



# Cambridge International AS & A Level

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**CHEMISTRY**

**9701/41**

Paper 4 A Level Structured Questions

**October/November 2023**

**2 hours**

You must answer on the question paper.

No additional materials are needed.

## INSTRUCTIONS

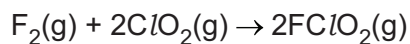
- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction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

- 1 Fluorine reacts with chlorine dioxide,  $\text{ClO}_2$ , as shown.



The rate of the reaction is first order with respect to the concentration of  $\text{F}_2$  and first order with respect to the concentration of  $\text{ClO}_2$ . No catalyst is involved.

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

step 1 →

step 2 →

[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  $\text{F}_2$  and  $\text{ClO}_2$  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  $\text{ClO}_2$ , the rate equation is as shown.

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

The half-life,  $t_{1/2}$ , of the concentration of  $\text{F}_2$  is 4.00 s under these conditions.

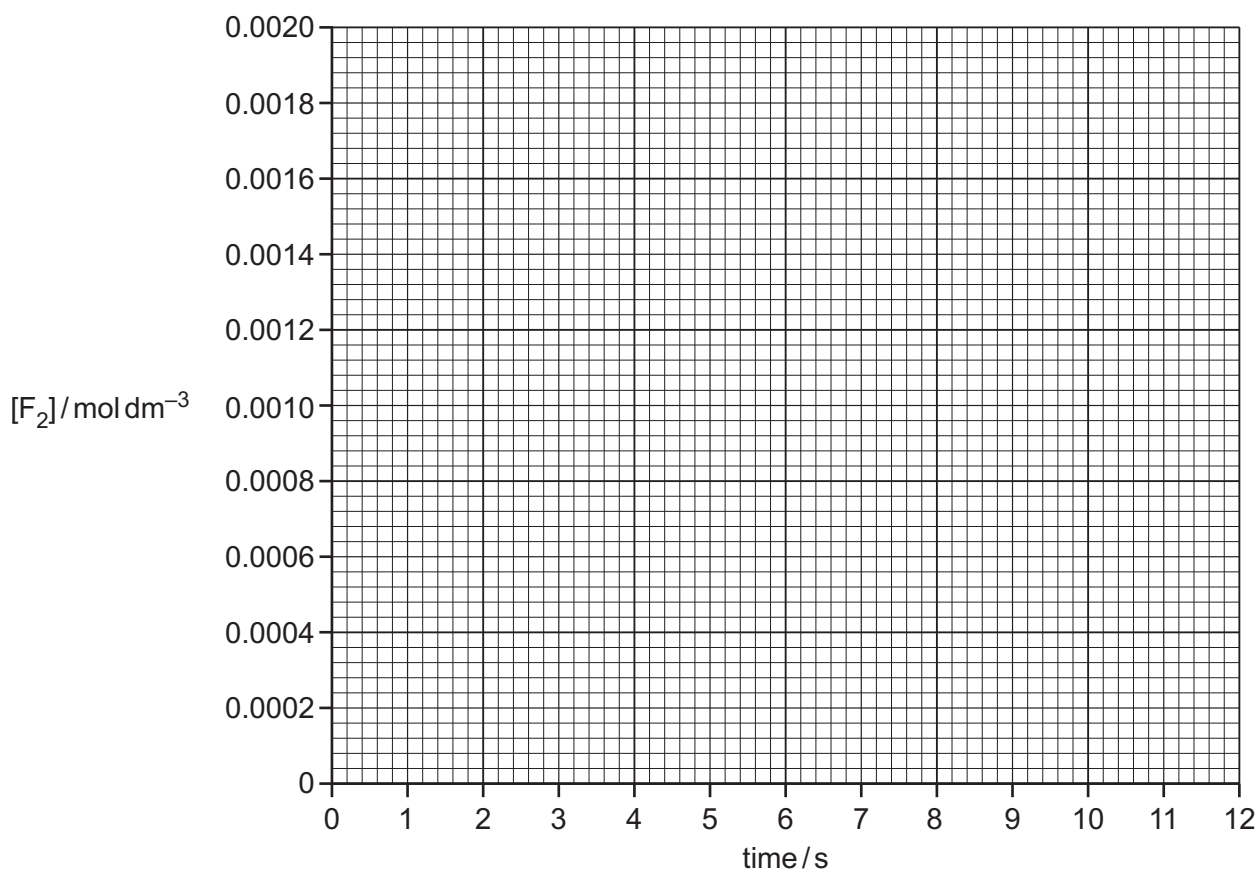
- (i) Calculate the numerical value of  $k_1$ , giving its units.

