



eduresourceza.com

--

--	--	--	--	--

--	--	--	--

9701/41

October/November 2023

2 hours

You must answer on the question paper.

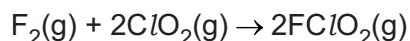
No additional materials are needed.

- 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.

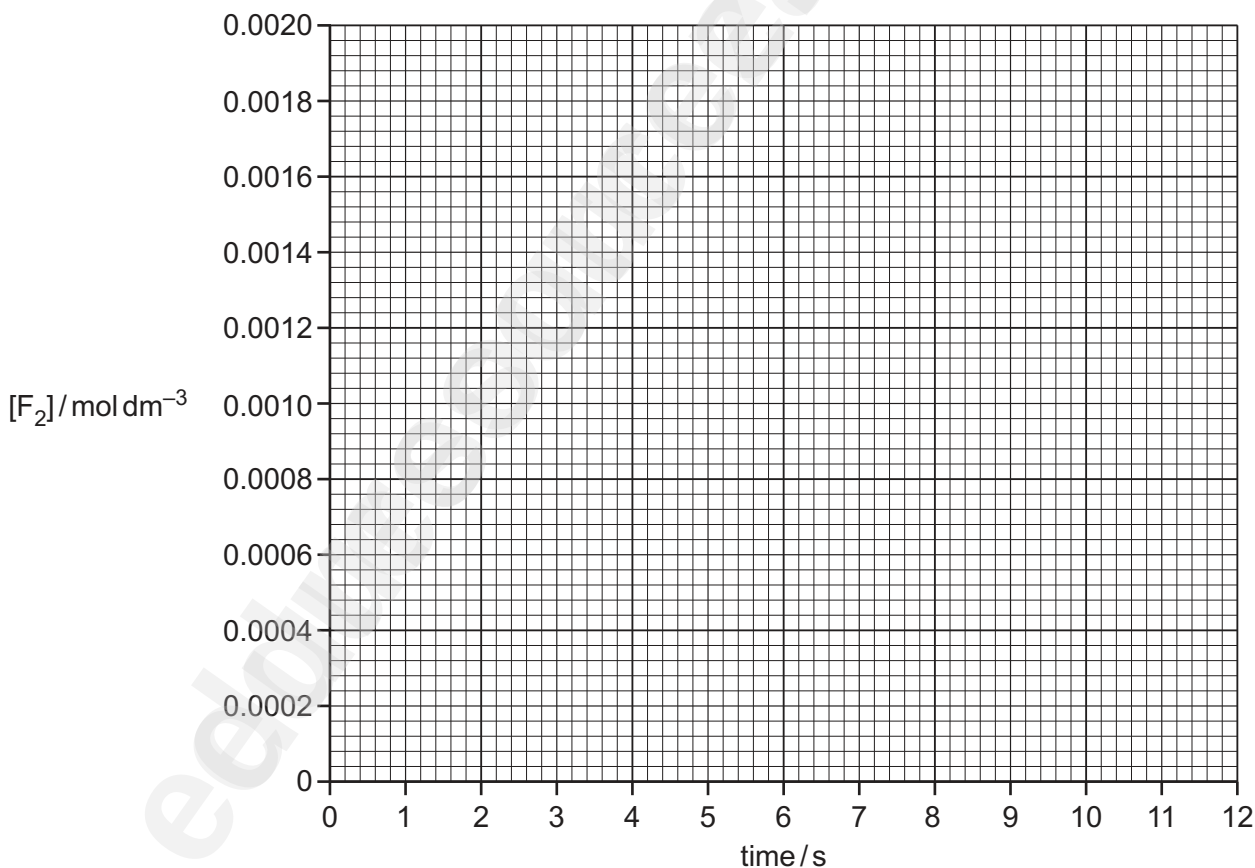


Fig. 1.1

[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]

[Turn over]

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

$K_w =$ [1]

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

- **V** is HCl(aq) .
- **W** is NaOH(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 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]

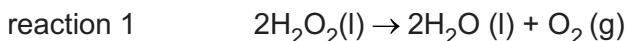
- (iv) **Q** is more soluble in hexane than it is in water.

