



CANDIDATE
NAME

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9701/41

October/November 2023

2 hours

You must answer on the question paper.

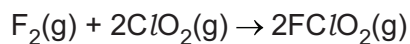
No additional materials are needed.

- 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.

- 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.

- 1 Fluorine reacts with chlorine dioxide, ClO_2 , as shown.



The rate of the reaction is first order with respect to the concentration of F_2 and first order with respect to the concentration of ClO_2 . No catalyst is involved.

- (a) (i) Suggest a two-step mechanism for this reaction.

step 1 $\rightarrow$

step 2 $\rightarrow$

[2]

- (ii) Identify the rate-determining step in this mechanism. Explain your answer.

.....

..... [1]

- (b) When the rate of the reaction is measured in $\text{mol dm}^{-3} \text{s}^{-1}$ the numerical value of the rate constant, k , is 1.22 under certain conditions.

- (i) Complete the rate equation for this reaction, stating the overall order of the reaction.

rate =

overall order of reaction =

[1]

- (ii) Use your rate equation in (i) to calculate the rate of the reaction when the concentrations of F_2 and ClO_2 are both $2.00 \times 10^{-3} \text{ mol dm}^{-3}$.

rate = ... $\text{mol dm}^{-3} \text{s}^{-1}$ [1]

- (c) Under different conditions, and in the presence of a large excess of ClO_2 , the rate equation is as shown.

$$\text{rate} = k_1[\text{F}_2]$$

The half-life, $t_{1/2}$, of the concentration of F_2 is 4.00 s under these conditions.

- (i) Calculate the numerical value of k_1 , giving its units.

Give your answer to **three** significant figures.

$$k_1 = \dots\dots\dots \text{units} \dots\dots\dots [2]$$

- (ii) An experiment is performed under these conditions in which the starting concentration of F_2 is $0.00200 \text{ mol dm}^{-3}$.

Draw a graph on the grid in Fig. 1.1 to show how the concentration of F_2 changes over the first 12 s of the reaction.

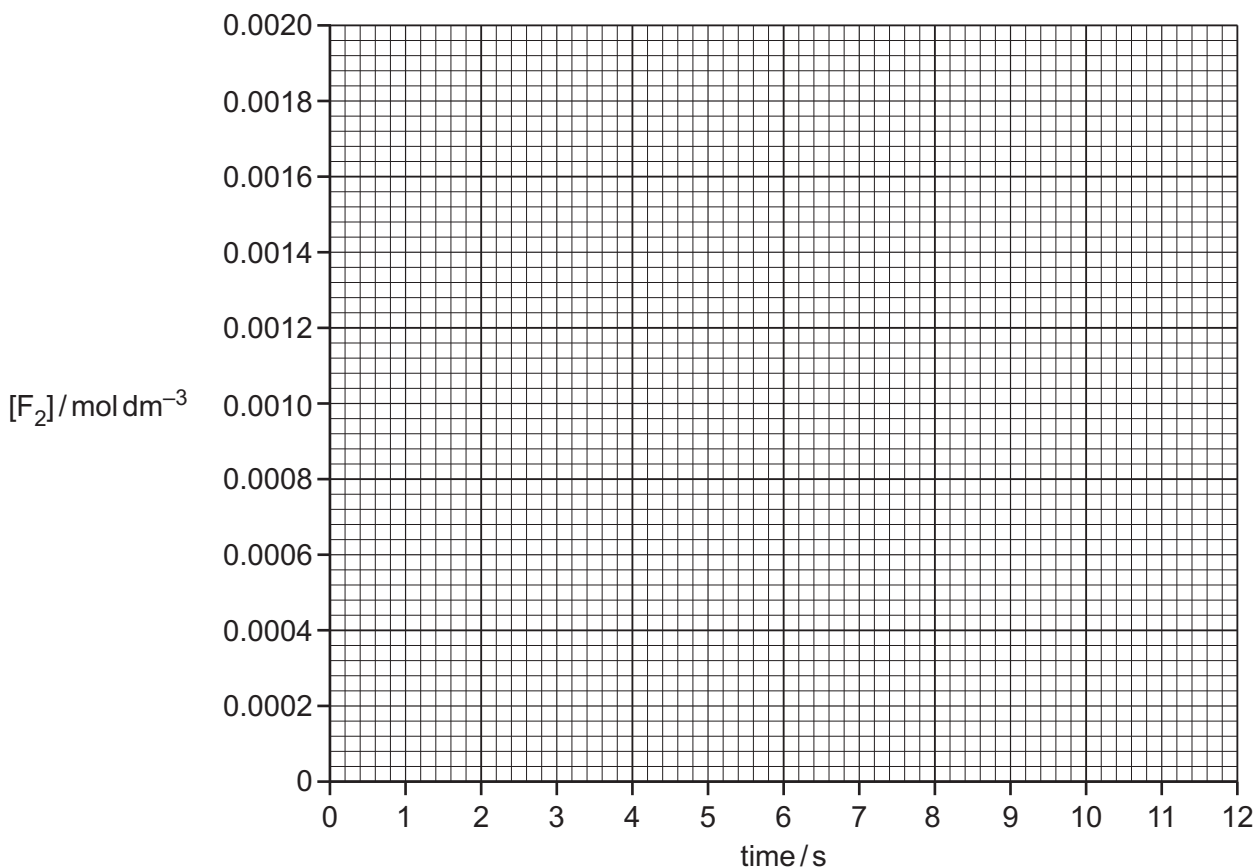


Fig. 1.1

[1]

- (iii) Use your graph in Fig. 1.1 to find the rate of the reaction when the concentration of F_2 is $0.00100 \text{ mol dm}^{-3}$. Show your working on the graph.

$$\text{rate} = \dots\dots\dots \text{mol dm}^{-3} \text{s}^{-1} [1]$$

[Total: 9]

- 2 (a) Define K_w mathematically by completing the expression.

$K_w =$ [1]

- (b) Two solutions, **V** and **W**, are described.

- **V** is $\text{HCl}(\text{aq})$.
- **W** is $\text{NaOH}(\text{aq})$.
- The concentration of HCl in **V** is the same as the concentration of NaOH in **W**.
- The pH values of **V** and **W** differ by exactly 11.00 at 298 K.

- (i) Calculate the concentration of HCl in **V**.

concentration of HCl in **V** = ... mol dm^{-3} [2]

- (ii) Equal volumes of the two solutions **V** and **W** are mixed, giving solution **X**.

Name solution **X** and state its pH.

solution **X** pH [1]

- (iii) A 1 cm^3 sample of 1.0 mol dm^{-3} HNO_3 is added to 100 cm^3 of solution **X**, forming mixture **Y**.

A 1 cm^3 sample of 1.0 mol dm^{-3} KOH is added to 100 cm^3 of solution **X**, forming mixture **Z**.

Estimate the pH of mixtures **Y** and **Z**. No calculations are required.

mixture **Y** mixture **Z** [1]

- (c) (i) $\text{CH}_3\text{CH}_2\text{COOH}$, $\text{CH}_3\text{CCl}_2\text{COOH}$ and H_2SO_4 are all acidic.

Suggest the trend in the relative acid strength of these three compounds.

Explain your answer.

.....
strongest acid weakest acid

explanation

.....
.....
.....
.....

[3]

- (ii) When concentrated H_2SO_4 is added to water a series of acid-base reactions occurs. There are three conjugate acid-base pairs that can be identified during this series of reactions. Write the formulae of these three conjugate acid-base pairs.

conjugate acid 1 conjugate base 1
 conjugate acid 2 conjugate base 2
 conjugate acid 3 conjugate base 3 [2]

- (d) The partition coefficient, K_{pc} , of a substance, **Q**, between hexane and water is 7.84 at 298 K.

Q is more soluble in hexane than it is in water.

- (i) Define partition coefficient, K_{pc} .

.....
 [1]

- (ii) 5.00 g of **Q** is shaken with a mixture of 100.0 cm^3 of water and 100.0 cm^3 of hexane at 298 K and left until there is no further change in concentrations.

Calculate the mass of **Q** dissolved in the water.

mass of **Q** = ... g [1]

- (iii) A sample of **Q** is shaken with a different mixture of water and hexane and left until there is no further change in concentrations.

It is found that the mass of **Q** dissolved in each solvent is the same.

Use the K_{pc} value to suggest possible values for the volume of water used and the volume of hexane used.

volume of water = ... cm^3

volume of hexane = ... cm^3
 [1]

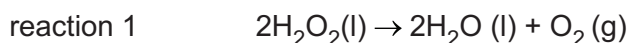
- (iv) **Q** is more soluble in hexane than it is in water.

It is suggested that **Q** is one of KCl , $\text{CH}_3(\text{CH}_2)_4\text{OH}$ or HCOOH .

Identify **Q**. Explain your answer.

.....
 [1]

- 3 Hydrogen peroxide is a liquid at 298K. It is moderately stable under room conditions but will decompose quickly if a catalyst is added.



- (a) (i) Define entropy.

.....
 [1]

- (ii) Predict the sign of the standard entropy change of reaction 1.

Explain your answer.

sign

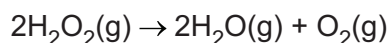
explanation
 [1]

- (b) Some bond energy data are shown in Table 3.1.

Table 3.1

type of bond	bond energy / kJ mol^{-1}
O–O	150
O–H	460
O=O	496

Use the data in Table 3.1 to show that the enthalpy change of the following reaction is -196 kJ mol^{-1} .



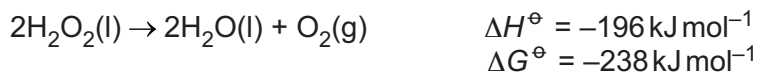
[1]

- (c) Some standard entropies, $S^\ominus$, are shown in Table 3.2.

Table 3.2

substance	$S^\ominus / \text{JK}^{-1} \text{mol}^{-1}$
$\text{H}_2\text{O}_2(\text{l})$	+102
$\text{H}_2\text{O}(\text{l})$	+70

The enthalpy change and Gibbs free energy change for the following reaction are shown.



Use the data given to calculate the standard entropy of oxygen, $S^\ominus$, $\text{O}_2(\text{g})$.

$$S^\ominus, \text{O}_2(\text{g}) = \dots\dots\dots \text{JK}^{-1} \text{mol}^{-1} \quad [3]$$

- (d) The decomposition of $\text{H}_2\text{O}_2(\text{aq})$ is catalysed by aqueous iron(III) chloride and by silver metal.

Identify which of these two catalysts is acting as a homogeneous catalyst.

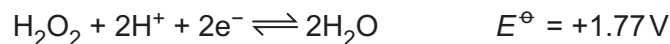
Explain your answer.

homogeneous catalyst

explanation

[1]

(e) The $E^\ominus$ values for two electrode reactions are given.



(i) An electrochemical cell is constructed with the following half-cells (electrodes):

- an acidified solution of H_2O_2 , a platinum wire
- Cr^{2+} mixed with Cr^{3+} , a platinum wire.

Identify the positive half-cell and calculate the standard cell potential, $E_{\text{cell}}^\ominus$.

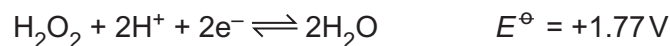
positive half-cell $E_{\text{cell}}^\ominus = \dots\dots\dots \text{ V}$

[1]

(ii) Calculate the value of $\Delta G^\ominus$ for the cell reaction that occurs, per mole of H_2O_2 .

$\Delta G^\ominus = \dots\dots\dots \text{ kJ mol}^{-1}$ [2]

(f) The $E^\ominus$ values for two electrode reactions are given.



An electrochemical cell is constructed with the following half-cells.

half-cell 1 an acidified solution of H_2O_2 under standard conditions, a platinum wire

half-cell 2 a solution containing $0.020 \text{ mol dm}^{-3} \text{ Co}^{3+}$ and $2.0 \text{ mol dm}^{-3} \text{ Co}^{2+}$, a platinum wire

(i) Use the Nernst equation to calculate the value of E , the electrode potential of half-cell 2 under these conditions.

$E = \dots\dots\dots \text{ V}$ [2]

(ii) Write an equation for the cell reaction that occurs in this cell under these conditions.

..... [1]

(g) (i) Define enthalpy change of hydration, ΔH_{hyd} .

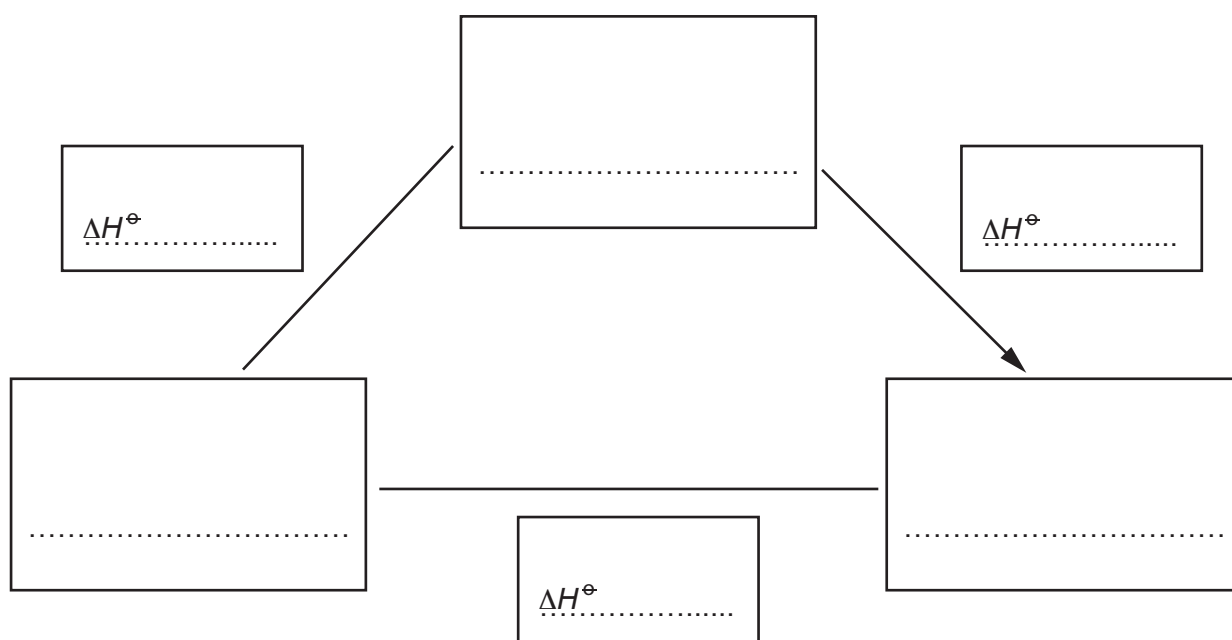
.....
 [1]

(ii) Aluminium fluoride, AlF_3 , is an ionic solid.

Complete and label the energy cycle to show the relationship between:

- the enthalpy change of solution of AlF_3 , $\Delta H_{\text{sol}}^\ominus$
- the lattice energy of AlF_3 , $\Delta H_{\text{latt}}^\ominus$
- the enthalpy changes of hydration of Al^{3+} and F^- , $\Delta H_{\text{hyd}}^\ominus$.

Include state symbols for all substances and ions.



[2]

(iii) Relevant data for this question are given.

$$\Delta H_{\text{sol}}^\ominus \text{AlF}_3 = -209 \text{ kJ mol}^{-1}$$

$$\Delta H_{\text{hyd}}^\ominus \text{Al}^{3+} = -4690 \text{ kJ mol}^{-1}$$

$$\Delta H_{\text{hyd}}^\ominus \text{F}^- = -506 \text{ kJ mol}^{-1}$$

Use these data and your energy cycle in (g)(ii) to calculate the $\Delta H_{\text{latt}}^\ominus$ of AlF_3 .

$$\Delta H_{\text{latt}}^\ominus \text{ of } \text{AlF}_3 = \text{..... kJ mol}^{-1} \quad [1]$$

[Total: 17]

- 4 (a) Cobalt(II) nitrate, $\text{Co}(\text{NO}_3)_2$, is a reddish-brown crystalline solid. It dissolves in water to form a solution containing $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ complex ions.

- (i) Complete Table 4.1 giving the formula of the cobalt-containing species that is formed in each of the three reactions described.

