

CANDIDATE
NAME

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CENTRE
NUMBER

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CANDIDATE
NUMBER

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9701/21

October/November 2022

1 hour 15 minutes

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 60.
- 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 **16** pages.

- 1 Atoms with nuclei containing an odd number of protons tend to have fewer isotopes than those with an even number of protons.

(a) Gallium has two stable isotopes, ^{69}Ga and ^{71}Ga .

- (i) Complete Table 1.1 to show the numbers of protons, neutrons and electrons in the two stable isotopes of gallium.

Table 1.1

isotope	number of protons	number of neutrons	number of electrons
^{69}Ga			
^{71}Ga			

[2]

- (ii) Define relative atomic mass.

.....

.....

..... [2]

- (iii) The relative atomic mass of gallium, A_r , is 69.723.
The relative isotopic masses of ^{69}Ga and ^{71}Ga are:

^{69}Ga , 68.926; ^{71}Ga , 70.925.

Use this information to calculate the percentage abundance of ^{69}Ga in elemental gallium.
Show your working.

Assume that the element contains only the ^{69}Ga and ^{71}Ga isotopes.
Give your answer to **four** significant figures.

percentage abundance of ^{69}Ga = ... %
[2]

(b) Potassium also has two stable isotopes. Both isotopes have the same chemical properties.

(i) Explain why both isotopes of potassium have the same chemical properties.

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

(ii) State the full electronic configuration of an atom of potassium.

..... [1]

(iii) The first, second and third ionisation energies of potassium are 418, 3070 and 4600 kJ mol⁻¹, respectively.

Use this information to explain why potassium is in Group 1.

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

[Total: 10]

2 Magnesium shows reactions typical of a Group 2 metal.

(a) Draw a labelled diagram to show the bonding in magnesium metal.

[2]

(b) Fig. 2.1 shows some reactions of magnesium and its compounds.

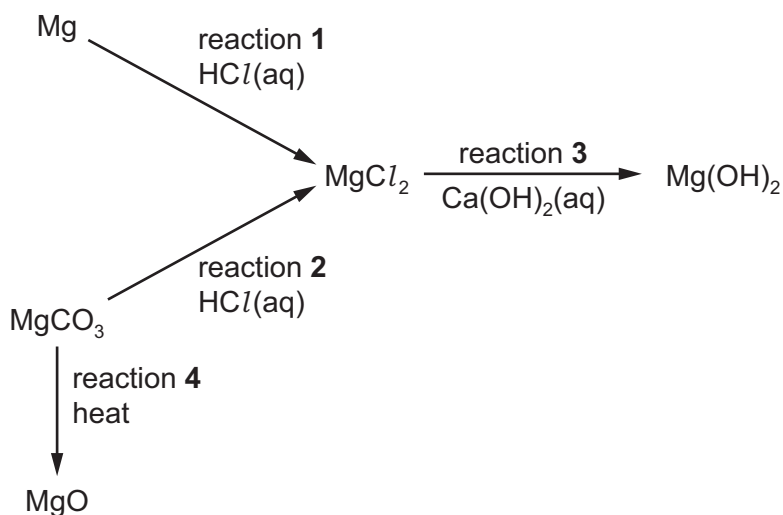


Fig. 2.1

(i) Identify the other products of reactions 1 and 2.

reaction 1

reaction 2 [2]

(ii) Reaction 3 is used to form a precipitate of Mg(OH)₂ from MgCl₂(aq).

State why Ca(OH)₂(aq) would **not** form a precipitate of Ba(OH)₂ from BaCl₂(aq).

.....

..... [1]

(iii) State the type of reaction that occurs in reaction 4.

..... [1]

- (c) 1 cm^3 of $\text{MgCl}_2(\text{aq})$ is placed in a test-tube. A few drops of $\text{AgNO}_3(\text{aq})$ are added, followed by 1 cm^3 of dilute $\text{NH}_3(\text{aq})$.

State in full what is observed in this experiment.

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

- (d) When 1 cm^3 of $\text{MgCl}_2(\text{aq})$ is added to 1 cm^3 of $\text{Br}_2(\text{aq})$ in a test-tube, the solution remains orange.

Explain this observation.

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

[Total: 9]

3 Some of the common chlorides of Period 3 elements are shown in the list.



(a) From this list, identify:

(i) all the chlorides that have giant ionic structures in the solid state

..... [1]

(ii) all the chlorides that react vigorously with water to form strongly acidic solutions

..... [1]

(iii) the chloride that dissolves in water to form a neutral solution

..... [1]

(iv) the chloride formed from the **element** with the highest melting point.

..... [1]

(b) NaCl is one product of the reaction of chlorine gas and cold aqueous sodium hydroxide.

Identify the other products.

..... [1]

(c) PCl_5 reacts with alcohols to form chloroalkanes.

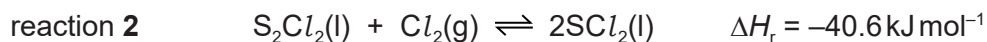
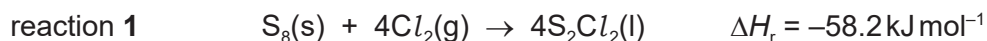
(i) Identify this type of reaction.

..... [1]

(ii) Draw the structure of the organic product formed in the reaction of an excess of PCl_5 with butane-1,3-diol.

[1]

- (d) Sulfur, S_8 , reacts with chlorine to form several different chlorides. The most common are S_2Cl_2 and SCl_2 . SCl_2 forms when sulfur reacts with an excess of chlorine.



- (i) SCl_2 is a cherry-red liquid that reacts vigorously with water to form an acidic solution.