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

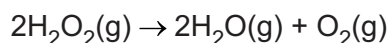
explanation
 [1]

- (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} .



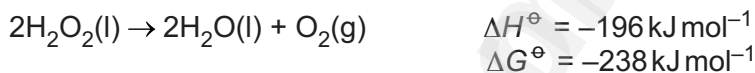
[1]

- (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.

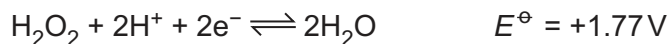
Explain your answer.

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, $E_{\text{cell}}^\ominus$.

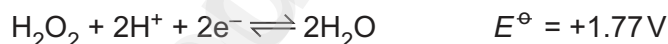
positive half-cell $E_{\text{cell}}^\ominus = \dots\dots\dots \text{V}$

[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} .

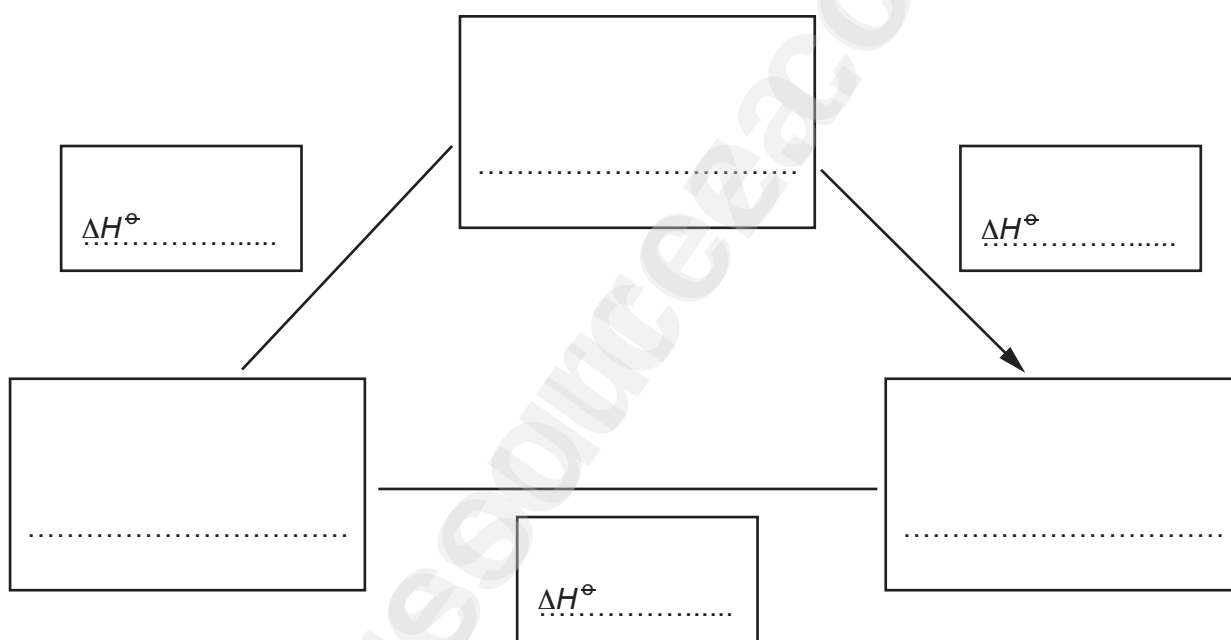
.....
 [1]

(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]

BLANK PAGE

eduresourceza.com

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

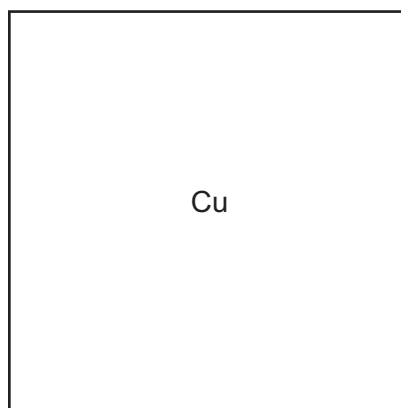
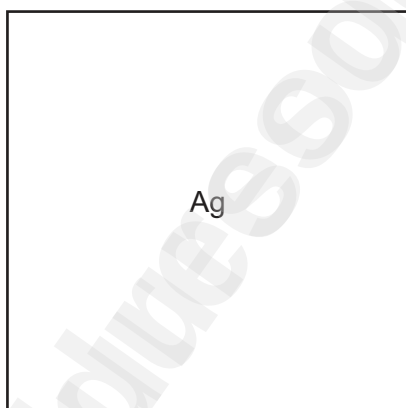
oxidation state

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.