Table 4.1

reaction	reagent added to $[\text{Co}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$	cobalt-containing species formed
1	$\text{NaOH}(\text{aq})$	
2	an excess of $\text{NH}_3(\text{aq})$	
3	an excess of conc. $\text{HCl}(\text{aq})$	

[2]

- (ii) Describe the colour change seen in reaction 3.

original colour of $[\text{Co}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$

final colour after addition of an excess of conc. $\text{HCl}(\text{aq})$

[1]

- (b) Calcium nitrate, $\text{Ca}(\text{NO}_3)_2$, is a white crystalline solid. When heated, it starts to decompose at approximately 500°C .

- (i) Write an equation for the decomposition of $\text{Ca}(\text{NO}_3)_2$.

..... [1]

- (ii) Suggest temperatures at which $\text{Mg}(\text{NO}_3)_2$ and $\text{Ba}(\text{NO}_3)_2$ start to decompose.

Explain your answer.

temperature at which $\text{Mg}(\text{NO}_3)_2$ starts to decompose $^\circ\text{C}$

temperature at which $\text{Ba}(\text{NO}_3)_2$ starts to decompose $^\circ\text{C}$

explanation

.....

.....

.....

.....

[3]

[Total: 7]

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5 Transition elements behave as catalysts and can form complex ions.

(a) Explain why transition elements behave as catalysts.

.....

.....

..... [2]

(b) Silver forms the linear complex ion $[\text{Ag}(\text{CN})_2]^-$.

Copper forms the tetrahedral complex ion $[\text{Cu}(\text{CN})_4]^{3-}$.

Titanium forms the complex $[\text{TiCl}_4(\text{diars})_2]$, where *diars* is a neutral bidentate ligand.

(i) State the oxidation state and the coordination number of titanium in $[\text{TiCl}_4(\text{diars})_2]$.

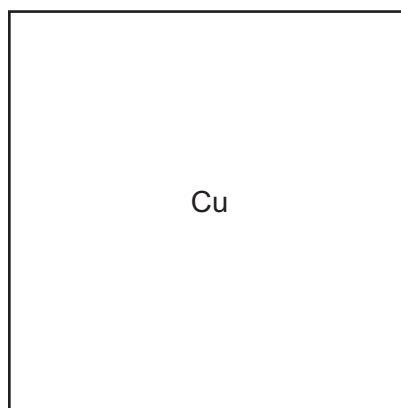
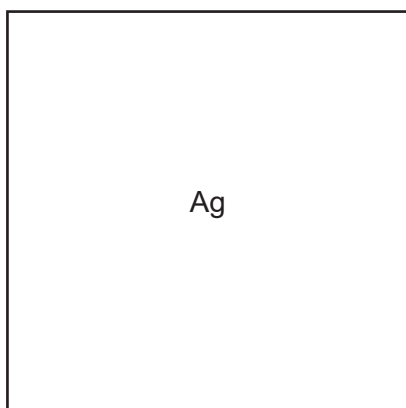
oxidation state

coordination number

[1]

(ii) Draw three-dimensional diagrams to show the shapes of $[\text{Ag}(\text{CN})_2]^-$ and $[\text{Cu}(\text{CN})_4]^{3-}$, in the boxes.

Label one bond angle on each diagram.



[2]

(c) The numerical value of the stability constant, K_{stab} , of the copper(I) complex $[\text{Cu}(\text{CN})_4]^{3-}$ is 2.0×10^{27} .

(i) Write an expression for the K_{stab} of $[\text{Cu}(\text{CN})_4]^{3-}$.

$$K_{\text{stab}} =$$

[1]

- (ii) In a solution the concentrations of CN^- and $[\text{Cu}(\text{CN})_4]^{3-}$ are both $0.0010 \text{ mol dm}^{-3}$.

Use your expression from (c)(i) and the value of K_{stab} to calculate the concentration of $\text{Cu}^+(\text{aq})$ in this solution.

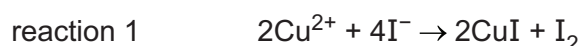
concentration of $\text{Cu}^+(\text{aq}) = \dots\dots\dots \text{mol dm}^{-3}$ [1]

- (d) A piece of a copper-containing alloy has a mass of 0.567 g. It is dissolved in an acid giving 100.0 cm^3 of a blue solution in which all the copper is present as Cu^{2+} ions.

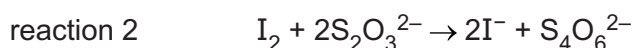
An excess of $\text{KI}(\text{aq})$ is added to a 25.0 cm^3 sample of this solution.

All of the copper is precipitated as white $\text{CuI}(\text{s})$.

Cu^{2+} ions are the only component in the solution that react with $\text{KI}(\text{aq})$. This is reaction 1.



The liberated I_2 is then titrated with $0.0200 \text{ mol dm}^{-3} \text{ S}_2\text{O}_3^{2-}$. This is reaction 2.



The titration requires 20.10 cm^3 of $0.0200 \text{ mol dm}^{-3} \text{ S}_2\text{O}_3^{2-}$ to reach the end-point.

- (i) Calculate the number of moles of I_2 that are reduced in this titration.

number of moles of $\text{I}_2 = \dots\dots\dots \text{mol}$ [1]

- (ii) Calculate the number of moles of copper in the original piece of alloy.

number of moles of copper = $\dots\dots\dots \text{mol}$ [1]

- (iii) Calculate the percentage of copper in the alloy.

percentage of copper = $\dots\dots\dots \%$ [1]

- (iv) Suggest why a solution of Cu^{2+} is coloured but solid CuI is white.

.....

 [2]

[Total: 12]

- 6 (a) Five ligands are listed in Table 6.1.

Table 6.1

ligand	type of ligand
NH_3	
EDTA^{4-}	
CN^-	
$\text{H}_2\text{NCH}_2\text{CH}_2\text{NHCH}_2\text{CH}_2\text{NH}_2$	tridentate
$\text{C}_2\text{O}_4^{2-}$	

- (i) Complete Table 6.1 using the words monodentate, bidentate and polydentate only.

Each of these three words may be used once, more than once, or not at all. [2]

- (ii) The molecule $\text{H}_2\text{NCH}_2\text{CH}_2\text{NHCH}_2\text{CH}_2\text{NH}_2$ is a tridentate ligand.

Suggest the meaning of tridentate ligand.

.....
 [1]

- (iii) Suggest how $\text{H}_2\text{NCH}_2\text{CH}_2\text{NHCH}_2\text{CH}_2\text{NH}_2$ acts as a tridentate ligand.

.....
 [1]

- (b) Nickel forms the octahedral complex $[\text{Ni}(\text{en})_2(\text{H}_2\text{O})_2]^{2+}$. This complex can exist in three isomeric forms, listed in Table 6.2.

One of these forms is a trans isomer, the other forms are two different cis isomers.

Table 6.2

isomer	polarity
trans isomer	
cis isomer 1	
cis isomer 2	

- (i) Complete Table 6.2 using the terms polar or non-polar.

Each term may be used once, more than once, or not at all. [1]

- (ii) Describe the difference between cis isomer 1 and cis isomer 2.

.....
 [1]

[Total: 6]

- 7 Sunset Yellow is an additive used for colouring foods.

A synthetic route for making Sunset Yellow is shown.

Molecules **E** and **G** each contain one SO_3^- group. These groups are unchanged in the formation of Sunset Yellow.

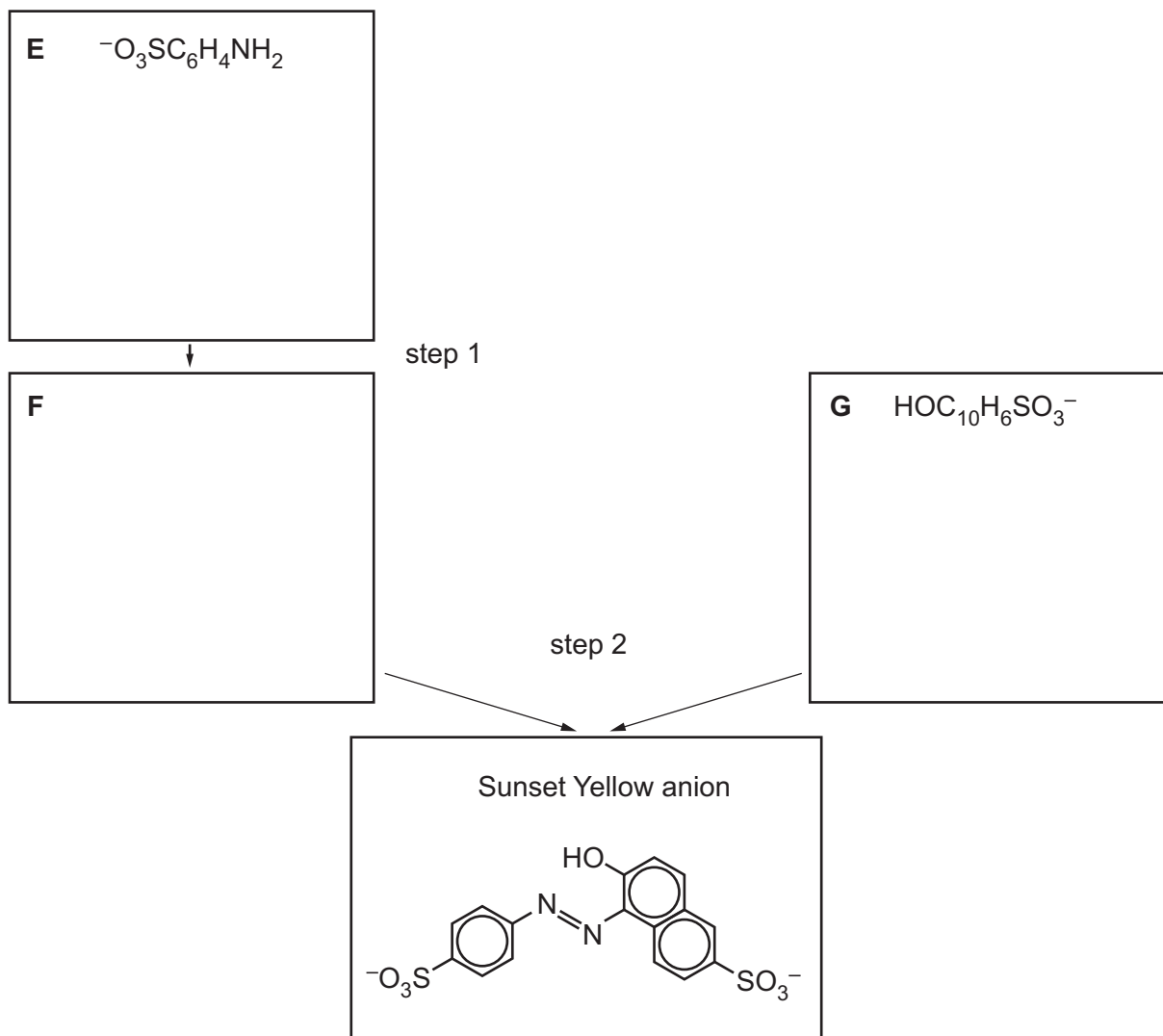
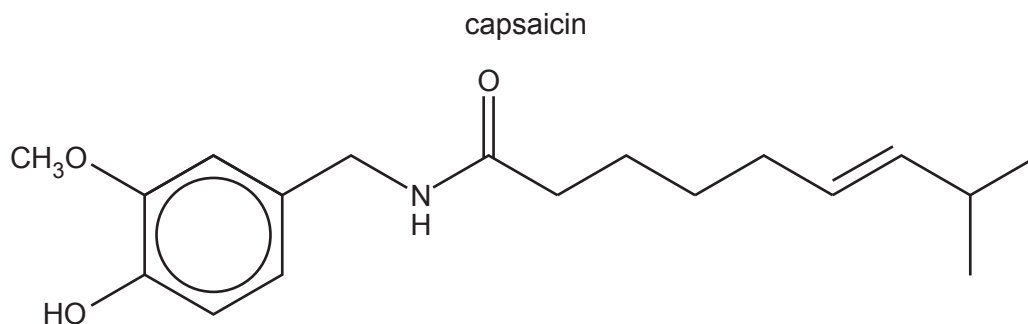


Fig. 7.1

- (a) State the molecular formula of the Sunset Yellow anion.
 [1]
- (b) Deduce the structures of **E**, **F** and **G** and draw them in the boxes in Fig. 7.1. [3]
- (c) Suggest suitable reagents and conditions for step 1 and 2.
 step 1
 step 2 [3]
- (d) Predict the number of peaks in the carbon-13 NMR spectrum of the Sunset Yellow anion.
 [1]

[Total: 8]

- 8 Capsaicin is found in chilli peppers.



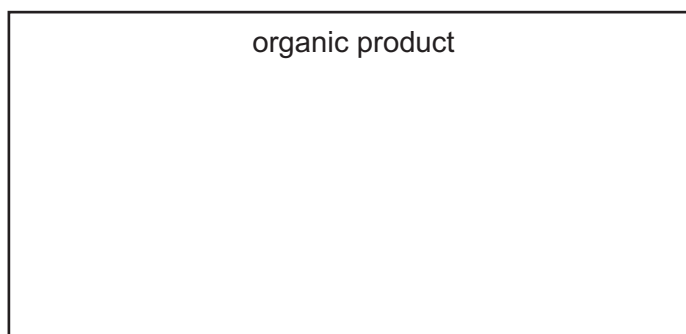
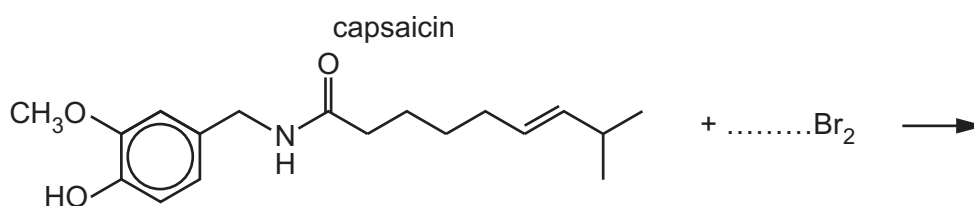
You should assume the CH_3O group is unreactive in the reactions involved in this question.

- (a) Name all the functional groups in capsaicin in addition to the CH_3O group.

..... [1]

- (b) Complete the equation for the reaction of capsaicin with an excess of $\text{Br}_2(\text{aq})$ in the dark.

Draw the structure of the organic product in the labelled box.



+

[3]

- (c) Capsaicin is heated with an excess of hydrogen gas in the presence of platinum metal.

The six-membered ring reacts in the same way as benzene under these conditions.

Draw the structure of the organic product formed.

[2]

(d) When capsaicin is treated with reagent **J** under suitable conditions one of the products is methylpropanoic acid, $\text{CH}_3\text{CH}(\text{CH}_3)\text{COOH}$.

(i) Identify reagent **J** and any necessary conditions.

..... [1]

(ii) There are three different peaks in the proton (^1H) NMR spectrum of $\text{CH}_3\text{CH}(\text{CH}_3)\text{COOH}$ in CDCl_3 .

Table 8.1

environment of proton	example	chemical shift range δ/ppm
alkane	$-\text{CH}_3$, $-\text{CH}_2-$, $>\text{CH}-$	0.9–1.7
alkyl next to $\text{C}=\text{O}$	$\text{CH}_3-\text{C}=\text{O}$, $-\text{CH}_2-\text{C}=\text{O}$, $>\text{CH}-\text{C}=\text{O}$	2.2–3.0
alkyl next to aromatic ring	CH_3-Ar , $-\text{CH}_2-\text{Ar}$, $>\text{CH}-\text{Ar}$	2.3–3.0
alkyl next to electronegative atom	CH_3-O , $-\text{CH}_2-\text{O}$, $-\text{CH}_2-\text{Cl}$	3.2–4.0
attached to alkene	$=\text{CHR}$	4.5–6.0
attached to aromatic ring	$\text{H}-\text{Ar}$	6.0–9.0
aldehyde	HCOR	9.3–10.5
alcohol	ROH	0.5–6.0
phenol	$\text{Ar}-\text{OH}$	4.5–7.0
carboxylic acid	RCOOH	9.0–13.0

Use Table 8.1 to complete Table 8.2 and state:

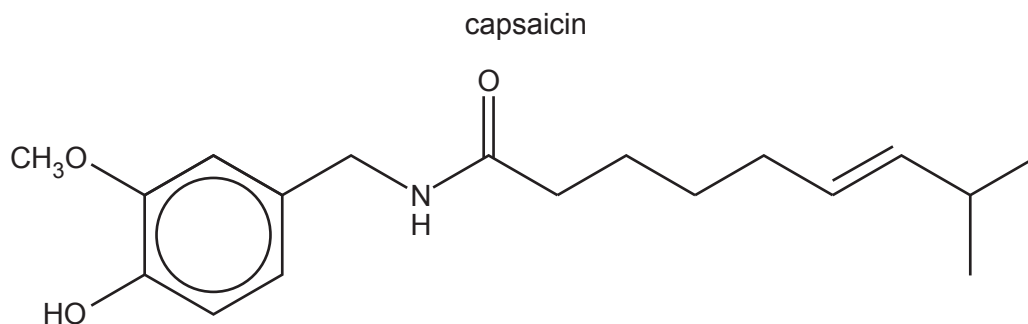
- the typical proton (^1H) chemical shift values (δ) for the protons
- the splitting pattern (singlet, doublet, triplet, quartet or multiplet) shown by each peak
- the explanation for the splitting patterns of the CH_3 protons and the CH proton.

