



Cambridge International AS & A Level

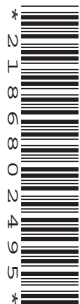
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CHEMISTRY

9701/43

Paper 4 A Level Structured Questions

October/November 2023

2 hours

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

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

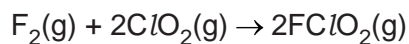
INFORMATION

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

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

2

- 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]

3

- (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.

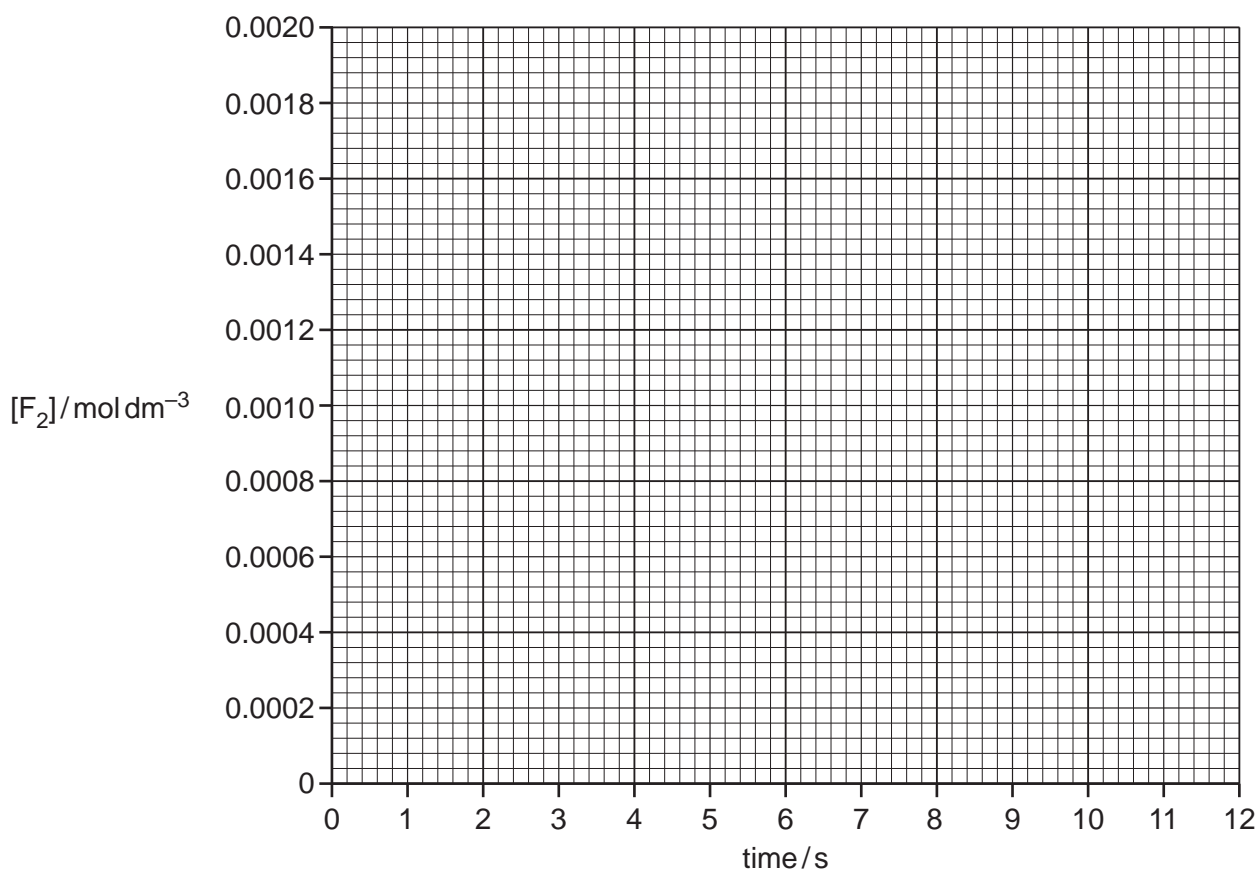


Fig. 1.1

[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 $1.0 \text{ mol dm}^{-3} \text{ HNO}_3$ is added to 100 cm^3 of solution **X**, forming mixture **Y**.

