ANGLO CHINESE

# H2 CHEMISTRY

2022

JUNIOR COLLEGE PRELIM

ANGEL J CHINESE

!!? CHEMISTRY

2022

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1　Which species deflects the most in an electric field?

A　$^7Li^+$

B　$^{24}Mg^{2+}$

C　$^{32}S^{2-}$

D　$^{27}Al^{3+}$

2　The shape of each p-orbital is represented as two lobes.

How many 3d orbitals have four lobes?

A　2

B　3

C　4

D　5

3　Which species has the greatest number of unpaired electrons in its ground state?

A　Cu^+

B　CH_3^-

C　Mg

D　F

4　Which species contains a dative bond?

　　1　CO

　　2　NO_3^-

　　3　O_3

A　1, 2 and 3

B　1 and 2 only

C　1 and 3 only

D　2 only

　　　　9729/01/Prelim/2022　　　　**[Turn over**

5   Which row correctly describes the shape and polarity of the species?

	species	shape	polarity
A	$AlCl_3$	trigonal planar	polar
B	SiF_4	square planar	non-polar
C	BrF_3	trigonal pyramidal	polar
D	$BeCl_2$	linear	non-polar

6   Which graph shows the behaviour of a fixed mass of an ideal gas at a constant temperature?

A

pM_r

V

B

pV

p

C

p

$\dfrac{1}{V}$

D

p

p
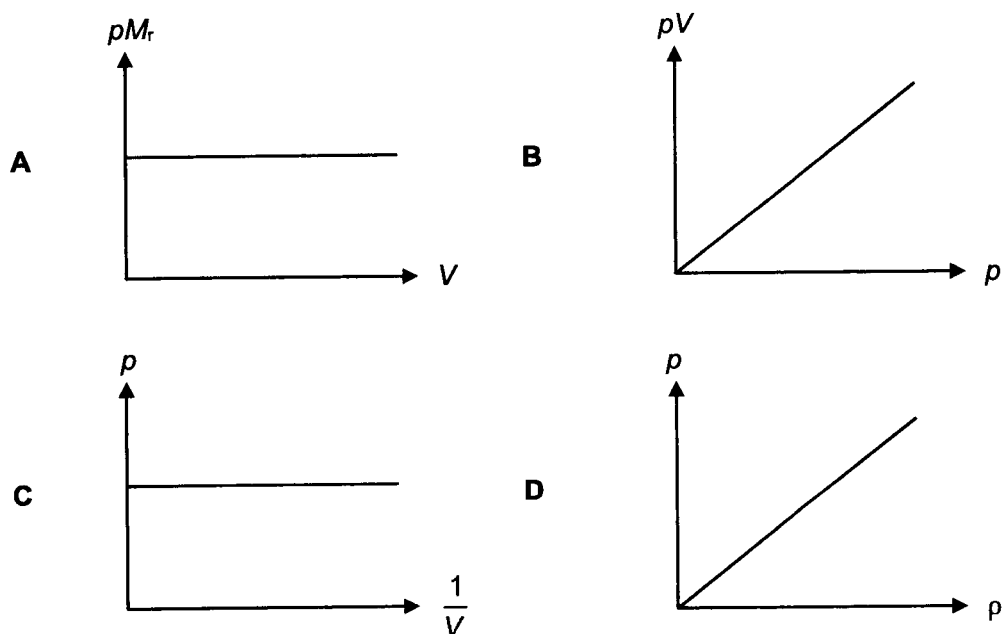
7   Which statements explain the difference in ionic radius between Na^+ and F^-?

1   Outermost electrons of F^- experience weaker nuclear charge than those of Na^+.

2   Outermost electrons of Na^+ experience greater shielding effect than those of F^-.

3   Outermost electrons of Na^+ are nearer to the nucleus than those of F^-.

A   3 only

B   1 and 2 only

C   1 and 3 only

D   1, 2 and 3

8   0.1 mol of compound **X** dissolves in 1 dm^3 of water to give a solution with a pH of 1.

What is the identity of **X**?

A $AlCl_3$

B CH_3COCl

C NH_4NO_3

D CH_3COOH

9   Wüstite, containing both Fe^{2+} and Fe^{3+} ions, has the formula $Fe_{20}O_x$. Fe^{2+} constitutes 90% of the iron ions present in the compound.

What is the value of x?

A   18

B   19

C   21

D   22

10   Which option involves a positive entropy change?

A   the homolytic fission of gaseous chlorine

B   the lattice energy of sodium chloride

C   the contraction of an ideal gas at a constant temperature

D   cooling a copper strip from 373 K to 273 K

11 The reaction between NO and Br_2 is proposed to proceed via the following mechanism:

step 1: $NO + Br_2 \rightleftharpoons NOBr_2$ (fast)

step 2: $NOBr_2 + NO \longrightarrow 2NOBr$ (slow)
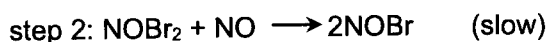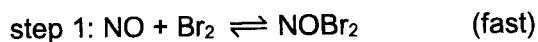
Which statements are correct?

1   $NOBr_2$ is a radical.

2   The rate equation for this reaction is rate = $k[Br_2][NO]^2$.

3   $NOBr_2$ is a transition state.

A   1 and 2 only

B   1, 2 and 3

C   1 and 3 only

D   2 and 3 only

12 Which statement regarding catalysts is correct?

A   Catalysts change the ΔH value of a reaction.

B   Catalysts increase the yield of product in a reaction.

C   Catalysts provide a different mechanism for a reaction.

D   Catalysts change the K_c value of a reaction.

13 In aqueous solution, an equilibrium is established between chromate, CrO_4^{2-} (yellow) and dichromate ions, $Cr_2O_7^{2-}$ (orange).

$$2CrO_4^{2-}(aq) + 2H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(l)$$
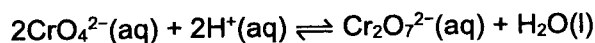
Which statement regarding the ions and the equilibrium is correct?

A   The oxidation number of chromium in both chromium-containing ions is different.

B   The difference in colour between CrO_4^{2-} and $Cr_2O_7^{2-}$ is due to a difference in energy gap between the 3d orbitals.

C   The K_c expression for the equilibrium is $K_c = \dfrac{[Cr_2O_7^{2-}][H_2O]}{[CrO_4^{2-}]^2[H^+]^2}$.

D   Increasing the pH turns the solution yellow.

14 Nitrogen dioxide dimerises in a closed system and establishes the following equilibrium:

$$2NO_2(g) \rightleftharpoons N_2O_4(g)$$
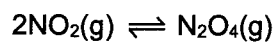
When 46.0 g of NO_2 was introduced into an evacuated rigid vessel with an initial pressure 2 atm at constant temperature, the apparent M_r value of the equilibrium mixture is 64.4.

What is the K_p value of this equilibrium?

A   0.281

B   0.556

C   0.778

D   1.11

15 Which solution will solid silver phosphate, Ag_3PO_4, be the least soluble in, at 25 °C?

The numerical value of $K_{sp}(Ag_3PO_4)$ is 8.89×10^{-17}.

A   pure water

B   2.0 mol dm^{-3} $AgNO_3(aq)$

C   2.0 mol dm^{-3} $NH_3(aq)$

D   2.0 mol dm^{-3} $K_3PO_4(aq)$

16 In an acid-base titration, 0.10 mol dm^{-3} solution of an acid is added to 25 cm^3 of 0.10 mol dm^{-3} solution of a base.

The pH value of the solution is plotted against the volume, V, of acid added as shown in the diagram.
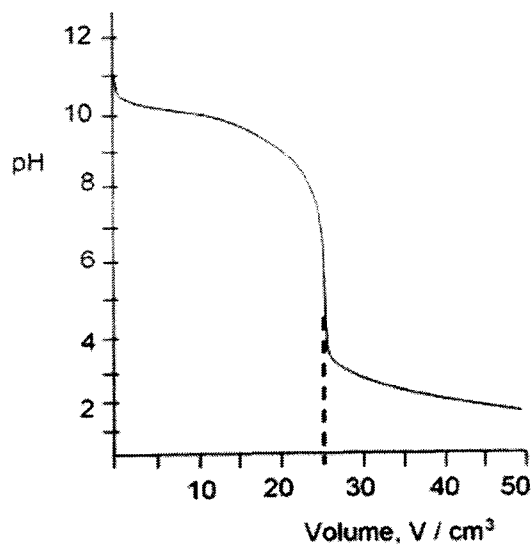
Which statement is **incorrect**?

A Maximum buffering capacity occurs at V = 12.5 cm^3.

B The pair of solutions could have been HCl(aq) and CH$_3$NH$_2$(aq).

C Methyl orange is a suitable indicator for the above titration.

D When the concentration of the acid is doubled, the pH at equivalence point remains unchanged.

17   Some vegetable oils contain 'trans fats' that are associated with undesirable increases in the amount of cholesterol in the blood. In the structures below, R_1 and R_2 are different saturated hydrocarbon chains.

Which structure correctly illustrates an optically active 'trans fat'?

A

B

C

D
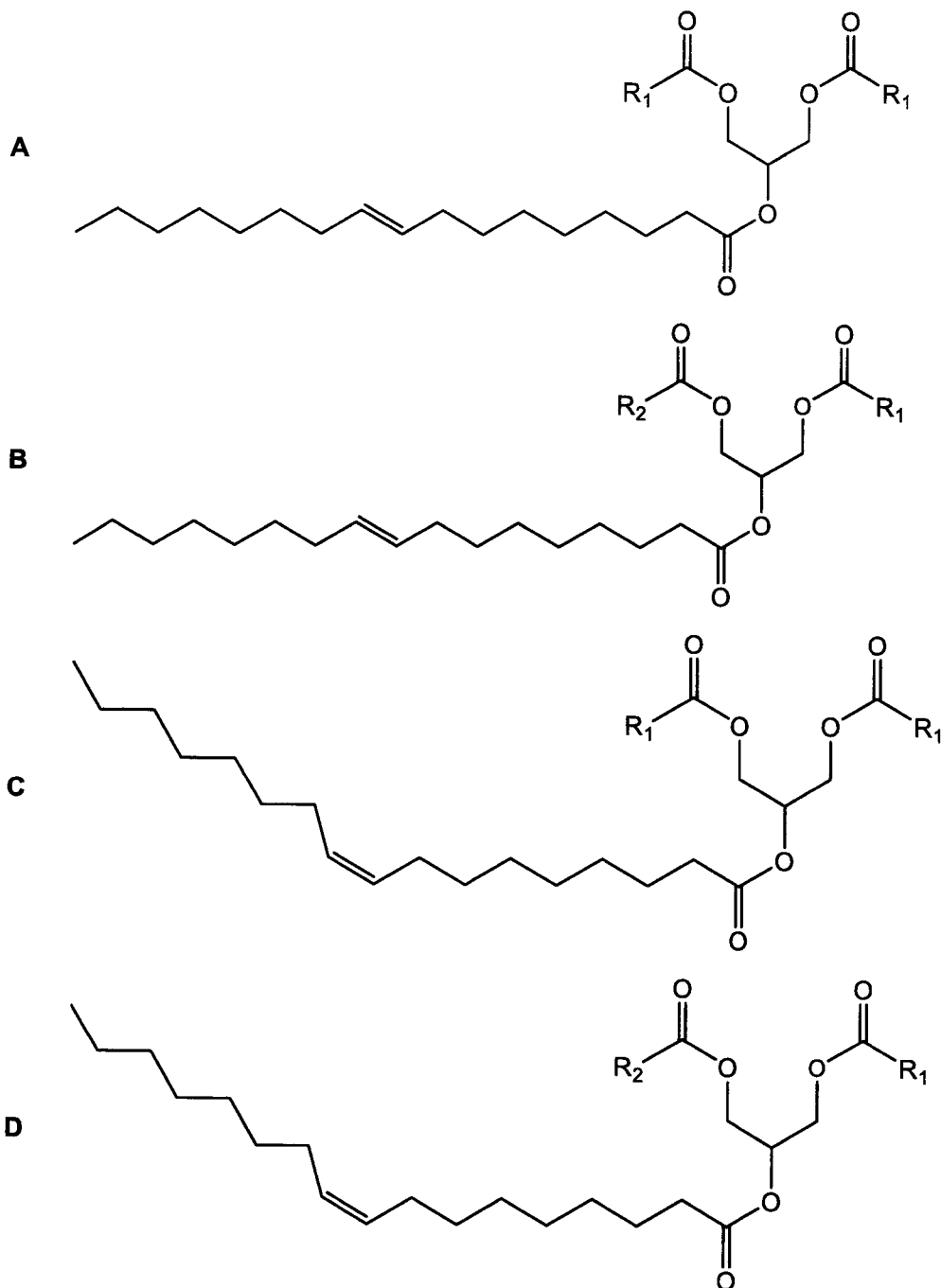
18 A hydrocarbon reacted with bromine under suitable conditions to give the following product.

$$
\begin{array}{c}
CH_2Br \\
| \\
H_3C—CH \\
| \\
CH_2Br
\end{array}
$$
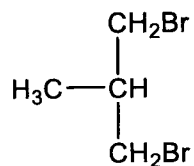
What type of reaction occurred between the hydrocarbon and bromine?