Use this information to deduce the bonding and structure shown by SCl_2 .
Explain your answer.

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

- (ii) Calculate the enthalpy change of formation, ΔH_f , of $SCl_2(l)$. You may find it useful to use Hess's Law to construct an energy cycle.

enthalpy change of formation of $SCl_2(l)$, $\Delta H_f = \dots\dots\dots \text{ kJ mol}^{-1}$
[2]

- (iii) State the effect of a decrease in pressure on the position of equilibrium in reaction 2.
Explain your answer.

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

Fig. 3.1 shows the two structural isomers of S_2Cl_2 .

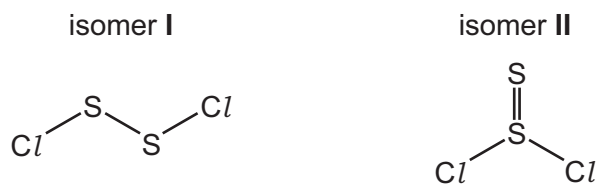


Fig. 3.1

(iv) Define the term structural isomer.

.....
 [2]

(v) Suggest a value for the Cl-S-S bond angle in isomer I. Explain your answer.

bond angle = ... $^{\circ}$

explanation

 [2]

(vi) Draw a dot-and-cross diagram to show the bonding in isomer II. Show outer shell electrons only.

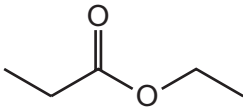
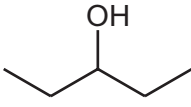
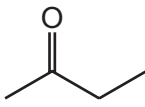
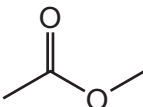
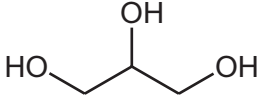
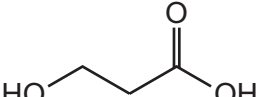
[2]

[Total: 18]

Question 4 starts on the next page.

- 4 Organic compounds can be distinguished using chemical tests. Table 4.1 shows four pairs of compounds.

Table 4.1

organic compounds		reagent	positive result of chemical test on identified compound
A1 	A2 		
B1 	B2 		
C1 	C2 		
D1 	D2 		

(a) Complete Table 4.1 to:

- identify a reagent that could distinguish between the compounds in each pair
- give the **positive** result of the chemical test **and** identify which compound shows this result.

Use a different reagent for each test.

[8]

(b) **C1** has melting point -94°C and boiling point $+49^{\circ}\text{C}$.

Explain these properties by referring to the type of van der Waals' forces between molecules.

.....

.....

..... [2]

(c) Draw the structure of the cis isomer of **C2**.

[1]

(d) **C2** forms a polymer when heated gently.

(i) Identify the type of polymer that forms from **C2**.

..... [1]

(ii) Draw one repeat unit of the polymer formed from **C2**.

[2]

[Total: 14]

- 5 Lactones are cyclic esters. Under suitable conditions, lactones form from molecules that have both an alcohol and a carboxylic acid functional group.
Equation 1 shows an example of the formation of a lactone.

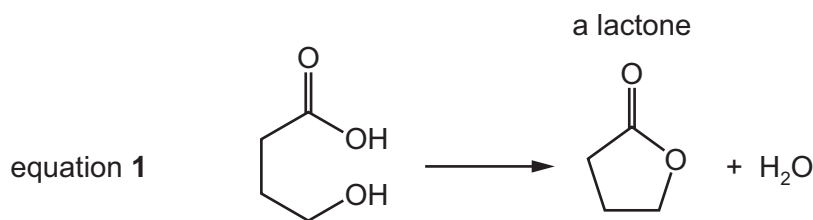


Fig. 5.1 shows the synthesis of lactone **P** from compound **M**.

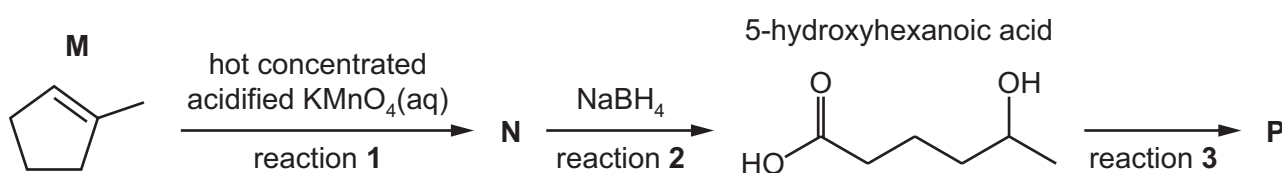


Fig. 5.1

- (a) (i) **M** reacts with hot concentrated acidified $\text{KMnO}_4(\text{aq})$ to form **N**, $\text{C}_6\text{H}_{10}\text{O}_3$, in reaction 1.

Draw the structure of **N**.

[1]

- (ii) **N** is reduced by NaBH_4 to form 5-hydroxyhexanoic acid in reaction 2.

Construct an equation for reaction 2 using molecular formulae.

In the equation, use $[\text{H}]$ to represent one atom of hydrogen from the reducing agent.

..... [1]

- (iii) Reaction 2 is a nucleophilic addition.

Suggest why reaction 2 creates a mixture of two organic compounds.

.....

..... [2]

(iv) Draw lactone **P**, the product of reaction **3**.

[1]

(b) A student monitors the progress of reaction **2** using infrared spectroscopy.

Use Table 5.1 to suggest why it is difficult to distinguish between **N** and 5-hydroxyhexanoic acid using infrared spectroscopy.

.....