A 1 cm^3 sample of $1.0 \text{ mol dm}^{-3} \text{ KOH}$ 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 cm³ of water and 100.0 cm³ 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 = cm³

volume of hexane = cm³
 [1]

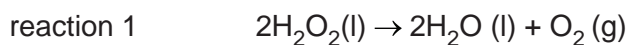
- (iv) **Q** is more soluble in hexane than it is in water.

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 298 K. 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

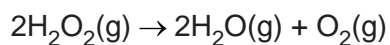
..... [1]

- (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.

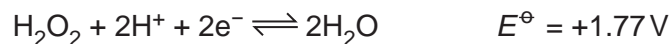
Explain your answer.

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.

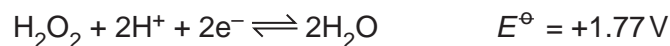
Identify the positive half-cell and calculate the standard cell potential, E_{cell}^\ominus .

positive half-cell $E_{\text{cell}}^\ominus = \dots\dots\dots \text{V}$ [1]

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

$\Delta G^\ominus = \dots\dots\dots \text{kJmol}^{-1}$ [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, $\Delta H_{\text{hyd}}^{\ominus}$.

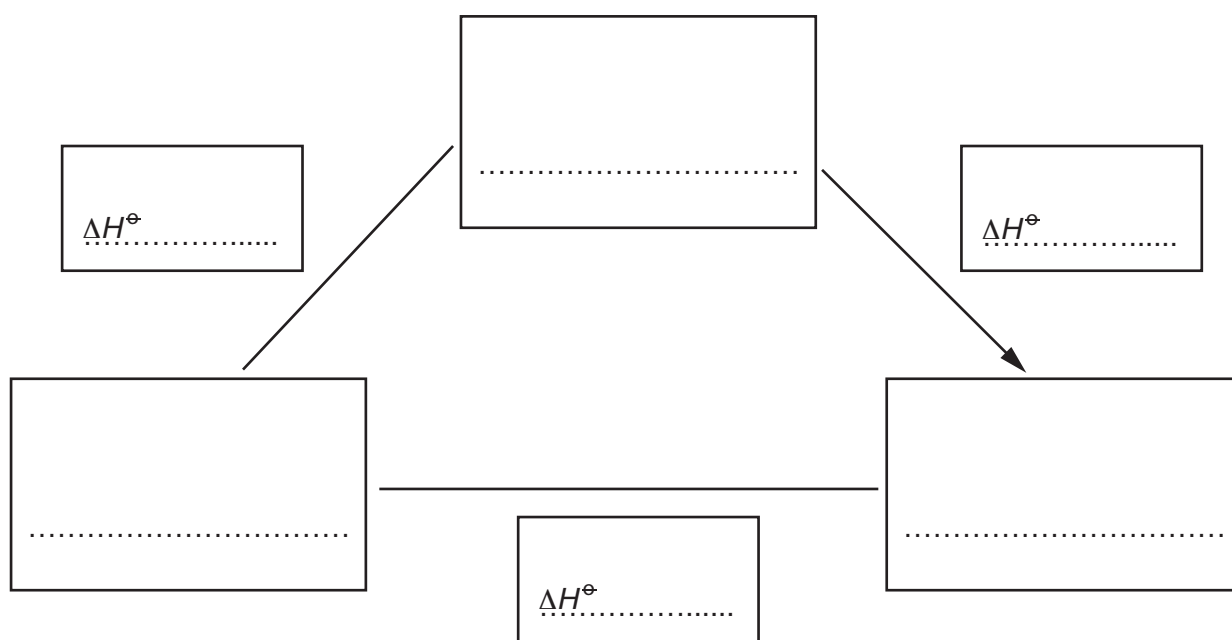
.....
 [1]

(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 .

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

[Total: 17]

10

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 $[\text{TiCl}_4(\text{diars})_2]$.