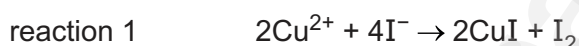
concentration of $\text{Cu}^+(\text{aq}) = \dots\dots\dots \text{mol dm}^{-3}$ [1]

- (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.

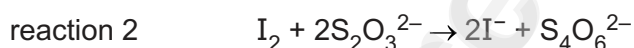
An excess of $\text{KI}(\text{aq})$ is added to a 25.0 cm^3 sample of this solution.

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.

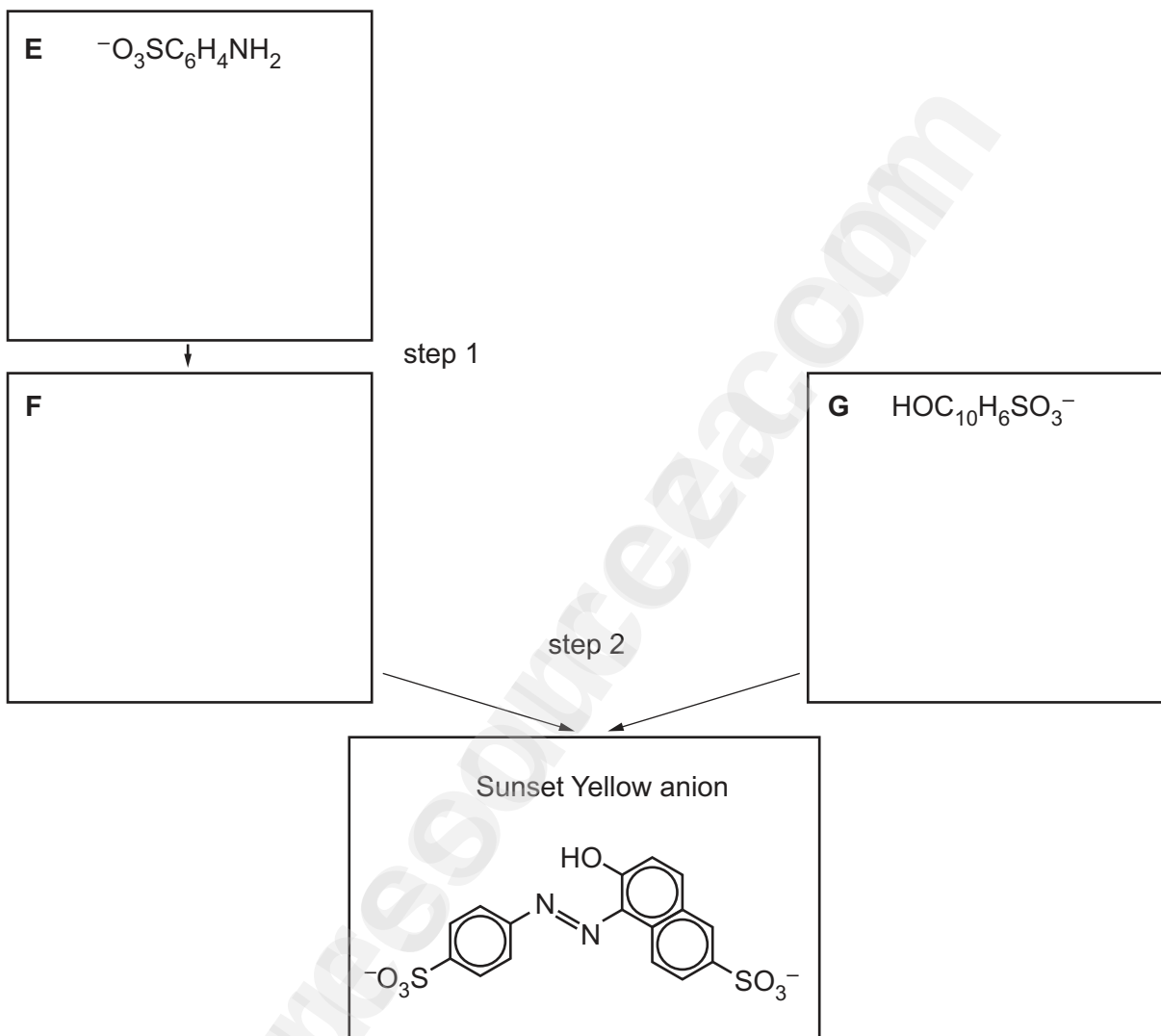


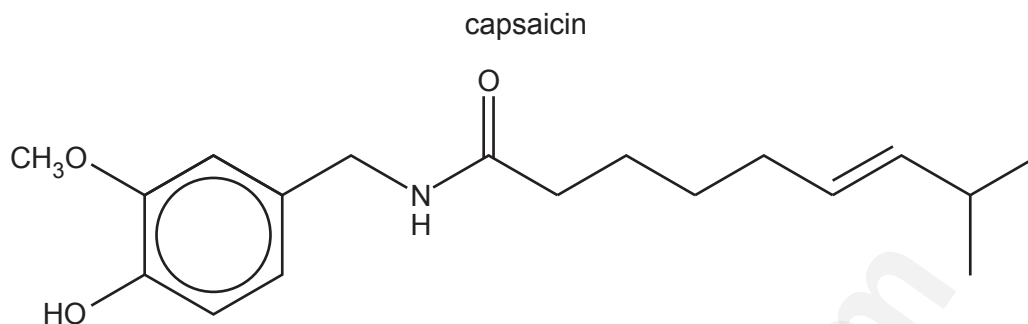
Fig. 7.1

- (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]

[Turn over]

- 8 Capsaicin is found in chilli peppers.