..... [2]

Table 5.1

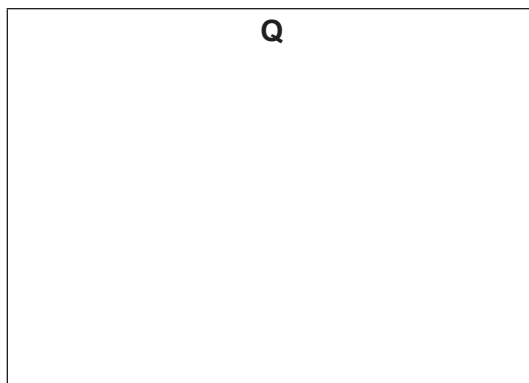
bond	functional group containing the bond	characteristic infrared absorption range (in wavenumbers)/cm ⁻¹
C–O	hydroxy, ester	1040–1300
C=C	aromatic compound, alkene	1500–1680
C=O	amide carbonyl, carboxyl ester	1640–1690 1670–1740 1710–1750
C≡N	nitrile	2200–2250
C–H	alkane	2850–3100
N–H	amine, amide	3300–3500
O–H	carboxyl hydroxy	2500–3000 3200–3650

- (c) Unknown lactone **Q** is analysed using mass spectrometry. Table 5.2 shows information from the mass spectrum.

Table 5.2

peak	m/e	abundance
M+	72	95.5
M+1	73	3.15

Use these data to deduce the structure of **Q**.
Show your working.



[2]

[Total: 9]

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

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NAME

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1 Species such as NH_4^+ , CO_3^{2-} and PO_4^{3-} are examples of molecular ions.

(a) Ionic and covalent bonds both involve an electrostatic attraction between different species.

Identify the species that are electrostatically attracted to one another in:

- an ionic bond

.....

- a covalent bond.

.....

[2]

(b) Complete Table 1.1 to show the total numbers of protons and electrons in the molecular ions NH_4^+ , CO_3^{2-} and PO_4^{3-} .

Table 1.1

molecular ion	total number of protons	total number of electrons
NH_4^+		
CO_3^{2-}		
PO_4^{3-}		

[3]

(c) NH_4^+ is a Brønsted–Lowry acid.

(i) Define Brønsted–Lowry acid.

.....

..... [1]

(ii) When $\text{NH}_4^+(\text{aq})$ is heated with $\text{NaOH}(\text{aq})$, a pungent gas is produced.

Write an ionic equation for this reaction.

..... [1]

- (iii) The nitrogen atom in NH_4^+ is sp^3 hybridised. sp^3 orbitals form from the mixing of one 2s and three 2p orbitals.

Sketch the shapes of a 2s and a 2p_x orbital on the axes in Fig. 1.1.

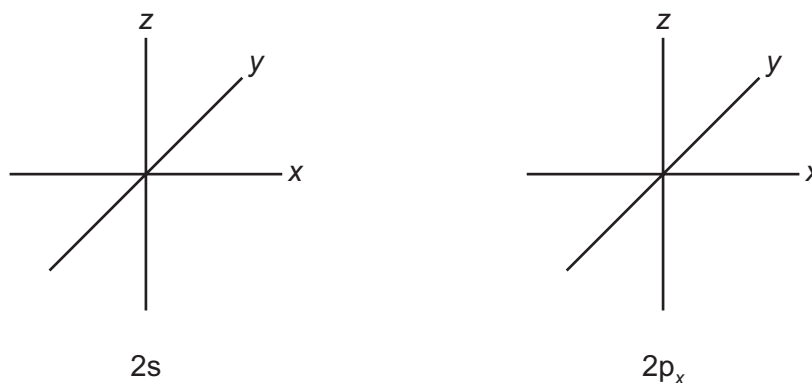


Fig. 1.1

[2]

- (d) There are many naturally occurring hydrated compounds that contain the anion PO_4^{3-} .

- (i) Name the anion PO_4^{3-} .

..... [1]

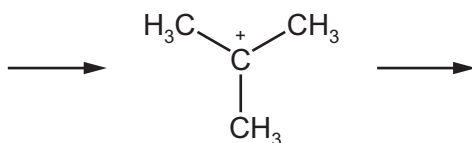
- (ii) Struvite is a soft hydrated mineral with $M_r = 245.3$. The anhydrous form of the mineral has the formula NH_4MgPO_4 .

Calculate the number of molecules of water of crystallisation in struvite.

Give your answer to the nearest integer. Show your working.

number of molecules of water of crystallisation = ... [2]

- (e) OH^- (aq) reacts with 2-bromo-2-methylpropane in an $\text{S}_{\text{N}}1$ reaction. The molecular ion $(\text{CH}_3)_3\text{C}^+$ forms as the intermediate in this reaction.
- (i) Draw the mechanism for the $\text{S}_{\text{N}}1$ reaction of OH^- with 2-bromo-2-methylpropane. Include charges, dipoles, lone pairs of electrons and curly arrows as appropriate. Draw the structures of the organic reactant and organic product.



[3]

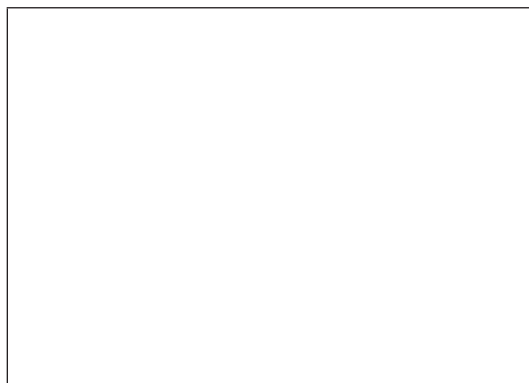
- (ii) 2-bromo-2-methylpropane is a tertiary bromoalkane.

Define tertiary bromoalkane.