Table 8.2

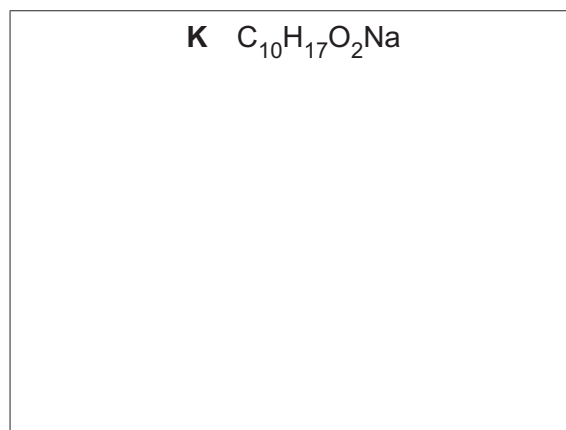
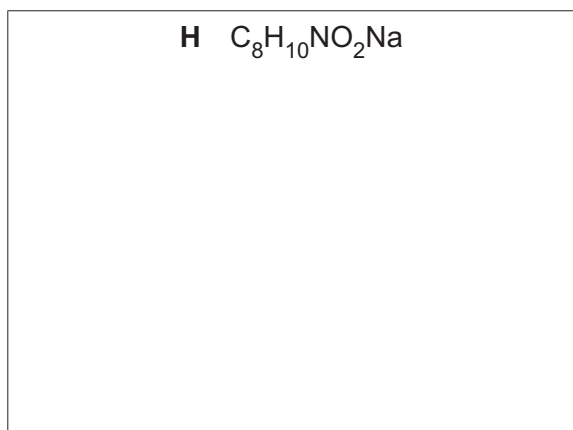
environment	δ/ppm	splitting pattern	explanation for splitting pattern
CH_3			
CH			
COOH			

[3]

- (e) (i) Capsaicin is heated with an excess of hot aqueous NaOH.



Draw the structures of the two organic products **H** and **K**.

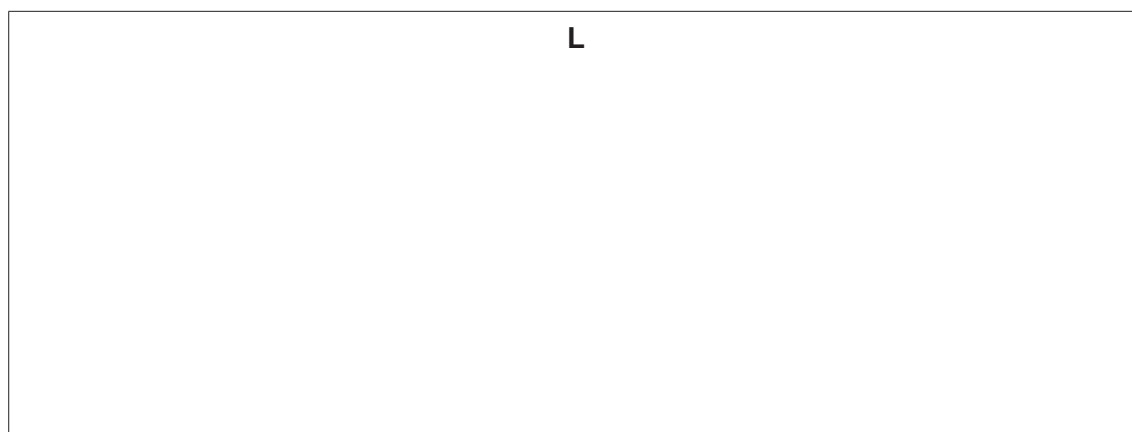


[2]

- (ii) Name the **two** types of reaction occurring in (e)(i).

..... [1]

- (f) Draw the structure of the organic product **L** formed when capsaicin is treated with LiAlH_4 in dry ether.



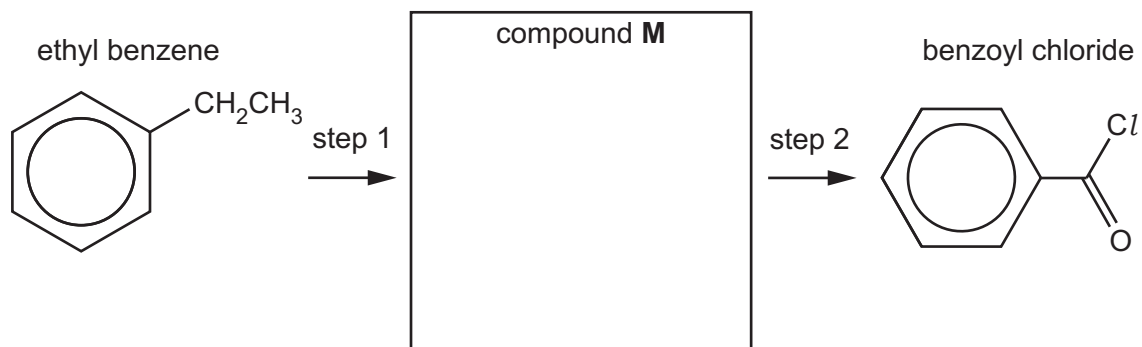
[1]

[Total: 14]

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- 9 (a) Benzoyl chloride, $\text{C}_6\text{H}_5\text{COCl}$, can be made from ethyl benzene in a two-step process.

A reaction scheme is shown.



- (i) Draw the intermediate organic compound **M** in the box. [1]

- (ii) Suggest suitable reagents and conditions for step 1 and step 2.

step 1

step 2 [2]

- (iii) Identify the type of reaction in step 1 and step 2.

step 1

step 2 [2]

(b) $\text{C}_6\text{H}_5\text{COCl}$ reacts with phenol, $\text{C}_6\text{H}_5\text{OH}$, to give the ester phenyl benzoate, $\text{C}_6\text{H}_5\text{COOC}_6\text{H}_5$.

An incomplete description of the mechanism of this reaction is shown in Fig. 9.1.

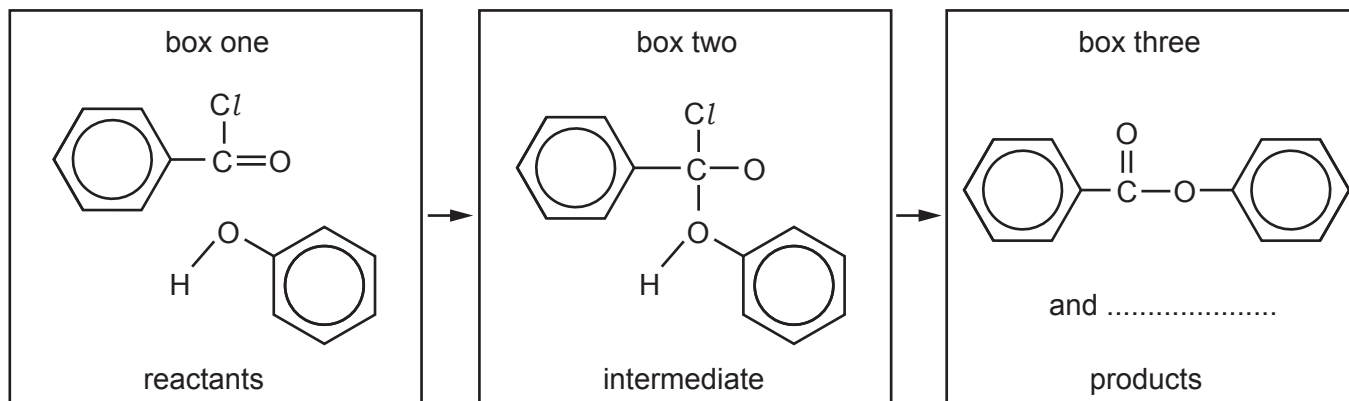


Fig. 9.1

(i) Complete the mechanism in Fig. 9.1 and include:

- all relevant dipoles (δ^+ and δ^-) and full electric charges (+ and -) on the species in box one and in box two
- all relevant lone pairs on the species in box one and in box two
- all relevant curly arrows to show the movement of electron pairs in box one and in box two
- the formula of the second product in box three.

[4]

(ii) Name this mechanism.

..... [1]

(c) Benzoyl chloride, chlorobenzene and chloroethane differ in their rates of hydrolysis when each compound is added separately to water at 25°C .

Suggest the relative ease of hydrolysis of these three compounds.

Explain your answer.

.....
hardest to hydrolyse

.....

.....
easiest to hydrolyse

explanation

.....

.....

.....

.....

[3]

[Total: 13]

Important values, constants and standards

molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
Avogadro constant	$L = 6.022 \times 10^{23} \text{ mol}^{-1}$
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	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (4.18 J g ⁻¹ K ⁻¹)

The Periodic Table of Elements

Group																						
1	2													13	14	15	16	17	18			
														1 H hydrogen 1.0								2 He helium 4.0



CANDIDATE
NAME

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CENTRE
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9701/42

October/November 2023

2 hours

You must answer on the question paper.

No additional materials are needed.

- 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.

- 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 **28** pages. Any blank pages are indicated.

- 1 Propanone, CH_3COCH_3 , reacts with iodine, I_2 , in the presence of an acid catalyst.



The rate equation for this reaction is shown.

$$\text{rate} = k[\text{CH}_3\text{COCH}_3][\text{H}^+]$$

- (a) Complete Table 1.1 to describe the order of the reaction.

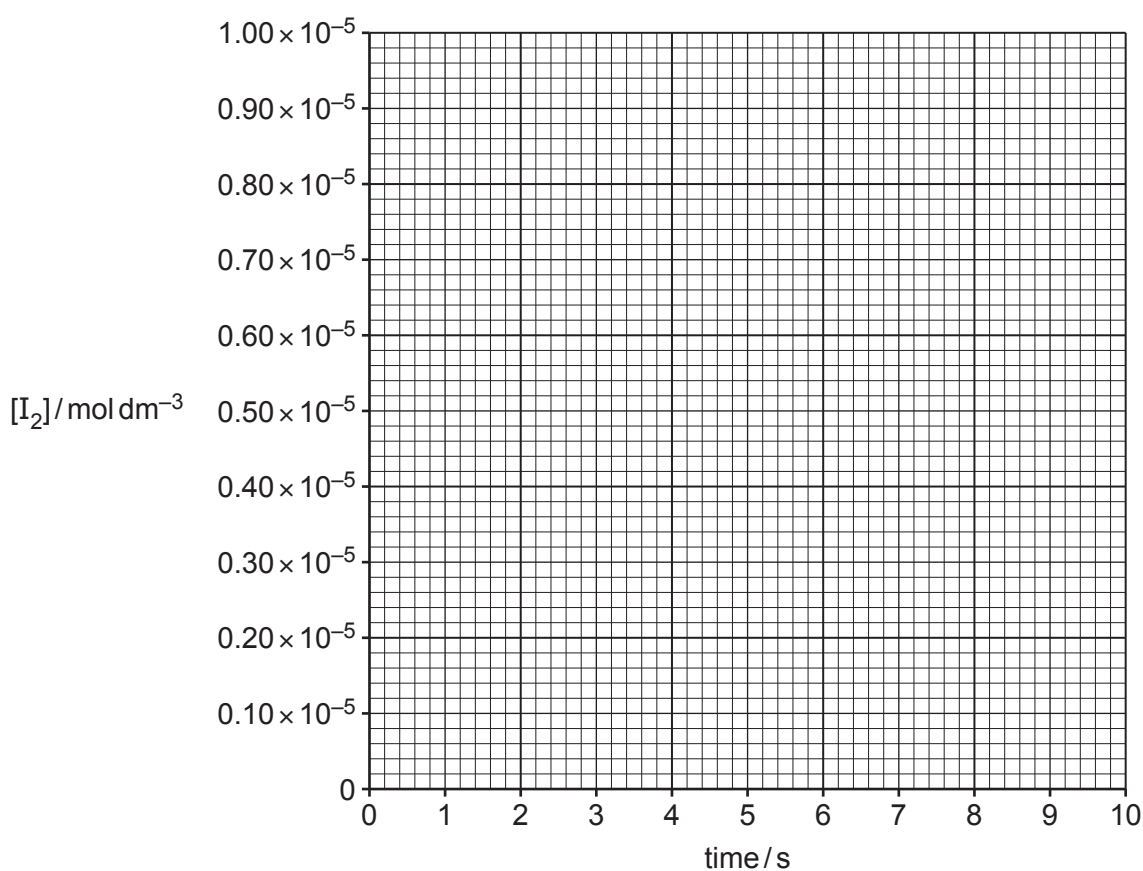
Table 1.1

order of the reaction with respect to $[\text{CH}_3\text{COCH}_3]$	
order of the reaction with respect to $[\text{I}_2]$	
order of the reaction with respect to $[\text{H}^+]$	
overall order of the reaction	

[2]

- (b) An experiment is performed using a large excess of CH_3COCH_3 and a large excess of $\text{H}^+(\text{aq})$. The initial concentration of I_2 is $1.00 \times 10^{-5} \text{ mol dm}^{-3}$. The initial rate of decrease in the I_2 concentration is $2.27 \times 10^{-7} \text{ mol dm}^{-3} \text{ s}^{-1}$.

- (i) Use the axes to draw a graph of $[\text{I}_2]$ against time for the first 10 seconds of the reaction.



[1]

- (ii) State whether it is possible to calculate the numerical value of the rate constant, k , for this reaction from your graph. Explain your answer.

.....
 [1]

- (c) The experiment is repeated at a different temperature. The initial concentrations of H^+ ions, I_2 and CH_3COCH_3 are all $0.200 \text{ mol dm}^{-3}$.

The value of k at this temperature is $2.31 \times 10^{-5} \text{ mol}^{-1} \text{ dm}^3 \text{ s}^{-1}$.

Calculate the initial rate of this reaction.

rate = ... $\text{mol dm}^{-3} \text{ s}^{-1}$ [1]

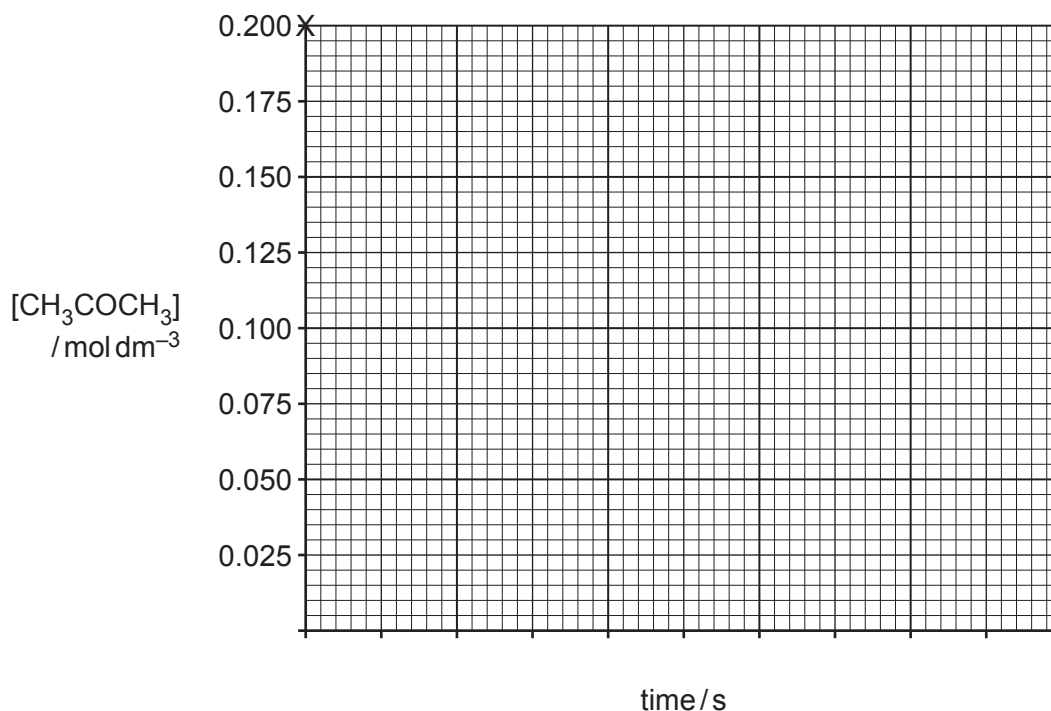
- (d) The experiment is repeated using an excess of $\text{H}^+(\text{aq})$. The new rate equation is shown.

$$\text{rate} = k_1[\text{CH}_3\text{COCH}_3]$$

- (i) The value of k_1 is $1.1 \times 10^{-3} \text{ s}^{-1}$. Calculate the value of the half-life, $t_{1/2}$.