A   electrophilic addition

B   free radical substitution

C   electrophilic substitution

D   nucleophilic addition

19 Ferulic acid is an antioxidant that occurs widely in plants.

Assume that the CH_3O- group is inert.

$$HO—\text{(ring)}—CH=CHCO_2H$$
$$H_3CO$$
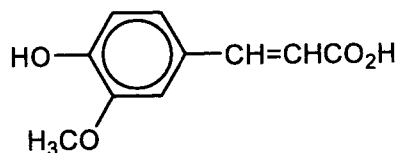
ferulic acid

Which statements about ferulic acid are correct?

1   It decolourises aqueous bromine.

2   It is not very soluble in water but dissolves in aqueous NaOH.

3   It can be prepared from $HO—\text{(ring)}—CH=CHCH_2OH$ (H_3CO) using hot acidified $K_2Cr_2O_7$ (aq).

A   1 only   B   1 and 2 only   C   2 and 3 only   D   1, 2 and 3

               [Turn over

20 Unsaturated carbonyl compounds can undergo a useful reaction known as the Diels-Alder reaction with a diene. An example is shown below.
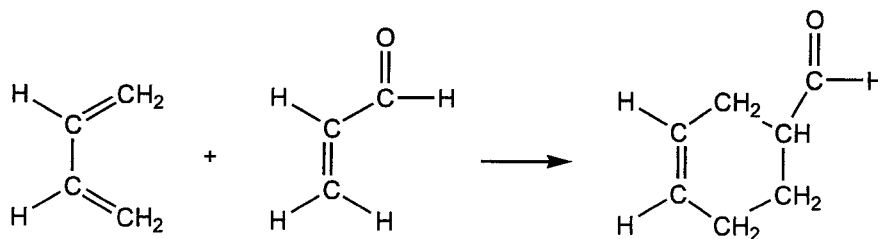
A student reacted the following diene and carbonyl compound together in a Diels-Alder reaction.
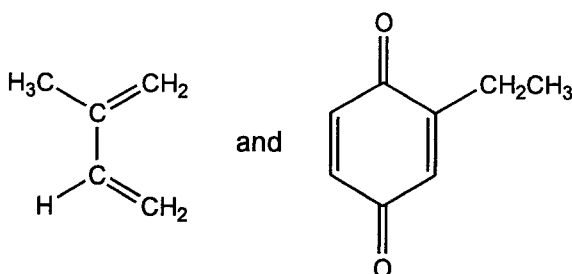
Which product will **not** be formed?

A

B

C

D
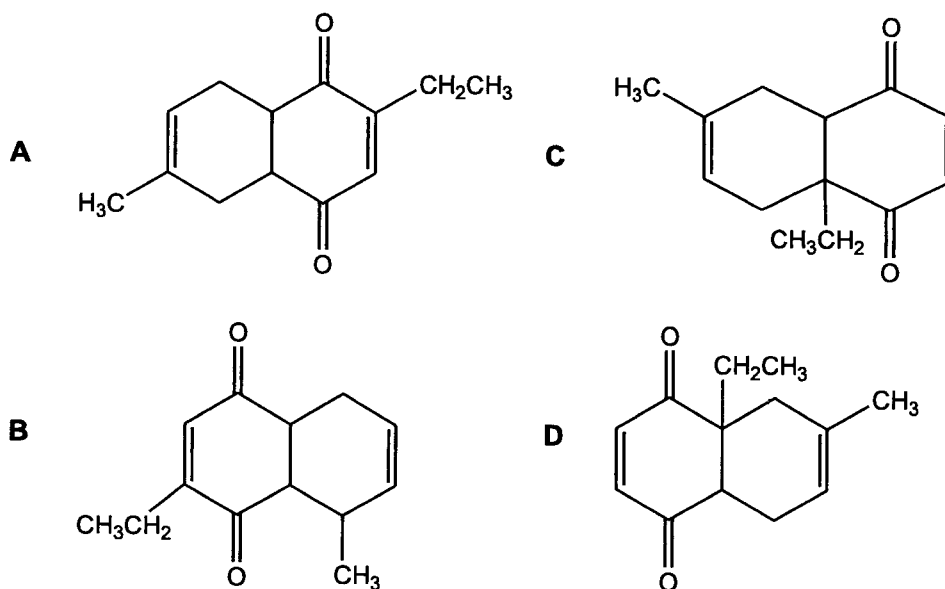
21 Deuterium, D, is a heavy isotope of hydrogen. Deuteriobenzene reacts with chlorine and $AlCl_3$ under controlled conditions so that only monochlorination takes place.

Assuming that the carbon-deuterium bond is broken as easily as a carbon-hydrogen bond, what is the proportion of 2-chlorodeuteriobenzene in the mono-chlorinated products?
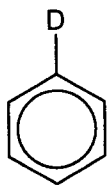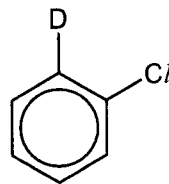
deuteriobenzene   2-chlorodeuteriobenzene

A   16%   B   20%   C   33%   D   40%

22 Two female sex hormones are oestrone and oestradiol.
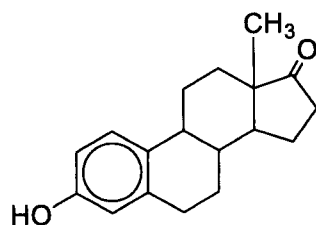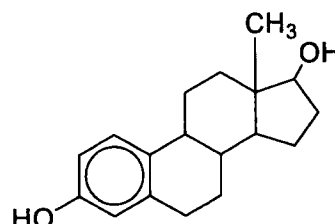
oestrone   oestradiol

Which reagents could be used to distinguish between the two hormones?

1    $SOCl_2$
2   2,4-dinitrophenylhydrazine
3    $LiAlH_4$ in dry ether

A   1 and 2 only   B   1 only   C   2 and 3 only   D   1, 2 and 3

23 Many different compounds have been used in aerosol sprays, refrigerators and in making foamed plastics.

Which compound will cause the most ozone depletion?

A CCl_3F
B $CH_2FCHClF$
C $CH_3CH_2CH_2CH_3$
D $CH_2=CHCl$

24 Which reagent reacts with the following organic compound to give only one organic product?

Assume that the CH_3O- group is inert.

$$CH_3O-\langle\text{ring}\rangle-CH=CHCO_2CH_2CH\begin{matrix}CH_2CH_3\\CH_2CH_2CH_2CH_3\end{matrix}$$
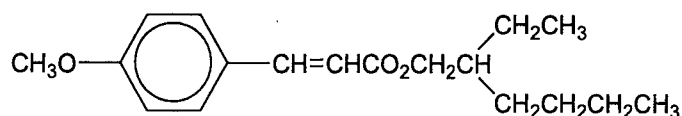
A   hot NaOH(aq)

B   hot acidified K_2CrO_7(aq)

C H_2(g), Pt

D HCl(g)

25 The amino acids glutamine and glutamic acid can react with each other to form amide linkages.
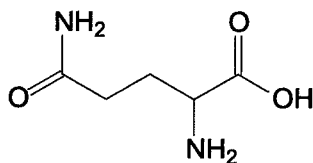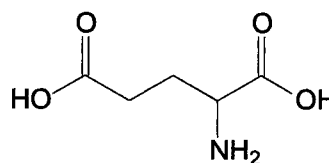
glutamine   glutamic acid

What is the maximum number of different compounds that can be formed from one molecule of glutamine and one molecule of glutamic acid?

A 2   B 3   C 4   D 5

26 0.01 mol of KIO_n reacts with 0.05 mol of KI stoichiometrically to produce I_2 under acidic conditions.

In this reaction, all the iodine containing reactants were converted to I_2(aq).

What is the value of n?

A 1

B 2

C 3

D 4

27 Use of the *Data Booklet* is relevant to this question.

By considering relevant $E^{\ominus}$ values, which metal will not dissolve in 1 mol dm^{-3} HCl(aq)?

A V   B Ag   C Mg   D Sn

28 The Kolbe reaction involves decarboxylative dimerisation of carboxylate ions by electrolysis. When an aqueous solution of sodium carboxylate is electrolysed, the overall equation is as follows:

$$2RCO_2Na + 2H_2O \longrightarrow R-R + 2CO_2 + 2NaOH + H_2 \text{ where } R = C_nH_{2n+1}$$
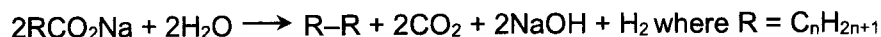
Which statements about the anode and cathode are correct?

	anode	cathode
1	The solution around the anode turns moist blue litmus red.	The solution around the cathode turns moist red litmus blue.
2	RCO$_2$Na is oxidised to R–R at the positive terminal.	H$_2$O is reduced to H$_2$ at the negative terminal.
3	The standard electrode potential involving H$_2$O is the least positive.	The standard electrode potential involving H$_2$O is the most positive.

A 1 only   B 1 and 2 only   C 2 and 3 only   D 1, 2 and 3

29 Use of the *Data Booklet* is relevant to this question.

15.7 g of the metal gadolinium (Gd) was deposited in electrolysis by a current of 5.0 A for 96.5 minutes.

What is the formula of the gadolinium ion? [A_r of Gd = 157]

A Gd$^+$ B Gd^{2+} C Gd^{3+} D Gd^{4+}

30 X is a transition metal. Under a high concentration of Cl^-, the cation of X forms a coloured complex ion, [XCl_4]$^{2-}$. When [XCl_4]$^{2-}$ is reduced to [XCl_2]$^-$, the solution turns colourless.

What is the ground state electronic configuration of X?

A [Ar] 3d^5 4s^1 B [Ar] 3d^{10} 4s^1 C [Ar] 3d^5 4s^2 D [Ar] 3d^9 4s^2

3

Answer **all** the questions in the spaces provided.

1 **(a)** Table 1.1 shows the solubility of two organic molecules at 25 °C.

Table 1.1

	solubility in water / g dm^{-3}
propanone	miscible
chloromethane	5.04

(i) Identify the type of intermolecular force present between the molecules.

propanone: ....

chloromethane: ....[1]

(ii) Give a reason for the difference in their solubilities in water.

....

....[1]

(b) The boiling point of three ligands are shown in Table 1.2.

Table 1.2

ligand	formula	boiling point / °C
water	H_2O	100
ammonia	NH_3	−33.3
hydrazine	N_2H_4	114

(i) Explain what is meant by the term *ligand*.

....

....[1]

(ii) Explain the difference in the boiling points of the three ligands.

....

....

....

....

....[2]

4

(c) Polydentate ligands are ligands which form more than one bond with the metal atom or ion.

Salicylaldehyde, ethane-1,2-diamine and H_2salen are examples of such ligands. H_2salen can be synthesised from salicylaldehyde and ethane-1,2-diamine.

salicylaldehyde   ethane-1,2-diamine H_2salen
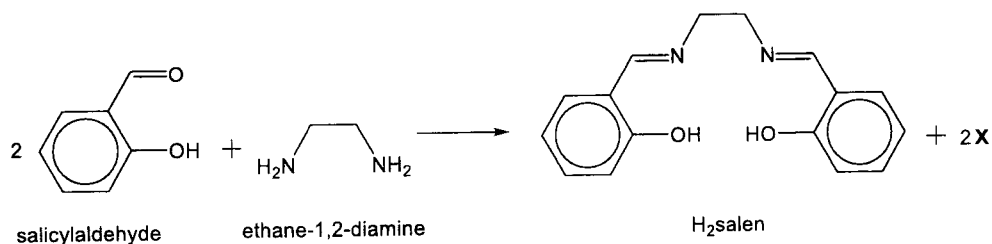
When the phenolic groups of H_2salen are deprotonated, $salen^{2-}$ acts as a ligand. It has a high affinity for Co^{2+} ions and forms a planar complex Co(salen).

(i) Suggest the identity of molecule **X**.

....[1]

(ii) Draw the structure of a $salen^{2-}$ ligand and circle the atoms which are used to coordinate to a Co^{2+} ion.

$salen^{2-}$

[2]
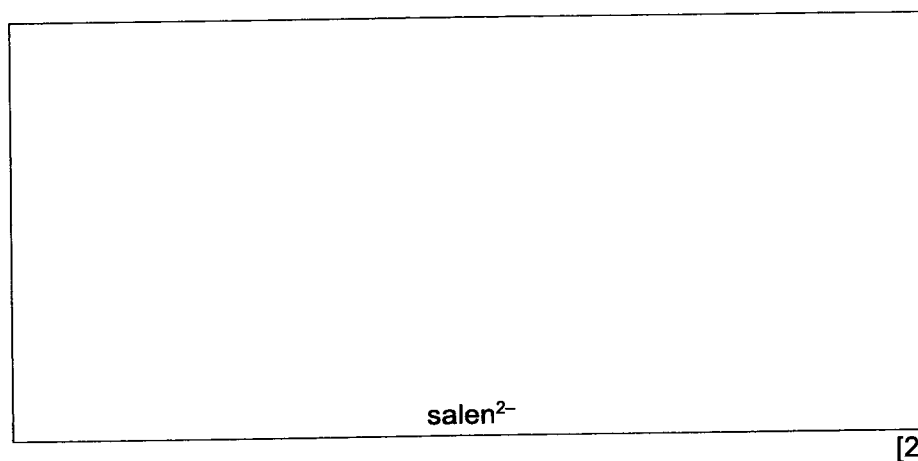
(iii) State the coordination number of the Co^{2+} ion in Co(salen).