.....
 [1]

- (iii) Organic compound **M** forms when 2-bromo-2-methylpropane is heated with **ethanolic** OH^- .

Draw the structure of **M**.



[1]

[Total: 17]

2 The chlorides of some of the Period 3 elements are shown in Table 2.1.

Table 2.1

Period 3 chloride	NaCl	AlCl_3	SiCl_4	PCl_5	PCl_3	SCl_2
bonding					C	C
structure					S	S
oxidation state of Period 3 element						

(a) Complete Table 2.1.

- Identify the bonding shown by each chloride under standard conditions.
Use C = covalent, I = ionic, M = metallic.
- Identify the structure shown by each chloride under standard conditions.
Use G = giant, S = simple.
- Deduce the oxidation state of the Period 3 element in each chloride.

[4]

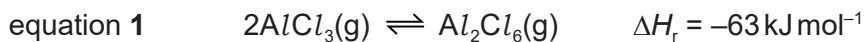
(b) Write equations for the reactions of NaCl and PCl_5 with water.
Include state symbols in both equations.

NaCl

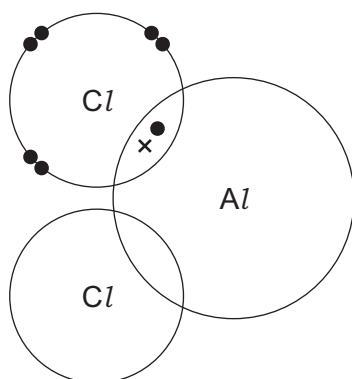
PCl_5

[3]

(c) In the gas phase, $\text{AlCl}_3(\text{g})$ exists at equilibrium with $\text{Al}_2\text{Cl}_6(\text{g})$ as shown.



(i) Complete the dot-and-cross diagram to show the bonding in Al_2Cl_6 .



[2]

(ii) State the effect of an increase in temperature on the equilibrium mixture in equation 1. Explain your answer.

.....

..... [1]

(d) A 3.30 g sample of a Period 3 chloride is heated to 500 K in a sealed flask. At this temperature, the chloride is a gas of volume 250 cm^3 and the pressure in the flask is 323 kPa.

Use the ideal gas equation $pV = nRT$ to calculate the M_r of the Period 3 chloride. Deduce its formula.

$M_r = \dots\dots\dots$

formula of Period 3 chloride = $\dots\dots\dots$

[3]

- (e) (i) An excess of $\text{Cl}^{-}(\text{aq})$ is added to 1 cm^3 of $\text{Br}_2(\text{aq})$.

Describe what is observed. Explain your answer.

.....

 [2]

- (ii) SCl_2 has $M_r = 103.1$ and is a liquid at room temperature. SBr_2 has $M_r = 191.9$ and is a gas at room temperature.

Explain the difference in the physical state of SCl_2 and SBr_2 . Give your answer in terms of intermolecular forces.

.....

 [2]

- (f) Bismuth is a dense metal in the same group as phosphorus.

- (i) Draw a labelled diagram to show the bonding in bismuth metal.

[2]

- (ii) Bismuth reacts with chlorine to form BiCl_3 .
 BiCl_3 is a solid at room temperature. It melts when heated gently.
 BiCl_3 reacts vigorously with water at room temperature to form an acidic solution.

Suggest the type of bonding and structure shown by BiCl_3 . Explain your answer.

.....

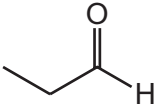
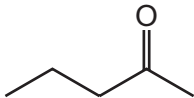
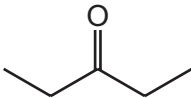
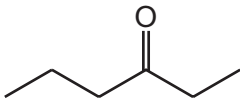
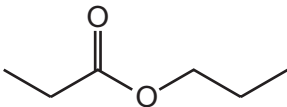
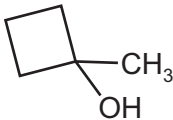
 [2]

[Total: 21]

3 Organic compounds can be distinguished using chemical tests and analytical techniques.

(a) Table 3.1 shows four pairs of organic compounds.

Table 3.1

organic compounds		reagent	positive result of chemical test on identified compound
A1 	A2 		
B1 	B2 		
C1 	C2 		
D1 	D2 		

(i) Complete Table 3.1 to:

- identify a reagent which can distinguish between the compounds in each pair
- give the **positive** result of the chemical test **and** identify which compound shows this result.

Use a different reagent for each test.

[8]

(ii) **A1** and **A2** are structural isomers.

Define structural isomers.

.....

..... [1]

(iii) Give the systematic name of **B2**.

..... [1]

(iv) Deduce the molecular formula of **D1**.

..... [1]

(b) **D2** forms polymer **Z** when heated gently.

(i) Identify the type of polymer that forms from **D2**.

..... [1]

(ii) Draw one repeat unit of polymer **Z**.

[2]

(c) Organic compound **E** contains three carbon atoms.

E reacts with cold dilute acidified $\text{KMnO}_4(\text{aq})$ to form a single compound **F** with $M_r = 154.9$.

Fig. 3.1 shows the infrared spectrum of **E**.

Fig. 3.2 shows the infrared spectrum of **F**.