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  $\text{F}_2$  is  $0.00200 \text{ mol dm}^{-3}$ .

Draw a graph on the grid in Fig. 1.1 to show how the concentration of  $\text{F}_2$  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  $\text{F}_2$  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  $\text{HCl}$  in **V** is the same as the concentration of  $\text{NaOH}$  in **W**.
- The pH values of **V** and **W** differ by exactly 11.00 at 298 K.

- (i) Calculate the concentration of  $\text{HCl}$  in **V**.

concentration of  $\text{HCl}$  in **V** = .....  $\text{mol dm}^{-3}$  [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  $1 \text{ cm}^3$  sample of  $1.0 \text{ mol dm}^{-3} \text{ HNO}_3$  is added to  $100 \text{ cm}^3$  of solution **X**, forming mixture **Y**.

A  $1 \text{ cm}^3$  sample of  $1.0 \text{ mol dm}^{-3} \text{ KOH}$  is added to  $100 \text{ cm}^3$  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  $\text{H}_2\text{SO}_4$  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  $\text{H}_2\text{SO}_4$  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<sup>3</sup> of water and 100.0 cm<sup>3</sup> 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<sup>3</sup>

volume of hexane = ..... cm<sup>3</sup>  
 [1]

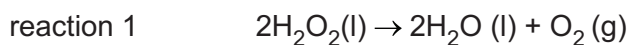
- (iv) **Q** is more soluble in hexane than it is in water.

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

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 .....

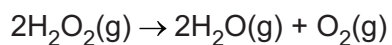
..... [1]

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

**Table 3.1**

type of bond	bond energy / $\text{kJ mol}^{-1}$
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  $-196 \text{ kJ mol}^{-1}$ .



[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.

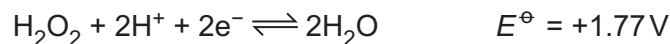
Explain your answer.

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  $\text{H}_2\text{O}_2$ , a platinum wire
- $\text{Cr}^{2+}$  mixed with  $\text{Cr}^{3+}$ , a platinum wire.

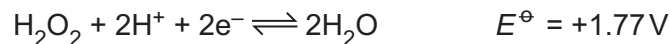
Identify the positive half-cell and calculate the standard cell potential,  $E_{\text{cell}}^\ominus$ .

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  $\text{H}_2\text{O}_2$ .

$\Delta G^\ominus = \dots\dots\dots \text{kJmol}^{-1}$  [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  $\text{H}_2\text{O}_2$  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,  $\Delta H_{\text{hyd}}^{\ominus}$ .

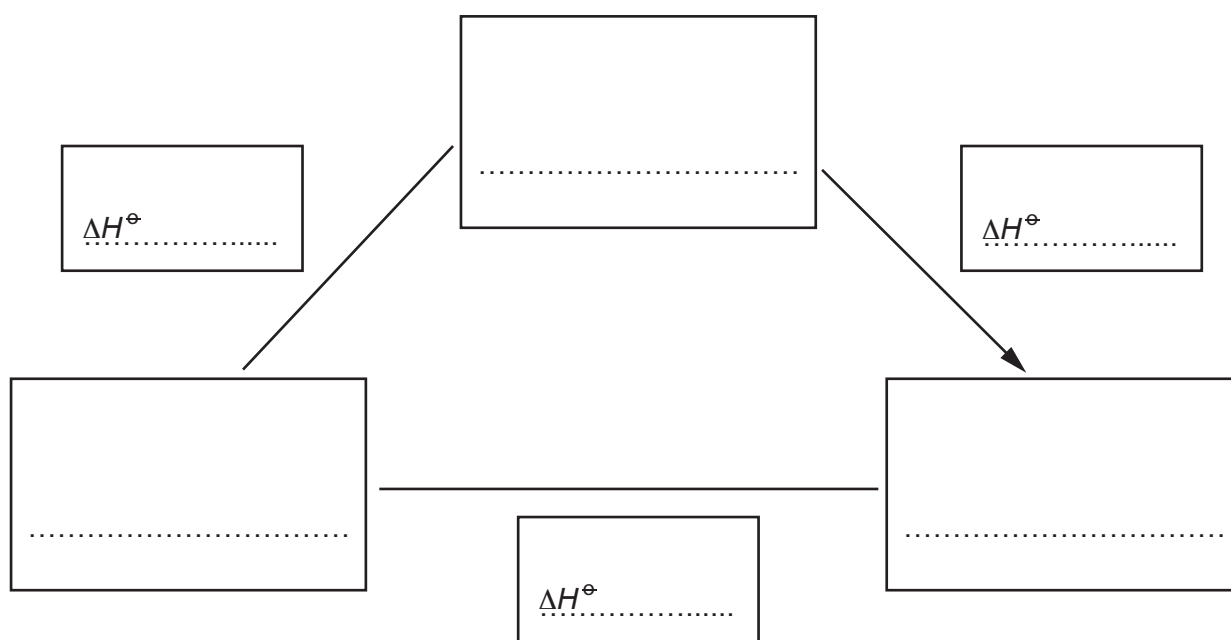
.....  
 ..... [1]