....[1]

(d) Ozonolysis is a method to oxidatively cleave alkenes using ozone, O_3, to form carbonyl compounds.
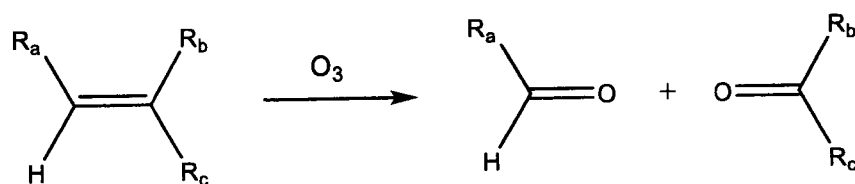
5

(i)
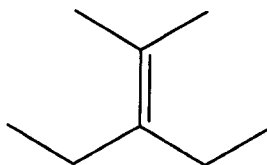
2-methyl-3-ethylpent-2-ene

Draw the structure of the organic products when 2-methyl-3-ethylpent-2-ene undergoes ozonolysis.

$(CH_3)_2C=O$	$(CH_3CH_2)_2C=O$
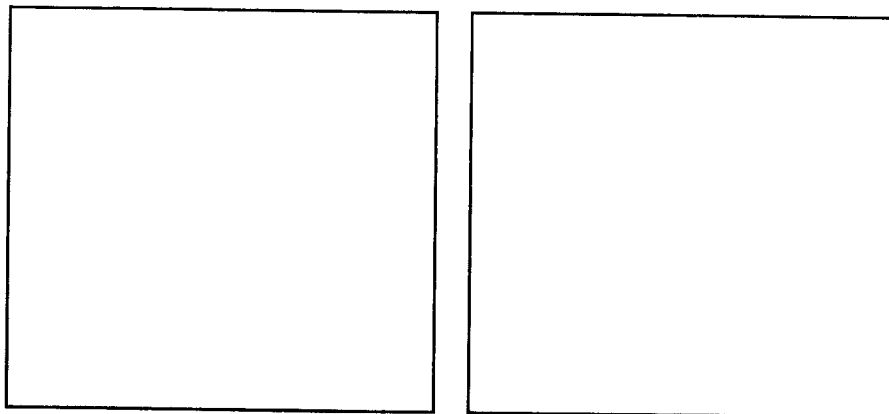
[2]

(ii) Ozonolysis of A, C_6H_{10}, gives a single compound, B, $C_6H_{10}O_2$.

B gives a yellow precipitate when treated with alkaline aqueous iodine and forms a red-brown precipitate when treated with Fehling's solution.

Draw the structures of the compounds A and B.

A	**B**

[2]

[Total: 13]

6
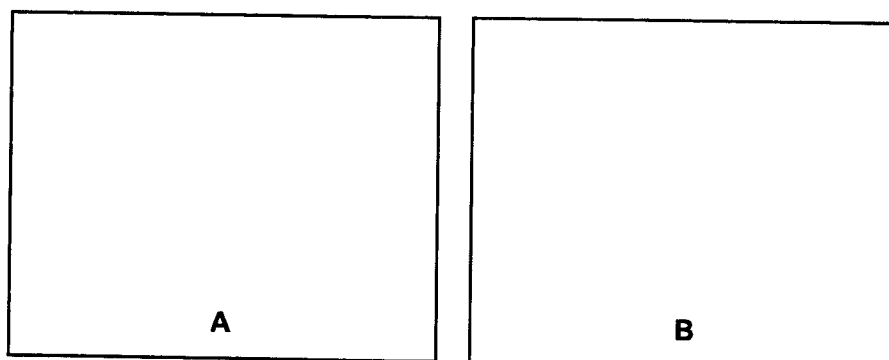
2 Chromium is a transition metal that is valued for its high resistance to corrosion and is added to steel to form stainless steel.

While chromium can exist in various oxidation states, the most common oxidation state is the +3 state.

(a) Hydrated chromium (III) chloride exists as isomers, with the general formula of $CrCl_3.6H_2O$. One such isomer is $[CrCl_2(H_2O)_4]Cl.2H_2O$ and it appears dark green.

Suggest the formula of two other isomers of hydrated chromium (III) chloride.

isomer 1 ....

isomer 2 ....[2]

(b) When a sample of hydrated chromium (III) chloride is added to excess water, a green solution of $CrCl_3(aq)$ is obtained. Fig. 2.1 shows the reactions that aqueous $CrCl_3$ can undergo.

$CrCl_3(aq)$ green solution — $Na_2CO_3(aq)$ → grey-green precipitate **A** + effervescence of gas **B**

left to stand ↓

D violet solution

excess NaOH(aq) ↓

C dark green solution

$H_2O_2(aq)$, heat ↓

$CrO_4{}^{2-}(aq)$ yellow solution
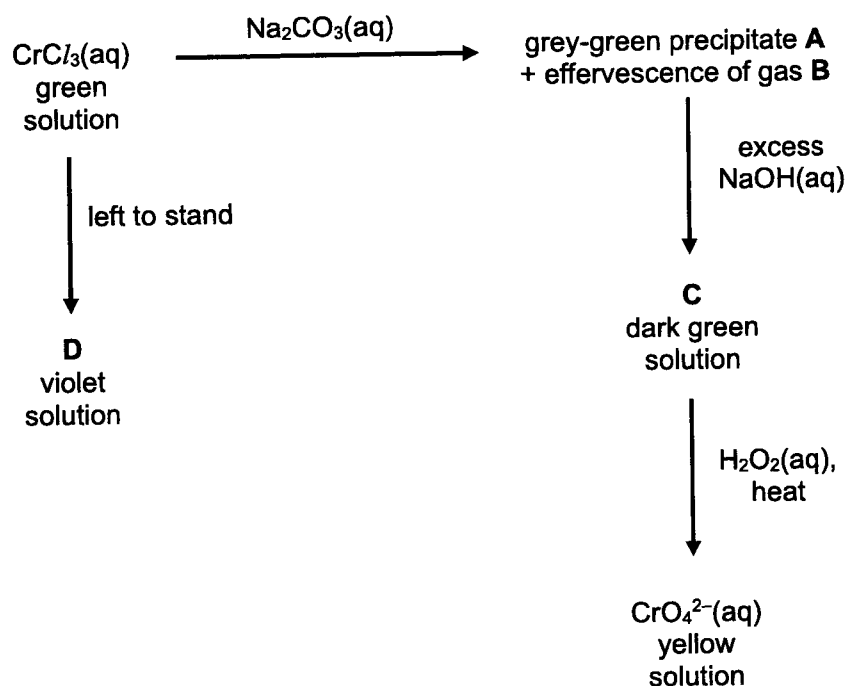
Fig. 2.1

(i) Identify precipitate **A** and gas **B**.

precipitate **A**: ....

gas **B**: ....[2]

(ii) Suggest the formula of compound **C**.

....[1]

(iii) Explain why solutions of transition metal compounds are often coloured.

....

....

....

....

....

....

....

....

....

....

....

.... [3]

(iv) Given that the oxidation state of chromium in compound **D** is still +3, suggest what happened that caused the colour change from green to violet.

....

....

....

....

....

....

....[2]

(v) State the role of $H_2O_2(aq)$.

....[1]

(vi) Write a balanced equation for the formation of CrO_4^{2-} from **C**.

....[1]

8

(c) Fig. 2.2 shows the first seven ionisation energies of calcium and chromium.
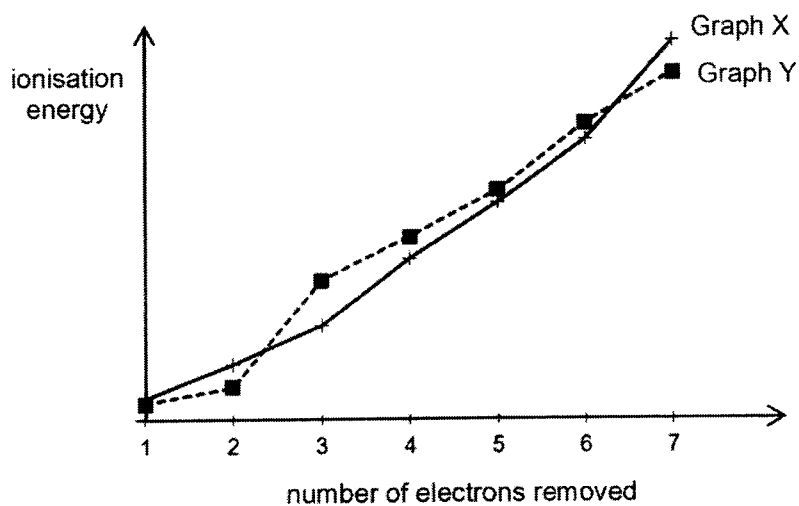
Fig. 2.2

State and explain which graph shows the successive ionisation energies for calcium.

....

....

....

....

....

....

.... [2]

[Total: 14]

9

3 **(a)** The variation of the volume with temperature of a fixed mass of an ideal gas at constant pressure may be represented by a relationship known as Charles's law,

$$V = k\,T$$

where V is the volume of a gas, T is the temperature in Kelvin and k is a constant.

An experiment was carried out to attempt to verify this law using a gas, phosphine, PH_3.

The experiment was repeated several times at different temperatures.

Fig. 3.1 was plotted to determine the relationship between the volume of the gas and its temperature.

Fig. 3.1

9729/02/Prelim/2022 **[Turn over**

10
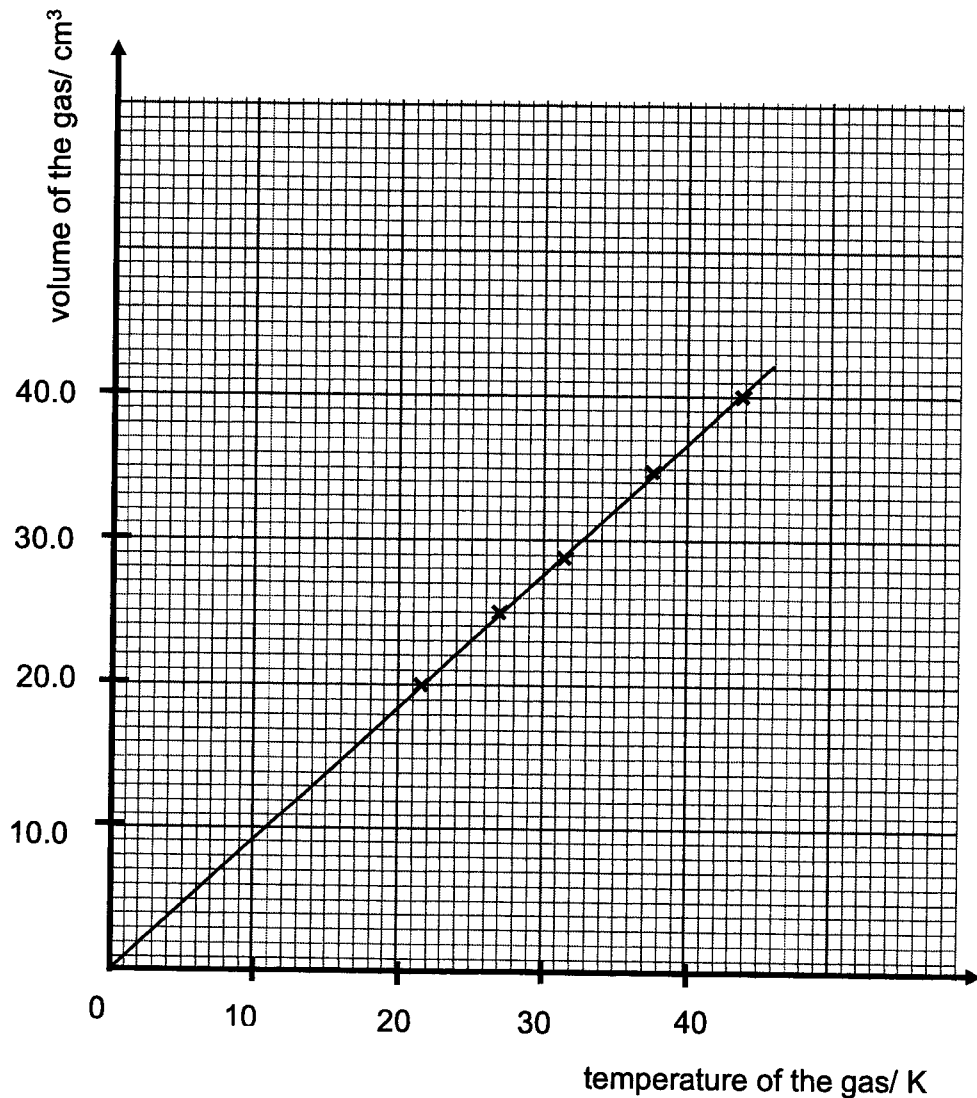
(i) Based on Fig. 3.1, state whether the result is consistent with Charles's law. Give a reason for your answer.

