



Cambridge International AS & A Level

CANDIDATE
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CHEMISTRY

9701/42

Paper 4 A Level Structured Questions

May/June 2022

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.

$$\Delta H_{sol} = \Delta H_{hyd} - \Delta H_{latt}$$

ex: $-7 - (-4) = -7 + 4 = -3$

Answer **all** the questions in the spaces provided.

solubility of salt depends on ΔH_{sol} , the more exothermic its value is, the more 'soluble' the salt

- 1 (a) The solubility of the Group 2 hydroxides increases down the group.

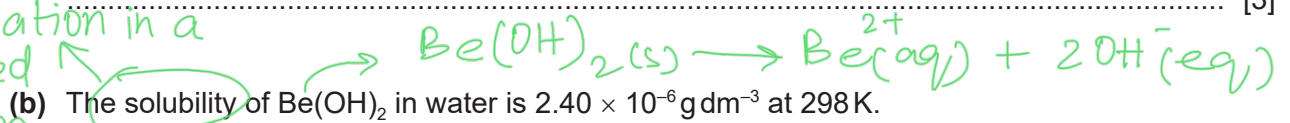
Explain this trend.

→ Growing down the group enthalpy change of lattice and enthalpy of hydration become less exothermic

→ ΔH_{latt} changes more, (ΔH_{hyd} is more -ve than ΔH_{latt})

→ ΔH_{sol} becomes more exothermic [3]

maximum concentration in a saturated solution



- (i) Write an expression for the solubility product, K_{sp} , of $\text{Be}(\text{OH})_2$ and state its units.

$$K_{sp} = [\text{Be}^{2+}][\text{OH}^{-}]^2$$

$\text{mol dm}^{-3} \times (\text{mol dm}^{-3})^2$

units = $\text{mol}^3 \text{dm}^{-3}$ [2]

- (ii) Calculate the numerical value of K_{sp} for $\text{Be}(\text{OH})_2$ at 298 K.

1 → convert solubility from g dm^{-3} to mol dm^{-3} , $\frac{2.4 \times 10^{-6}}{43} \rightarrow \text{mass} = 5.58 \times 10^{-8}$

2 → use ratio of K_{sp} equation for conc. of OH^{-} , $43 \rightarrow \text{Mr} \rightarrow [\text{Be}^{2+}]$

$$[\text{OH}^{-}] = [2 \times 5.58 \times 10^{-8}]^2 = 4 \times (5.58 \times 10^{-8})^2$$

$$K_{sp} = [\text{Be}^{2+}][\text{OH}^{-}]^2 = 4 \times (5.58 \times 10^{-8})^3$$

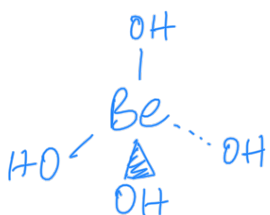
$K_{sp} = 6.95 \times 10^{-22}$ [2]

- (c) $\text{Be}(\text{OH})_2$ is soluble in aqueous solutions containing an excess of hydroxide ions and forms the complex ion $[\text{Be}(\text{OH})_4]^{2-}$. This complex ion has a similar shape to that of $[\text{CuCl}_4]^{2-}$.

- (i) Define the term complex ion.

A molecule or ion formed by central metal atom or ion dative bonded to one or more ligands [1]

- (ii) Draw a three-dimensional diagram to show the structure of the complex ion $[\text{Be}(\text{OH})_4]^{2-}$. Name the shape of the $[\text{Be}(\text{OH})_4]^{2-}$ complex ion.



shape tetrahedral

4 ligands so tetrahedral, or square planar → if stated as such in question

[1]

- (d) (i) Explain why transition elements can form complex ions.

Empty d-orbitals in the elements allow them to form dative bonds with ligands [1]

by forming dative bonds

- (ii) Complete Table 1.1 to show the coordination number of each metal ion, and the shapes and overall polarities of the complex ions listed.

Table 1.1

complex ion	shape	coordination number	polar or non-polar
<i>cis</i> -[Pt(H ₂ NCH ₂ CH ₂ NH ₂)Cl ₂]	square planar	4	polar
[Ag(NH ₃) ₂] ⁺	linear	2	non-polar
[Fe(C ₂ O ₄) ₃] ³⁻	octahedral	6	non-polar

number of bonds

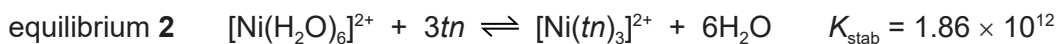
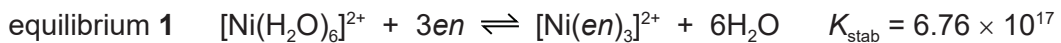
dipoles do not cancel

dipoles cancel out [2]

- (e) (i) Define stability constant, K_{stab} .

The equilibrium constant for the formation of a complex ion in a solvent [1]

- (ii) Nickel can form complexes with the ligands *en*, H₂NCH₂CH₂NH₂, and *tn*, H₂NCH₂CH₂CH₂NH₂, as shown.



Construct an expression for the stability constant, K_{stab} , for equilibrium 1.