(ii) Aluminium fluoride,  $\text{AlF}_3$ , is an ionic solid.

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

- the enthalpy change of solution of  $\text{AlF}_3$ ,  $\Delta H_{\text{sol}}^{\ominus}$
- the lattice energy of  $\text{AlF}_3$ ,  $\Delta H_{\text{latt}}^{\ominus}$
- the enthalpy changes of hydration of  $\text{Al}^{3+}$  and  $\text{F}^-$ ,  $\Delta H_{\text{hyd}}^{\ominus}$ .

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  $\text{AlF}_3$ .

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

[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  $500^\circ\text{C}$ .

(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]



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

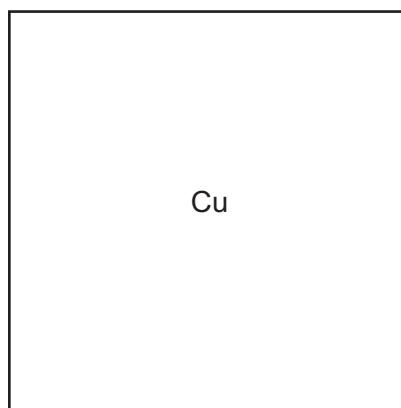
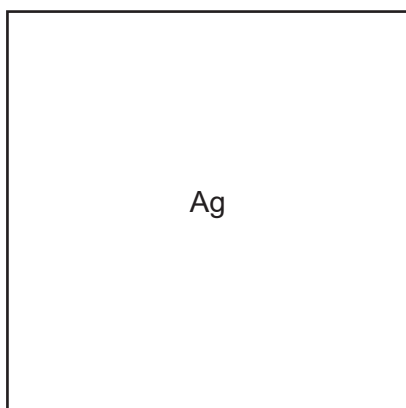
oxidation state .....

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,  $K_{\text{stab}}$ , of the copper(I) complex  $[\text{Cu}(\text{CN})_4]^{3-}$  is  $2.0 \times 10^{27}$ .

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

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

[1]

- (ii) In a solution the concentrations of  $\text{CN}^-$  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  $K_{\text{stab}}$  to calculate the concentration of  $\text{Cu}^+(\text{aq})$  in this solution.

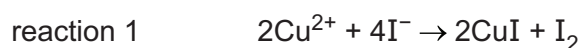
concentration of  $\text{Cu}^+(\text{aq}) = \dots\dots\dots \text{ mol dm}^{-3}$  [1]

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

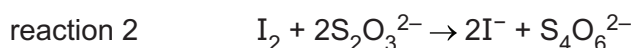
An excess of  $\text{KI}(\text{aq})$  is added to a  $25.0 \text{ cm}^3$  sample of this solution.

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

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



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



The titration requires  $20.10 \text{ cm}^3$  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  $\text{I}_2$  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  $\text{Cu}^{2+}$  is coloured but solid  $\text{CuI}$  is white.

.....  
 .....  
 ..... [2]

[Total: 12]

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

**Table 6.1**

ligand	type of ligand
$\text{NH}_3$	
$\text{EDTA}^{4-}$	
$\text{CN}^-$	
$\text{H}_2\text{NCH}_2\text{CH}_2\text{NHCH}_2\text{CH}_2\text{NH}_2$	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.