....

....

....[1]

(ii) State the **two** properties of a gas necessary for it to approach ideal behaviour.

....

....

....

....

....[1]

(b) Orange street lamps contain sodium with a small amount of neon. The light is produced when gaseous atoms are ionised in an electric field. When it is first turned on, the lamps emit a red glow characteristic of neon, but after some time, the orange glow of sodium predominates.

Explain the order for the appearance of the colours. Use relevant data from the *Data Booklet* in your answer.

....

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....

....

....

....

....

....[2]

(c) 4–chloromethylbenzene and (chloromethyl)benzene are isomers.
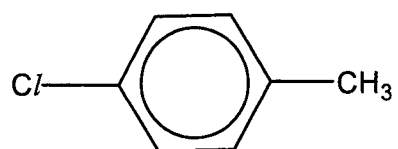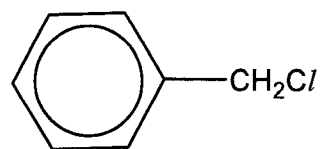
4-chloromethylbenzene   (chloromethyl)benzene

(i) Explain the difference in their reactivities towards hot aqueous sodium hydroxide.

....

....

....

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....

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....

....

....

....[2]

(ii) Alkyl halides can undergo nucleophilic substitution, with the simplified general mechanism as shown below:

The mechanism involves the heterolytic fission of the C–X bond, resulting in X leaving with a pair of electrons as X^-. X^- is called the leaving group.

When alkyl halide undergoes nucleophilic substitution, one factor that affects its reactivity is the basicity of X^-. In general, when X^- is a stronger base, it is a poorer leaving group. This results in the alkyl halide being less reactive towards nucleophilic substitution.

Using the data given in Table 3.1 and relevant data from the *Data Booklet*, suggest **two** reasons to explain why (iodomethyl)benzene reacts much faster than (chloromethyl)benzene.

Table 3.1

halide	pK_b
Cl^-	21.0
I^-	24.0

....

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....

....

....[2]

(d) The first known synthesis of an amino acid occurred in 1850 in the laboratory of Adolf Strecker.
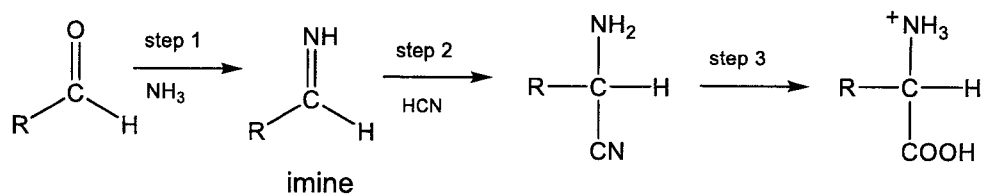
imine

(i) Name the type of reaction in step 1.

....[1]

(ii) In step 2, the reaction proceeds via two stages:

(I) acid-base reaction between the N atom in imine and HCN

(II) nucleophilic attack on C atom by CN⁻

Draw the mechanism of step 2. Show all relevant charges, dipoles, lone pairs and curly arrows.

[2]

14

(iii) An imine intermediate is also formed in preparing secondary amines from ketones.

imine
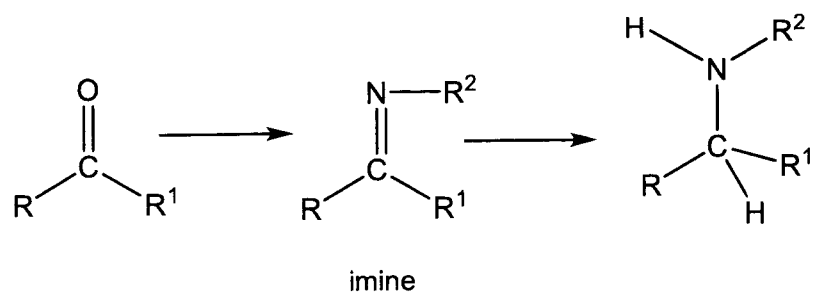
Suggest the synthetic route by giving all the reagents, conditions and intermediate for the preparation of $(CH_3)_2CHNH(CH_2CH_3)$.

[4]

(iv) Another amine **X**, $CH_3CH(NH_2)CH_2NH_2$, reacts with ethanedioyl dichloride $(COCl)_2$ to produce compound **Y** with molecular formula $C_5H_8N_2O_2$. Suggest the structure for compound **Y**.

[1]

[Total: 16]

4 **(a)** Umbelliferone is a yellowish-white crystalline solid occurring naturally in carrots and is used as a sunscreen agent. It has the structure shown below:
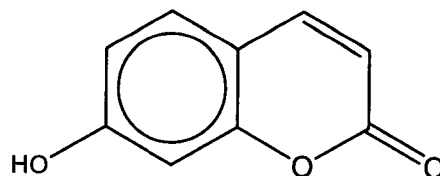
The following reaction scheme shows how umbelliferone may be synthesised from compound **F**, which has a molecular formula of $C_8H_8O_3$.

In the boxes provided, fill in the missing
- reagents and conditions,
- structures of compounds **F** and **G**.

HCN, traces of KCN

H_2SO_4 (aq) heat under reflux
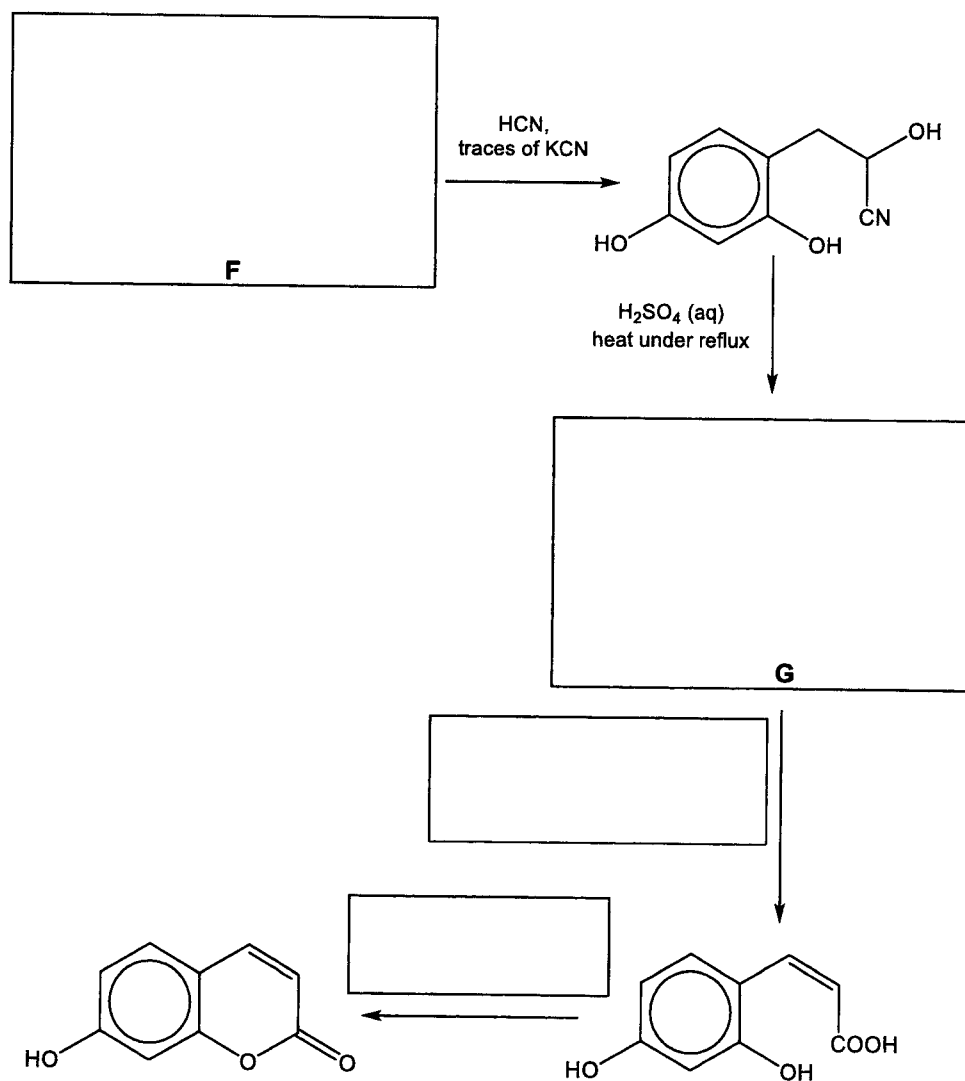
[4]

(b) The Mannich reaction is an organic reaction which consists of an amino alkylation of the hydrogen atom adjacent to a carbonyl functional group, by methanal and a primary amine, secondary amine or ammonia, in the presence of acid.

carbonyl   methanal   amine
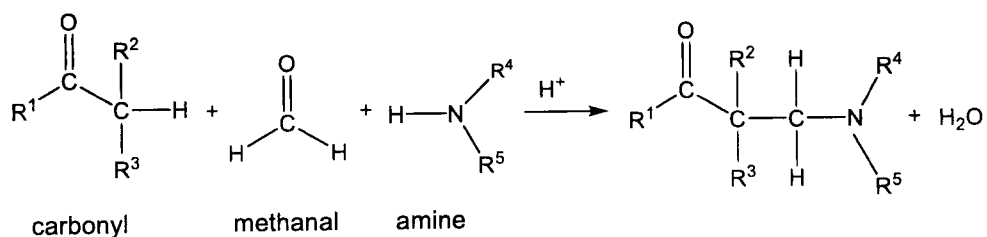
(i) Predict the structure of **V**, $C_7H_{15}NO$, when the following compounds undergo the Mannich reaction.

V
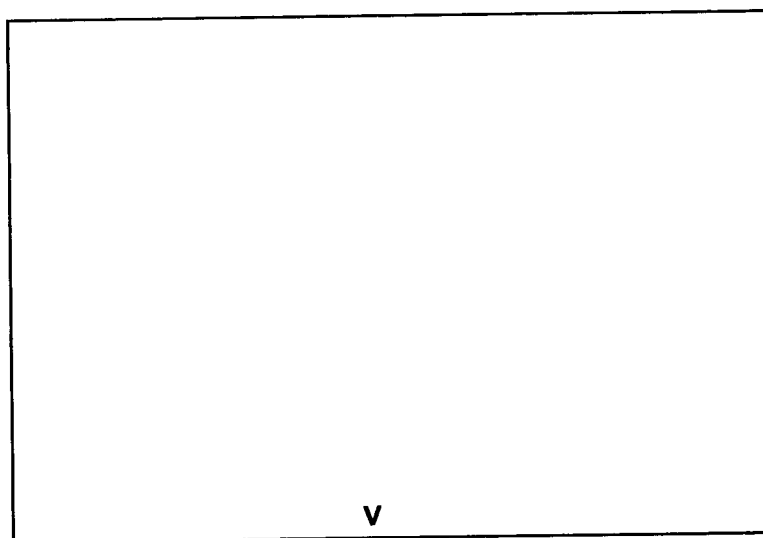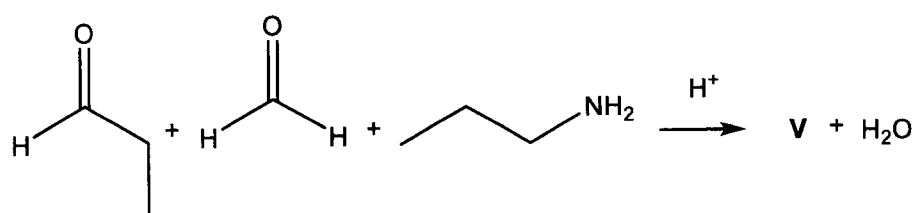
[1]

(ii) The proposed mechanism for the Mannich reaction is as follows:
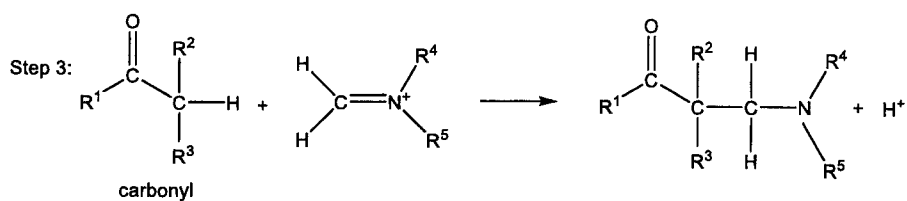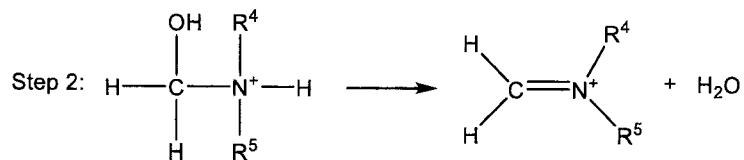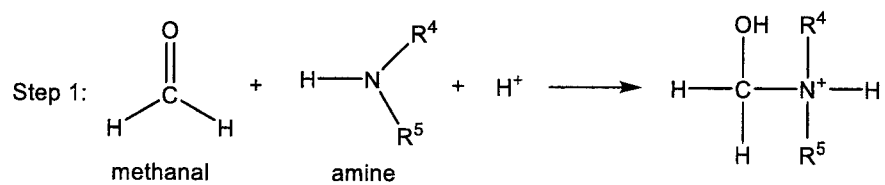
Suggest the type of reaction that occurred in step 1 and 2.