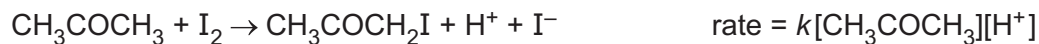
$t_{1/2} = \dots\dots\dots \text{ s}$ [1]

- (ii) Use your answer to (i) to draw a graph of $[\text{CH}_3\text{COCH}_3]$ against time for this reaction. The initial value of $[\text{CH}_3\text{COCH}_3]$ on your graph should be $0.200 \text{ mol dm}^{-3}$. The final value of $[\text{CH}_3\text{COCH}_3]$ on your graph should be $0.0250 \text{ mol dm}^{-3}$.

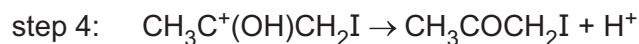
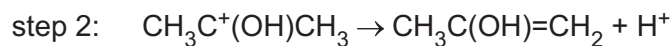
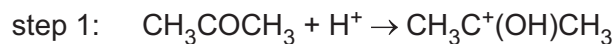


[1]

(e) A four-step mechanism is suggested for the overall reaction.



Part of this mechanism is shown.



(i) Write an equation for step 3.

..... [1]

(ii) Suggest the slowest step of the mechanism. Explain your answer.

.....
 [1]

(iii) Identify one conjugate acid-conjugate base pair in the mechanism.

conjugate acid conjugate base [1]

[Total: 10]

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- 2 Benzoic acid, $\text{C}_6\text{H}_5\text{COOH}$, is a weak acid. The K_a of benzoic acid is $6.31 \times 10^{-5} \text{ mol dm}^{-3}$ at 298 K.

A 1.00 dm^3 buffer solution is made at 298 K containing 1.00 g of $\text{C}_6\text{H}_5\text{COOH}$ and a slightly greater mass of sodium benzoate, $\text{C}_6\text{H}_5\text{COO}^-\text{Na}^+$.

This buffer solution has a pH of 4.15.

- (a) Define buffer solution.

.....
 [1]

- (b) Write equations to show how this solution acts as a buffer solution when the named substances are added to it:

- (i) dilute aqueous sodium hydroxide

..... [1]

- (ii) dilute aqueous nitric acid.

..... [1]

- (c) Calculate the H^+ concentration and the $\text{C}_6\text{H}_5\text{COOH}$ concentration in the buffer solution described. Use the expression for the K_a of $\text{C}_6\text{H}_5\text{COOH}$ to calculate the concentration of $\text{C}_6\text{H}_5\text{COO}^-\text{Na}^+$ in the buffer solution.

Show your working and give each answer to a minimum of **three** significant figures.

$$[\text{H}^+] = \dots\dots\dots \text{mol dm}^{-3}$$

$$[\text{C}_6\text{H}_5\text{COOH}] = \dots\dots\dots \text{mol dm}^{-3}$$

$$[\text{C}_6\text{H}_5\text{COO}^-\text{Na}^+] = \dots\dots\dots \text{mol dm}^{-3}$$

[3]

- (d) A 10.0 cm^3 sample of the buffer solution is mixed with 10.0 cm^3 of 1.00 mol dm^{-3} KOH. Both solutions are at 298 K . A reaction is allowed to occur without stirring.

Two observations are recorded:

- the temperature, after the reaction is complete, is fractionally above 298 K
- the pH, after the reaction, is greater than 13.

Explain these two observations.

.....

 [2]

- (e) Magnesium benzoate, $\text{Mg}(\text{C}_6\text{H}_5\text{COO})_2$, has a solubility in water of less than 1.00 g dm^{-3} at 298 K .

$$K_{\text{sp}} = [\text{Mg}^{2+}][\text{C}_6\text{H}_5\text{COO}^-]^2 = 1.76 \times 10^{-7} \text{ at } 298\text{ K}$$

- (i) Calculate the solubility of $\text{Mg}(\text{C}_6\text{H}_5\text{COO})_2$ in water at 298 K . Give your answer in g dm^{-3} .

Show your working.

$[M_r: \text{Mg}(\text{C}_6\text{H}_5\text{COO})_2, 266.3]$

solubility = ... g dm^{-3} [2]

- (ii) An excess of $\text{Mg}(\text{C}_6\text{H}_5\text{COO})_2$ is added to a sample of 0.50 mol dm^{-3} MgSO_4 at 298 K .

State whether the equilibrium concentration of $\text{Mg}(\text{C}_6\text{H}_5\text{COO})_2$ is higher than, the same as, or lower than your answer to (i). Explain your answer.

The concentration is the concentration in (i).

explanation

..... [1]

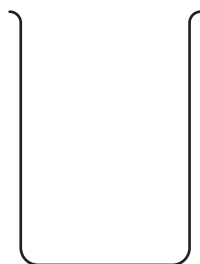
[Total: 11]

- 3 Some electrode potentials are shown in Table 3.1.

Table 3.1

electrode reaction	$E^\ominus/V$
$V^{2+} + 2e^- \rightleftharpoons V$	-1.20
$V^{3+} + e^- \rightleftharpoons V^{2+}$	-0.26
$VO^{2+} + 2H^+ + e^- \rightleftharpoons V^{3+} + H_2O$	+0.34
$VO_2^+ + 2H^+ + e^- \rightleftharpoons VO^{2+} + H_2O$	+1.00
$Fe^{2+} + 2e^- \rightleftharpoons Fe$	-0.44
$Fe^{3+} + 3e^- \rightleftharpoons Fe$	-0.04
$Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$	+0.77
$2H^+ + 2e^- \rightleftharpoons H_2$	0.00
$ClO^- + H_2O + 2e^- \rightleftharpoons Cl^- + 2OH^-$	+0.89

- (a) (i) Complete the diagram to show a standard hydrogen electrode.
Label your diagram. Identify all substances. You do **not** need to state standard conditions.



[1]

- (ii) An electrochemical cell is set up using an Fe^{3+}/Fe^{2+} electrode and a standard hydrogen electrode.

Identify the positive electrode in the electrochemical cell and the direction of electron flow in the external circuit.

positive electrode

Electrons flow from the electrode to the electrode.

[1]

- (b) The vanadium-containing species in the electrode reactions given in Table 3.1 are V, V^{2+} , V^{3+} , VO^{2+} and VO_2^+ .

- (i) Identify **one** vanadium-containing species that does **not** react with Fe^{2+} ions under standard conditions.

Use data from Table 3.1 to explain your answer.

.....
 [1]

- (ii) Identify **all** the vanadium-containing species that will react with Fe^{2+} ions under standard conditions.

..... [1]

- (iii) Write an equation for **one** of the possible reactions identified in (ii).

..... [1]

- (c) Another electrochemical cell is set up using an Fe^{3+}/Fe^{2+} electrode and an alkaline ClO^-/Cl^- electrode.

The concentration of Fe^{3+} is 1000 times greater than the concentration of Fe^{2+} in the Fe^{3+}/Fe^{2+} electrode. All other conditions are standard.

- (i) Use the Nernst equation to calculate the E value of the Fe^{3+}/Fe^{2+} electrode.

Show your working.

$E = \dots\dots\dots V$ [2]

- (ii) Write an equation for the reaction that occurs in the cell, under these conditions.

..... [1]

- (d) Another electrochemical cell is set up using an Fe^{2+}/Fe electrode and an alkaline ClO^-/Cl^- electrode under standard conditions.

Calculate the value of $\Delta G^\ominus$ for the cell.

$\Delta G^\ominus = \dots\dots\dots \text{kJ mol}^{-1}$ [3]

- (e) A solution of iron(II) sulfate, $\text{FeSO}_4(\text{aq})$ is electrolysed with iron electrodes. Under the conditions used, no gas is evolved at the cathode.

A current of 0.640 A is passed for 17.0 minutes. The mass of the cathode increases by 0.185 g.

Use these results to calculate an experimental value for the Avogadro constant, L .

Show your working.

$$L = \dots\dots\dots \text{mol}^{-1} \quad [3]$$

- (f) Iron(II) chloride, FeCl_2 , is oxidised by chlorine to form iron(III) chloride, FeCl_3 , under standard conditions.

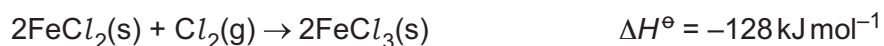


Table 3.2

species	$S^\ominus / \text{JK}^{-1} \text{mol}^{-1}$
$\text{Cl}_2(\text{g})$	223
$\text{FeCl}_2(\text{s})$	120
$\text{FeCl}_3(\text{s})$	142

- (i) Use Table 3.2 and other data to calculate the Gibbs free energy change, $\Delta G^\ominus$, for this reaction.

Show your working.

$$\Delta G^\ominus = \dots\dots\dots \text{kJ mol}^{-1} \quad [3]$$

- (ii) Predict whether this reaction becomes more or less feasible at a higher temperature.

Explain your answer.

The reaction becomes feasible.

explanation

.....

[1]

[Total: 18]

- 4 The structure of the polydentate ligand, EDTA⁴⁻, is shown in Fig. 4.1.

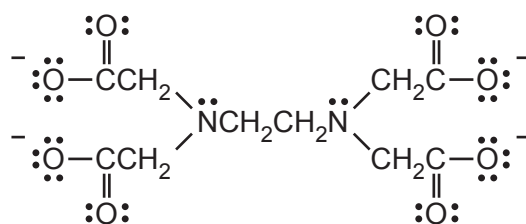


Fig. 4.1

The stability constants, at 298 K, of five octahedral complexes are given in Table 4.1.

Table 4.1

complex	K_{stab}
$[\text{Cu}(\text{EDTA})]^{2-}$	6.31×10^{19}
$[\text{Cr}(\text{EDTA})]^{2-}$	1.00×10^{13}
$[\text{Cr}(\text{EDTA})]^{-}$	1.00×10^{24}
$[\text{Fe}(\text{EDTA})]^{2-}$	2.00×10^{14}
$[\text{Fe}(\text{EDTA})]^{-}$	1.26×10^{25}

- (a) Define stability constant.

.....
 [1]

- (b) Calculate the oxidation states of Cu in $[\text{Cu}(\text{EDTA})]^{2-}$ and Cr in $[\text{Cr}(\text{EDTA})]^{-}$.

Cu

Cr

[1]

- (c) Deduce the number of lone pairs donated by each EDTA⁴⁻ ligand in a single $[\text{Fe}(\text{EDTA})]^{2-}$ complex ion.

..... [1]

- (d) Identify the most stable complex in Table 4.1. Explain your choice.

.....
 [1]

- (e) In a solution at equilibrium at 298 K, $[\text{Cu}(\text{H}_2\text{O})_6]^{2+} = 3.00 \times 10^{-10} \text{ mol dm}^{-3}$ and $[\text{EDTA}^{4-}] = 5.00 \times 10^{-12} \text{ mol dm}^{-3}$.

Use the expression for K_{stab} to calculate the concentration of $[\text{Cu}(\text{EDTA})]^{2-}$ in this solution.

Show your working.

$$[\text{Cu}(\text{EDTA})]^{2-} = \dots\dots\dots \text{ mol dm}^{-3} \quad [2]$$

- (f) A solution of $[\text{Cu}(\text{EDTA})]^{2-}$ ions is pale blue while a solution of $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$ ions is deep blue.

Explain this difference in colour.

.....

 [2]

[Total: 8]

- 5 Some of the ionic compounds of Group 2 elements undergo thermal decomposition.

Thermal decomposition of solid anhydrous magnesium ethanedioate, MgC_2O_4 , occurs above 650°C . The products are magnesium oxide and a mixture of two different gases, one of which gives a white precipitate with saturated calcium hydroxide solution.

- (a) Complete the equation for the thermal decomposition of MgC_2O_4 .

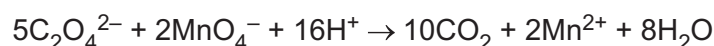


- (b) Suggest which of MgC_2O_4 or CaC_2O_4 undergoes thermal decomposition at a **lower** temperature. Explain your answer.

.....

 [2]

- (c) The ethanedioate ion is oxidised by acidified KMnO_4 .



An experiment is performed to find the solubility of MgC_2O_4 in water.

A 40.0cm^3 sample of saturated aqueous MgC_2O_4 requires 27.05cm^3 of $0.00200\text{mol dm}^{-3}$ acidified KMnO_4 to oxidise all the $\text{C}_2\text{O}_4^{2-}$ ions.

Calculate the solubility, in mol dm^{-3} , of MgC_2O_4 in water. Show your working.

solubility = ... mol dm^{-3} [3]

[Total: 6]

- 6 (a) Phosphine, :PH_3 , and carbon monoxide, :CO , are monodentate ligands found in some transition element complexes.

(i) Define monodentate ligand.

.....
 [1]

(ii) Define transition element complex.

.....
 [1]

(iii) Explain why transition elements form complexes.

.....
 [1]

(b) The formulae of six complexes are given in Table 6.1.

The abbreviation *en* is used for 1,2-diaminoethane.

The abbreviation *dien* is used for the tridentate ligand $\text{H}_2\text{NCH}_2\text{CH}_2\text{NHCH}_2\text{CH}_2\text{NH}_2$.

The *dien* ligand forms three bonds to the gold ion in $[\text{Au}(\textit{dien})(\text{H}_2\text{O})_2\text{Cl}]^{2+}$ and $\text{Au}(\textit{dien})\text{Cl}_3$.

These three bonds all lie in the same plane.

The CO ligand coordinates through the carbon atom in $[\text{Rh}(\text{CO})_2\text{Cl}_2]^+$.

Table 6.1

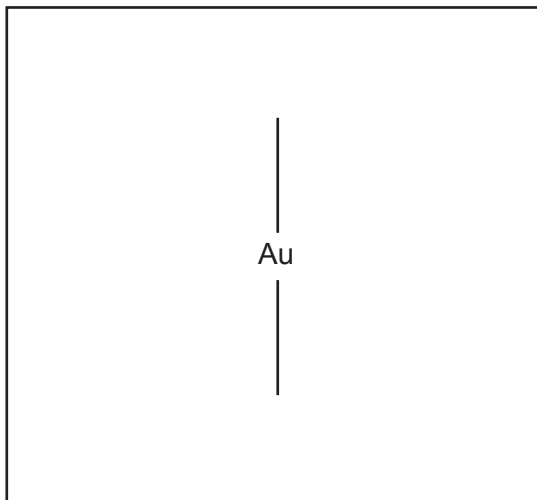
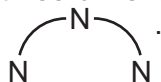
formula	isomerism shown	geometry
$[\text{Rh}(\textit{en})_2\text{Cl}_2]^+$	yes	
$[\text{Rh}(\text{CO})_2\text{Cl}_2]^+$	yes	
$[\text{Au}(\textit{dien})(\text{H}_2\text{O})_2\text{Cl}]^{2+}$		
$\text{Au}(\textit{dien})\text{Cl}_3$	no	octahedral
$\text{Ni}(\text{PH}_3)_2\text{Cl}_2$	no	
$[\text{Ni}(\text{H}_2\text{O})_2(\text{NH}_3)_4]^{2+}$	yes	

(i) Complete Table 6.1 to state the geometry of the first three complexes. Each complex is either square planar, tetrahedral or octahedral. [1]

(ii) Use complexes $[\text{Au}(\textit{dien})(\text{H}_2\text{O})_2\text{Cl}]^{2+}$ and $\text{Au}(\textit{dien})\text{Cl}_3$ to write an equation showing ligand exchange.