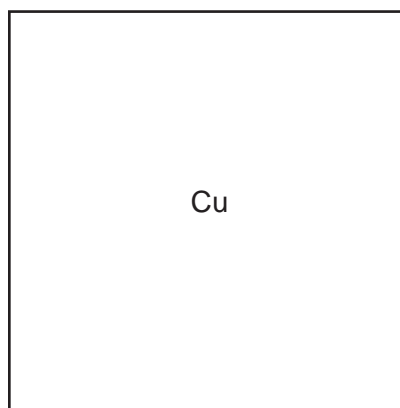
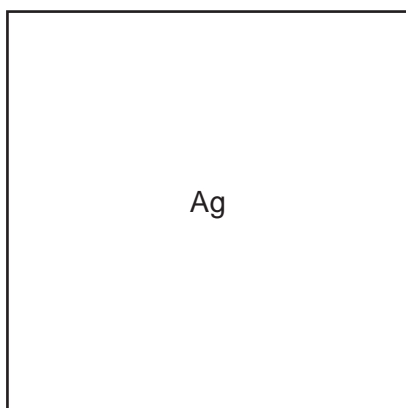
oxidation state

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.

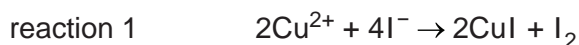
concentration of $\text{Cu}^+(\text{aq}) = \dots\dots\dots \text{ mol dm}^{-3}$ [1]

- (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.

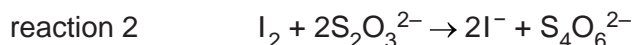
An excess of $\text{KI}(\text{aq})$ is added to a 25.0 cm^3 sample of this solution.

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.