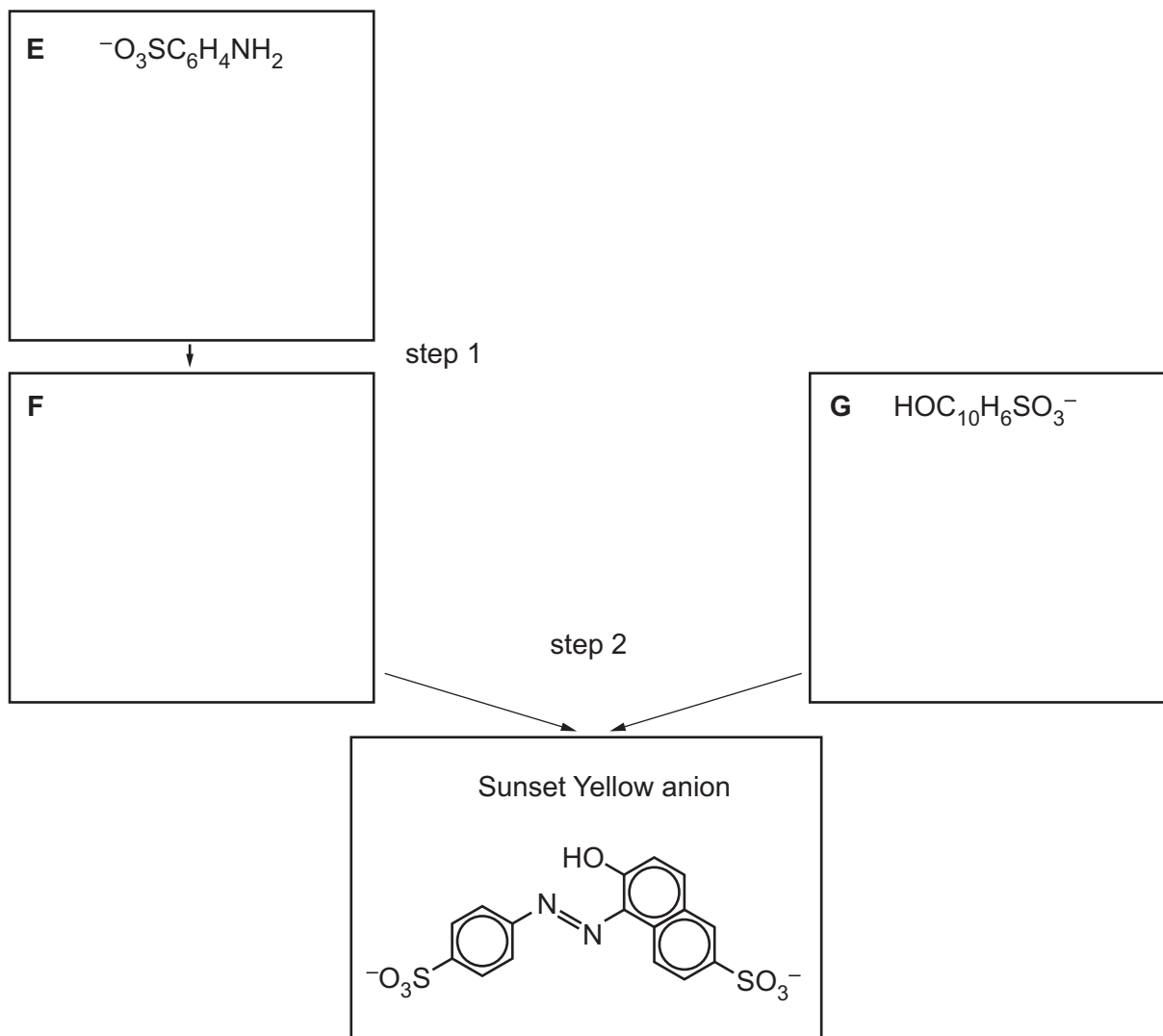


Fig. 7.1

(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 .....

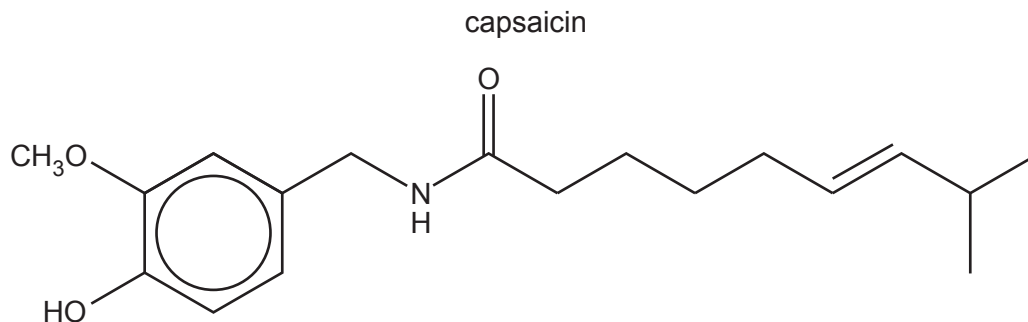
[3]

(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.