State the units for K_{stab} .

units:

$$K_{\text{stab}} = \frac{[\text{Ni}(\text{en})_3]^{2+}}{[\text{Ni}(\text{H}_2\text{O})_6]^{2+} [\text{en}]^3}$$

units = $\frac{\text{mol}^{-1} \text{dm}^3}{(\text{mol} \text{dm}^{-3})^3} = (\text{mol}^{-1} \text{dm}^3)^3$ units = $\text{mol}^{-3} \text{dm}^9$ [2]

units cancel

- (iii) Describe what the K_{stab} values indicate about the position of equilibrium for equilibrium 1 and 2. Use the K_{stab} values to deduce which complex, [Ni(en)₃]²⁺ or [Ni(tn)₃]²⁺, is more stable.

Both equilibria lie to the right, and [Ni(en)₃]²⁺ is more stable [1]

[Total: 16]

as K_{stab} values are greater than 1

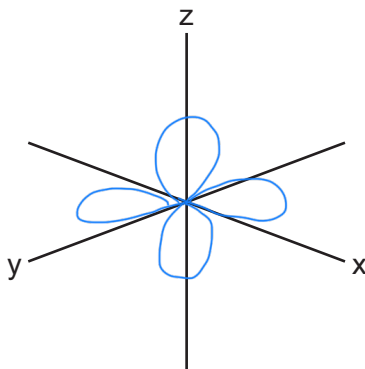
[Turn over

- 2 (a) Explain why transition elements have variable oxidation states.

Electrons have similar energies in 4s and 3d orbitals

[1]

- (b) Sketch the shape of a $3d_{xy}$ orbital.



[1]

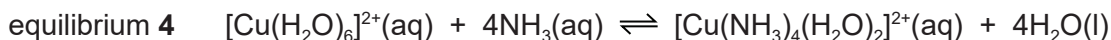
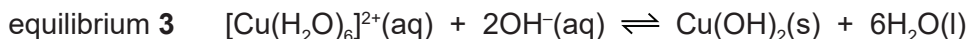
- (c) Explain why transition elements form coloured compounds.

The d orbitals of transition element split into two sets of orbitals in presence of ligands. Electrons are promoted to higher energy levels by absorbing visible light of specific frequency, and complementary colour of light is seen.

[3]

(d) Aqueous solutions of copper(II) salts contain $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ ions.

Equilibrium 3 and equilibrium 4 show two reactions of these ions.



(i) State the colour of $\text{Cu}(\text{OH})_2(\text{s})$ and $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}(\text{aq})$.

colour of $\text{Cu}(\text{OH})_2(\text{s})$ pale blue

colour of $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}(\text{aq})$ dark blue

[1]

(ii) Use Le Chatelier's principle to explain why a precipitate is formed when $\text{NaOH}(\text{aq})$ is added dropwise to $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}(\text{aq})$.

It increases concentration of OH^- and equilibrium 3 shifts to right hand side

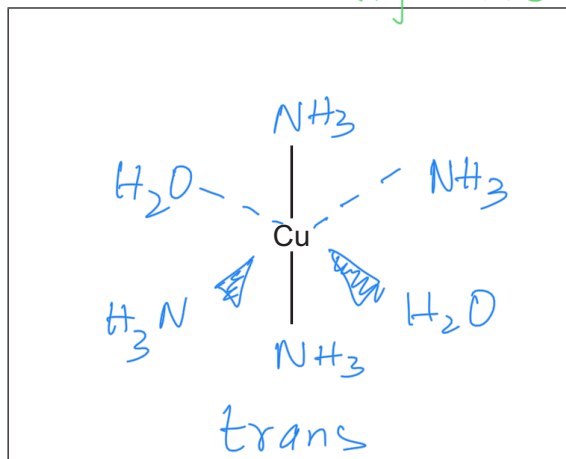
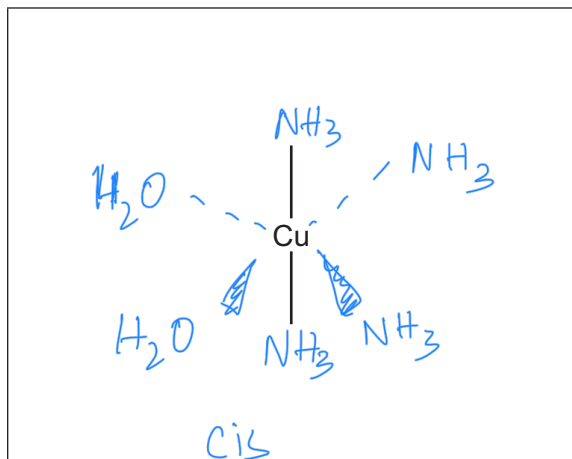
[1]

to or more bidentate ligands \rightarrow cis \rightarrow trans \rightarrow 2 or more monodentate ligands

(e) There are two possible stereoisomers with the formula $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$.

Draw three-dimensional diagrams to show the two stereoisomers.

\rightarrow all monodentate ligand so cis-trans



[2]

[Total: 9]

3 (a) (i) Define first electron affinity.

Energy change when one mole of electrons
is gained by one mole of gaseous atoms

[2]

(ii) The first electron affinity of an atom is usually an exothermic process, whereas the second electron affinity is an endothermic process.

Suggest why.

positive nucleus attracts
negative electron
Energy is required to overcome repulsion
between anion and incoming electron

[1]

(iii) Describe the general trend in first electron affinities for Cl, Br and I. Explain your answer.