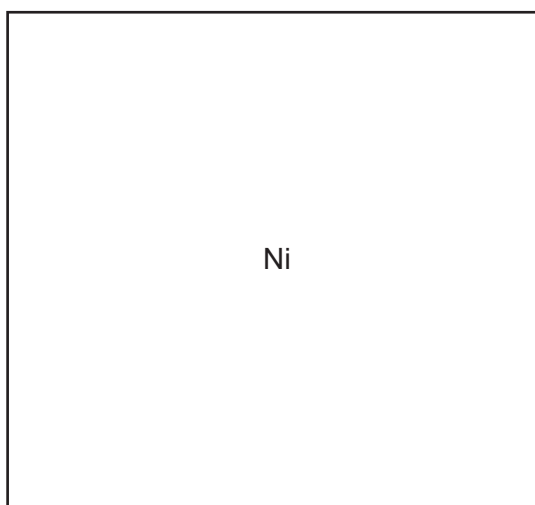
..... [1]

- (iii) Draw the three-dimensional structure of $\text{Au}(\text{dien})\text{Cl}_3$ in the box. The *dien* ligand can be drawn as



[1]

- (iv) Draw the three-dimensional structure of $\text{Ni}(\text{PH}_3)_2\text{Cl}_2$ in the box.



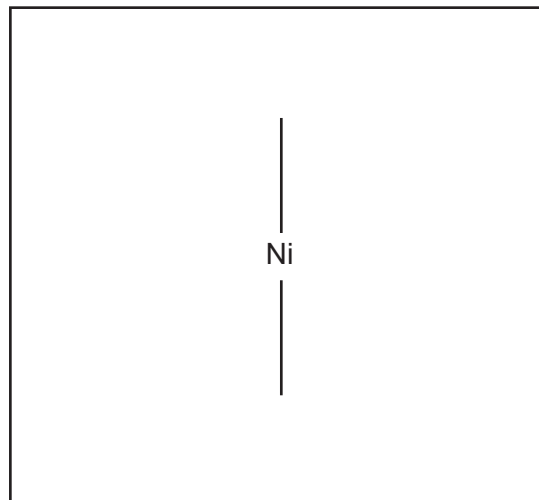
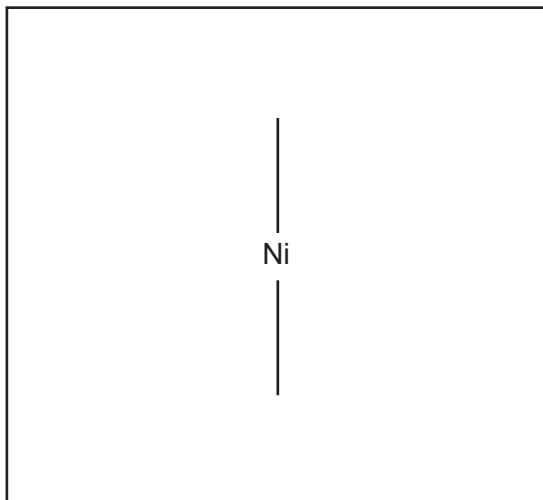
[1]

- (v) One of the complexes, $[\text{Rh}(\text{en})_2\text{Cl}_2]^+$ or $[\text{Rh}(\text{CO})_2\text{Cl}_2]^+$, can exist in three isomeric forms. Identify this complex and the types of isomerism shown.

.....

..... [1]

- (vi) Draw the three-dimensional structures of the two isomers of $[\text{Ni}(\text{H}_2\text{O})_2(\text{NH}_3)_4]^{2+}$ in the boxes and identify the type of isomerism shown.



type of isomerism shown

[2]

[Total: 10]

7 Benzene can be used to make benzoic acid in the two-step process shown in Fig. 7.1.

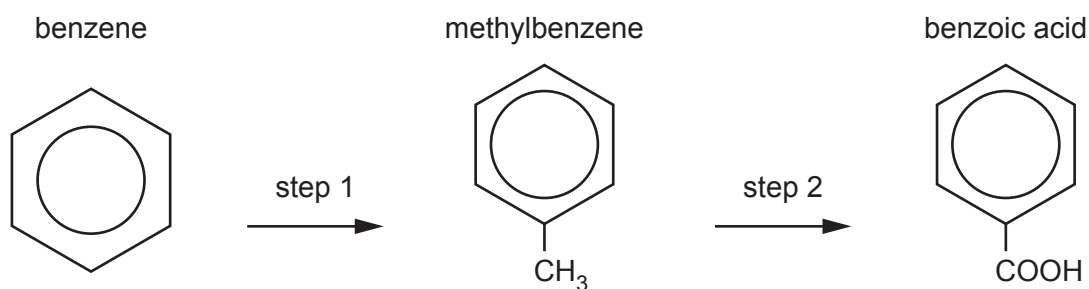


Fig. 7.1

(a) Give the reagents and conditions for step 1 and step 2.

step 1

step 2

[2]

(b) Methylbenzene and benzoic acid each have five different peaks in the carbon (^{13}C) NMR spectrum.

Table 7.1

hybridisation of the carbon atom	environment of carbon atom	example	chemical shift range /ppm
sp^3	alkyl	CH_3- , $-\text{CH}_2-$, $-\text{CH}<$, $>\text{C}<$	0–50
sp^3	next to alkene/arene	$-\text{C}=\text{C}$, $-\text{C}-\text{Ar}$	25–50
sp^3	next to carbonyl/carboxyl	$\text{C}-\text{COR}$, $\text{C}-\text{O}_2\text{R}$	30–65
sp^3	next to halogen	$\text{C}-\text{X}$	30–60
sp^3	next to oxygen	$\text{C}-\text{O}$	50–70
sp^2	alkene or arene	$>\text{C}=\text{C}<$, 	110–160
sp^2	carboxyl	$\text{R}-\text{COOH}$, $\text{R}-\text{COOR}$	160–185
sp^2	carbonyl	$\text{R}-\text{CHO}$, $\text{R}-\text{CO}-\text{R}$	190–220
sp	nitrile	$\text{R}-\text{C}\equiv\text{N}$	100–125

Use Table 7.1 to complete the two sentences to suggest descriptions of these two spectra.

The carbon (^{13}C) NMR spectrum of methylbenzene:

- has peak(s) in the chemical shift range of and
- has peak(s) in the chemical shift range of

The carbon (^{13}C) NMR spectrum of benzoic acid:

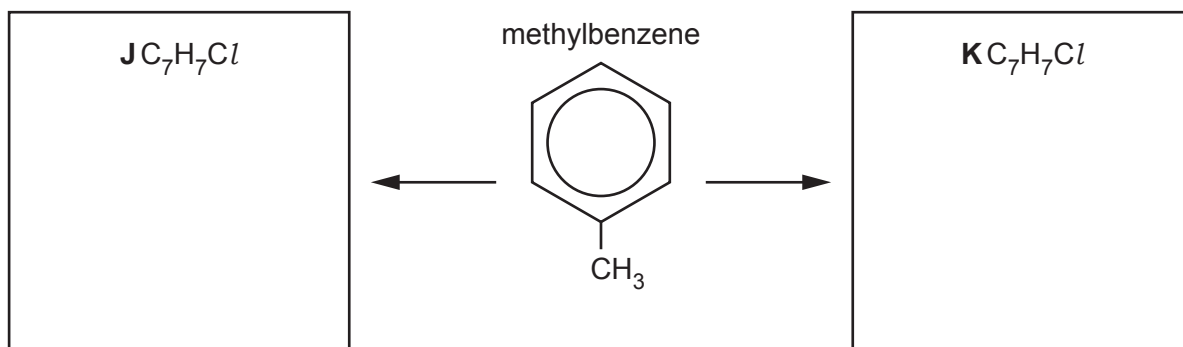
- has peak(s) in the chemical shift range of and
- has peak(s) in the chemical shift range of

[2]

(c) (i) When treated with Cl_2 under suitable conditions, methylbenzene forms compound **J**.

When treated with Cl_2 under **different** conditions with **different** reagents, methylbenzene forms compound **K**.

Suggest and draw structures of compounds **J** and **K** in the boxes. The molecular formula of each compound is given.



State the reagents and conditions required to form each product.

to form compound **J**

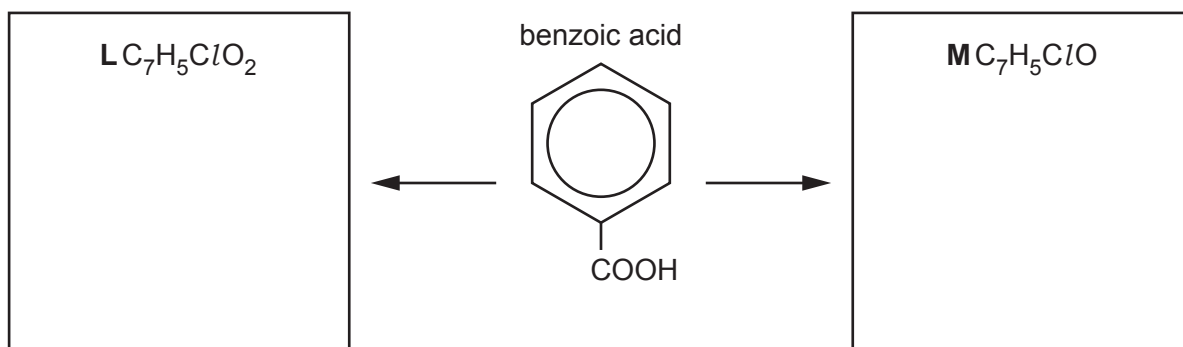
to form compound **K**

[4]

(ii) When treated with a chlorine-containing reagent under suitable conditions, benzoic acid forms compound **L**.

When treated with a **different** chlorine-containing reagent under **different** conditions, benzoic acid forms compound **M**.

Suggest and draw structures of compounds **L** and **M** in the boxes. The molecular formula of each product is given.



State the reagents and conditions to form compound **M** from benzoic acid.

..... [3]

- 8 Lactic acid, $\text{CH}_3\text{CH}(\text{OH})\text{COOH}$, is the only monomer needed to form the polymer polylactic acid, PLA.

- (a) (i) Draw a short length of the PLA polymer chain, including a minimum of two monomer residues. The methyl groups may be written as $-\text{CH}_3$ but all other bonds should be shown fully displayed.

Label one repeat unit of polylactic acid on your diagram.

[2]

- (ii) Give the name of the type of polymerisation involved in the formation of PLA and the name of the functional group that forms between the monomers.

type of polymerisation

functional group

[1]

- (iii) Predict whether PLA is readily biodegradable. Explain your answer.

.....

..... [1]

- (b) The proton (^1H) NMR spectrum of $\text{CH}_3\text{CH}(\text{OH})\text{COOH}$ in CDCl_3 is shown in Fig. 8.1. The proton NMR chemical shift ranges are shown in Table 8.1.

Lactic acid

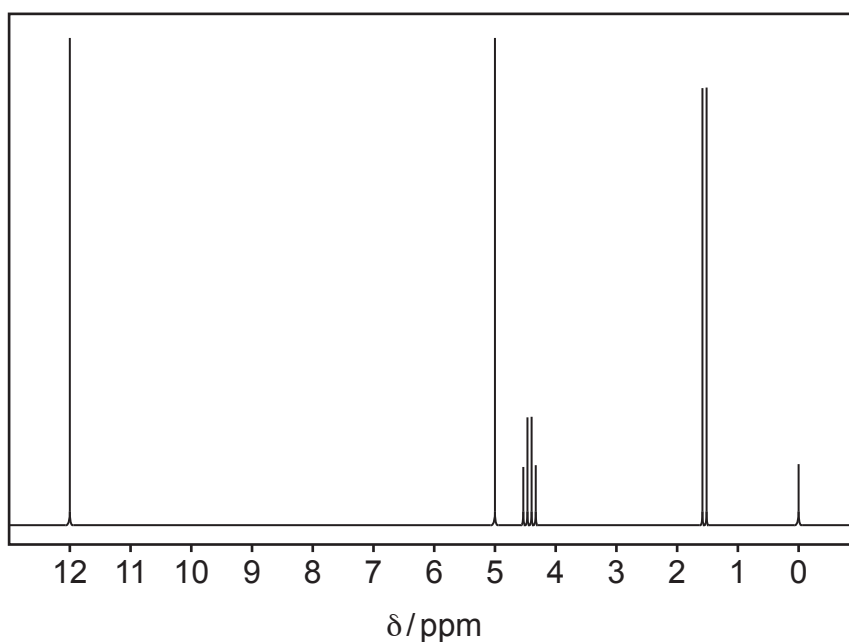


Fig. 8.1

Table 8.1

environment of proton	example	chemical shift range δ /ppm
alkane	$-\text{CH}_3$, $-\text{CH}_2-$, $>\text{CH}-$	0.9–1.7
alkyl next to $\text{C}=\text{O}$	$\text{CH}_3-\text{C}=\text{O}$, $-\text{CH}_2-\text{C}=\text{O}$, $>\text{CH}-\text{C}=\text{O}$	2.2–3.0
alkyl next to aromatic ring	CH_3-Ar , $-\text{CH}_2-\text{Ar}$, $>\text{CH}-\text{Ar}$	2.3–3.0
alkyl next to electronegative atom	CH_3-O , $-\text{CH}_2-\text{O}$, $-\text{CH}_2-\text{Cl}$	3.2–4.0
attached to alkene	$=\text{CHR}$	4.5–6.0
attached to aromatic ring	$\text{H}-\text{Ar}$	6.0–9.0
aldehyde	HCOR	9.3–10.5
alcohol	ROH	0.5–6.0
phenol	$\text{Ar}-\text{OH}$	4.5–7.0
carboxylic acid	RCOOH	9.0–13.0

(i) Use Fig. 8.1 and Table 8.1 to complete Table 8.2.

Table 8.2

proton environment	chemical shift (δ)	name of splitting pattern
$-\text{COOH}$		
$\geq\text{CH}$		
$-\text{OH}$		
$-\text{CH}_3$		

[3]

(ii) Name the substance responsible for the peak at $\delta = 0.0$.

..... [1]

(iii) Explain why CDCl_3 is a better solvent than CHCl_3 for use in proton NMR.

.....
 [1]

- (c) An impure sample of $\text{CH}_3\text{CH}(\text{OH})\text{COOH}$ contains pentan-3-one as the only contaminant. The mixture is analysed using gas/liquid chromatography. The pentan-3-one is found to have a longer retention time than the lactic acid.

(i) Explain what is meant by retention time.

.....
..... [1]

(ii) Suggest suitable substances, or types of substances, that could be used as the mobile and stationary phases.

mobile phase
stationary phase [1]

(iii) Describe how the percentage composition of the mixture can be determined from the gas/liquid chromatogram.

.....
..... [1]

[Total: 12]

- 9 (a) State the reactants and conditions for two different types of reactions that both produce diethylamine, $\text{CH}_3\text{CH}_2\text{NHCH}_2\text{CH}_3$.

reaction one

.....

reaction two

.....

[4]

- (b) Describe the relative basicities of diethylamine, phenylamine and ammonia in aqueous solution.

Explain your answer in terms of structure.

.....

least basic

most basic

explanation

.....

.....

.....

.....

[3]

- (c) Phenylamine reacts with $\text{HNO}_2(\text{aq})$ at 4°C to form compound **P**. Compound **P** reacts with phenol under alkaline conditions at 4°C . The product of this reaction is acidified, forming azo compound **Q**.

Draw the structure of compound **Q**.

Circle the azo group on your structure.

State one use of an azo compound such as **Q**.

compound **Q**:

An azo compound can be used

[2]

- (d) $\text{CH}_3\text{CH}_2\text{NHCH}_2\text{CH}_3$ reacts with ethanoyl chloride, CH_3COCl , to give the amide N,N-diethylethanamide, $\text{CH}_3\text{CON}(\text{C}_2\text{H}_5)_2$.

An incomplete description of the mechanism of this reaction is shown in Fig. 9.1.

