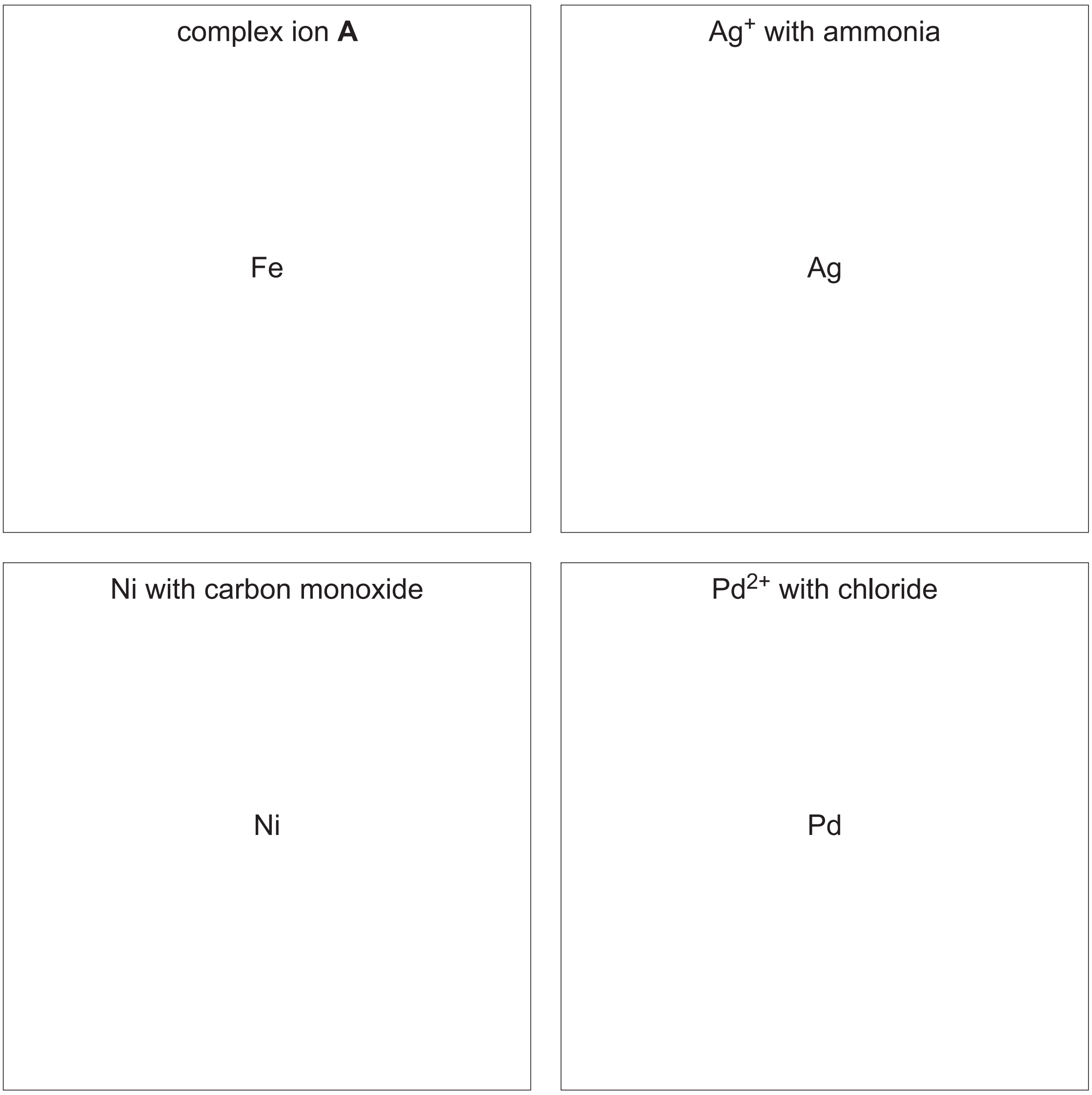


Fig. 6.1

[4]

[Total: 8]

7 A hydrocarbon is known to be either compound **D** or compound **E**.

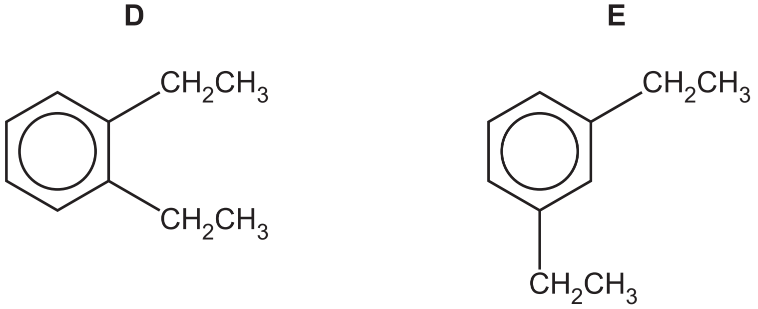


Fig. 7.1

(a) Give the systematic name of **E**.