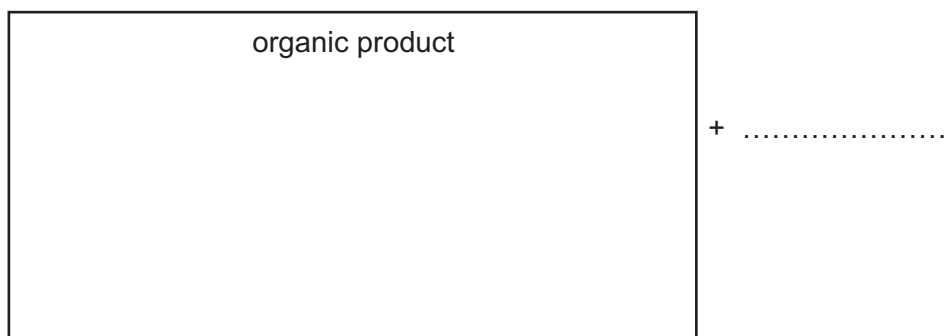
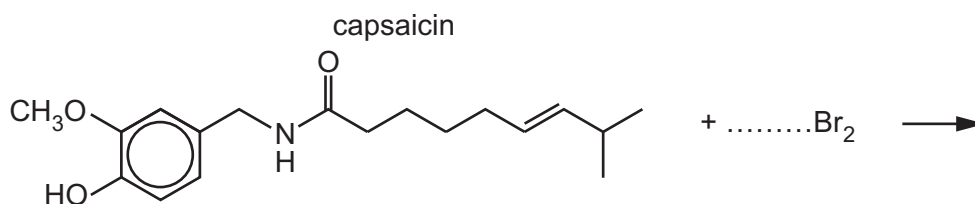
You should assume the  $\text{CH}_3\text{O}$  group is unreactive in the reactions involved in this question.

- (a) Name all the functional groups in capsaicin in addition to the  $\text{CH}_3\text{O}$  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 ( $^1\text{H}$ ) NMR spectrum of  $\text{CH}_3\text{CH}(\text{CH}_3)\text{COOH}$  in  $\text{CDCl}_3$ .

**Table 8.1**

environment of proton	example	chemical shift range $\delta/\text{ppm}$
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	$\text{CH}_3-\text{Ar}$ , $-\text{CH}_2-\text{Ar}$ , $>\text{CH}-\text{Ar}$	2.3–3.0
alkyl next to electronegative atom	$\text{CH}_3-\text{O}$ , $-\text{CH}_2-\text{O}$ , $-\text{CH}_2-\text{Cl}$	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	$\text{HCOR}$	9.3–10.5
alcohol	$\text{ROH}$	0.5–6.0
phenol	$\text{Ar}-\text{OH}$	4.5–7.0
carboxylic acid	$\text{RCOOH}$	9.0–13.0

Use Table 8.1 to complete Table 8.2 and state:

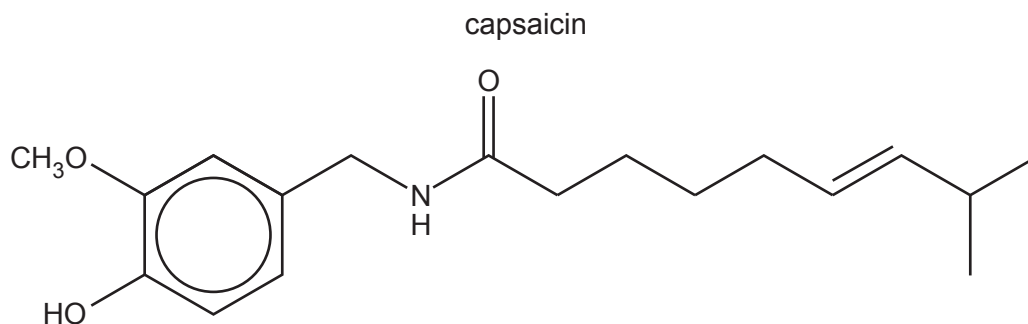
- the typical proton ( $^1\text{H}$ ) chemical shift values ( $\delta$ ) for the protons
- the splitting pattern (singlet, doublet, triplet, quartet or multiplet) shown by each peak
- the explanation for the splitting patterns of the  $\text{CH}_3$  protons and the  $\text{CH}$  proton.