step 1 ....

step 2 .... [2]

(c) The Claisen condensation of esters involves the formation of a new carbon-carbon bond between two esters. The products are a keto-ester and an alcohol. The reaction takes place in the presence of a strong base e.g. CH_3O^-.

keto-ester
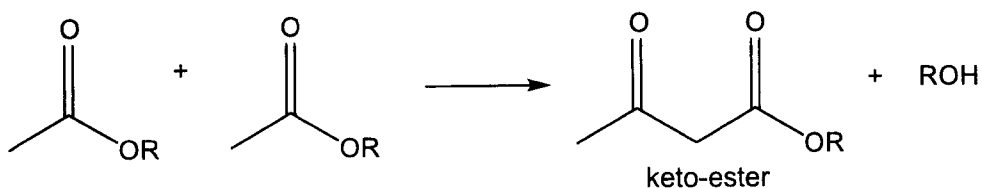
(i) The first step in Claisen condensation involves the strong base CH_3O^- removing an α-hydrogen atom (i.e. the hydrogen atom bonded to the carbon atom next to the carbonyl carbon atom) in an acid-base reaction as shown below.
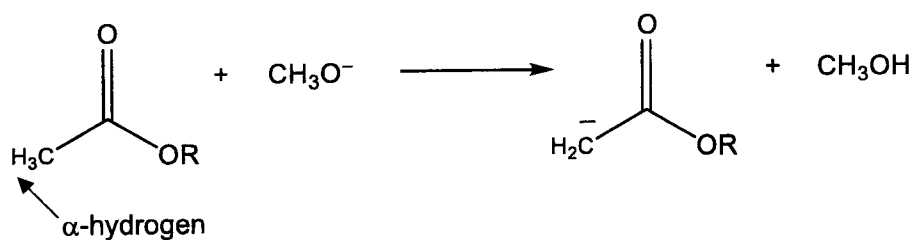
α-hydrogen

Suggest a reason why the α-hydrogen atom of the ester is acidic.

....

....[1]

(ii) With reference to the acid-base reaction mentioned in **(c)(i)**, suggest why each of the following reactions does not take place in the presence of CH_3O^-.

(1) $CH_3CH_3 \longrightarrow {}^-CH_2CH_3$

(2) $CH_3COOH \longrightarrow {}^-CH_2COOH$

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....[2]

(iii) Draw **two** possible structures of the keto-esters formed when a mixture of $CH_3CO_2CH_2CH_3$ and $CH_3CH_2CO_2CH_2CH_3$ undergo the Claisen condensation.

[2]

(iv) Draw the structure of the reactant that can be used to prepare the following compound by the Claisen condensation.
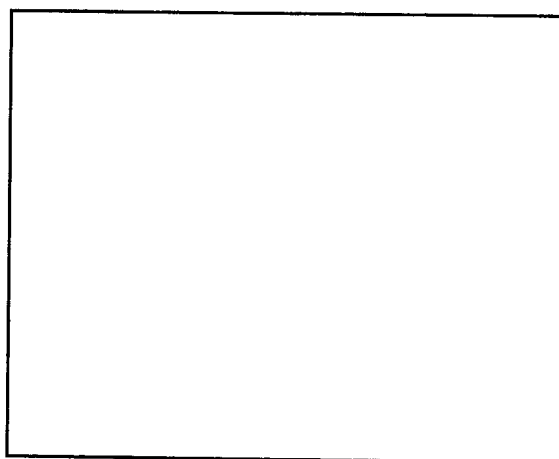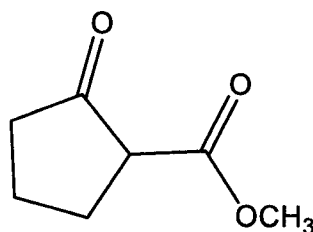
[1]

[Total: 13]

5   Hydrogen fuel cells use hydrogen gas with oxygen gas to form water and generate electricity. Two types of hydrogen fuel cells have been used to power vehicles.

Alkaline fuel cells (AFCs) use an aqueous solution of potassium hydroxide as the electrolyte. In recent years, novel AFCs that use an alkaline polymer membrane as the electrolyte have been developed. Fig. 5.1 shows the diagram of an AFC.
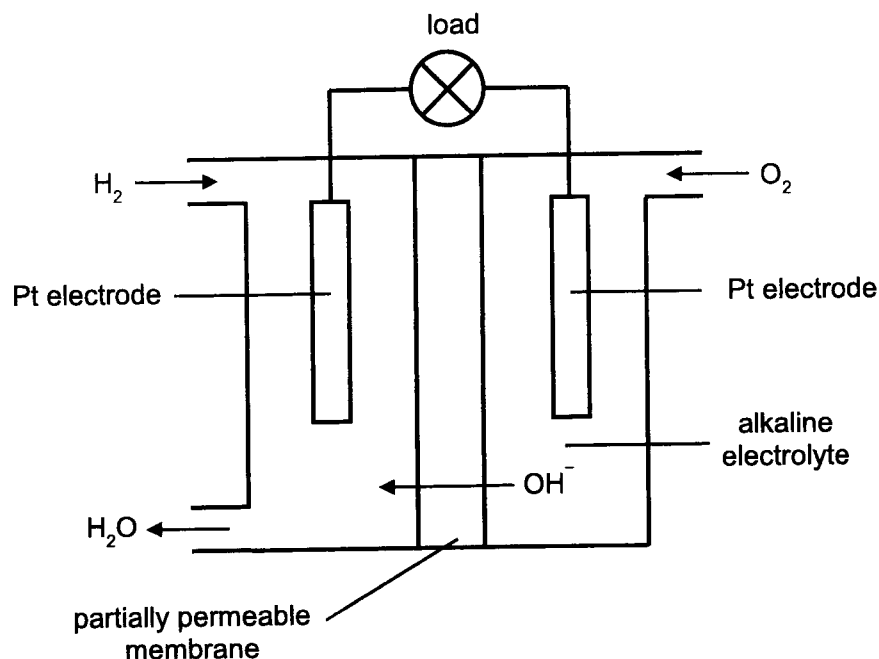
Fig. 5.1

Proton exchange membrane (PEM) fuel cells use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum or platinum alloy catalyst. It has the same overall reaction as the AFC but uses an acidic electrolyte.

(a)   (i)   On Fig. 5.1, draw the direction of electron flow.   [1]

(ii)   When adjusted for standard conditions, an AFC is known to generate 1.23 V of electromotive force. With reference to the *Data Booklet*, write the half equation for each electrode and the overall equation.

anode ....

cathode ....

overall .... [2]

(iii)   Using information from (a)(ii), calculate the Gibbs free energy change per mol of water generated in the AFC.

[1]

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(iv) Calculate the E_{cell}° of the PEM fuel cell.

[2]

(v) Comment on the voltages generated by the AFC and PEM fuel cell.

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(b) The disadvantage of transporting hydrogen gas is one of the factors limiting the use of hydrogen fuel cells. More recently, **liquid organic hydrogen carriers (LOHC)** such as the methylbenzene / methylcyclohexane system have been used to transport hydrogen safely over long distances.

At its source, hydrogen is 'loaded' on the LOHC by reacting hydrogen with methylbenzene in the presence of platinum catalyst to produce methylcyclohexane. Hydrogen is 'unloaded' from the LOHC by reacting methylcyclohexane with the catalyst to regenerate methylbenzene.

Table 5.1 contains information about hydrogen and methylcyclohexane.

Table 5.1

liquids	density under conditions for transportation / kg m^{-3}	boiling point at 1 atm / °C	flammability
hydrogen	71	−252.9	very high
methylcyclohexane	770	101	high

(i) Write a balanced equation for the loading of hydrogen on the LOHC.

.... [1]

(ii) State the **type** of catalyst used in the loading of the LOHC. Describe how it catalyses the reaction.

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.... [3]

(iii) Calculate the mass of H_2 transported per m^3 of methylcyclohexane.

[2]

(iv) Suggest whether it is advantageous for the transport of hydrogen to be changed from liquid hydrogen to the use of LOHC.

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.... [1]

(c) The hydrogen supply for fuel cells has been classified according to its impact on the environment. Green hydrogen refers to the gas that is produced using renewable energy, without greenhouse gas emissions. The electrolysis of water powered by solar, wind or geothermal energy produces green hydrogen.

(i) Currently the most common method for generating hydrogen gas involves two successive reactions:

1) steam-methane reformation
2) water-gas shift reaction

Using this method, methane reacts with steam to form four times the amount of hydrogen gas along with a side product.

Write the overall balanced equation for the above method.

.... [1]

(ii) Hence suggest whether the method in **(c)(i)** is a source of green hydrogen.

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.... [1]

(iii) Hydrogen produced by steam-methane reformation may contain trace contaminants such as ethene.

Draw a 'dot-and-cross' diagram of ethene. State the bond angle and shape around the carbon atom.

shape: ....

bond angle: .... [2]

BP~36

(d) Electric vehicles (EVs) have been known as a greener form of transportation than petrol powered vehicles because greenhouse gases are not emitted from EVs.

By considering the source of the electrical energy, comment on the validity of this claim.

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[Total: 19]

Section A

Answer **all** the questions in this section.

1 **(a)** Explain what is meant by the term *Lewis acid*. [1]

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(b) The water molecule can react in various ways: as an acid, as a base, as a nucleophile, as an oxidising agent and as a reducing agent.

Study the following reactions and decide in which way water is reacting in each case.

Explain your answers fully.

(i) $2F_2 + 2H_2O \rightarrow 4HF + O_2$ [1]

(ii) $CH_3COCl + H_2O \rightarrow CH_3COOH + HCl$ [1]

(iii) $H_2PO_4^- + H_2O \rightleftharpoons HPO_4^{2-} + H_3O^+$ [1]

(iv) $Li + H_2O \rightarrow LiOH + \frac{1}{2}H_2$ [1]

(v) $NO_2^- + H_2O \rightleftharpoons HNO_2 + OH^-$ [1]

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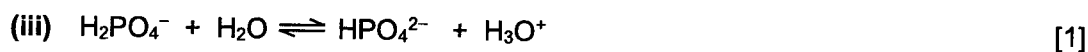
(c) The pK_a values of three acids are listed in Table 1.1.

Table 1.1

acid	formula	pK_a
1	CH_3CH_2COOH	4.9
2	$CH_3CHClCOOH$	2.8
3	CH_2ClCH_2COOH	z

(i) Explain the difference in pK_a values between acid 1 and acid 2. [2]

(ii) Suggest a value for z and explain your answer. [1]

(iii) Peroxyacids are weak acids. One way to prepare peroxypropanoic acid is to treat the corresponding carboxylic acid with hydrogen peroxide.

acid 1   peroxypropanoic acid
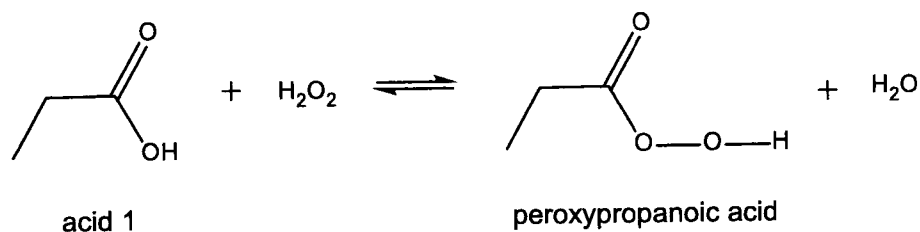
Suggest why the pK_a of peroxypropanoic acid is higher than that of acid 1. [1]

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(d) **A**, **B** and **C** are isomers with the molecular formula $C_5H_6O_2$. All three compounds decolourise bromine water in the dark.

A produces effervescence in the presence of Na_2CO_3(aq) whereas **B** and **C** do not. **A** also reacts with hot acidified $KMnO_4$ to form **D**, $C_3H_2O_5$.

B forms a brick-red precipitate when heated with Fehling's solution.

C reacts with hot aqueous sodium hydroxide. Upon acidification, it forms $C_5H_8O_3$.

$$\underset{\text{HO}}{} \diagup \diagdown \diagup \underset{\text{OH}}{\overset{\overset{\text{O}}{\|}}{C}}$$

$C_5H_8O_3$
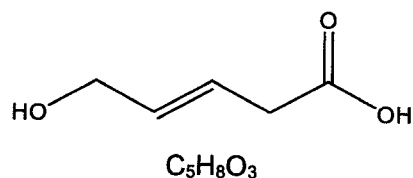
When **B** and **C** are separately reacted with hot acidified $KMnO_4$, they form the same mixture of **E**, $C_3H_4O_4$, and **F**, $C_2H_2O_4$. **F** undergoes further oxidation to give effervescence.