.... [1]

(b) The proton (^{1}H) NMR spectra of **D** and **E** are compared. They are very similar.
The proton (^{1}H) NMR spectrum of **D** is shown in Fig. 7.2.

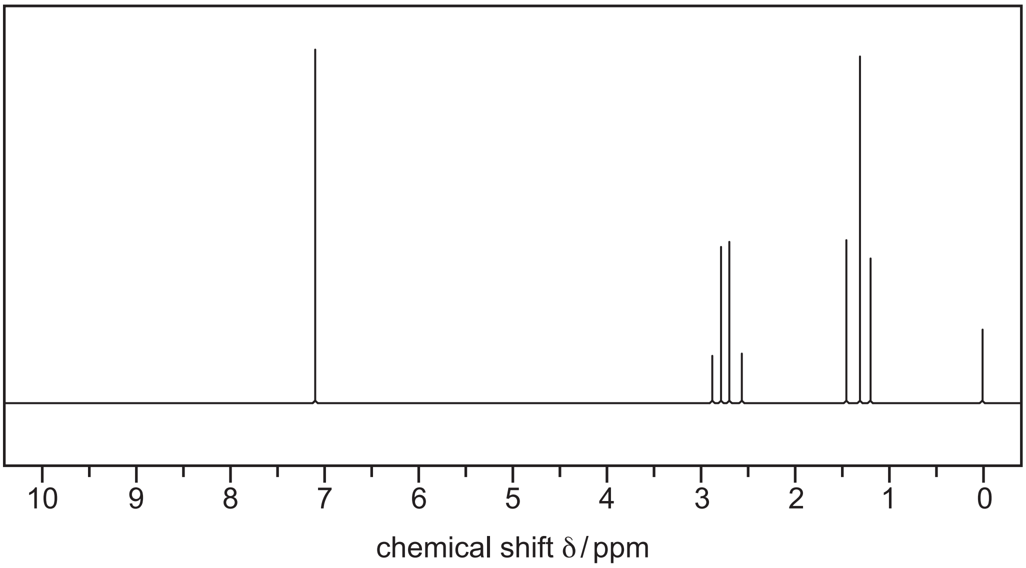


Fig. 7.2

(i) Suggest a suitable solvent for obtaining the spectrum in Fig. 7.2.

.... [1]

(ii) The proton (^{1}H) NMR spectrum of **E** is obtained twice, once before and once after shaking with D_2O.

Describe any differences between these two spectra. Explain your answer.

....

.... [1]

(iii) Complete Table 7.1 for the proton (^1H) NMR spectrum of **D**.

Table 7.1

chemical shift δ / ppm	number of ^1H atoms responsible for the peak	group responsible for the peak	splitting pattern
1.3			
2.7			
7.1		☒	☒

[3]

Table 7.2

environment of proton	example	chemical shift range δ / ppm
alkane	$-CH_3$, $-CH_2-$, $>CH-$	0.9–1.7
alkyl next to C=O	$CH_3-C=O$, $-CH_2-C=O$, $>CH-C=O$	2.2–3.0
alkyl next to aromatic ring	CH_3-Ar, $-CH_2-Ar$, $>CH-Ar$	2.3–3.0
alkyl next to electronegative atom	CH_3-O, $-CH_2-O$, $-CH_2-Cl$	3.2–4.0
attached to alkene	=C**H**R	4.5–6.0
attached to aromatic ring	**H**–Ar	6.0–9.0
aldehyde	**H**COR	9.3–10.5
alcohol	RO**H**	0.5–6.0
phenol	Ar–O**H**	4.5–7.0
carboxylic acid	RCOO**H**	9.0–13.0
alkyl amine	R–N**H**–	1.0–5.0
aryl amine	$Ar-NH_2$	3.0–6.0
amide	RCON**H**R	5.0–12.0

(iv) Compounds **D** and **E** can be distinguished by carbon-13 NMR spectroscopy.