**Table 8.2**

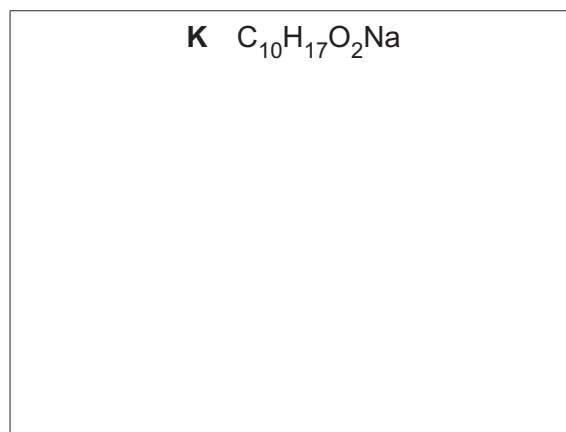
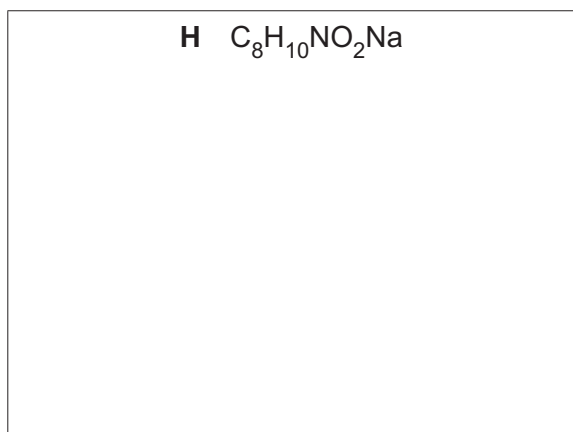
environment	$\delta/\text{ppm}$	splitting pattern	explanation for splitting pattern
$\text{CH}_3$			
$\text{CH}$			
$\text{COOH}$			

[3]

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



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

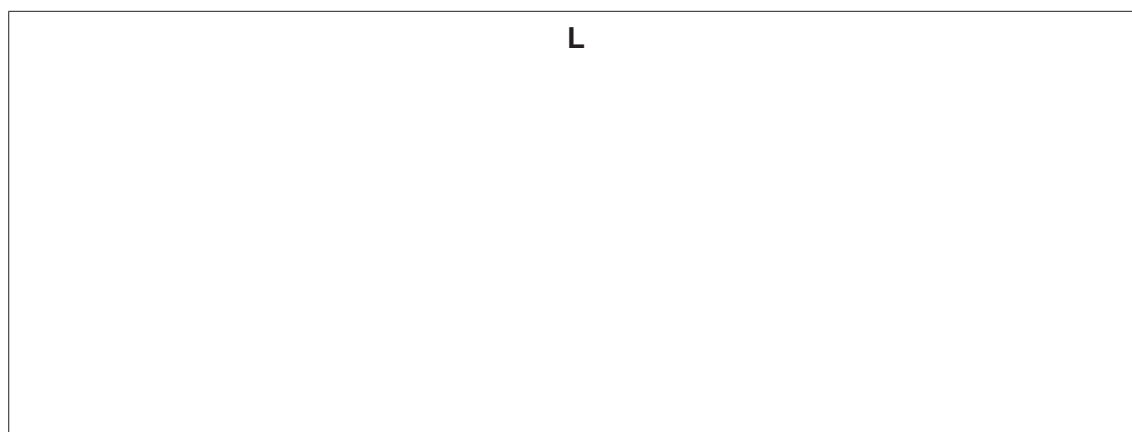


[2]

- (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.



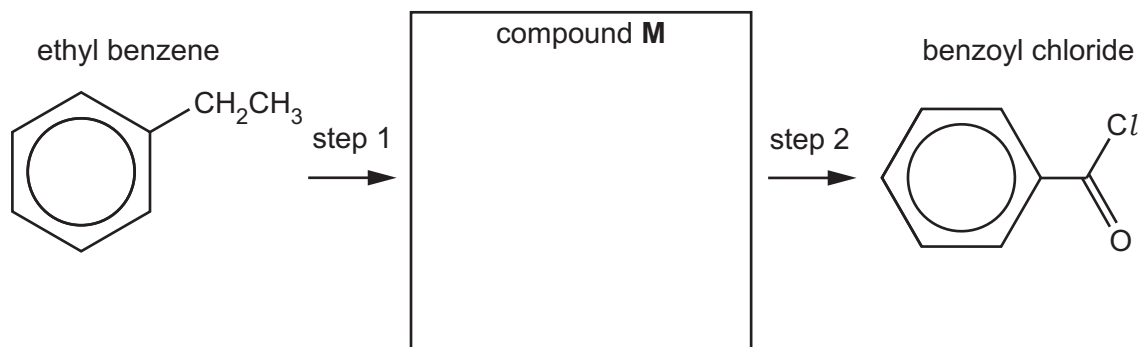
[1]