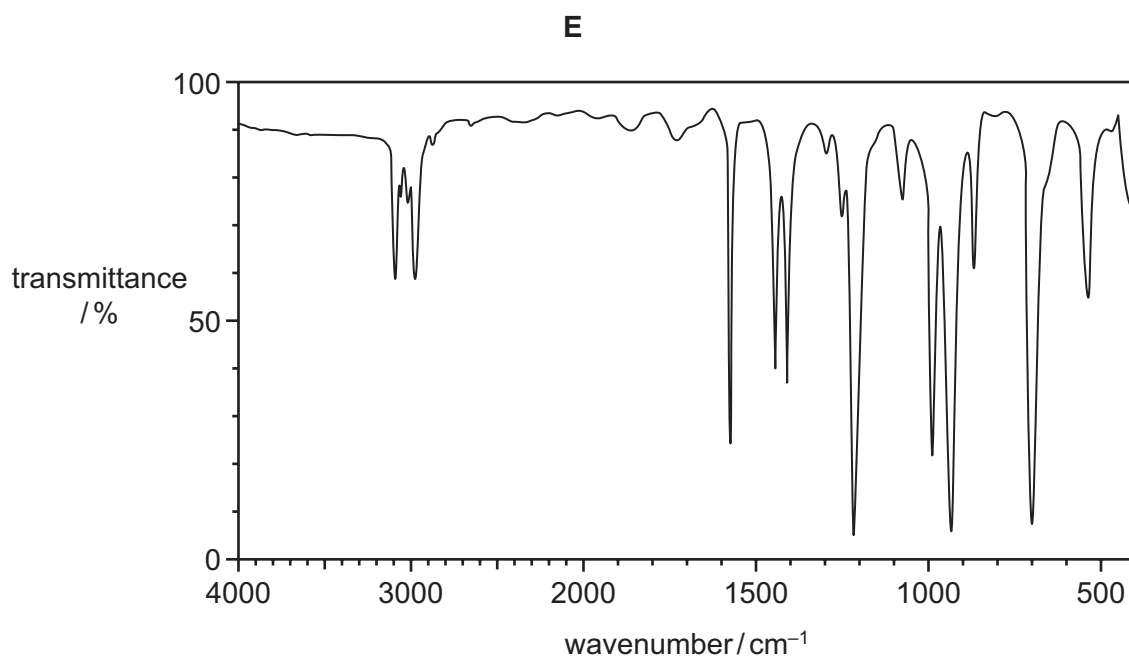


Fig. 3.1

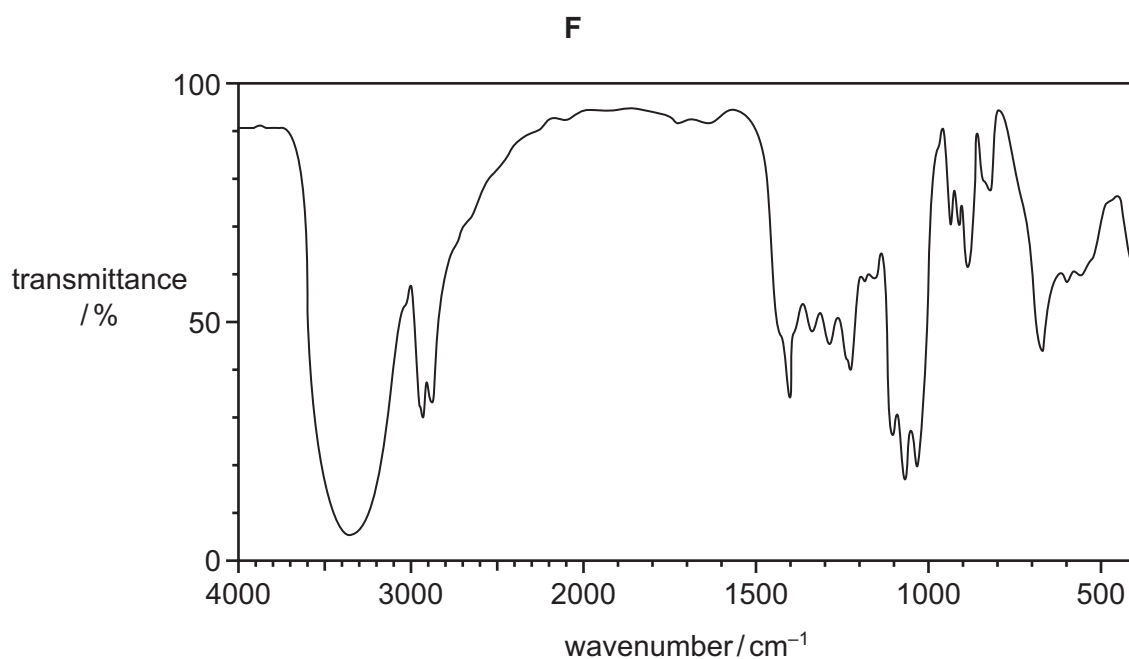


Fig. 3.2

Table 3.2

bond	functional group containing the bond	characteristic infrared absorption range (in wavenumbers)/cm ⁻¹
C–O	hydroxy, ester	1040–1300
C=C	aromatic compound, alkene	1500–1680
C=O	amide carbonyl, carboxyl ester	1640–1690 1670–1740 1710–1750
C≡N	nitrile	2200–2250
C–H	alkane	2850–3100
N–H	amine, amide	3300–3500
O–H	carboxyl hydroxy	2500–3000 3200–3650

Both spectra show absorptions between 2850 and 2950 cm⁻¹ owing to C–H bonds in each molecule.

- (i) Use the two infrared spectra and Table 3.2 to identify the functional group present only in **E**.
Explain your answer, referring only to absorptions at frequencies greater than 1500 cm⁻¹.

functional group

explanation

[1]

- (ii) Use the infrared spectrum of **F** to identify the functional group formed when **E** reacts with cold dilute acidified KMnO₄(aq).
Explain your answer, referring only to absorptions at frequencies greater than 1500 cm⁻¹.

functional group

explanation

[1]

- (iii) The mass spectrum of **E** shows a molecular ion peak and an M+2 peak of approximately equal abundance at $m/e = 120$ and 122 .