It becomes less exothermic down the
group, as atomic radius increase the attraction
between nucleus and incoming electron decreases

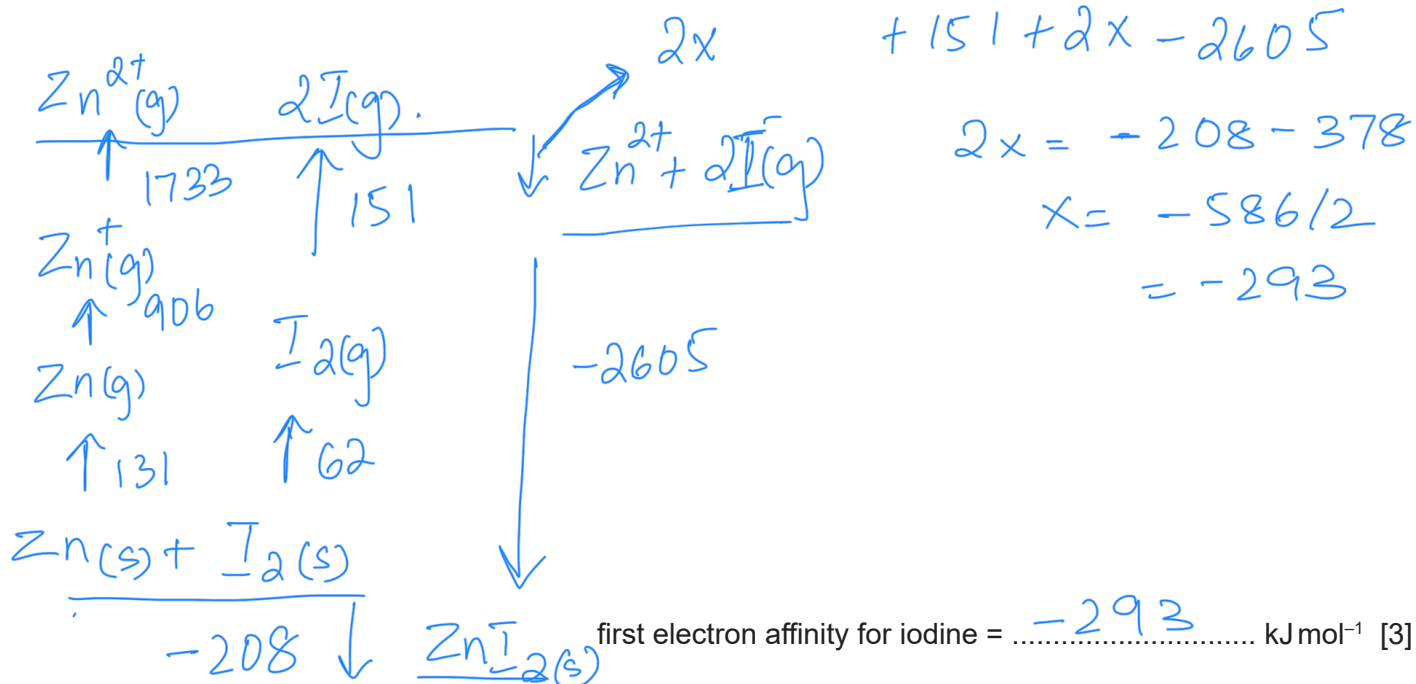
[2]

(b) Table 3.1 shows energy changes to be used in this question and in (c).

Table 3.1

energy change	value / kJ mol ⁻¹
standard enthalpy change of atomisation of zinc	+131
first ionisation energy of zinc	+906
second ionisation energy of zinc	+1733
standard enthalpy change of formation of ZnI ₂ (s)	-208
lattice energy, $\Delta H_{\text{latt}}^{\circ}$, of zinc iodide, ZnI ₂ (s)	-2605
first ionisation energy of iodine	+1008
second ionisation energy of iodine	+1846
I-I bond energy	+151
enthalpy change of sublimation of iodine, I ₂ (s) → I ₂ (g)	+62

Calculate the first electron affinity for iodine. Use relevant data from Table 3.1 in your working. It may be helpful to draw a labelled energy cycle. Show all working.



- (c) Predict how $\Delta H_{\text{latt}}^{\ominus}$ of $\text{CdI}_2(\text{s})$ differs from $\Delta H_{\text{latt}}^{\ominus}$ of $\text{ZnI}_2(\text{s})$. Place a tick (✓) in the appropriate box in Table 3.2.

Table 3.2

$\Delta H_{\text{latt}}^{\ominus}$ of $\text{CdI}_2(\text{s})$ is less negative than $\Delta H_{\text{latt}}^{\ominus}$ of $\text{ZnI}_2(\text{s})$	$\Delta H_{\text{latt}}^{\ominus}$ of $\text{CdI}_2(\text{s})$ is the same as $\Delta H_{\text{latt}}^{\ominus}$ of $\text{ZnI}_2(\text{s})$	$\Delta H_{\text{latt}}^{\ominus}$ of $\text{CdI}_2(\text{s})$ is more negative than $\Delta H_{\text{latt}}^{\ominus}$ of $\text{ZnI}_2(\text{s})$
✓		

Explain your answer.

Cd^{2+} has larger ionic radius and same charge so charge density is smaller. Attraction between Cd^{2+} and I^{-} is weaker [1]

[Total: 9]

- 4 (a) Calcium carbonate decomposes on heating.