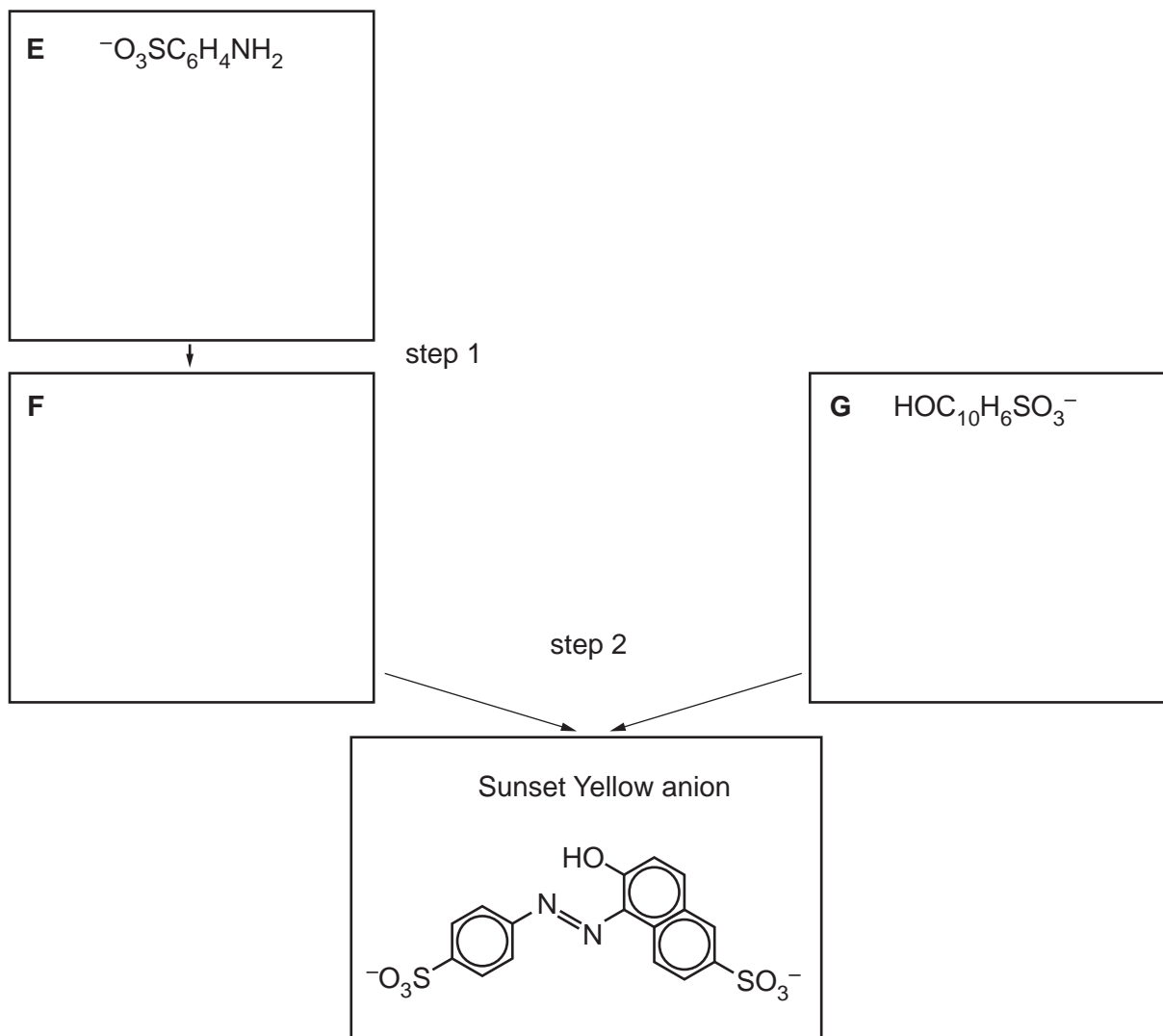


Fig. 7.1

(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

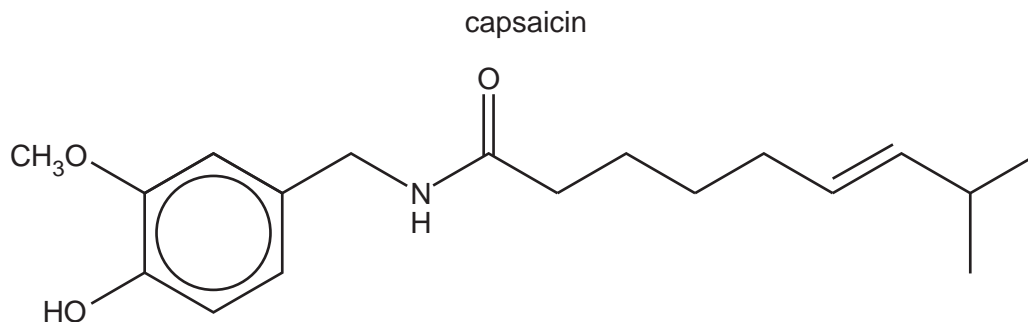
[3]

(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.



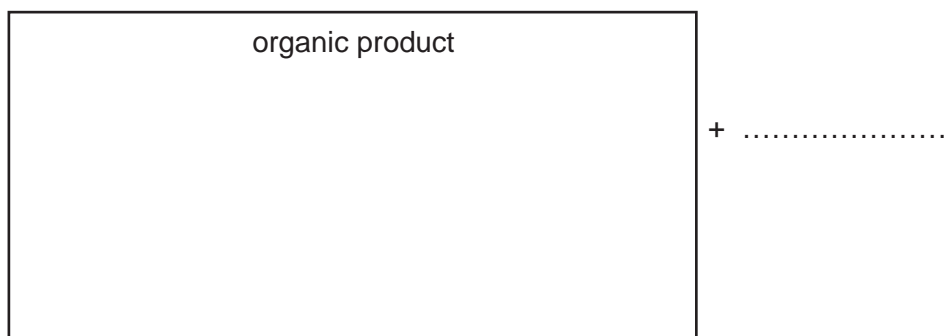
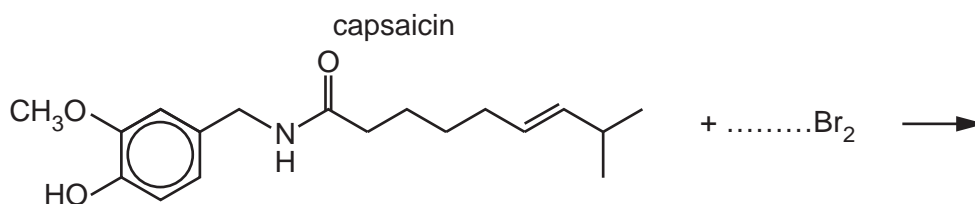
You should assume the CH_3O group is unreactive in the reactions involved in this question.