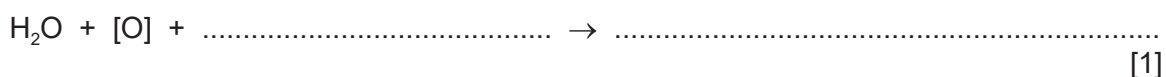
Deduce the relative molecular mass, M_r , of **E**.

$M_r = \dots\dots\dots$ [1]

(iv) Use the information in **3(c)** to suggest a structure for **E**.

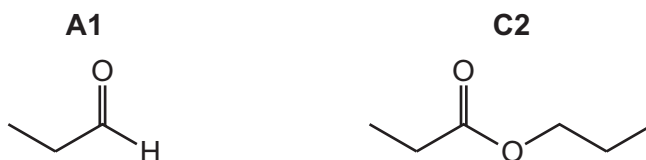
[1]

(v) Complete the equation for the reaction of **E** with cold dilute acidified $\text{KMnO}_4(\text{aq})$ to form **F**. In the equation, [O] represents cold dilute acidified $\text{KMnO}_4(\text{aq})$.



[1]

(d) **C2** can be synthesised using **A1** as a single organic reactant.



Devise a multi-step synthetic route to form **C2** from **A1**. Identify relevant reagents and conditions, and state the organic products of each step.

.....

.....

.....

.....

.....

..... [3]

[Total: 22]

Important values, constants and standards

molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Faraday constant	$F = 9.65 \times 10^4 \text{ C mol}^{-1}$
Avogadro constant	$L = 6.022 \times 10^{23} \text{ mol}^{-1}$
electronic charge	$e = -1.60 \times 10^{-19} \text{ C}$
molar volume of gas	$V_m = 22.4 \text{ dm}^3 \text{ mol}^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0 \text{ dm}^3 \text{ mol}^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18 \text{ kJ kg}^{-1} \text{ K}^{-1}$ (4.18 J g ⁻¹ K ⁻¹)

The Periodic Table of Elements

Group																				
1	2	Key												13	14	15	16	17	18	
		atomic number atomic symbol name relative atomic mass																		
1	2	1 H hydrogen 1.0																		
3	4													5	6	7	8	9		
Li lithium 6.9	Be beryllium 9.0													B boron 10.8	C carbon 12.0	N nitrogen 14.0	O oxygen 16.0	F fluorine 19.0	Ne neon 20.2	
11	12													13	14	15	16	17	18	
Na sodium 23.0	Mg magnesium 24.3													Al aluminium 27.0	Si silicon 28.1	P phosphorus 31.0	S sulfur 32.1	Cl chlorine 35.5	Ar argon 39.9	
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36			
K potassium 39.1	Ca calcium 40.1	Sc scandium 45.0	Ti titanium 47.9	V vanadium 50.9	Cr chromium 52.0	Mn manganese 54.9	Fe iron 55.8	Co cobalt 58.9	Ni nickel 58.7	Cu copper 63.5	Zn zinc 65.4	Ga gallium 69.7	Ge germanium 72.6	As arsenic 74.9	Se selenium 79.0	Br bromine 79.9	Kr krypton 83.8			
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54			
Rb rubidium 85.5	Sr strontium 87.6	Y yttrium 88.9	Zr zirconium 91.2	Nb niobium 92.9	Mo molybdenum 95.9	Tc technetium —	Ru ruthenium 101.1	Rh rhodium 102.9	Pd palladium 106.4	Ag silver 107.9	Cd cadmium 112.4	In indium 114.8	Sn tin 118.7	Sb antimony 121.8	Te tellurium 127.6	I iodine 126.9	Xe xenon 131.3			
55	56	57–71 lanthanoids	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86			
Cs caesium 132.9	Ba barium 137.3													Tl thallium 204.4	Pb lead 207.2	Bi bismuth 209.0	Po polonium —	At astatine —	Rn radon —	
87	88	89–103 actinoids	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118			
Fr francium —	Ra radium —													Nh nihonium —	Fl flerovium —	Mc moscovium —	Lv livermorium —	Ts tennessine —	Og oganeson —	

CANDIDATE
NAME

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CENTRE
NUMBER

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CANDIDATE
NUMBER

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9701/23

October/November 2022

1 hour 15 minutes

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 60.
- 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 **16** pages.

- 1 Atoms with nuclei containing an odd number of protons tend to have fewer isotopes than those with an even number of protons.

(a) Gallium has two stable isotopes, ^{69}Ga and ^{71}Ga .

- (i) Complete Table 1.1 to show the numbers of protons, neutrons and electrons in the two stable isotopes of gallium.

Table 1.1

isotope	number of protons	number of neutrons	number of electrons
^{69}Ga			
^{71}Ga			

[2]

- (ii) Define relative atomic mass.

.....

 [2]

- (iii) The relative atomic mass of gallium, A_r , is 69.723.
 The relative isotopic masses of ^{69}Ga and ^{71}Ga are:

^{69}Ga , 68.926; ^{71}Ga , 70.925.

Use this information to calculate the percentage abundance of ^{69}Ga in elemental gallium.
 Show your working.

Assume that the element contains only the ^{69}Ga and ^{71}Ga isotopes.
 Give your answer to **four** significant figures.

percentage abundance of ^{69}Ga = ... %
 [2]

(b) Potassium also has two stable isotopes. Both isotopes have the same chemical properties.

(i) Explain why both isotopes of potassium have the same chemical properties.

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

(ii) State the full electronic configuration of an atom of potassium.

..... [1]

(iii) The first, second and third ionisation energies of potassium are 418, 3070 and 4600 kJ mol⁻¹, respectively.

Use this information to explain why potassium is in Group 1.