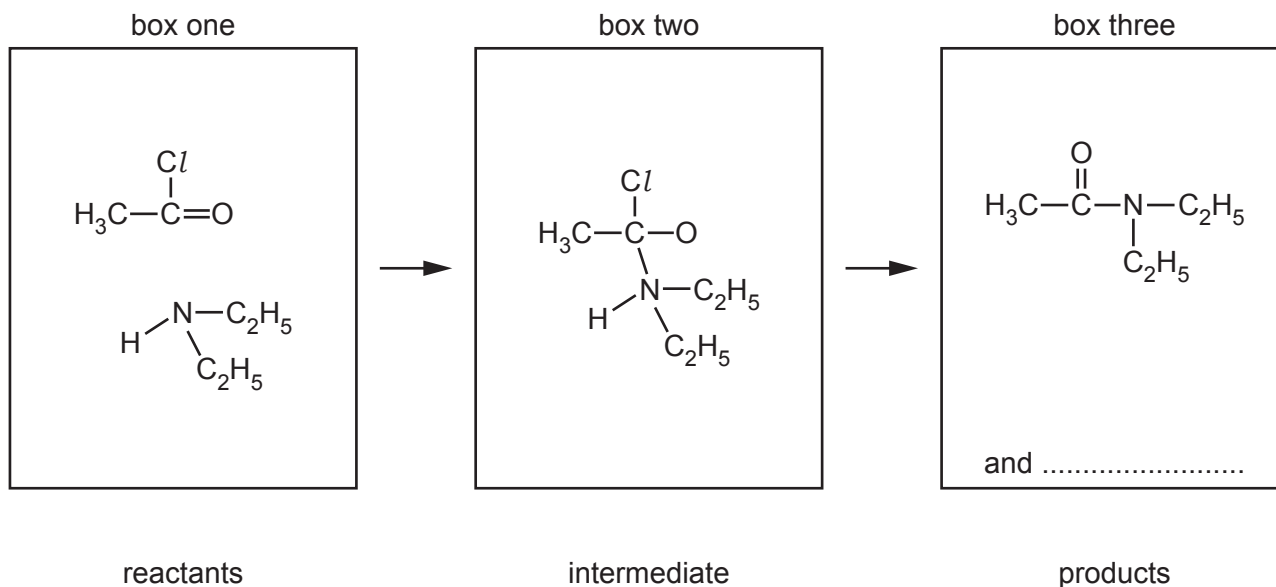


Fig. 9.1

- (i) Complete the mechanism in Fig. 9.1. You should include:

- all relevant dipoles ($\delta+$ and $\delta-$) and full electric charges (+ and -) on the species in box one and in box two
- all relevant lone pairs on the species in box one and in box two
- all relevant curly arrows to show the movement of electron pairs in box one and in box two
- the formula of the second product in box three.

[4]

- (ii) Name this mechanism.

..... [1]

[Total: 14]

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Important values, constants and standards

molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
Avogadro constant	$L = 6.022 \times 10^{23} \text{ mol}^{-1}$
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	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (4.18 J g ⁻¹ K ⁻¹)

The Periodic Table of Elements

Group																																																	
1	2													13	14	15	16	17	18																														
1 H hydrogen 1.0 Key atomic number atomic symbol name relative atomic mass 2 He helium 4.0																		3		4		5		6		7		8		9		10		11		12		13		14		15		16		17		18	
Li	Be																					5		6		7		8		9		10																	
lithium	beryllium																					boron		carbon		nitrogen		oxygen		fluorine		neon																	
6.9	9.0																					10.8		12.0		14.0		16.0		19.0		20.2																	
11	12																					13		14		15		16		17		18																	
Na	Mg																					Al		Si		P		S		Cl		Ar																	
sodium	magnesium																					aluminium		silicon		phosphorus		sulfur		chlorine		argon																	
23.0	24.3																					27.0		28.1		31.0		32.1		35.5		39.9																	
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54														
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe														
potassium	calcium	scandium	titanium	vanadium	chromium	manganese	iron	cobalt	nickel	copper	zinc	gallium	germanium	arsenic	selenium	bromine	krypton	rubidium	strontium	yttrium	zirconium	niobium	molybdenum	technetium	ruthenium	rhodium	palladium	silver	cadmium	indium	tin	antimony	tellurium	iodine	xenon														
39.1	40.1	45.0	47.9	50.9	52.0	54.9	55.8	58.9	58.7	63.5	65.4	69.7	72.6	74.9	79.0	79.9	83.8	85.5	87.6	88.9	91.2	92.9	95.9	—	101.1	102.9	106.4	107.9	112.4	114.8	118.7	127.6	126.9	131.3	132.9														
55	56	57–71		72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89–103		104	105	106	107	108	109	110	111	112	113	114	115	116	117	118												
Cs	Ba	lanthanoids		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	Ba	Ra	actinoids		Rf	Db	Sg	Bh	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og													
caesium	barium			hafnium	tantalum	tungsten	rhenium	osmium	iridium	platinum	gold	mercury	thallium	lead	bismuth	polonium	astatine	radon					rutherfordium	dubnium	seaborgium	bohrium	meitnerium	darmstadtium	roentgenium	copernicium	flerovium	moscovium	livermorium	tennessine	oganeson														
132.9	137.3			178.5	180.9	183.8	186.2	190.2	192.2	195.1	197.0	200.6	204.4	207.2	209.0	—	—	—	—	—			—	—	—	—	—	—	—	—	—	—	—	—	—	—													
87	88	89–103		104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	87	88	89–103		104	105	106	107	108	109	110	111	112	113	114	115	116	117	118												
Fr	Ra			—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—			—	—	—	—	—	—	—	—	—	—	—	—	—	—													
francium	radium			—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—			—	—	—	—	—	—	—	—	—	—	—	—	—	—													
lanthanoids																																																	
57	La			58	Ce	59	Pr	60	Nd	61	Pm	62	Sm	63	Eu	64	Gd	65	Tb	66	Dy	67	Ho	68	Er	69	Tm	70	Yb	71	Lu																		
	lanthanum			cerium	praseodymium	neodymium	samarium	europium	gadolinium	terbium	dysprosium	holmium	erbium	thulium	ytterbium	lutetium																																	
	138.9			140.1	140.9	144.4	150.4	152.0	157.3	158.9	162.5	164.9	167.3	168.9	173.1	175.0																																	
actinoids																																																	
89	Ac			90	Th	91	Pa	92	U	93	Np	94	Pu	95	Am	96	Cm	97	Bk	98	Cf	99	Es	100	Fm	101	Md	102	No	103	Lr																		
	actinium			thorium	protactinium	uranium	neptunium	plutonium	americium	curium	berkelium	californium	einsteinium	fermium	mendelevium	nobelium	lawrencium																																
	—			232.0	234.0	238.0	244.0	247.0	250.0	252.0	257.1	261.0	269.1	270.1	271.0	272.0	283.1	285.1	287.1	289.1	290.1	294.0	297.0	301.0	304.0	307.0	310.0	312.0	314.0	316.0	318.0	319.0	321.0	323.0															

lanthanoids

actinoids



CANDIDATE
NAME

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CENTRE
NUMBER

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CANDIDATE
NUMBER

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9701/43

October/November 2023

2 hours

You must answer on the question paper.

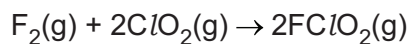
No additional materials are needed.

- 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.

- 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.

- 1 Fluorine reacts with chlorine dioxide, ClO_2 , as shown.



The rate of the reaction is first order with respect to the concentration of F_2 and first order with respect to the concentration of ClO_2 . No catalyst is involved.

- (a) (i) Suggest a two-step mechanism for this reaction.

step 1 $\rightarrow$

step 2 $\rightarrow$

[2]

- (ii) Identify the rate-determining step in this mechanism. Explain your answer.

.....

..... [1]

- (b) When the rate of the reaction is measured in $\text{mol dm}^{-3} \text{s}^{-1}$ the numerical value of the rate constant, k , is 1.22 under certain conditions.

- (i) Complete the rate equation for this reaction, stating the overall order of the reaction.

rate =

overall order of reaction =

[1]

- (ii) Use your rate equation in (i) to calculate the rate of the reaction when the concentrations of F_2 and ClO_2 are both $2.00 \times 10^{-3} \text{ mol dm}^{-3}$.

rate = ... $\text{mol dm}^{-3} \text{s}^{-1}$ [1]

- (c) Under different conditions, and in the presence of a large excess of ClO_2 , the rate equation is as shown.

$$\text{rate} = k_1[\text{F}_2]$$

The half-life, $t_{1/2}$, of the concentration of F_2 is 4.00 s under these conditions.

- (i) Calculate the numerical value of k_1 , giving its units.

Give your answer to **three** significant figures.

$$k_1 = \dots\dots\dots \text{units} \dots\dots\dots [2]$$

- (ii) An experiment is performed under these conditions in which the starting concentration of F_2 is $0.00200 \text{ mol dm}^{-3}$.

Draw a graph on the grid in Fig. 1.1 to show how the concentration of F_2 changes over the first 12 s of the reaction.

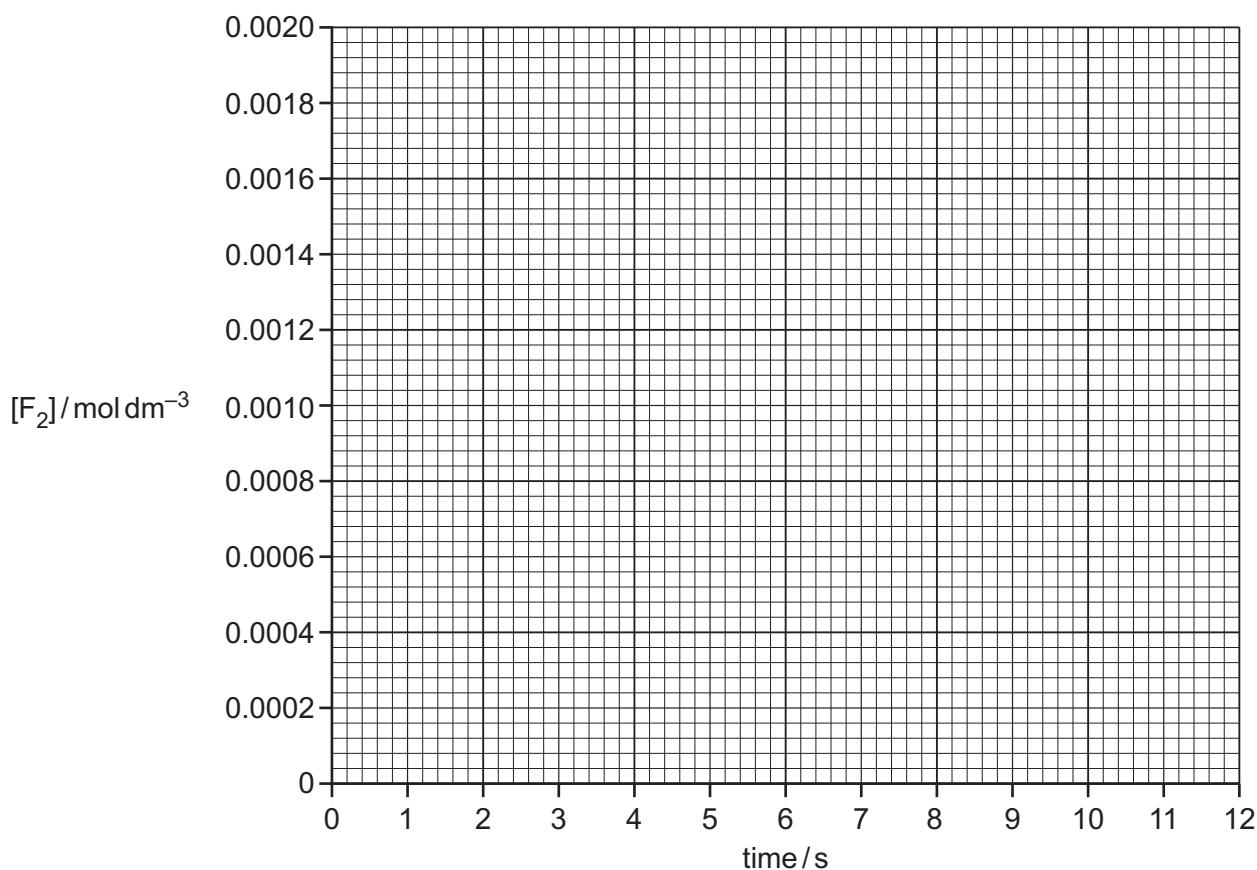


Fig. 1.1

[1]

- (iii) Use your graph in Fig. 1.1 to find the rate of the reaction when the concentration of F_2 is $0.00100 \text{ mol dm}^{-3}$. Show your working on the graph.

$$\text{rate} = \dots\dots\dots \text{mol dm}^{-3} \text{s}^{-1} [1]$$

[Total: 9]

- 2 (a) Define K_w mathematically by completing the expression.

$K_w =$ [1]

- (b) Two solutions, **V** and **W**, are described.

- **V** is $\text{HCl}(\text{aq})$.
- **W** is $\text{NaOH}(\text{aq})$.
- The concentration of HCl in **V** is the same as the concentration of NaOH in **W**.
- The pH values of **V** and **W** differ by exactly 11.00 at 298 K.

- (i) Calculate the concentration of HCl in **V**.

concentration of HCl in **V** = ... mol dm^{-3} [2]

- (ii) Equal volumes of the two solutions **V** and **W** are mixed, giving solution **X**.

Name solution **X** and state its pH.

solution **X** pH [1]

- (iii) A 1 cm^3 sample of 1.0 mol dm^{-3} HNO_3 is added to 100 cm^3 of solution **X**, forming mixture **Y**.

A 1 cm^3 sample of 1.0 mol dm^{-3} KOH is added to 100 cm^3 of solution **X**, forming mixture **Z**.

Estimate the pH of mixtures **Y** and **Z**. No calculations are required.

mixture **Y** mixture **Z** [1]

- (c) (i) $\text{CH}_3\text{CH}_2\text{COOH}$, $\text{CH}_3\text{CCl}_2\text{COOH}$ and H_2SO_4 are all acidic.

Suggest the trend in the relative acid strength of these three compounds.

Explain your answer.

.....
strongest acid weakest acid

explanation

.....

.....

.....

..... [3]

- (ii) When concentrated H_2SO_4 is added to water a series of acid-base reactions occurs. There are three conjugate acid-base pairs that can be identified during this series of reactions. Write the formulae of these three conjugate acid-base pairs.

conjugate acid 1 conjugate base 1
 conjugate acid 2 conjugate base 2
 conjugate acid 3 conjugate base 3 [2]

- (d) The partition coefficient, K_{pc} , of a substance, **Q**, between hexane and water is 7.84 at 298 K.

Q is more soluble in hexane than it is in water.

- (i) Define partition coefficient, K_{pc} .

.....
 [1]

- (ii) 5.00 g of **Q** is shaken with a mixture of 100.0 cm^3 of water and 100.0 cm^3 of hexane at 298 K and left until there is no further change in concentrations.

Calculate the mass of **Q** dissolved in the water.

mass of **Q** = ... g [1]

- (iii) A sample of **Q** is shaken with a different mixture of water and hexane and left until there is no further change in concentrations.

It is found that the mass of **Q** dissolved in each solvent is the same.

Use the K_{pc} value to suggest possible values for the volume of water used and the volume of hexane used.

volume of water = ... cm^3

volume of hexane = ... cm^3
 [1]

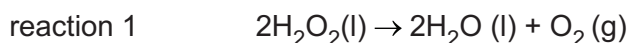
- (iv) **Q** is more soluble in hexane than it is in water.

It is suggested that **Q** is one of KCl , $\text{CH}_3(\text{CH}_2)_4\text{OH}$ or HCOOH .

Identify **Q**. Explain your answer.

.....
 [1]

- 3 Hydrogen peroxide is a liquid at 298K. It is moderately stable under room conditions but will decompose quickly if a catalyst is added.



- (a) (i) Define entropy.

.....
 [1]

- (ii) Predict the sign of the standard entropy change of reaction 1.

Explain your answer.

sign

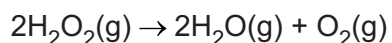
explanation
 [1]

- (b) Some bond energy data are shown in Table 3.1.

Table 3.1

type of bond	bond energy / kJ mol^{-1}
O–O	150
O–H	460
O=O	496

Use the data in Table 3.1 to show that the enthalpy change of the following reaction is -196 kJ mol^{-1} .



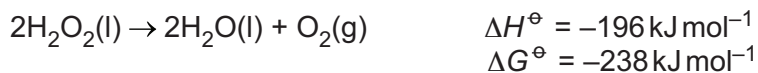
[1]

- (c) Some standard entropies, $S^\ominus$, are shown in Table 3.2.