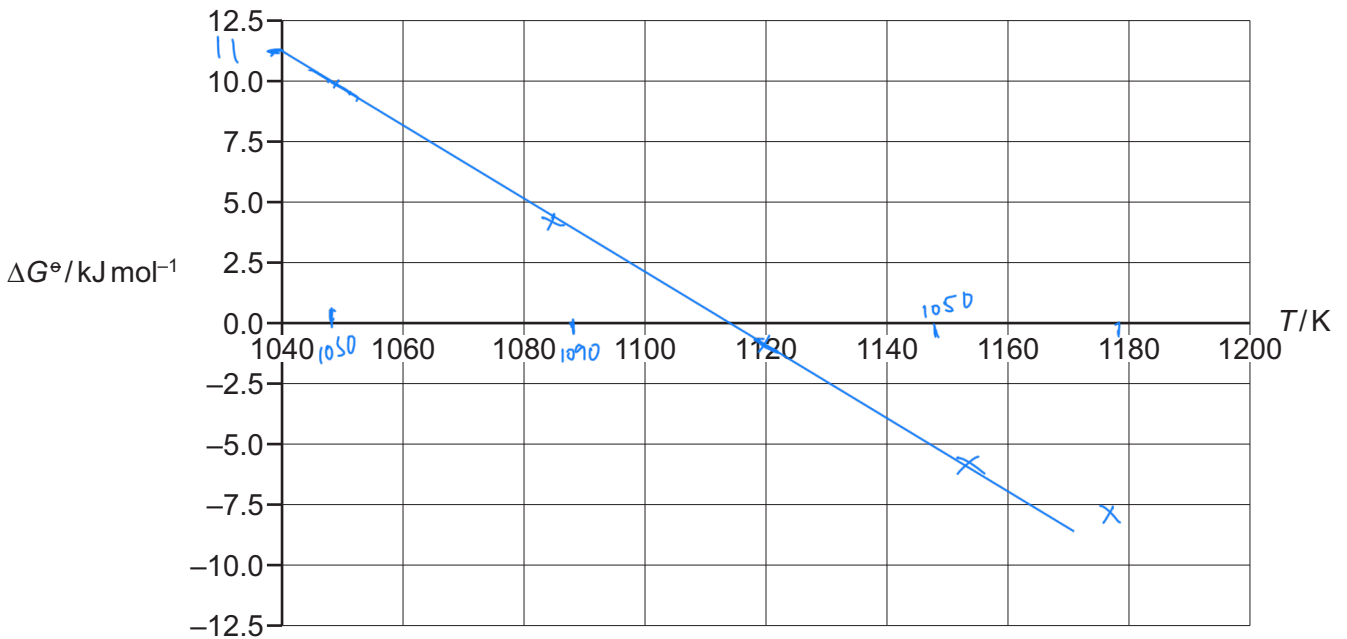
Table 4.1 shows the values of the Gibbs free energy change, ΔG° , for this reaction at various temperatures.

Table 4.1

T/K	$\Delta G^\circ/\text{kJ mol}^{-1}$
1050	9.9
1085	4.3
1120	-1.3
1148	-5.8
1176	-10.3

Assume the standard enthalpy change, ΔH° , and the standard entropy change, ΔS° , for this reaction remain constant over this temperature range.

- (i) Use the data in Table 4.1 to plot a graph of ΔG° against T on the grid.



[2]

- (ii) Calculate the gradient of your graph. Determine the ΔS° in $\text{JK}^{-1}\text{mol}^{-1}$ for this reaction. Show all working.

$$y = \Delta G \quad x = T \quad m = -\Delta S \quad c = \Delta H$$

$$y = mx + c$$

$$\Delta G = -T\Delta S + \Delta H$$

$$\Delta S^\circ = \dots\dots\dots 160 \dots\dots\dots \text{JK}^{-1}\text{mol}^{-1} \quad [2]$$

$$m = \frac{-5.8 - 9.9}{1148 - 1050} = -0.160 \text{ kJ K}^{-1}\text{mol}^{-1} = -160 \text{ J K}^{-1}\text{mol}^{-1}$$

$$m = -\Delta S$$

$$\text{so } \Delta S = 160$$

(b) Group 1 hydrogencarbonates, MHCO_3 , decompose on gentle heating to give the corresponding metal carbonate, carbon dioxide and water vapour.

(i) Write an ionic equation for the decomposition of the hydrogencarbonate ion.



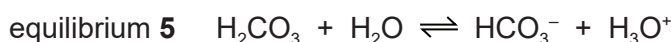
(ii) The thermal stability of Group 1 hydrogencarbonates increases down the group.

Suggest an explanation for the trend in thermal stability of the Group 1 hydrogencarbonates.

Going down the group, radius of cation increases and charge density decreases. Polarisation of HCO_3^- decreases, so $\text{C}=\text{O}$ bond is less weakened

so attraction between M^{2+} and HCO_3^- decreases

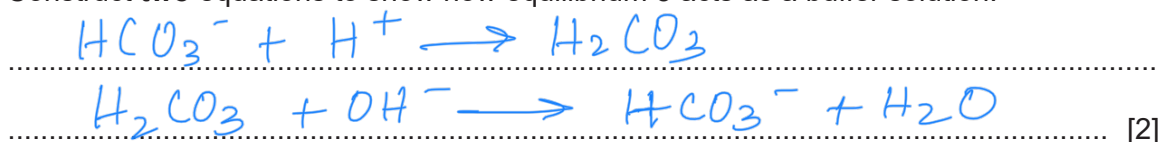
(c) The buffer system in seawater contains a mixture of HCO_3^- and H_2CO_3 .



(i) Define a buffer solution.

A solution which resists changes to pH when small amounts of acid or alkali are added to it

(ii) Construct **two** equations to show how equilibrium 5 acts as a buffer solution.