[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.

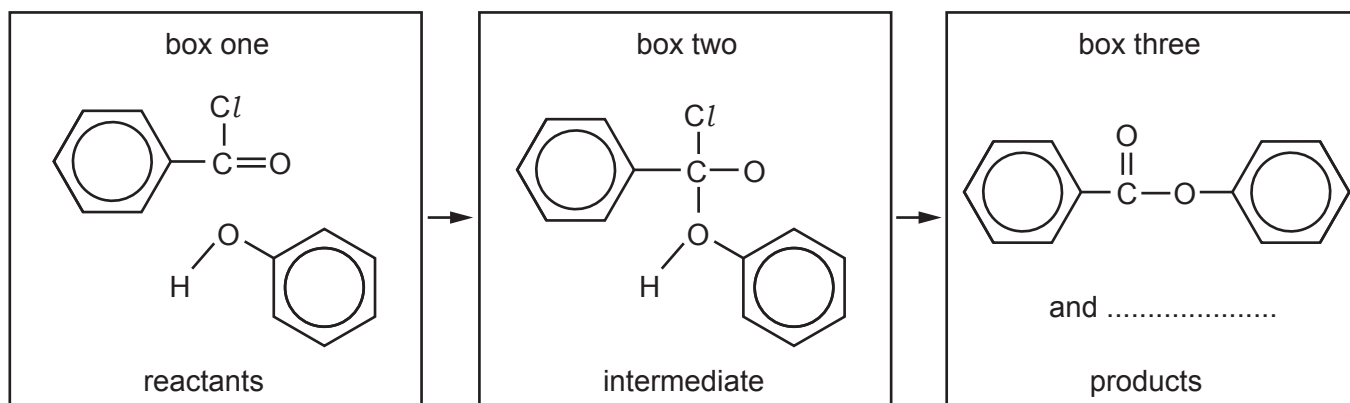


Fig. 9.1

(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 <sup>-1</sup> K <sup>-1</sup> )