(i) Draw the structures of **D**, **E** and **F**. [3]

(ii) Deduce the structures of **A**, **B** and **C** with reasoning. [7]

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[Total: 20]

2 (a) The acid-base behaviour of aluminium oxide, Al_2O_3, shows similarities to that of magnesium oxide, MgO, on the one hand, and sulfur trioxide, SO_3, on the other.

Describe what these similarities are, and explain why aluminium oxide occupies this in-between position.

Write equations for all the reactions you choose to illustrate your answer.   [5]

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(b) (i) Explain what is meant by the term *standard enthalpy change of atomisation of magnesium*.
   [1]

   (ii) An experiment was carried out by adding 0.05 g of magnesium ribbon to 50 cm^3 of excess hydrochloric acid solution. The increase in temperature was 4.5 °C.

   Reaction 1 is represented by the ionic equation as shown:

   reaction 1 $Mg(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$ $\Delta H_1^\ominus$
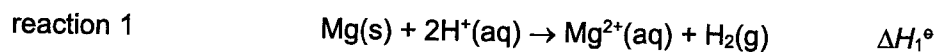
   Use data from the *Data Booklet* to calculate $\Delta H_1^\ominus$, the standard enthalpy change of reaction 1.
   [2]

(iii) Besides using an experimental method, another way to determine ΔH_1^e, the standard enthalpy change of reaction 1, is to construct an energy cycle.

Use the data in Table 2.1, together with data from the *Data Booklet*, calculate another value of ΔH_1^e. [4]

Table 2.1

	ΔH^e / kJ mol^{-1}
standard enthalpy change of atomisation of Mg(s)	+148
standard enthalpy change of hydration of Mg^{2+}(g)	−1921
standard enthalpy change of hydration of H$^+$(g)	−1090

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(c) 2,3-dichlorobutane exhibits stereoisomerism, one of which is enantiomerism. One enantiomer of 2,3-dichlorobutane is shown below.
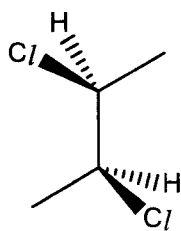
(i) Draw the other enantiomer. [1]

(ii) A molecule with n chiral centres can have a maximum of 2^n stereoisomers. 2,3-dichlorobutane has two chiral centres but it only has three stereoisomers.

Draw the third stereoisomer of 2,3-dichlorobutane and explain why it has only three stereoisomers. [2]

(iii) The structure of 1,2-dichlorocyclobutane is shown below.
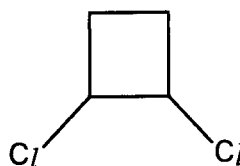
Suggest why 1,2-dichlorocyclobutane can exhibit cis–trans isomerism and draw the pair of cis–trans isomers. [2]

(iv) A cumulene is a hydrocarbon with three or more consecutive double bonds. The simplest molecule in this class is butatriene, C_4H_4.
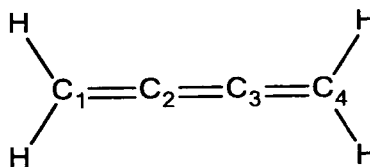
With the aid of a labelled diagram, describe the orbitals that form the $C_1=C_2$ bond in butatriene and state the type of hybridisation involved. [3]

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[Total: 20]

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[Turn over

3 (a) The Maillard reaction is an important process that occurs between sugars with amino acids during cooking. Its occurrence is responsible for the golden brown colouration and crispy texture that makes food appealing and tasty.

In 2002, it was discovered that the Maillard reaction involving asparagine, an amino acid, forms acrylamide, a known carcinogen. Reaction 1 shows the chemical equation for the formation of acrylamide.
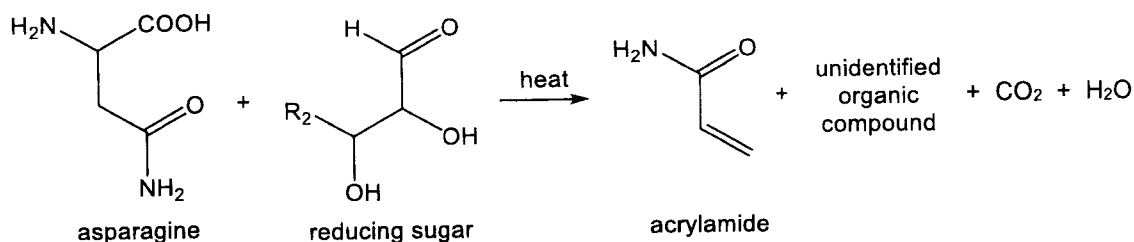
reaction 1

To determine the kinetics of reaction 1, three experiments were carried out and the results are shown in Table 3.1.

Table 3.1

experiment	concentration / mol dm^{-3}		initial rate / 10^{-3} mol dm^{-3} s^{-1}
	asparagine	reducing sugar	
1	0.100	0.500	2.46
2	0.100	0.625	3.08
3	0.200	0.750	3.69

(i) Deduce the order of reaction with respect to asparagine and the reducing sugar. Hence write the rate equation. [3]

(ii) The reducing sugar is at an initial concentration of 1.60 mol dm^{-3} and its half-life is 140 s.

Sketch a graph of the concentration of the reducing sugar against time for reaction 1. [2]

(iii) Determine the rate constant, k, for reaction 1. [1]

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(b) The reaction between the reducing sugar and aqueous sodium borohydride is a nucleophilic addition reaction.

Draw the mechanism for this reaction, assuming that sodium borohydride produces the hydride ion, :H⁻, as the reacting species. In your answer, you may represent the reducing sugar as RCHO. [3]

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(c) The following mechanism in Fig. 3.1 has been proposed for the Maillard reaction involving asparagine.
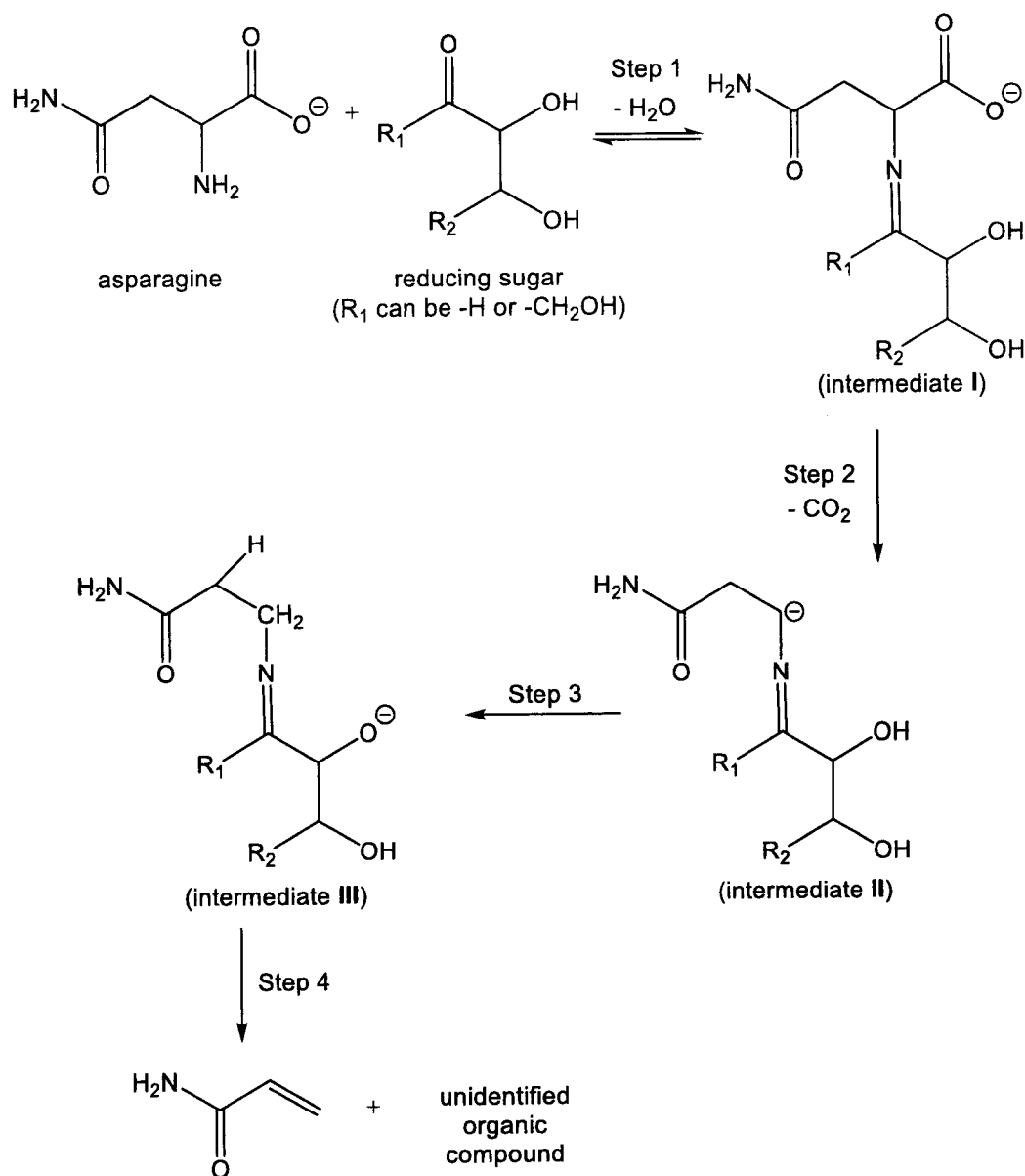
Fig. 3.1

(i) State the role of asparagine in step 1. [1]

(ii) Suggest and explain the effect on the rate of step 1 when R_1 is changed from –H to –CH$_2$OH. [1]

(iii) Draw the structure of the unidentified organic compound in step 4. [1]

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.... **[Turn over**

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(d) Compare and explain the base strength of the atoms N_a and N_b in asparagine. [2]

$$H_2N_a—CH—\overset{\overset{\displaystyle O}{\|}}{C}—OH$$

with side chain CH_2, $C=O$, N_bH_2
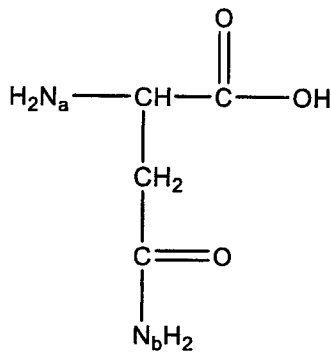
asparagine

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(e) In the 2020 Olympic Games, winners received medals made from recycled gold, silver and bronze. These metals were recycled from electronic waste collected throughout Japan. In the recycling process, metal parts are physically removed from the plastics, and the metals are sorted by elements and levels of purity.

Low purity silver is refined using electrolysis to remove metal impurities such as gold and copper.

(i) The electrode potential for Au^+/Au is given below.

$$Au^+ + e^- \rightleftharpoons Au \qquad E^\ominus = + 1.83 \text{ V}$$

Define the term *standard electrode potential of Au⁺/Au*. [1]

(ii) Describe the electrode reactions that take place during this electrolysis, and explain in detail how each of the two impurity metals is removed from silver. [3]

(iii) The electrolytic refining of silver was carried out for 90 minutes using a current of 10.2 A.

Using data from the *Data Booklet*, calculate the expected mass of silver deposited in this process. [2]

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[Total: 20]

Section B

Answer **one** question from this section.

4 (a) (i) A glass rod was heated in a Bunsen burner flame and placed into a sample of hydrogen chloride gas.

The experiment was repeated using a sample of hydrogen iodide gas.

Use data from the *Data Booklet* to explain why a colour change was observed for hydrogen iodide but not hydrogen chloride. [2]

(ii) Hydrogen chloride can be oxidised to chlorine in the presence of $CuCl$.

Likewise, hydrogen cyanide can be oxidised to cyanogen in the presence of Cu according to the following equation.

$$2HCN + \tfrac{1}{2}O_2 \rightarrow (CN)_2 + H_2O$$
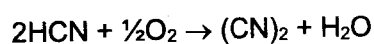
State the change in oxidation state of carbon which occurs during this reaction. [1]

(iii) Cyanogen can be converted to ethanedioic acid by heating with aqueous acid. State the type of reaction for this conversion. [1]

9729/03/Prelim/2022 **[Turn over**

To determine the solubility product, K_{sp}, of calcium ethanedioate, CaC_2O_4, at 20 °C, an excess of solid calcium ethanedioate was shaken with Solution **A** which contains 100 cm³ of 1.0×10^{-4} mol dm⁻³ sodium ethanedioate.

The resulting mixture was allowed to equilibrate at 20 °C in a water bath and then the mixture was filtered to obtain the filtrate, Solution **B**, which contains a saturated solution of calcium ethanedioate.

25.0 cm³ of Solution **B** was titrated with 5.0×10^{-5} mol dm⁻³ of acidified potassium manganate(VII). 16.60 cm³ of potassium manganate(VII) was required for complete reaction.