(iii) The $[\text{HCO}_3^-]/[\text{H}_2\text{CO}_3]$ ratio in a sample of seawater is 14.1.

Calculate the pH of this sample.

[pK_a : H_2CO_3 , 6.35]

$$K_a = \frac{[\text{H}^+][\text{HCO}_3^-]}{[\text{H}_2\text{CO}_3]}$$

$$[\text{H}^+] = \frac{K_a \times [\text{H}_2\text{CO}_3]}{[\text{HCO}_3^-]}$$

$$K_a = 10^{-pK_a} = 10^{-6.35} = 4.47 \times 10^{-7}$$

$$\frac{[\text{H}_2\text{CO}_3]}{[\text{HCO}_3^-]} = \frac{1}{14.1}$$

$$[\text{H}^+] = \frac{4.47 \times 10^{-7}}{14.1} = 3.17 \times 10^{-8}$$

$$\text{pH} = -\log [\text{H}^+] = -\log [3.17 \times 10^{-8}] = 7.5$$

[Total: 14]

- 5 (a) Complete Table 5.1 to predict the substance liberated at each electrode during electrolysis of the indicated electrolyte with inert electrodes.

Table 5.1

electrolyte	substance liberated at the anode	substance liberated at the cathode
PbBr ₂ (l)	Br ₂	Pb
concentrated NaCl(aq)	Cl ₂	H ₂
Cu(NO ₃) ₂ (aq)	O ₂	Cu

[3]

- (b) An electrolytic cell is set up to determine a value for the Avogadro constant, L . The electrolyte is dilute sulfuric acid and both electrodes are copper.

When a current of 0.600A is passed through the acid for 30.0 minutes, the anode decreases in mass by 0.350g.

copper metal turns to Cu²⁺ by losing e⁻

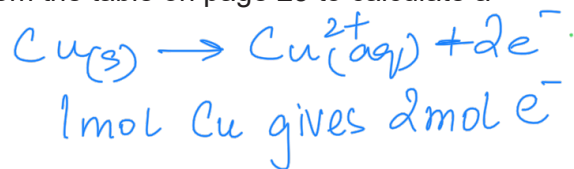
- (i) State the relationship between the Faraday constant, F , and the Avogadro constant, L .

$$F = Le$$

[1]

- (ii) Use the experimental information in (b) and data from the table on page 23 to calculate a value for the Avogadro constant, L .

Show all working.



$$L = \frac{\text{charge on 1 mole e}^{-}}{\text{charge on one e}^{-}} \rightarrow \text{to be found}$$

$$\text{charge on one e}^{-} \rightarrow 1.6 \times 10^{-19} \text{ C}$$

$$\text{charge} = I \times t = 0.6 \times 30 \times 60 = 1080 \text{ C}$$

$$\text{moles of Cu}^{2+} \text{ formed} = \frac{0.35 \text{ (m)}}{63.5 \text{ (Mr)}} = 5.51 \times 10^{-3}, \text{ so}$$

$$\text{moles of electrons} = 5.51 \times 10^{-3} \times 2 = 0.01102$$

$$\text{charge on one mole e}^{-} = \frac{1080}{0.01102} = 98003$$

$$L = \frac{98003 \text{ C}}{1.6 \times 10^{-19} \text{ C}} = 6.12 \times 10^{23}$$

$$\text{Avogadro constant, } L = 6.12 \times 10^{23} \dots [4]$$

[Total: 8]

- 6 (a) The reagent and conditions required for the nitration of benzene, benzoic acid and phenol are shown in Table 6.1.

Table 6.1

compound	reagents and conditions for nitration
benzene	concentrated HNO_3 , 50°C , concentrated H_2SO_4 catalyst
benzoic acid	concentrated HNO_3 , 100°C , concentrated H_2SO_4 catalyst
phenol	dilute $\text{HNO}_3(\text{aq})$, 20°C

Concentrated HNO_3 reacts with concentrated H_2SO_4 to generate the electrophile NO_2^+ .

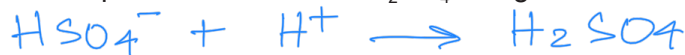
- (i) Complete Fig. 6.1 to show the mechanism of the reaction between benzene and NO_2^+ . Include all relevant curly arrows and charges.