The Periodic Table of Elements

Group																		
1	2	13	14	15	16	17	18											
		<b>1</b>	<b>H</b>															<b>2</b>
			hydrogen															helium
			1.0															4.0
<b>Key</b>																		
atomic number																		
atomic symbol																		
name																		
relative atomic mass																		
	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>	<b>12</b>	<b>13</b>	<b>14</b>	<b>15</b>	<b>16</b>	<b>17</b>	<b>18</b>	<b>2</b>	
	<b>Li</b>	<b>Be</b>															<b>Ne</b>	
	lithium	beryllium															neon	
	6.9	9.0															20.2	
	<b>11</b>	<b>12</b>															<b>18</b>	
	<b>Na</b>	<b>Mg</b>															<b>Ar</b>	
	sodium	magnesium															argon	
	23.0	24.3															39.9	
	<b>19</b>	<b>20</b>	<b>21</b>	<b>22</b>	<b>23</b>	<b>24</b>	<b>25</b>	<b>26</b>	<b>27</b>	<b>28</b>	<b>29</b>	<b>30</b>	<b>31</b>	<b>32</b>	<b>33</b>	<b>34</b>	<b>35</b>	<b>36</b>
	<b>K</b>	<b>Ca</b>	<b>Sc</b>	<b>Ti</b>	<b>V</b>	<b>Cr</b>	<b>Mn</b>	<b>Fe</b>	<b>Co</b>	<b>Ni</b>	<b>Cu</b>	<b>Zn</b>	<b>Ga</b>	<b>Ge</b>	<b>As</b>	<b>Se</b>	<b>Br</b>	<b>Kr</b>
	potassium	calcium	scandium	titanium	vanadium	chromium	manganese	iron	cobalt	nickel	copper	zinc	gallium	germanium	arsenic	selenium	bromine	krypton
	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
	<b>37</b>	<b>38</b>	<b>39</b>	<b>40</b>	<b>41</b>	<b>42</b>	<b>43</b>	<b>44</b>	<b>45</b>	<b>46</b>	<b>47</b>	<b>48</b>	<b>49</b>	<b>50</b>	<b>51</b>	<b>52</b>	<b>53</b>	<b>54</b>
	<b>Rb</b>	<b>Sr</b>	<b>Y</b>	<b>Zr</b>	<b>Nb</b>	<b>Mo</b>	<b>Tc</b>	<b>Ru</b>	<b>Rh</b>	<b>Pd</b>	<b>Ag</b>	<b>Cd</b>	<b>In</b>	<b>Sn</b>	<b>Sb</b>	<b>Te</b>	<b>I</b>	<b>Xe</b>
	rubidium	strontium	yttrium	zirconium	niobium	molybdenum	technetium	ruthenium	rhodium	palladium	silver	cadmium	indium	tin	antimony	tellurium	iodine	xenon
	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	121.8	127.6	126.9	131.3
	<b>55</b>	<b>56</b>	<b>57–71</b>	<b>72</b>	<b>73</b>	<b>74</b>	<b>75</b>	<b>76</b>	<b>77</b>	<b>78</b>	<b>79</b>	<b>80</b>	<b>81</b>	<b>82</b>	<b>83</b>	<b>84</b>	<b>85</b>	<b>86</b>
	<b>Cs</b>	<b>Ba</b>	lanthanoids	<b>Hf</b>	<b>Ta</b>	<b>W</b>	<b>Re</b>	<b>Os</b>	<b>Ir</b>	<b>Pt</b>	<b>Au</b>	<b>Hg</b>	<b>Tl</b>	<b>Pb</b>	<b>Bi</b>	<b>Po</b>	<b>At</b>	<b>Rn</b>
	caesium	barium		hafnium	tantalum	tungsten	rhenium	osmium	iridium	platinum	gold	mercury	thallium	lead	bismuth	polonium	astatine	radon
	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	—	—	—
	<b>87</b>	<b>88</b>	<b>89–103</b>	<b>104</b>	<b>105</b>	<b>106</b>	<b>107</b>	<b>108</b>	<b>109</b>	<b>110</b>	<b>111</b>	<b>112</b>	<b>113</b>	<b>114</b>	<b>115</b>	<b>116</b>	<b>117</b>	<b>118</b>
	<b>Fr</b>	<b>Ra</b>	actinoids	<b>Rf</b>	<b>Db</b>	<b>Sg</b>	<b>Bh</b>	<b>Hs</b>	<b>Mt</b>	<b>Ds</b>	<b>Rg</b>	<b>Cn</b>	<b>Nh</b>	<b>Fl</b>	<b>Mc</b>	<b>Lv</b>	<b>Ts</b>	<b>Og</b>
	francium	radium		rutherfordium	dubnium	seaborgium	bohrium	hassium	meitnerium	darmstadtium	roentgenium	coppernium	nihonium	flerovium	moscovium	livermorium	tennessine	oganesson
	—	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

lanthanoids		<b>57</b>	<b>La</b>	<b>Ce</b>	<b>Pr</b>	<b>Nd</b>	<b>Pm</b>	<b>Sm</b>	<b>Eu</b>	<b>Gd</b>	<b>Tb</b>	<b>Dy</b>	<b>Ho</b>	<b>Er</b>	<b>Tm</b>	<b>Yb</b>	<b>Lu</b>
		lanthanum	cerium	praseodymium	neodymium	europium	gadolinium	terbium	dysprosium	holmium	erbium	thulium	ytterbium	lutetium			
		138.9	140.1	140.9	144.4	152.0	157.3	158.9	162.5	164.9	167.3	168.9	173.1	175.0			
actinoids		<b>89</b>	<b>Ac</b>	<b>Th</b>	<b>Pa</b>	<b>U</b>	<b>Np</b>	<b>Pu</b>	<b>Am</b>	<b>Cm</b>	<b>Bk</b>	<b>Cf</b>	<b>Es</b>	<b>Fm</b>	<b>Md</b>	<b>No</b>	<b>Lr</b>
		actinium	thorium	protactinium	uranium	neptunium	plutonium	americium	curium	berkelium	californium	einsteinium	fermium	mendeleevium	nobelium	lawrencium	
		—	232.0	231.0	238.0	—	—	—	—	—	—	—	—	—	—	—	—

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