State the number of peaks in each spectrum.

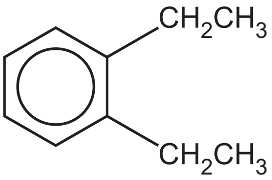
The carbon-13 NMR spectrum of **D** has .... peaks.

The carbon-13 NMR spectrum of **E** has .... peaks.

[1]

(c) Compound **D** can be oxidised to compound **F** by alkaline $KMnO_4$ followed by dilute acid.

D



F

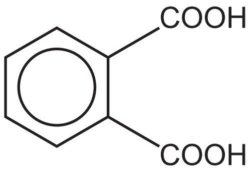


Fig. 7.3

(i) Write an equation for this reaction using molecular formulae for **D** and **F**. The products of this reaction are **F**, water and carbon dioxide.

Use [O] to represent one atom of oxygen from the oxidising agent.

.... [1]

(ii) **F** reacts with an excess of $SOCl_2$ to form compound **G**. The molecular formula of **G** is $C_8H_4Cl_2O_2$.

G reacts with ethane-1,2-diol, $HOCH_2CH_2OH$, to form a mixture of products that includes compounds **J**, molecular formula $C_{10}H_8O_4$, and **K**, molecular formula $C_{18}H_{12}Cl_2O_6$.

Draw the structures of compounds **G**, **J** and **K** in Fig. 7.4.

G, $C_8H_4Cl_2O_2$
J, $C_{10}H_8O_4$
K, $C_{18}H_{12}Cl_2O_6$

Fig. 7.4

[3]

[Total: 11]

8 Bromine reacts with methylbenzene in the dark in the presence of a suitable catalyst to form HBr and compound **L**, C_7H_7Br. **L** is one of three isomers that can form in this reaction.

(a) **(i)** The mechanism for the reaction involves methylbenzene reacting with a Br^+ ion. This ion is produced when bromine reacts with the catalyst.

Complete the equation for the reaction of Br_2 with the catalyst.

Br_2 + ... → Br^+ + ... [1]

(ii) One of the isomers of **L** forms in much smaller amounts than the other two isomers.

Draw the structure of this isomer and explain why it forms in the smallest amount.

....

....

[2]

(iii) Complete the mechanism in Fig. 8.1 for the reaction between methylbenzene and the Br^+ ion.

Include all relevant curly arrows and charges.

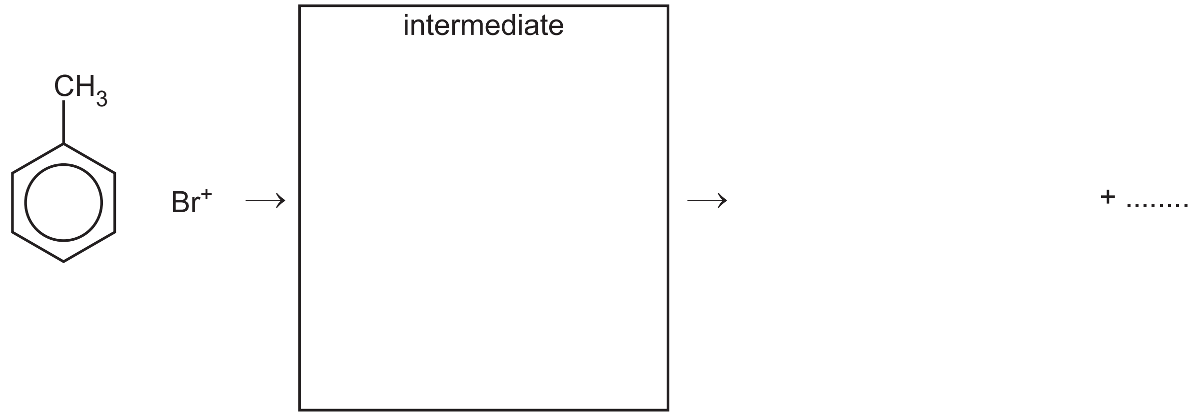


Fig. 8.1

[3]

(b) Chlorobutane and chlorobenzene are added separately to samples of warm aqueous $AgNO_3$.

One of the chloro-compounds reacts slowly and the other does **not** react.

(i) Identify the chloro-compound that reacts and describe any observations.

....