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

[Total: 10]

2 Magnesium shows reactions typical of a Group 2 metal.

(a) Draw a labelled diagram to show the bonding in magnesium metal.

[2]

(b) Fig. 2.1 shows some reactions of magnesium and its compounds.

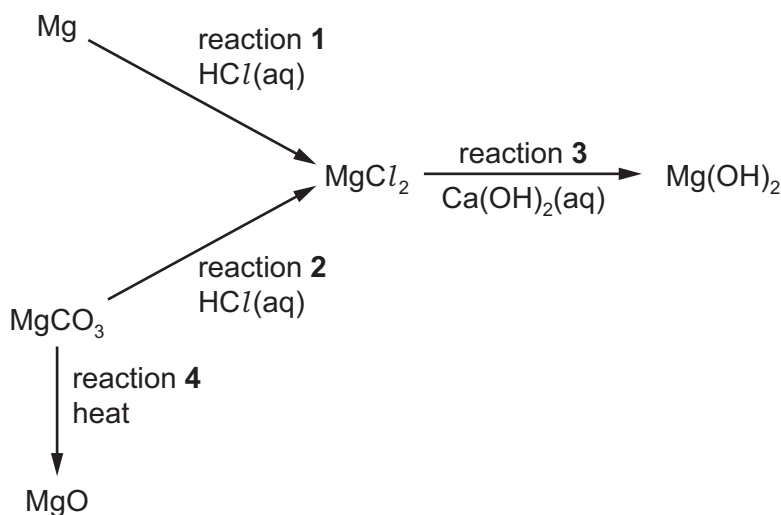


Fig. 2.1

(i) Identify the other products of reactions 1 and 2.

reaction 1

reaction 2 [2]

(ii) Reaction 3 is used to form a precipitate of Mg(OH)₂ from MgCl₂(aq).

State why Ca(OH)₂(aq) would **not** form a precipitate of Ba(OH)₂ from BaCl₂(aq).

.....

..... [1]

(iii) State the type of reaction that occurs in reaction 4.

..... [1]

- (c) 1 cm^3 of $\text{MgCl}_2(\text{aq})$ is placed in a test-tube. A few drops of $\text{AgNO}_3(\text{aq})$ are added, followed by 1 cm^3 of dilute $\text{NH}_3(\text{aq})$.

State in full what is observed in this experiment.

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

- (d) When 1 cm^3 of $\text{MgCl}_2(\text{aq})$ is added to 1 cm^3 of $\text{Br}_2(\text{aq})$ in a test-tube, the solution remains orange.

Explain this observation.

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

[Total: 9]

3 Some of the common chlorides of Period 3 elements are shown in the list.



(a) From this list, identify:

(i) all the chlorides that have giant ionic structures in the solid state

..... [1]

(ii) all the chlorides that react vigorously with water to form strongly acidic solutions

..... [1]

(iii) the chloride that dissolves in water to form a neutral solution

..... [1]

(iv) the chloride formed from the **element** with the highest melting point.

..... [1]

(b) NaCl is one product of the reaction of chlorine gas and cold aqueous sodium hydroxide.

Identify the other products.

..... [1]

(c) PCl_5 reacts with alcohols to form chloroalkanes.

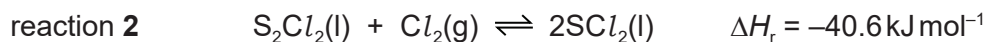
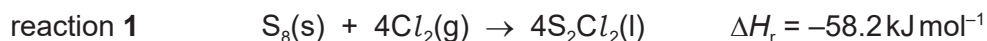
(i) Identify this type of reaction.

..... [1]

(ii) Draw the structure of the organic product formed in the reaction of an excess of PCl_5 with butane-1,3-diol.

[1]

- (d) Sulfur, S_8 , reacts with chlorine to form several different chlorides. The most common are S_2Cl_2 and SCl_2 . SCl_2 forms when sulfur reacts with an excess of chlorine.



- (i) SCl_2 is a cherry-red liquid that reacts vigorously with water to form an acidic solution.

Use this information to deduce the bonding and structure shown by SCl_2 .
Explain your answer.

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

- (ii) Calculate the enthalpy change of formation, ΔH_f , of $SCl_2(l)$. You may find it useful to use Hess's Law to construct an energy cycle.

enthalpy change of formation of $SCl_2(l)$, $\Delta H_f = \dots\dots\dots \text{ kJ mol}^{-1}$
[2]

- (iii) State the effect of a decrease in pressure on the position of equilibrium in reaction 2.
Explain your answer.

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

Fig. 3.1 shows the two structural isomers of S_2Cl_2 .

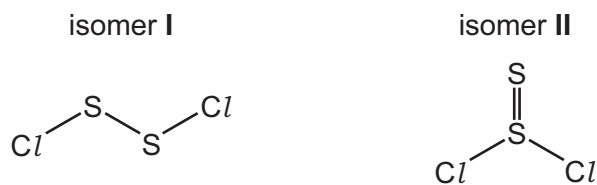


Fig. 3.1

(iv) Define the term structural isomer.

.....
 [2]

(v) Suggest a value for the Cl-S-S bond angle in isomer I. Explain your answer.

bond angle = ... $^{\circ}$

explanation

 [2]

(vi) Draw a dot-and-cross diagram to show the bonding in isomer II. Show outer shell electrons only.

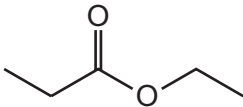
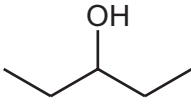
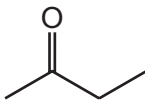
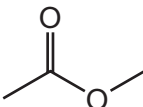
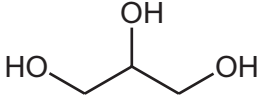
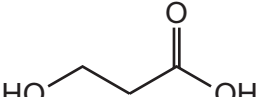
[2]

[Total: 18]

Question 4 starts on the next page.