Table 3.2

substance	$S^\ominus / \text{JK}^{-1} \text{mol}^{-1}$
$\text{H}_2\text{O}_2(\text{l})$	+102
$\text{H}_2\text{O}(\text{l})$	+70

The enthalpy change and Gibbs free energy change for the following reaction are shown.



Use the data given to calculate the standard entropy of oxygen, $S^\ominus$, $\text{O}_2(\text{g})$.

$$S^\ominus, \text{O}_2(\text{g}) = \dots\dots\dots \text{JK}^{-1} \text{mol}^{-1} \quad [3]$$

- (d) The decomposition of $\text{H}_2\text{O}_2(\text{aq})$ is catalysed by aqueous iron(III) chloride and by silver metal.

Identify which of these two catalysts is acting as a homogeneous catalyst.

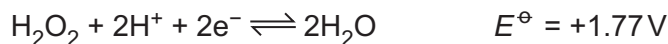
Explain your answer.

homogeneous catalyst

explanation

[1]

(e) The $E^\ominus$ values for two electrode reactions are given.



(i) An electrochemical cell is constructed with the following half-cells (electrodes):

- an acidified solution of H_2O_2 , a platinum wire
- Cr^{2+} mixed with Cr^{3+} , a platinum wire.

Identify the positive half-cell and calculate the standard cell potential, $E_{\text{cell}}^\ominus$.

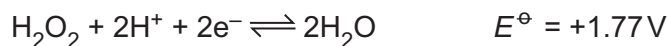
positive half-cell $E_{\text{cell}}^\ominus = \dots\dots\dots \text{ V}$

[1]

(ii) Calculate the value of $\Delta G^\ominus$ for the cell reaction that occurs, per mole of H_2O_2 .

$\Delta G^\ominus = \dots\dots\dots \text{ kJ mol}^{-1}$ [2]

(f) The $E^\ominus$ values for two electrode reactions are given.



An electrochemical cell is constructed with the following half-cells.

half-cell 1 an acidified solution of H_2O_2 under standard conditions, a platinum wire

half-cell 2 a solution containing $0.020 \text{ mol dm}^{-3} \text{Co}^{3+}$ and $2.0 \text{ mol dm}^{-3} \text{Co}^{2+}$, a platinum wire

(i) Use the Nernst equation to calculate the value of E , the electrode potential of half-cell 2 under these conditions.

$E = \dots\dots\dots \text{ V}$ [2]

(ii) Write an equation for the cell reaction that occurs in this cell under these conditions.

..... [1]

(g) (i) Define enthalpy change of hydration, ΔH_{hyd} .

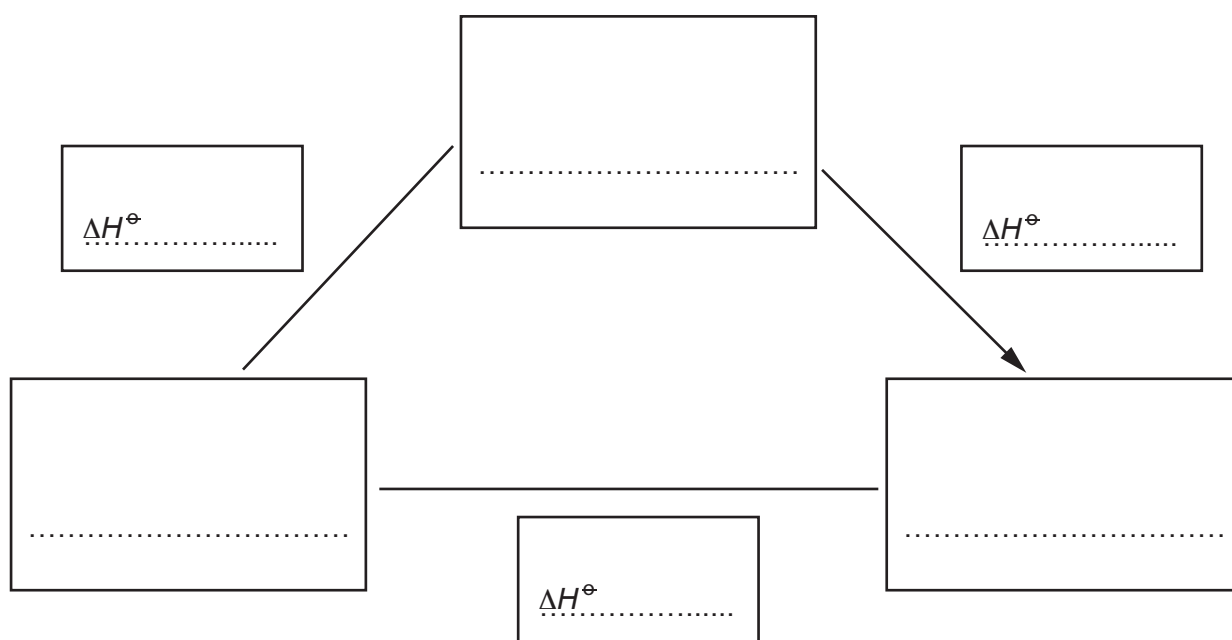
.....
 [1]

(ii) Aluminium fluoride, AlF_3 , is an ionic solid.

Complete and label the energy cycle to show the relationship between:

- the enthalpy change of solution of AlF_3 , $\Delta H_{\text{sol}}^\ominus$
- the lattice energy of AlF_3 , $\Delta H_{\text{latt}}^\ominus$
- the enthalpy changes of hydration of Al^{3+} and F^- , $\Delta H_{\text{hyd}}^\ominus$.

Include state symbols for all substances and ions.



[2]

(iii) Relevant data for this question are given.

$$\Delta H_{\text{sol}}^\ominus \text{AlF}_3 = -209 \text{ kJ mol}^{-1}$$

$$\Delta H_{\text{hyd}}^\ominus \text{Al}^{3+} = -4690 \text{ kJ mol}^{-1}$$

$$\Delta H_{\text{hyd}}^\ominus \text{F}^- = -506 \text{ kJ mol}^{-1}$$

Use these data and your energy cycle in (g)(ii) to calculate the $\Delta H_{\text{latt}}^\ominus$ of AlF_3 .

$$\Delta H_{\text{latt}}^\ominus \text{ of } \text{AlF}_3 = \dots\dots\dots \text{ kJ mol}^{-1} \quad [1]$$

[Total: 17]

- 4 (a) Cobalt(II) nitrate, $\text{Co}(\text{NO}_3)_2$, is a reddish-brown crystalline solid. It dissolves in water to form a solution containing $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ complex ions.

- (i) Complete Table 4.1 giving the formula of the cobalt-containing species that is formed in each of the three reactions described.

Table 4.1

reaction	reagent added to $[\text{Co}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$	cobalt-containing species formed
1	$\text{NaOH}(\text{aq})$	
2	an excess of $\text{NH}_3(\text{aq})$	
3	an excess of conc. $\text{HCl}(\text{aq})$	

[2]

- (ii) Describe the colour change seen in reaction 3.

original colour of $[\text{Co}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$

final colour after addition of an excess of conc. $\text{HCl}(\text{aq})$

[1]

- (b) Calcium nitrate, $\text{Ca}(\text{NO}_3)_2$, is a white crystalline solid. When heated, it starts to decompose at approximately 500°C .

- (i) Write an equation for the decomposition of $\text{Ca}(\text{NO}_3)_2$.

..... [1]

- (ii) Suggest temperatures at which $\text{Mg}(\text{NO}_3)_2$ and $\text{Ba}(\text{NO}_3)_2$ start to decompose.

Explain your answer.

temperature at which $\text{Mg}(\text{NO}_3)_2$ starts to decompose $^\circ\text{C}$

temperature at which $\text{Ba}(\text{NO}_3)_2$ starts to decompose $^\circ\text{C}$

explanation

.....

.....

.....

.....

[3]

[Total: 7]

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5 Transition elements behave as catalysts and can form complex ions.

(a) Explain why transition elements behave as catalysts.

.....

.....

..... [2]

(b) Silver forms the linear complex ion $[\text{Ag}(\text{CN})_2]^-$.

Copper forms the tetrahedral complex ion $[\text{Cu}(\text{CN})_4]^{3-}$.

Titanium forms the complex $[\text{TiCl}_4(\text{diars})_2]$, where *diars* is a neutral bidentate ligand.

(i) State the oxidation state and the coordination number of titanium in $[\text{TiCl}_4(\text{diars})_2]$.

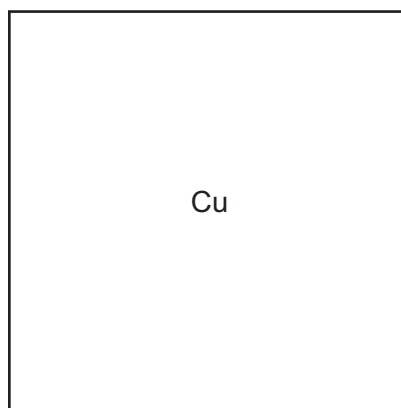
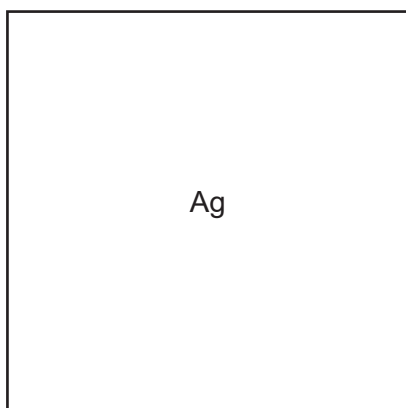
oxidation state

coordination number

[1]

(ii) Draw three-dimensional diagrams to show the shapes of $[\text{Ag}(\text{CN})_2]^-$ and $[\text{Cu}(\text{CN})_4]^{3-}$, in the boxes.

Label one bond angle on each diagram.



[2]

(c) The numerical value of the stability constant, K_{stab} , of the copper(I) complex $[\text{Cu}(\text{CN})_4]^{3-}$ is 2.0×10^{27} .

(i) Write an expression for the K_{stab} of $[\text{Cu}(\text{CN})_4]^{3-}$.

$$K_{\text{stab}} =$$

[1]

- (ii) In a solution the concentrations of CN^- and $[\text{Cu}(\text{CN})_4]^{3-}$ are both $0.0010 \text{ mol dm}^{-3}$.

Use your expression from (c)(i) and the value of K_{stab} to calculate the concentration of $\text{Cu}^+(\text{aq})$ in this solution.

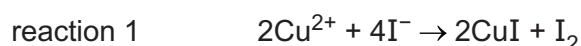
concentration of $\text{Cu}^+(\text{aq}) = \dots\dots\dots \text{mol dm}^{-3}$ [1]

- (d) A piece of a copper-containing alloy has a mass of 0.567 g. It is dissolved in an acid giving 100.0 cm^3 of a blue solution in which all the copper is present as Cu^{2+} ions.

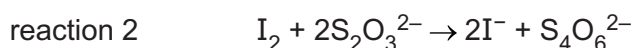
An excess of $\text{KI}(\text{aq})$ is added to a 25.0 cm^3 sample of this solution.

All of the copper is precipitated as white $\text{CuI}(\text{s})$.

Cu^{2+} ions are the only component in the solution that react with $\text{KI}(\text{aq})$. This is reaction 1.



The liberated I_2 is then titrated with $0.0200 \text{ mol dm}^{-3} \text{ S}_2\text{O}_3^{2-}$. This is reaction 2.



The titration requires 20.10 cm^3 of $0.0200 \text{ mol dm}^{-3} \text{ S}_2\text{O}_3^{2-}$ to reach the end-point.

- (i) Calculate the number of moles of I_2 that are reduced in this titration.

number of moles of $\text{I}_2 = \dots\dots\dots \text{mol}$ [1]

- (ii) Calculate the number of moles of copper in the original piece of alloy.

number of moles of copper = $\dots\dots\dots \text{mol}$ [1]

- (iii) Calculate the percentage of copper in the alloy.

percentage of copper = $\dots\dots\dots \%$ [1]

- (iv) Suggest why a solution of Cu^{2+} is coloured but solid CuI is white.

.....

 [2]

[Total: 12]

- 6 (a) Five ligands are listed in Table 6.1.

Table 6.1

ligand	type of ligand
NH_3	
EDTA^{4-}	
CN^-	
$\text{H}_2\text{NCH}_2\text{CH}_2\text{NHCH}_2\text{CH}_2\text{NH}_2$	tridentate
$\text{C}_2\text{O}_4^{2-}$	

- (i) Complete Table 6.1 using the words monodentate, bidentate and polydentate only.

Each of these three words may be used once, more than once, or not at all. [2]

- (ii) The molecule $\text{H}_2\text{NCH}_2\text{CH}_2\text{NHCH}_2\text{CH}_2\text{NH}_2$ is a tridentate ligand.

Suggest the meaning of tridentate ligand.

.....
 [1]

- (iii) Suggest how $\text{H}_2\text{NCH}_2\text{CH}_2\text{NHCH}_2\text{CH}_2\text{NH}_2$ acts as a tridentate ligand.

.....
 [1]

- (b) Nickel forms the octahedral complex $[\text{Ni}(\text{en})_2(\text{H}_2\text{O})_2]^{2+}$. This complex can exist in three isomeric forms, listed in Table 6.2.

One of these forms is a trans isomer, the other forms are two different cis isomers.

Table 6.2

isomer	polarity
trans isomer	
cis isomer 1	
cis isomer 2	

- (i) Complete Table 6.2 using the terms polar or non-polar.

Each term may be used once, more than once, or not at all. [1]

- (ii) Describe the difference between cis isomer 1 and cis isomer 2.

.....
 [1]

[Total: 6]

- 7 Sunset Yellow is an additive used for colouring foods.

A synthetic route for making Sunset Yellow is shown.

Molecules **E** and **G** each contain one $-\text{SO}_3^-$ group. These groups are unchanged in the formation of Sunset Yellow.

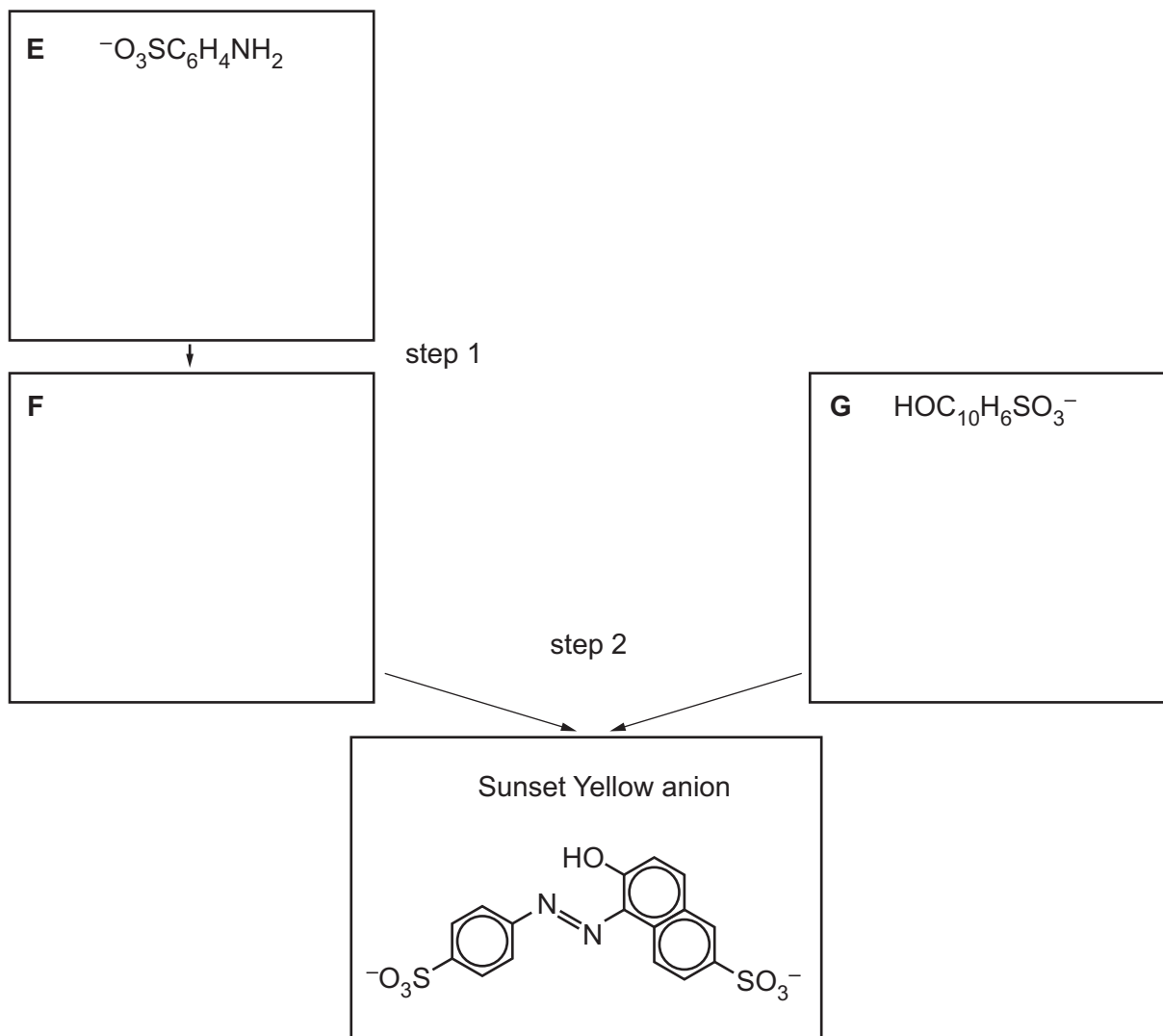
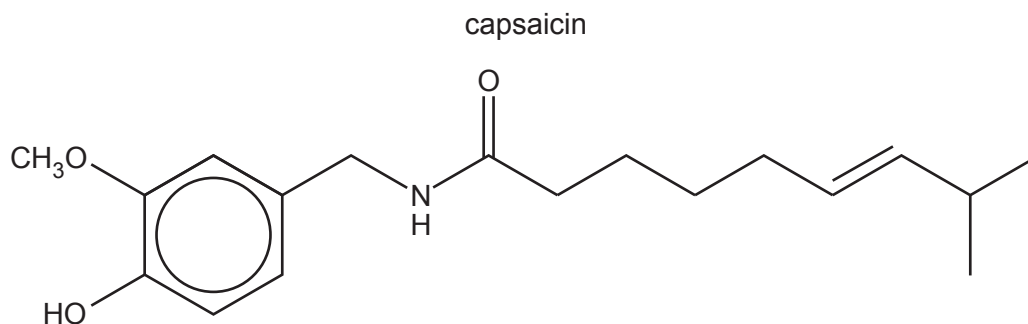