- (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:

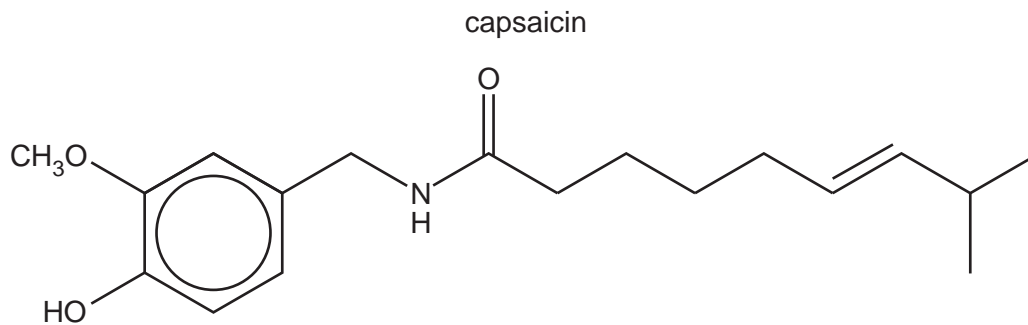
- the typical proton (^1H) chemical shift values (δ) for the protons
- the splitting pattern (singlet, doublet, triplet, quartet or multiplet) shown by each peak
- the explanation for the splitting patterns of the CH_3 protons and the CH proton.

Table 8.2

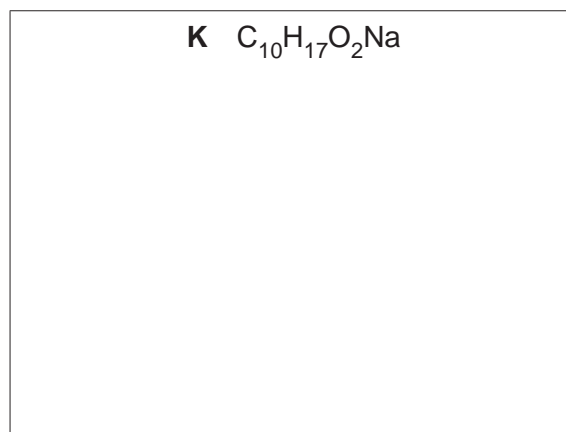
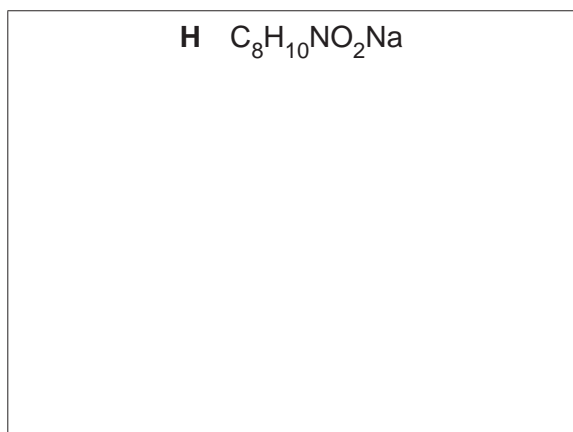
environment	δ/ppm	splitting pattern	explanation for splitting pattern
CH_3			
CH			
COOH			

[3]