Fig. 6.1

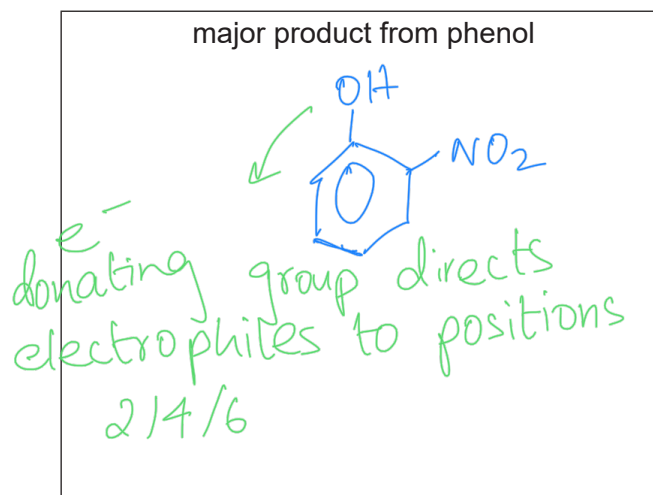
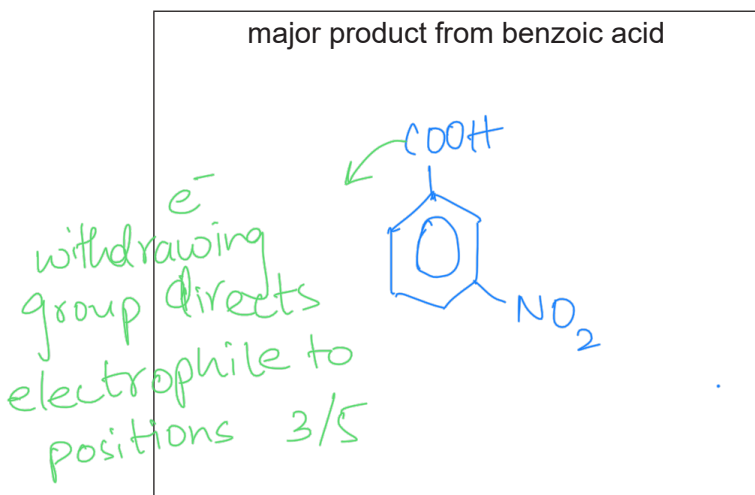
[3]

- (ii) Write an equation to show how H_2SO_4 is regenerated.



[1]

- (b) Draw the major products from the mononitration of benzoic acid and of phenol.



[2]

- (c) Compare the relative ease of nitration of benzene, benzoic acid and phenol. Explain your reasoning; include reference to the structures of the three compounds in your answer.

phenol > benzene > benzoic acid
easiest least easy

Lone pair on O in phenol is delocalised into the ring, so it attracts NO_2^+ more strongly than benzene. The electron withdrawing $\text{C}=\text{O}$ in benzoic acid decreases electron density in ring compared to benzene so attraction for NO_2^+ decreases

[4]

- (d) The azo compound Congo Red is used as an acid–base indicator and can be made by the route shown in Fig. 6.2.

In step 3 of this synthesis, compound **Y** reacts with compound **Z**. Compound **Z** is made from compound **X**. Assume that the $-\text{SO}_3^-\text{Na}^+$ groups do not react.