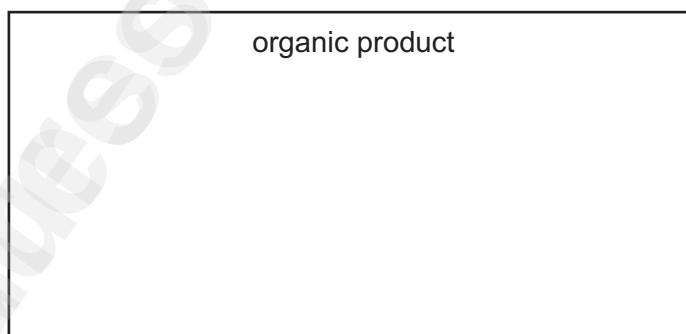
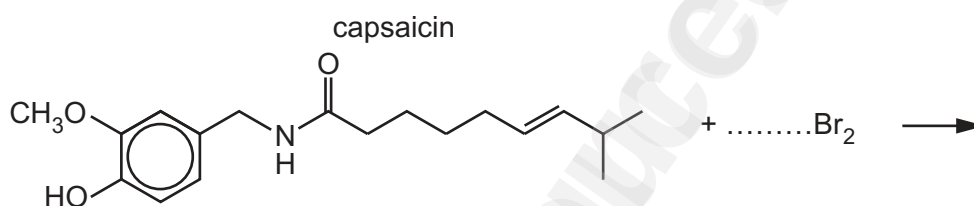
You should assume the CH_3O group is unreactive in the reactions involved in this question.

- (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.

(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:

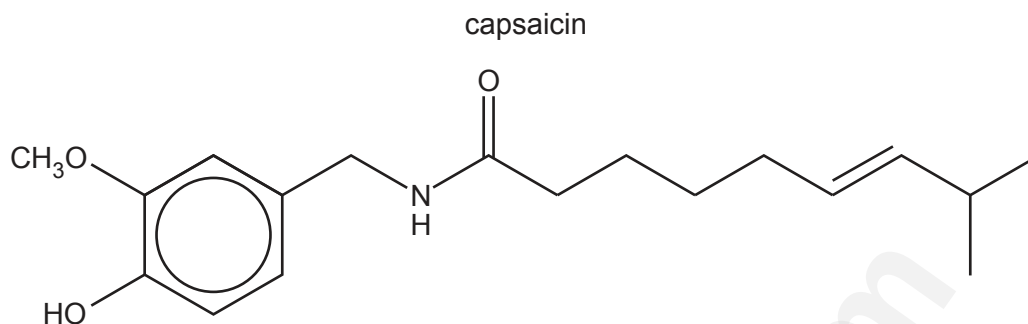
- the typical proton (^1H) chemical shift values (δ) for the protons
- the splitting pattern (singlet, doublet, triplet, quartet or multiplet) shown by each peak
- the explanation for the splitting patterns of the CH_3 protons and the CH proton.