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



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

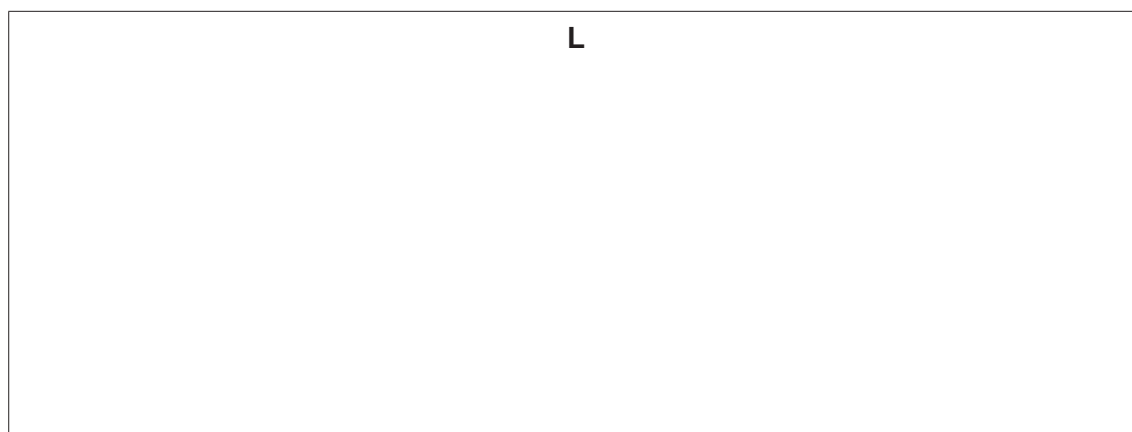


[2]

- (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.



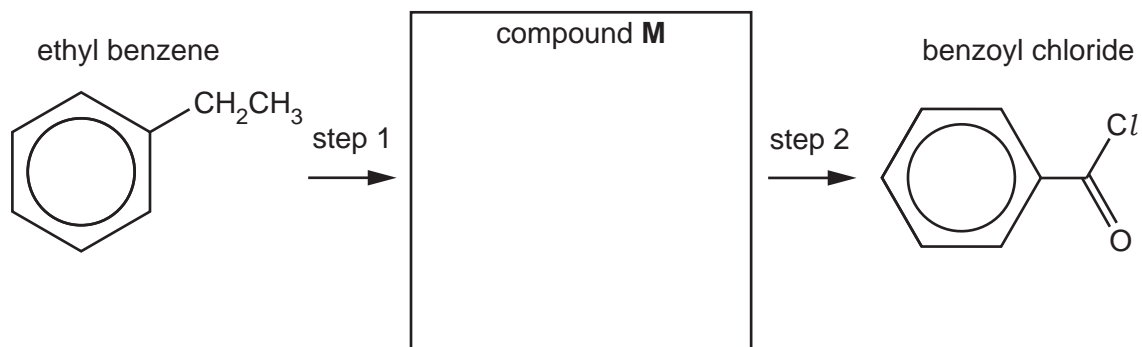
[1]

[Total: 14]

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- 9 (a) Benzoyl chloride, C_6H_5COCl , 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) C_6H_5COCl reacts with phenol, C_6H_5OH , to give the ester phenyl benzoate, $C_6H_5COOC_6H_5$.