The reaction of ethanedioate ions and acidified potassium manganate(VII) ions is shown below.

$$2MnO_4^- + 5C_2O_4^{2-} + 16H^+ \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$$
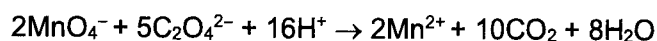
(b) (i) The reaction between ethanedioate ions and acidified potassium manganate(VII) ions has a high activation energy, hence solution **B** was heated to 60 °C before titration.

Explain why the reaction has a high activation energy. [1]

(ii) Calculate the amount of ethanedioate ions in 25.0 cm³ of Solution **B**. [2]

(iii) Calculate the amount of ethanedioate ions in 25.0 cm³ of Solution **A**. [1]

(iv) Calculate the amount of ethanedioate ions which was precipitated out as calcium ethanedioate. [1]

(v) Write an expression for the solubility product, K_{sp}, of calcium ethanedioate and calculate its value at 20 °C, stating the units clearly in your answer. [3]

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9729/03/Prelim/2022 **[Turn over**

(c) When a precipitate of calcium ethanedioate is formed, $\Delta G^{\ominus}_{ppt}$ in J mol^{-1}, is given by the following expression.

$$\Delta G^{\ominus}_{ppt} = RT \ln K_{sp}$$

(i) Given that the K_{sp} value of calcium ethanedioate at 25 °C is 2.70×10^{-9} mol^2 dm^{-6}, calculate the $\Delta G^{\ominus}_{ppt}$ of calcium ethanedioate. [1]

(ii) The standard entropy change of the precipitation of calcium ethanedioate, $\Delta S^{\ominus}_{ppt}$, is +93.2 J mol^{-1} K^{-1}.

Calculate the standard enthalpy change of precipitation of calcium ethanedioate, $\Delta H^{\ominus}_{ppt}$. [1]

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(d) The precipitation of calcium ethanedioate is one of the reasons for the formation of kidney stones.

Given that the stomach has a pH of about 2.0 while the kidney has a pH of about 6.5, explain why stones are not formed in the stomach but stones can be formed in the kidney. [2]

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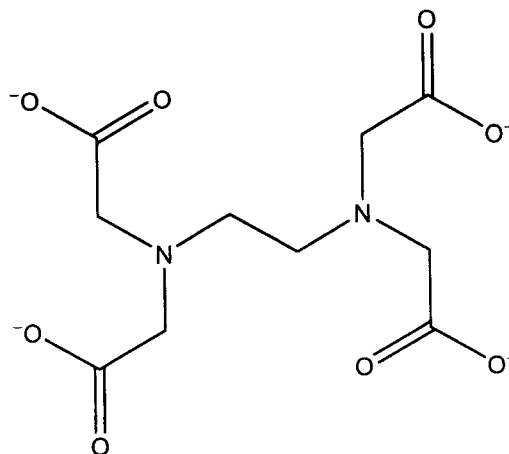..

(e) Ethylenediaminetetraacetate, also known as EDTA has the structure shown below.

Suggest a reason why EDTA can be used as a treatment for kidney stones. [2]

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(f) Calcium ethanedioate decomposes at a temperature of 400 °C according to the equation shown below.

$$CaC_2O_4(s) \rightarrow CaO(s) + CO_2(g) + CO(g)$$
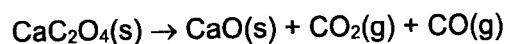
Explain why magnesium ethanedioate decomposes at a lower temperature than calcium ethanedioate. [2]

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[Total: 20]

5 (a) The equilibrium constant, K_p, of the following reaction is 1.64 at a certain temperature.
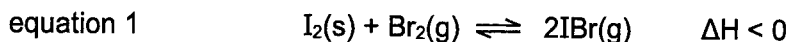
equation 1 $\qquad I_2(s) + Br_2(g) \rightleftharpoons 2IBr(g) \qquad \Delta H < 0$

In a study, some bromine gas was introduced into a vessel with excess solid iodine at the same temperature and the reaction was allowed to take place until equilibrium was reached. The partial pressure of IBr(g) at equilibrium was found to be 0.80 atm. Assume that all the bromine is in the gaseous state and that the vapour pressure of iodine is negligible.

(i) State the K_p expression for equation 1.

Hence, calculate the partial pressure of Br_2 at equilibrium. [2]

(ii) Hence calculate the initial pressure of Br_2 in the container. [1]

(iii) Sketch a graph of rate against time, showing how the rates of the forward and reverse reactions change with time, from the point of mixing to the point after equilibrium is established. Label your graphs clearly. [2]

(iv) State and explain the effect on the rate of production and yield of IBr when temperature is decreased. [3]

(v) State and explain the effect on the equilibrium partial pressure of Br_2 when the pressure of the system is halved at constant temperature. [2]

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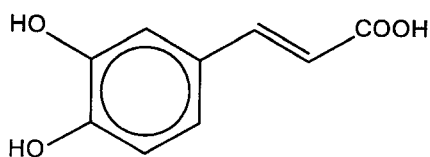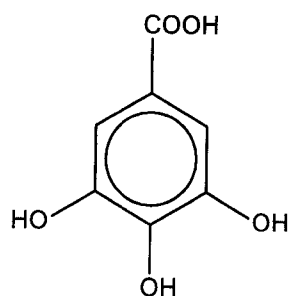..

(b) Caffeic acid and gallic acid are organic compounds that can be found in coffee and tea leaves respectively.

caffeic acid

gallic acid

(i) Describe a chemical test to distinguish between the above two compounds and state the expected observations. [2]

(ii) Draw the structure of the major product that is formed when caffeic acid reacts with HBr. [1]

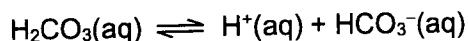...

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(c) Buffer solutions are very important in many biological reactions as enzymes need a specific pH range to function properly. One of the most important buffer systems is carbonic acid, H_2CO_3, and bicarbonate, HCO_3^-, buffer system in blood.

$$H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$$

The above equilibrium has a K_a value of 7.90×10^{-7} mol dm^{-3} and is responsible for buffering the pH of the blood at 7.4.

(i) A blood buffer can be simulated by mixing 0.500 mol dm^{-3} H_2CO_3 and 2.00 mol dm^{-3} of $NaHCO_3$.

Show that the volumes of H_2CO_3 and $NaHCO_3$ required to make 200 cm^3 of this buffer solution with pH 7.4 are 34 cm^3 and 166 cm^3 respectively [3]

(ii) With the aid of an equation, explain how the buffer solution prepared in c(i) helps to maintain the pH at around 7.4 when a small amount of sodium hydroxide is added. [2]

(iii) Hence calculate the resultant pH of the above buffer solution when 0.003 mol of solid sodium hydroxide is added. [2]

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[Total: 20]

Additional answer space

If you use the following pages to complete the answer to any question, the question number must be clearly shown.

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3

Answer **all** the questions in the spaces provided.

1 **Identification of an unknown organic acid by titration**

In this experiment, you will perform titrations to determine the relative molecular mass, M_r, of an unknown monoprotic organic acid, **FA 1,** and use it to identify the acid.

FA 1 is an aqueous solution containing 4.80 g dm^{-3} of an unknown monoprotic organic acid.

You are also provided with:
FA 2 is 0.110 mol dm^{-3} sodium hydroxide, NaOH.
thymol blue indicator

Prepare a table in the space provided below to record, to an appropriate level of precision, all your burette readings.

(a) Titration of FA 1 with FA 2

1. Fill the burette with **FA 2**.
2. Pipette 25.0 cm^3 of **FA 1** into a conical flask.
3. Add 3 to 4 drops of thymol blue indicator into the flask. The solution in the flask should turn pink.
4. Titrate **FA 1** in the conical flask with **FA 2**. The end-point is reached when the solution changes from yellow to green.
5. Record your burette readings in your table.
6. Repeat steps 2 to 5 until consistent results are obtained.

Titration Results

[5]

From your titrations, obtain a suitable volume of **FA 2**, to be used in your calculations. Show clearly how you obtained this volume.

volume of **FA 2** = ... [1]

4

(b) **(i)** Calculate the amount of sodium hydroxide present in the volume of **FA 2** that you calculated in **(a)**.

amount of NaOH reacted = ... [1]

(ii) Calculate the concentration of organic acid present, in mol dm^{-3}, in **FA 1**.

.

concentration of organic acid in **FA 1** = ... [1]

(iii) Calculate the relative molecular mass, M_r, of the organic acid in **FA 1**.

M_r of the organic acid = ... [1]

5

(iv) From another experiment, the identity of **FA 1** was narrowed down to these four acids.

CH_3COOH $HCOOH$ $CH_2=CHCO_2H$ $CH_3CH_2CO_2H$
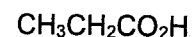
Given that sodium hydroxide reacts only with the COOH group in the organic acid, deduce the identity of the organic acid present in **FA 1**. Explain your answer.

[A_r: H, 1.0; C, 12.0; O, 16.0; Cl, 35.5]

....

.... [1]

(c) This identification method uses the calculated relative molecular mass of the acid.

As the relative molecular masses of $CH_2=CHCO_2H$ and $CH_3CH_2CO_2H$ are so similar, any slight inaccuracy in the titration could lead to an incorrect conclusion.

Describe a chemical test that would enable you to distinguish between $CH_2=CHCO_2H$ and $CH_3CH_2CO_2H$.

There is **no need** to carry out this test.

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.... [2]

(d) Another student was provided a solution of another unknown organic acid. It has the same concentration, in mol dm^{-3}, as that used in the titration above. However, this new unknown organic acid is a diprotic acid.

State and explain how the calculated relative molecular mass obtained will differ from that obtained in **b(iii)**.

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.... [2]

[Total: 14]

6

2 Determination of the concentration of NaOH and the enthalpy change of neutralisation, ΔH_{neut}

You are provided with the following solutions:

FA 3 is a solution of sodium hydroxide, NaOH

FA 4 is a solution of 2.00 mol dm^{-3} hydrochloric acid, HC*l*

In this question, you are to perform a series of 6 experiments where different volumes of **FA 3** and **FA 4** are mixed together to give a total volume of 50 cm^3. The temperature change, ΔT, for each experiment will be determined and a graph of ΔT against the volume of **FA 3** will be plotted.

You will then use the data from your graph to determine the concentration of NaOH in **FA 3**, and the enthalpy change of neutralisation for the reaction between aqueous sodium hydroxide and hydrochloric acid.

$$NaOH + HCl \rightarrow NaCl + H_2O \qquad \Delta H_{neut}$$
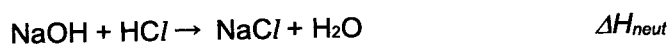
(a) Procedure

Experiment 1

1) Place one polystyrene cup inside a second polystyrene cup. Place these into a 250 cm^3 beaker to prevent them from tipping over.

2) Use a 50 cm^3 measuring cylinder to transfer 10.0 cm^3 of **FA 3** into the polystyrene cup.

3) Measure the temperature of **FA 3** in the polystyrene cup and record the initial temperature of **FA 3**, T_1, in Table 2.1 on page 7.

4) Use another 50 cm^3 measuring cylinder, transfer 40.0 cm^3 of **FA 4** into the same polystyrene cup.

5) Stir the mixture in the polystyrene cup with the thermometer. Measure and record the highest temperature, T_2 in Table 2.1 on page 7.

6) Rinse the polystyrene cup and thermometer with distilled water and dry them with paper towels.

7) Repeat steps **2** to **6** using 20.0 cm^3, 30.0 cm^3 and 40.0 cm^3 of **FA 3**, each time using appropriate volume of **FA 4**, such that the total volume of the reaction mixture is 50 cm^3.

8) Record all measurements of volume, temperature (T_1 and T_2) and temperature change, ΔT, in Table 2.1 on page 7.

7

(b) Results

Table 2.1

	experiment					
	1	**2**	**3**	**4**	**5**	**6**
volume of **FA 3** / cm^3	10.0	20.0	30.0	40.0		
volume of **FA 4** / cm^3	40.0					
initial temperature, T_1/ °C						
final temperature, T_2/ °C						
temperature change, ΔT/ °C						

[3]

(c) **(i)** Plot a graph of ΔT (y–axis) against volume of **FA 3** used (x–axis) using the four experimental results that you have obtained.

The scales for both axes must be chosen to provide an origin.