Fig. 7.1

- (a) State the molecular formula of the Sunset Yellow anion.
 [1]
- (b) Deduce the structures of **E**, **F** and **G** and draw them in the boxes in Fig. 7.1. [3]
- (c) Suggest suitable reagents and conditions for step 1 and 2.
 step 1
 step 2 [3]
- (d) Predict the number of peaks in the carbon-13 NMR spectrum of the Sunset Yellow anion.
 [1]

[Total: 8]

- 8 Capsaicin is found in chilli peppers.



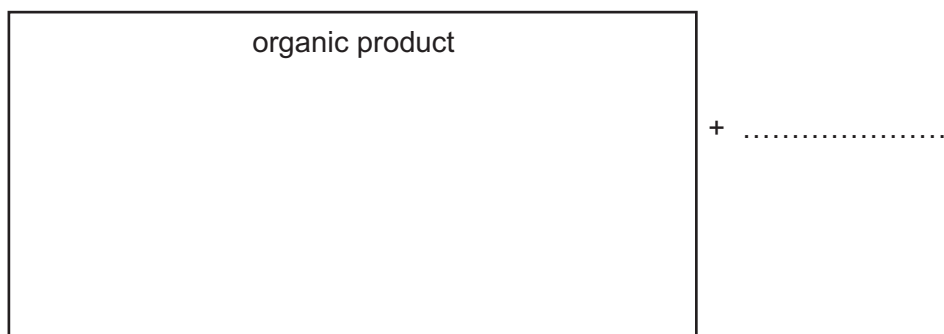
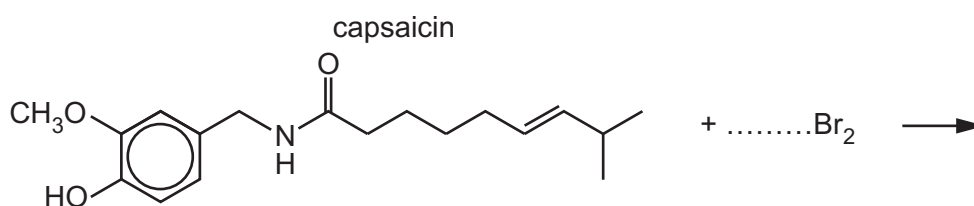
You should assume the CH_3O group is unreactive in the reactions involved in this question.

- (a) Name all the functional groups in capsaicin in addition to the CH_3O group.

..... [1]

- (b) Complete the equation for the reaction of capsaicin with an excess of $\text{Br}_2(\text{aq})$ in the dark.

Draw the structure of the organic product in the labelled box.



[3]

- (c) Capsaicin is heated with an excess of hydrogen gas in the presence of platinum metal.

The six-membered ring reacts in the same way as benzene under these conditions.

Draw the structure of the organic product formed.

[2]

(d) When capsaicin is treated with reagent **J** under suitable conditions one of the products is methylpropanoic acid, $\text{CH}_3\text{CH}(\text{CH}_3)\text{COOH}$.

(i) Identify reagent **J** and any necessary conditions.

..... [1]

(ii) There are three different peaks in the proton (^1H) NMR spectrum of $\text{CH}_3\text{CH}(\text{CH}_3)\text{COOH}$ in CDCl_3 .

Table 8.1

environment of proton	example	chemical shift range δ/ppm
alkane	$-\text{CH}_3$, $-\text{CH}_2-$, $>\text{CH}-$	0.9–1.7
alkyl next to $\text{C}=\text{O}$	$\text{CH}_3-\text{C}=\text{O}$, $-\text{CH}_2-\text{C}=\text{O}$, $>\text{CH}-\text{C}=\text{O}$	2.2–3.0
alkyl next to aromatic ring	CH_3-Ar , $-\text{CH}_2-\text{Ar}$, $>\text{CH}-\text{Ar}$	2.3–3.0
alkyl next to electronegative atom	CH_3-O , $-\text{CH}_2-\text{O}$, $-\text{CH}_2-\text{Cl}$	3.2–4.0
attached to alkene	$=\text{CHR}$	4.5–6.0
attached to aromatic ring	$\text{H}-\text{Ar}$	6.0–9.0
aldehyde	HCOR	9.3–10.5
alcohol	ROH	0.5–6.0
phenol	$\text{Ar}-\text{OH}$	4.5–7.0
carboxylic acid	RCOOH	9.0–13.0

Use Table 8.1 to complete Table 8.2 and state:

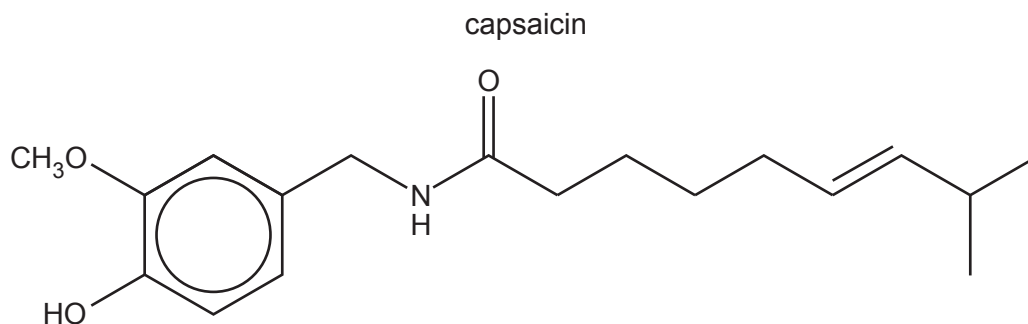
- the typical proton (^1H) chemical shift values (δ) for the protons
- the splitting pattern (singlet, doublet, triplet, quartet or multiplet) shown by each peak
- the explanation for the splitting patterns of the CH_3 protons and the CH proton.

Table 8.2

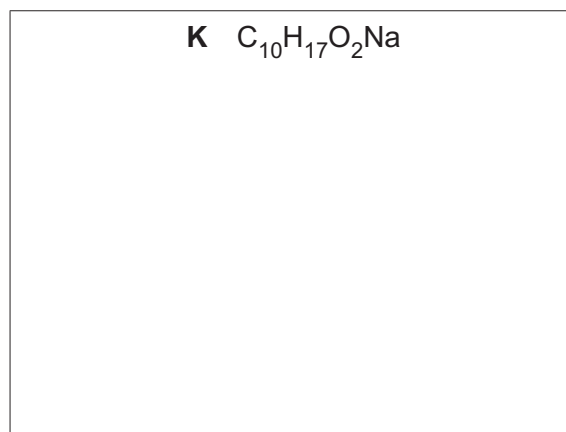
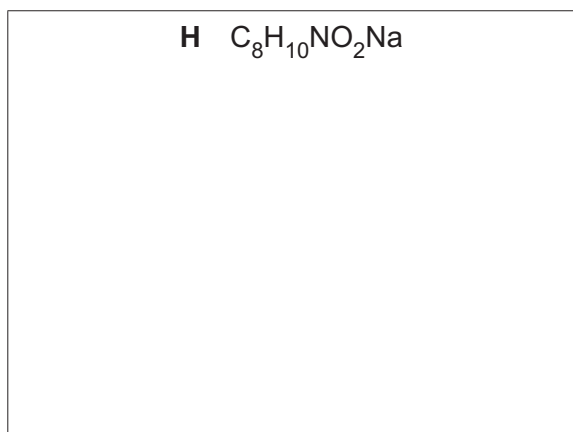
environment	δ/ppm	splitting pattern	explanation for splitting pattern
CH_3			
CH			
COOH			

[3]

- (e) (i) Capsaicin is heated with an excess of hot aqueous NaOH.



Draw the structures of the two organic products **H** and **K**.

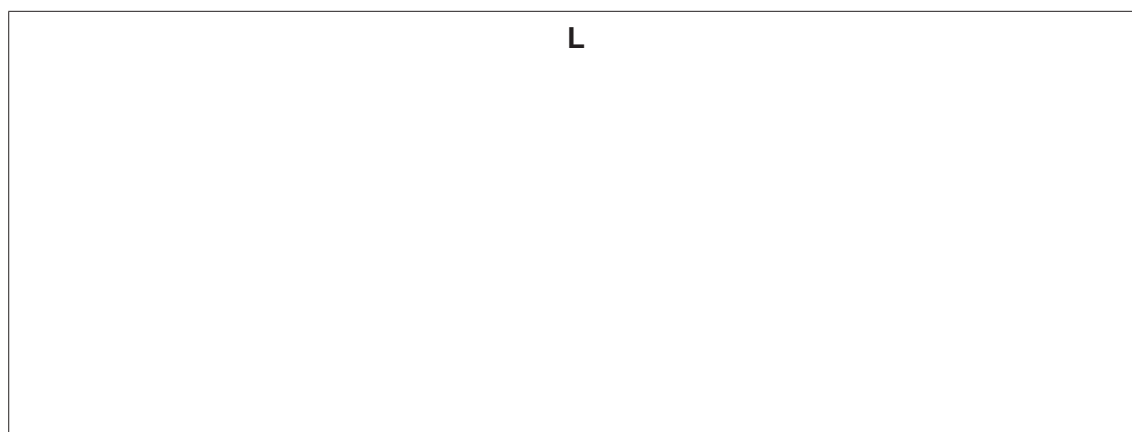


[2]

- (ii) Name the **two** types of reaction occurring in (e)(i).

..... [1]

- (f) Draw the structure of the organic product **L** formed when capsaicin is treated with LiAlH_4 in dry ether.



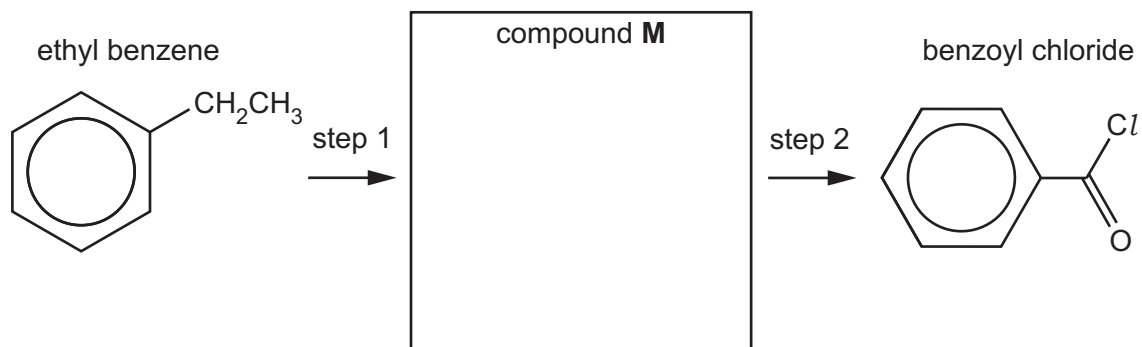
[1]

[Total: 14]

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- 9 (a) Benzoyl chloride, $\text{C}_6\text{H}_5\text{COCl}$, can be made from ethyl benzene in a two-step process.

A reaction scheme is shown.



- (i) Draw the intermediate organic compound **M** in the box. [1]

- (ii) Suggest suitable reagents and conditions for step 1 and step 2.

step 1

step 2 [2]

- (iii) Identify the type of reaction in step 1 and step 2.

step 1

step 2 [2]

(b) $\text{C}_6\text{H}_5\text{COCl}$ reacts with phenol, $\text{C}_6\text{H}_5\text{OH}$, to give the ester phenyl benzoate, $\text{C}_6\text{H}_5\text{COOC}_6\text{H}_5$.

An incomplete description of the mechanism of this reaction is shown in Fig. 9.1.

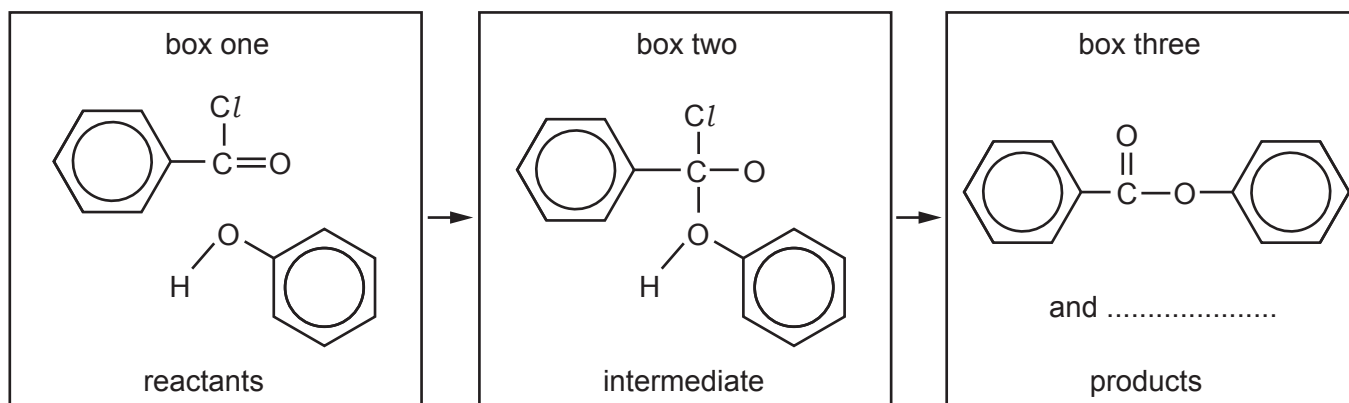


Fig. 9.1

(i) Complete the mechanism in Fig. 9.1 and include:

- all relevant dipoles (δ^+ and δ^-) and full electric charges (+ and -) on the species in box one and in box two
- all relevant lone pairs on the species in box one and in box two
- all relevant curly arrows to show the movement of electron pairs in box one and in box two
- the formula of the second product in box three.

[4]

(ii) Name this mechanism.

..... [1]

(c) Benzoyl chloride, chlorobenzene and chloroethane differ in their rates of hydrolysis when each compound is added separately to water at 25°C .

Suggest the relative ease of hydrolysis of these three compounds.

Explain your answer.

.....
hardest to hydrolyse easiest to hydrolyse

explanation

.....
.....
.....
.....

[3]

[Total: 13]

Important values, constants and standards

molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
Avogadro constant	$L = 6.022 \times 10^{23} \text{ mol}^{-1}$
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	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (4.18 J g ⁻¹ K ⁻¹)

The Periodic Table of Elements

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