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

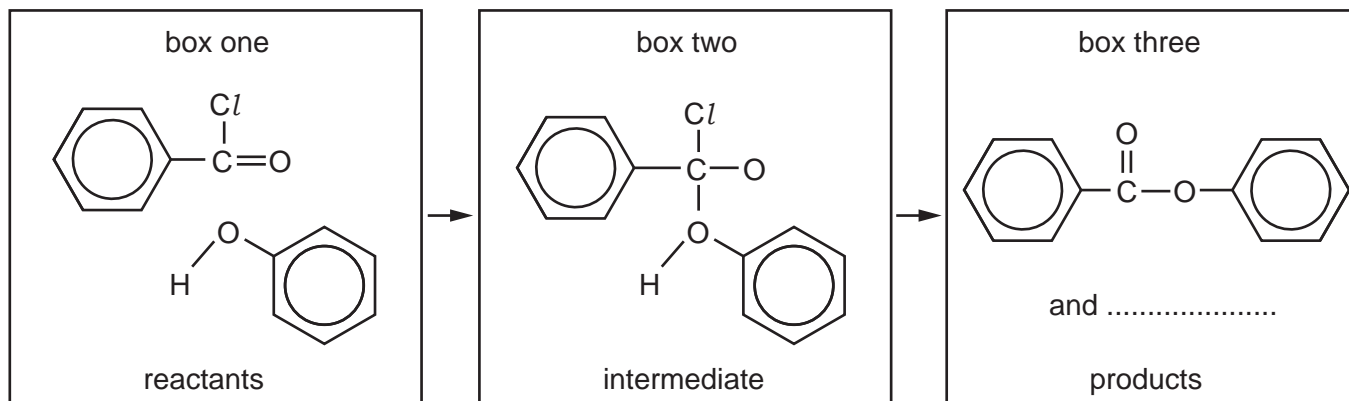


Fig. 9.1

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

- all relevant dipoles ($\delta+$ 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]

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

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	
		Key																
		atomic number																
		atomic symbol																
		name																
		relative atomic mass																
		1																
		H																
		hydrogen																
		1.0																
		2																
		4																
		Be																
		beryllium																
		9.0																
		12																
		Mg																
		magnesium																
		24.3																
		3																
		21																
		Sc																
		scandium																
		45.0																
		4																
		22																
		Ti																
		titanium																
		47.9																
		5																
		23																
		V																
		vanadium																
		50.9																
		6																
		24																
		Cr																
		chromium																
		52.0																
		7																
		25																
		Mn																
		manganese																
		54.9																
		8																
		26																
		Fe																
		iron																
		55.8																
		9																
		27																
		Co																
		cobalt																
		58.9																
		10																
		28																
		Ni																
		nickel																
		58.7																
		11																
		29																
		Cu																
		copper																
		63.5																
		12																
		30																
		Zn																
		zinc																
		65.4																
		13																
		13																
		Al																
		aluminium																
		27.0																
		14																
		14																
		Si																
		silicon																
		28.1																
		15																
		15																
		P																
		phosphorus																
		31.0																
		16																
		16																
		S																
		sulfur																
		32.1																
		17																
		17																
		Cl																
		chlorine																
		35.5																
		18																
		18																
		Ar																
		argon																
		39.9																
		19																
		20																
		Ca																
		calcium																
		40.1																
		20																
		38																
		Sr																
		strontium																
		87.6																
		21																
		57–71																
		lanthanoids																
		88.9																
		55																
		Cs																
		caesium																
		132.9																
		88																
		Ra																
		radium																
		226																
		87																
		Fr																
		francium																
		223																
		89–103																
		actinoids																
		227																
		89																
		Ac																
		actinium																
		227																
		57																
		La																
		lanthanum																
		138.9																
		58																
		Ce																
		cerium																
		140.1																
		59																
		Pr																
		praseodymium																
		140.9																
		60																
		Nd																
		neodymium																
		144.4																
		61																
		Pm																
		promethium																
		144.9																
		62																
		Sm																
		samarium																
		150.4																
		63																
		Eu																
		europium																
		152.0																
		64																
		Gd																
		gadolinium																
		157.3																
		65																
		Tb																
		terbium																
		158.9																
		66																
		Dy																
		dysprosium																
		162.5																
		67																
		Ho																
		holmium																
		164.9																
		68																
		Er																
		erbium																
		167.3																
		69																
		Tm																
		thulium																
		168.9																
		70																
		Yb																
		ytterbium																
		173.1																
		71																
		Lu																
		lutetium																
		175.0																
		103																
		Lr																
		lawrencium																
		260																

lanthanoids	57	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
	lanthanum	cerium	praseodymium	neodymium	promethium	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	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr
	actinium	thorium	protactinium	uranium	neptunium	plutonium	americium	curium	berkelium	californium	einsteinium	fermium	mendelevium	nobelium	lawrencium	
	—	232.0	231.0	238.0	—	—	—	—	—	—	—	—	—	—	—	—