Table 8.2

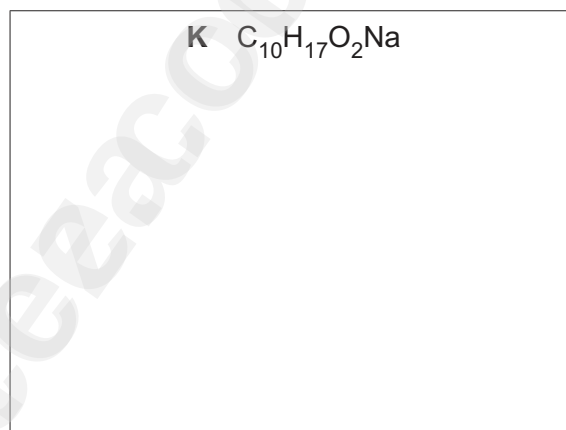
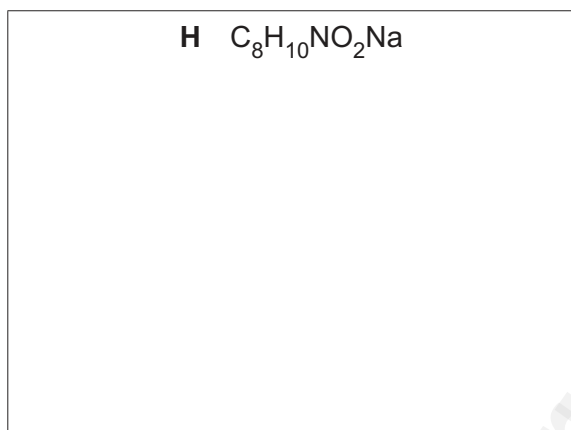
environment	δ/ppm	splitting pattern	explanation for splitting pattern
CH_3			
CH			
COOH			

[3]

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



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

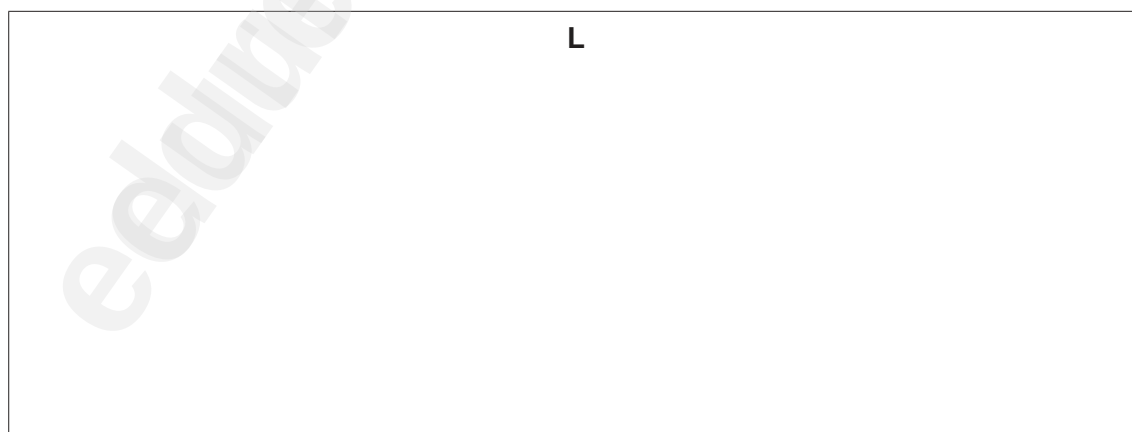


[2]

- (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]