.... [1]

(ii) Write **two** equations to explain any observations in **(b)(i)**.

....

.... [2]

(iii) Explain the difference in reactivity of chlorobutane and chlorobenzene with warm aqueous $AgNO_3$.

....

....

....

.... [2]

[Total: 11]

9 **(a)** Phenylamine, $C_6H_5NH_2$, and propylamine, $CH_3CH_2CH_2NH_2$, can be produced by different reduction reactions.

(i) Identify an organic compound that can be converted into $C_6H_5NH_2$ by a reduction reaction. State the reagents and conditions for this reaction.

organic compound ....

reagents ....

conditions ....

[2]

(ii) Identify an organic compound that can be converted into $CH_3CH_2CH_2NH_2$ by a reduction reaction. State the reagent for this reaction.

organic compound ....

reagent ....

[2]

(iii) Identify a single test that will distinguish between $C_6H_5NH_2$ and $CH_3CH_2CH_2NH_2$ by producing a white precipitate with **only** one of these amines.

Draw the structure of the compound that is precipitated.

testing reagent ....

amine that gives a precipitate ....

structure of the compound that is precipitated:

[2]

(b) Describe the relative basicities of $C_6H_5NH_2$, $CH_3CH_2CH_2NH_2$ and NH_3.

Explain your answer.

.... < .... < ....

least basic most basic

....

....

....

....

....

[4]

[Total: 10]

10 Propanoic acid, methanoic acid and ethanedioic acid are all weak acids.

(a) Draw the displayed formula of ethanedioic acid.

[1]

(b) The three acids, propanoic acid, methanoic acid and ethanedioic acid, can be distinguished using a combination of two chemical tests. Neither testing reagent is an acid–base indicator.

Identify **two** suitable testing reagents and complete Table 10.1 to show the observations from each test.

reagent 1 .... reagent 2 ....

Table 10.1

	observation when treated with reagent 1	observation when treated with reagent 2
propanoic acid		
methanoic acid		
ethanedioic acid		

[4]

(c) When propanoic acid is treated with chlorine gas in the presence of ultraviolet light, a mixture of products is formed. One of these products is 2,2-dichloropropanoic acid.

Explain why 2,2-dichloropropanoic acid is stronger than propanoic acid. Refer to the structure of each compound in your answer.

....

....

....

.... [2]

[Total: 7]

Important values, constants and standards

molar gas constant	$R = 8.31\,\text{J}\,\text{K}^{-1}\,\text{mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^{4}\,\text{C}\,\text{mol}^{-1}$
Avogadro constant	$L = 6.02 \times 10^{23}\,\text{mol}^{-1}$
electronic charge	$e = -1.60 \times 10^{-19}\,\text{C}$
molar volume of gas	$V_m = 22.4\,\text{dm}^3\,\text{mol}^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0\,\text{dm}^3\,\text{mol}^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14}\,\text{mol}^2\,\text{dm}^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18\,\text{kJ}\,\text{kg}^{-1}\,\text{K}^{-1}$ ($4.18\,\text{J}\,\text{g}^{-1}\,\text{K}^{-1}$)

The Periodic Table of Elements

Key

atomic number
atomic symbol
name
relative atomic mass

Group

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
							1 H hydrogen 1.0										2 He helium 4.0
3 Li lithium 6.9	4 Be beryllium 9.0											5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2
11 Na sodium 23.0	12 Mg magnesium 24.3											13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium –	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs caesium 132.9	56 Ba barium 137.3	57–71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium –	85 At astatine –	86 Rn radon –
87 Fr francium –	88 Ra radium –	89–103 actinoids	104 Rf rutherfordium –	105 Db dubnium –	106 Sg seaborgium –	107 Bh bohrium –	108 Hs hassium –	109 Mt meitnerium –	110 Ds darmstadtium –	111 Rg roentgenium –	112 Cn copernicium –	113 Nh nihonium –	114 Fl flerovium –	115 Mc moscovium –	116 Lv livermorium –	117 Ts tennessine –	118 Og oganesson –

lanthanoids	57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	61 Pm promethium –	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.1	71 Lu lutetium 175.0
actinoids	89 Ac actinium –	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium –	94 Pu plutonium –	95 Am americium –	96 Cm curium –	97 Bk berkelium –	98 Cf californium –	99 Es einsteinium –	100 Fm fermium –	101 Md mendelevium –	102 No nobelium –	103 Lr lawrencium –