8
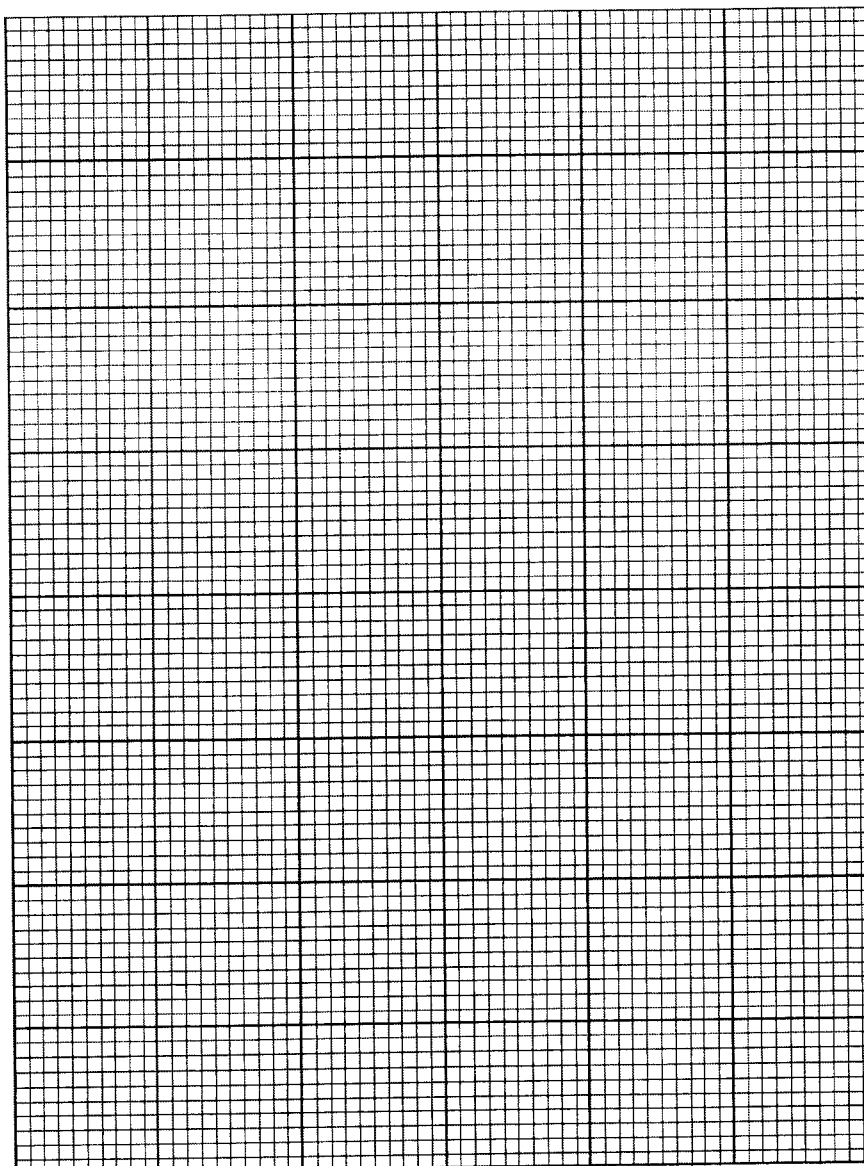
By considering your plotted points, perform two additional experiments to identify the volume of **FA 3** needed to produce the maximum temperature change, ΔT_{max}.

In each experiment, ensure that the total volume of the reaction mixture is 50 cm³. You may find it helpful to plot the results from each experiment before choosing the volumes to use in the next experiment.

Record all measurements of volume, temperature (T_1 and T_2) and temperature change, ΔT, in Table 2.1 on page 7.   [2]

(ii) Draw two straight lines of best fit. The first best fit line should be drawn using the plotted points where ΔT is increasing and the second best fit line should be drawn using the plotted points where ΔT is decreasing. Extrapolate these two lines until they cross.   [1]

9

(d) **(i)** Use your graph to determine the maximum temperature change, ΔT_{max}, as well as the volume of **FA 3**, V_{FA3}, used to obtain it.

ΔT_{max} = ... °C

V_{FA3} = ... cm³ [1]

(ii) Using your results in **(d)(i)**, calculate the concentration of NaOH in **FA 3**.

concentration of NaOH in **FA 3** = ... [2]

(iii) Hence, calculate the enthalpy change of neutralisation, ΔH_{neut}.

You may assume that the specific heat capacity of the reaction mixture is 4.18 J g⁻¹ K⁻¹, and that the density of the reaction mixture is 1.00 g cm⁻³.

ΔH_{neut} = ... [2]

10

(e) Predict and explain the following:

(i) the effect on ΔT_{max} when the volumes of **FA 3** and **FA 4** used in the reaction are doubled.

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.... [1]

(ii) the effect on ΔH_{neut} if the experiment was repeated with ethanoic acid, CH_3CO_2H, of the same concentration instead of hydrochloric acid.

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.... [1]

(f) State one significant source of error in the experiment and suggest an improvement that can be made to reduce this error.

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.... [1]

[Total: 14]

3 Inorganic Analysis

FA 5 is a solution which contains up to two cations and one anion.

Carry out the following tests and carefully record your observations in Table 3.1.

Using the observations in Table 3.1, you will then identify the ions present in **FA 5**.

Unless otherwise stated, the volumes given below are approximate and should be estimated rather than measured. Test and identify any gases evolved.

Table 3.1

		test	observations
(a)	**(i)**	Place one drop of **FA 5** solution on Universal Indicator paper.	
	(ii)	Add about 1 cm³ of dilute nitric acid to 1 cm depth of **FA 5** solution. Add barium nitrate dropwise until no further change is seen.	
	(iii)	Add sodium hydroxide to 1 cm depth of **FA 5** solution until no further change is seen. Gently warm the mixture.	

(iv)	Add aqueous ammonia to 1 cm depth of **FA 5** until no further change is seen.	
(v)	Add I⁻(aq) to 1 cm depth of **FA 5** solution until no further change is seen. Leave the mixture to stand.	

[5]

(b) **(i)** Identify the cation(s) and anion present in **FA 5**.

cation(s) in **FA 5** ....

anion in **FA 5**.. [3]

(ii) Write an equation to explain the observation in test **(a)(i)**.

.... [1]
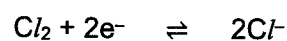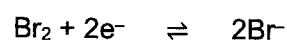
[Total: 9]

4 Determination of oxidising strength of oxidising agents

You are provided with samples of the following four aqueous solutions.

solution that contains bromide ions, Br^-
solution that contains iron(III) ions, Fe^{3+}
solution that contains aqueous iodine, I_2
solution that contains iodide ions, I^-

Carry out the tests in Table 4.1 to investigate possible redox reactions and rank the oxidising strength of the oxidising agents Br_2, Cl_2, Fe^{3+} and I_2.

$$Br_2 + 2e^- \rightleftharpoons 2Br^-$$
$$Cl_2 + 2e^- \rightleftharpoons 2Cl^-$$
$$Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$$
$$I_2 + 2e^- \rightleftharpoons 2I^-$$
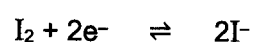
Your answers should correspond to the given observations/equations/deductions. The results of the first test have been given to you and you should use it as an example.

14

Table 4.1

		test	observations	deductions
(a)	**(i)**	Transfer 1 cm^3 of Br$^-$ to a test-tube. Add 1 cm^3 of Cl_2.	Solution turns yellow.	Cl_2 oxidises Br$^-$ to Br$_2$ $Cl_2 > Br_2$
	(ii)	Transfer 1 cm^3 of Fe^{3+} to a test-tube. Add 1 cm^3 of Br$^-$. Add aqueous NaOH dropwise until in excess.		
	(iii)	Transfer 1 cm^3 of Fe^{3+} to a test-tube. Add 1 cm^3 of I$^-$ then add 5 drops of starch solution.		
	(iv)	Transfer 1 cm^3 of I$_2$ to a test-tube. Add 1 cm^3 of Br$^-$ then add 5 drops of starch solution.		

[4]

[Turn over

(b) Use your information in Table 4.1 to rank the order of oxidising strengths of the species: Br_2, Cl_2, Fe^{3+}, I_2.

Note: In some of the tests performed in part **(a)** there will have been no reaction. Such tests can still help you to deduce the relative oxidising powers of the species involved.

.... [1]

(c) Using your observations, explain why aqueous FeI_3 cannot be prepared.

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.... [1]

[Total: 6]

16

5 Planning

When a solute is added to two immiscible solvents, **A** and **B**, some of the solute dissolves in each of the solvents and an equilibrium is set up between the two solvents. It has been shown that for dilute solutions, at equilibrium, the ratio of the two concentrations is a constant known as the partition coefficient, $K_{partition}$.

Trichloromethane, $CHCl_3$, and water separate into two immiscible layers when shaken together and allowed to stand. Ammonia can dissolve in both of these layers. The $K_{partition}$ for ammonia in these two solvents is given by:

$$K_{partition} = \frac{[NH_3]_{water}}{[NH_3]_{trichloromethane}}$$

50 cm^3 of trichloromethane and 50 cm^3 of aqueous ammonia are mixed and left to equilibrate for about an hour. Samples of the aqueous layer are obtained and the amount of ammonia present in the aqueous layer is determined by titration. The concentration of ammonia in the separate layers can be calculated and the value of $K_{partition}$ can then be determined.

(a) Explain why ammonia is likely to be more soluble in water than in trichloromethane.

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....[1]

(b) You are to plan a procedure that will allow you to obtain the titration results necessary to determine value of $K_{partition}$ of ammonia between water and trichloromethane at room temperature.

You are provided with the following
- trichloromethane, $CHCl_3$,
- 1.00 mol dm^{-3} aqueous ammonia,
- $0.500 \text{ mol dm}^{-3}$ hydrochloric acid,
- methyl orange indicator,
- 250 cm^3 conical flask with stopper,
- 10.0 cm^3 pipette,
- the laboratory apparatus normally found in a school.

In your plan you should include the following:
- an outline of how you would prepare the equilibrium mixture,
- practical details of how you would carry out the titration,
- appropriate apparatus and their capacities.

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....[7]

(c) It is unnecessary to titrate both layers of the partition. Explain why the titration is carried out on a sample of the aqueous layer rather than the trichloromethane layer.

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....[1]

18

(d) A student carried out the experiment and obtained a mean titre of 19.20 cm³.

    (i)   Using this mean titre value, calculate the equilibrium amounts of ammonia
            1. in the aqueous layer
            2. in the trichloromethane layer

amount of ammonia in the aqueous layer = ...[1]

amount of ammonia in the trichloromethane layer = ...[1]

    (ii)   Hence calculate the value of the partition coefficient, $K_{partition}$.

partition coefficient, $K_{partition}$ = ...[1]

[Total: 12]

Qualitative Analysis Notes
[ppt. = precipitate]

(a) Reactions of aqueous cations

cation	reaction with	
	NaOH(aq)	NH_3(aq)
aluminium, Al^{3+}(aq)	white ppt. soluble in excess	white ppt. insoluble in excess
ammonium, NH_4^+(aq)	ammonia produced on heating	–
barium, Ba^{2+}(aq)	no ppt. (if reagents are pure)	no ppt.
calcium, Ca^{2+}(aq)	white. ppt. with high $[Ca^{2+}$(aq)$]$	no ppt.
chromium(III), Cr^{3+}(aq)	grey-green ppt. soluble in excess giving dark green solution	grey-green ppt. insoluble in excess
copper(II), Cu^{2+}(aq)	pale blue ppt. insoluble in excess	blue ppt. soluble in excess giving dark blue solution
iron(II), Fe^{2+}(aq)	green ppt. turning brown on contact with air insoluble in excess	green ppt. turning brown on contact with air insoluble in excess
iron(III), Fe^{3+}(aq)	red-brown ppt. insoluble in excess	red-brown ppt. insoluble in excess
magnesium, Mg^{2+}(aq)	white ppt. insoluble in excess	white ppt. insoluble in excess
manganese(II), Mn^{2+}(aq)	off-white ppt. rapidly turning brown on contact with air insoluble in excess	off-white ppt. rapidly turning brown on contact with air insoluble in excess
zinc, Zn^{2+}(aq)	white ppt. soluble in excess	white ppt. soluble in excess

(b) Reactions of anions

anion	reaction
carbonate, CO_3^{2-}	CO_2 liberated by dilute acids
chloride, Cl^- (aq)	gives white ppt. with Ag^+(aq) (soluble in NH_3(aq))
bromide, Br^- (aq)	gives pale cream ppt. with Ag^+(aq) (partially soluble in NH_3(aq))
iodide, I^- (aq)	gives yellow ppt. with Ag^+(aq) (insoluble in NH_3(aq))
nitrate, NO_3^- (aq)	NH_3 liberated on heating with OH^-(aq) and Al foil
nitrite, NO_2^- (aq)	NH_3 liberated on heating with OH^-(aq) and Al foil; NO liberated by dilute acids (colourless NO → (pale) brown NO_2 in air)
sulfate, SO_4^{2-} (aq)	gives white ppt. with Ba^{2+}(aq) (insoluble in excess dilute strong acids)
sulfite, SO_3^{2-} (aq)	SO_2 liberated on warming with dilute acids; gives white ppt. with Ba^{2+}(aq) (soluble in dilute strong acids)

(c) Tests for gases

gas	test and test result
ammonia, NH_3	turns damp red litmus paper blue
carbon dioxide, CO_2	gives a white ppt. with limewater (ppt. dissolves with excess CO_2)
chlorine, Cl_2	bleaches damp litmus paper
hydrogen, H_2	"pops" with a lighted splint
oxygen, O_2	relights a glowing splint
sulfur dioxide, SO_2	turns aqueous acidified potassium manganate(VII) from purple to colourless

(d) Colour of halogens

halogen	colour of element	colour in aqueous solution	colour in hexane
chlorine, Cl_2	greenish yellow gas	pale yellow	pale yellow
bromine, Br_2	reddish brown gas / liquid	orange	orange-red
iodine, I_2	black solid / purple gas	brown	purple

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