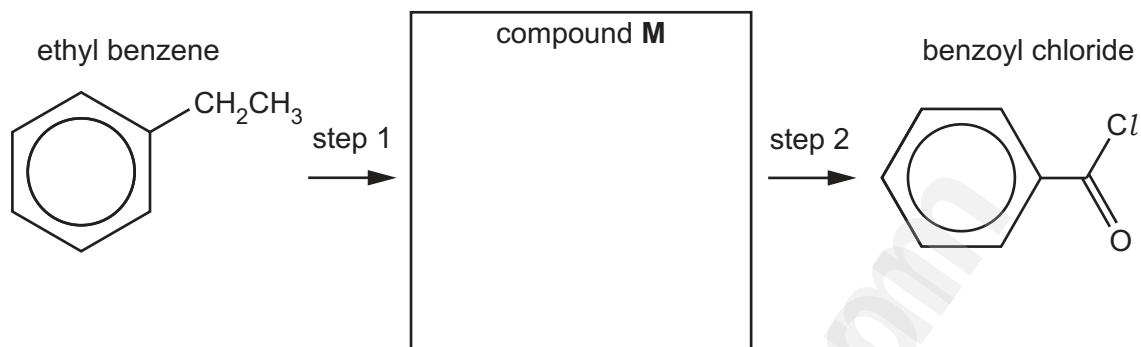
[Total: 14]

BLANK PAGE

eduresourceza.com

- 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.

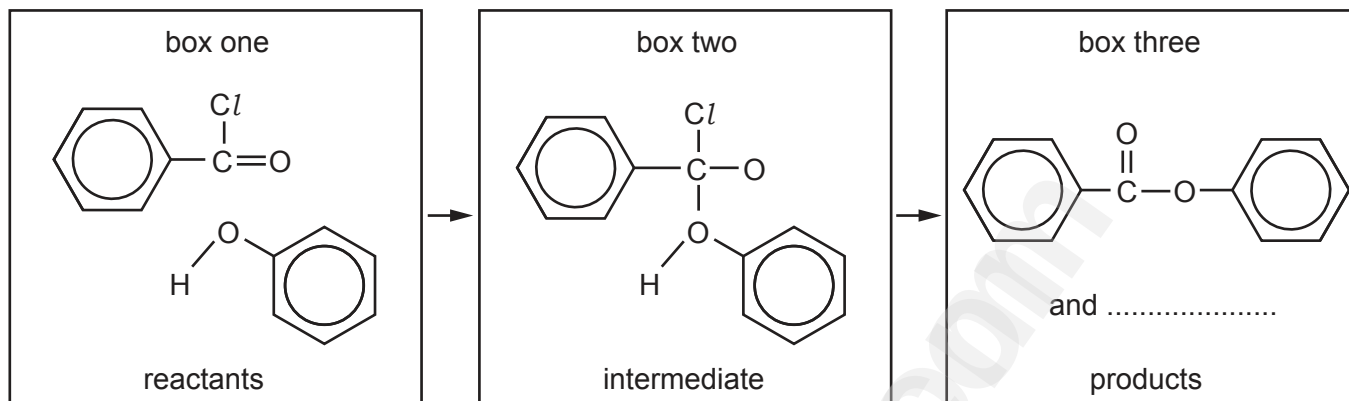


Fig. 9.1

(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]

BLANK PAGE

eduresourceza.com

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	1 H hydrogen 1.0														17	18																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		
		Key																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
3	4	atomic number atomic symbol name relative atomic mass																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
Li lithium 6.9	Be beryllium 9.0	11	12	13	14	15	16	17	18	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	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	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000
Li lithium 6.9	Be beryllium 9.0	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	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	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	Cs caesium 132.9	Ba barium 137.3	La lanthanoids —	Hf hafnium 178.5	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 —	Fr francium —	Ra radium —	Ac actinoids —	Rf rutherfordium —	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 oganeson —																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		

lanthanoids	57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.4	61 Pm promethium —	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.1	71 Lu lutetium 175.0
	89 Ac actinium —	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium —	94 Pu plutonium —	95 Am americium —	96 Cm curium —	97 Bk berkelium —	98 Cf californium —	99 Es einsteinium —	100 Fm fermium —	101 Md mendelevium —	102 No nobelium —	103 Lr lawrencium —