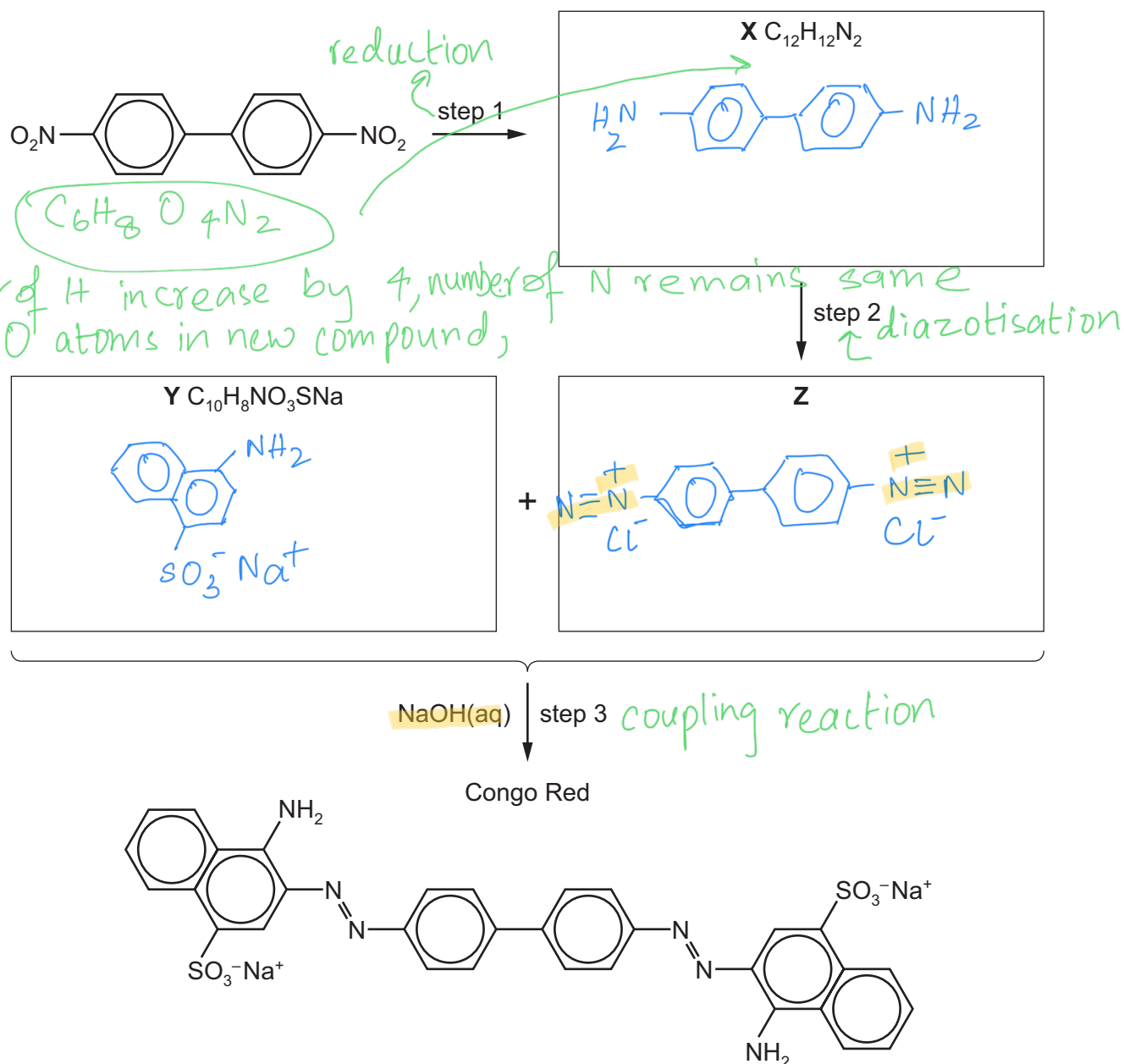


Fig. 6.2

- (i) Suggest structures for compounds **X**, **Y** and **Z** and draw them in the boxes in Fig. 6.2. [3]
- (ii) Give the reagents and conditions for step 1 and step 2.
- step 1 $\text{Sn} + \text{concentrated HCl} + \text{heat}$
- step 2 $\text{HNO}_2 + \text{HCl}$ at temperature $\leq 10^\circ\text{C}$

[3]

[Total: 16]

7 (a) State the uses of TMS and D₂O in NMR spectroscopy.

TMS *reference*
 D₂O *solvent*

→ ¹H NMR

→ ¹³C NMR

(b) The three isomeric ketones with molecular formula C₅H₁₀O are: [1]
line of symmetry

- pentan-2-one
- pentan-3-one
- 3-methylbutanone.

(i) Complete Table 7.1 to show the number of peaks observed in the proton (¹H) NMR spectrum and in the carbon-13 NMR spectrum for each compound listed.

Table 7.1

ketone	number of peaks observed in the proton (¹ H) NMR spectrum	number of peaks observed in the carbon-13 NMR spectrum
pentan-2-one	4	5
pentan-3-one	2	3
3-methylbutanone	3	4

[2]

(ii) State **all** the ketones with molecular formula C₅H₁₀O that have:

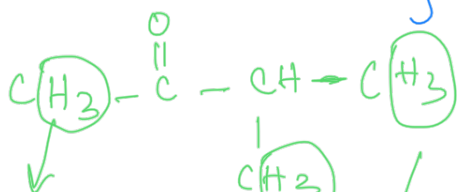
a doublet in their proton (¹H) NMR spectrum

3-methyl butanone

a singlet in their proton (¹H) NMR spectrum.

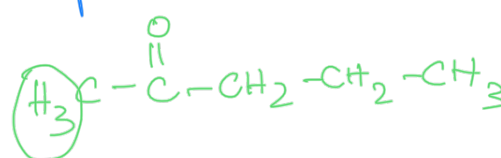
3-methyl butanone and pentan-2-one

[2]



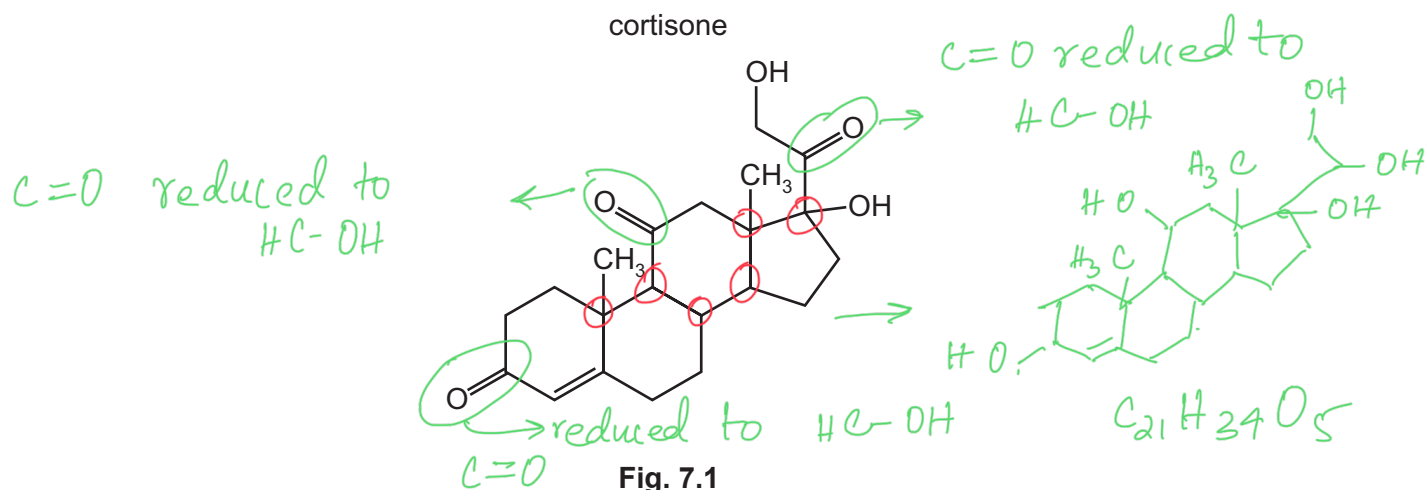
peak is a singlet as adjacent C has no H atoms

peak is a doublet as adjacent C atom is bonded to 1H atom



peak is singlet as adjacent C atom is bonded to no H atom

(c) Cortisone, $C_{21}H_{28}O_5$, is a naturally occurring chemical that contains chiral carbon atoms.



(i) Deduce the number of chiral carbon atoms in one molecule of cortisone.

6

[1]

(ii) Cortisone is reacted with an excess of $NaBH_4$.