- 4 Organic compounds can be distinguished using chemical tests. Table 4.1 shows four pairs of compounds.

Table 4.1

organic compounds		reagent	positive result of chemical test on identified compound
A1 	A2 		
B1 	B2 		
C1 	C2 		
D1 	D2 		

(a) Complete Table 4.1 to:

- identify a reagent that could distinguish between the compounds in each pair
- give the **positive** result of the chemical test **and** identify which compound shows this result.

Use a different reagent for each test.

[8]

(b) **C1** has melting point -94°C and boiling point $+49^{\circ}\text{C}$.

Explain these properties by referring to the type of van der Waals' forces between molecules.

.....

.....

..... [2]

(c) Draw the structure of the cis isomer of **C2**.

[1]

(d) **C2** forms a polymer when heated gently.

(i) Identify the type of polymer that forms from **C2**.

..... [1]

(ii) Draw one repeat unit of the polymer formed from **C2**.

[2]

[Total: 14]

- 5 Lactones are cyclic esters. Under suitable conditions, lactones form from molecules that have both an alcohol and a carboxylic acid functional group.
Equation 1 shows an example of the formation of a lactone.

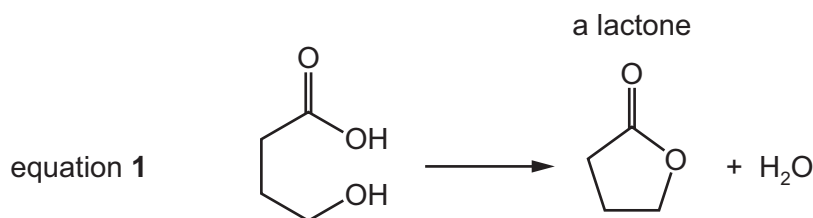


Fig. 5.1 shows the synthesis of lactone **P** from compound **M**.

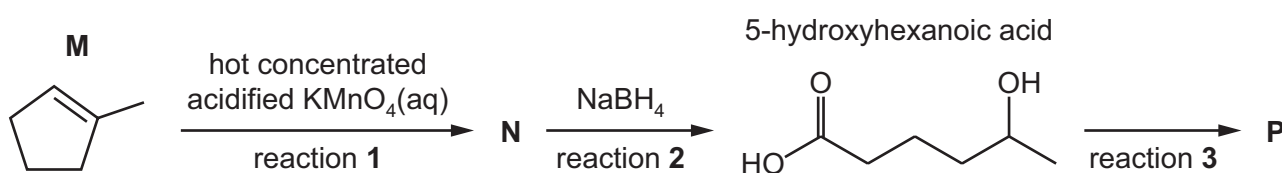


Fig. 5.1

- (a) (i) **M** reacts with hot concentrated acidified $\text{KMnO}_4(\text{aq})$ to form **N**, $\text{C}_6\text{H}_{10}\text{O}_3$, in reaction 1.

Draw the structure of **N**.

[1]

- (ii) **N** is reduced by NaBH_4 to form 5-hydroxyhexanoic acid in reaction 2.

Construct an equation for reaction 2 using molecular formulae.

In the equation, use $[\text{H}]$ to represent one atom of hydrogen from the reducing agent.

..... [1]

- (iii) Reaction 2 is a nucleophilic addition.

Suggest why reaction 2 creates a mixture of two organic compounds.

.....

..... [2]

(iv) Draw lactone **P**, the product of reaction **3**.

[1]

(b) A student monitors the progress of reaction **2** using infrared spectroscopy.

Use Table 5.1 to suggest why it is difficult to distinguish between **N** and 5-hydroxyhexanoic acid using infrared spectroscopy.

.....

..... [2]

Table 5.1

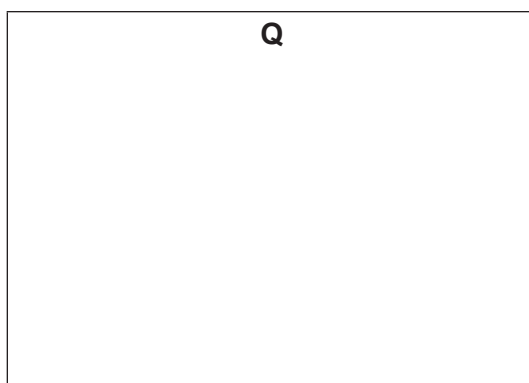
bond	functional group containing the bond	characteristic infrared absorption range (in wavenumbers)/cm ⁻¹
C–O	hydroxy, ester	1040–1300
C=C	aromatic compound, alkene	1500–1680
C=O	amide carbonyl, carboxyl ester	1640–1690 1670–1740 1710–1750
C≡N	nitrile	2200–2250
C–H	alkane	2850–3100
N–H	amine, amide	3300–3500
O–H	carboxyl hydroxy	2500–3000 3200–3650

- (c) Unknown lactone **Q** is analysed using mass spectrometry. Table 5.2 shows information from the mass spectrum.

Table 5.2

peak	m/e	abundance
M+	72	95.5
M+1	73	3.15

Use these data to deduce the structure of **Q**.
Show your working.



[2]

[Total: 9]

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

lanthanoids

actinoids

57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
lanthanum	cerium	praseodymium	neodymium	promethium	samarium	euroium	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
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
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	mendeleevium	nobelium	lawrencium
—	232.0	231.0	238.0	—	—	—	—	—	—	—	—	—	—	—