→ weak reducing agent
cannot reduce alkene
group, only reduces
aldehydes & ketones

State the molecular formula of the organic compound formed.

$C_{21}H_{34}O_5$

[1]

(iii) Cortisone is an optically active molecule.

Explain what is meant by optically active.

A substance that is able to rotate the
plane of polarised light in opposite
directions

[1]

[Total: 8]

the stronger an acid, the more easily it dissociates to donate H^+ , and stronger organic acids ¹⁶ have weaker O-H bond

- 8 (a) Compare the relative acidities of ethanol, ethanoic acid, chloroethanoic acid and phenol. Explain your reasoning.

chloroethanoic acid > ethanoic acid > phenol > ethanol
most acidic least acidic

Greater acidity weakens O-H bond.

In chloroethanoic acid, O-H bond is weakened by electron withdrawing Cl. In ethanoic acid, the electronegative C=O weakens O-H bond. Lone pair of electrons of O are delocalised into ring of phenol which weakens O-H bond. The electron donating alkyl group in ethanol strengthens O-H bond [4]

- (b) An excess of ethanedioic acid, HOOC-COOH(aq), is reacted with warm acidified $KMnO_4(aq)$.

State the type of reaction undergone by ethanedioic acid.

Describe what you would observe.

Write an equation for this reaction.

Your equation can use [O] or [H] as necessary.

type of reaction oxidation

observations solution turns from purple to pale pink

equation $HOOC-COOH + [O] \rightarrow 2CO_2 + H_2O$

[2]

(c) A section of a polyester is shown.

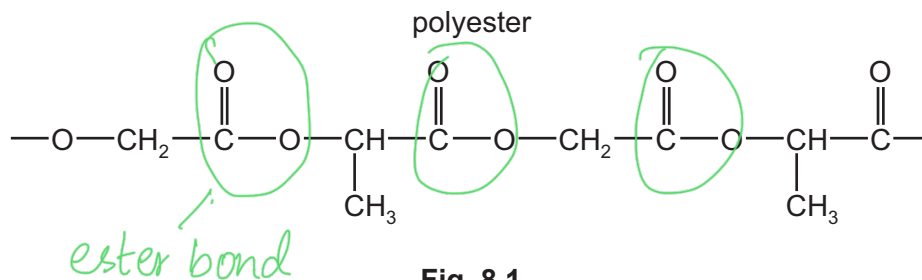
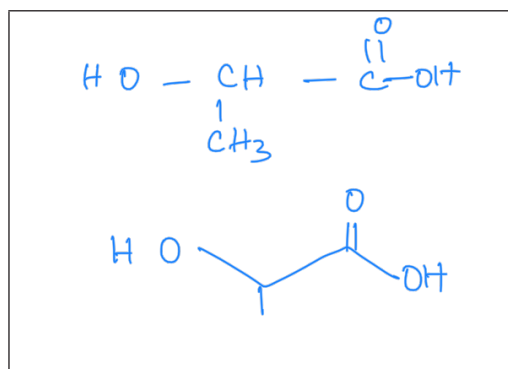
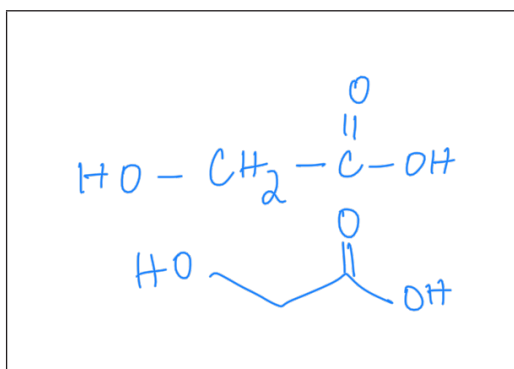


Fig. 8.1

Draw the structures of the two monomers that form this polyester.



[2]

(d) Serine can polymerise to form two different types of condensation polymer; a polyester and a polypeptide.

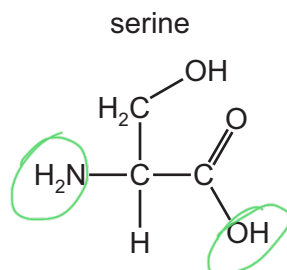
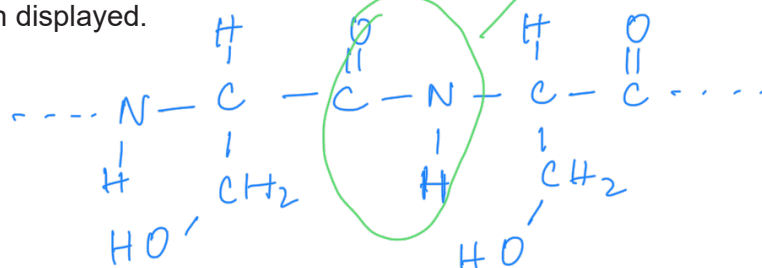


Fig. 8.2

Draw the structure of the polypeptide showing two repeat units. The peptide linkage should be shown displayed.



[2]

(e) Explain why condensation polymers normally biodegrade more readily than addition polymers.

Condensation polymers can be hydrolysed

[1]

[Total: 11]

9 The structure of cyclohexylamine is shown in Fig. 9.1.

cyclohexylamine

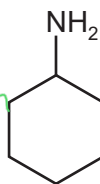


Fig. 9.1

NH₃



depends on ease of acceptance of H⁺ by N atom
the higher the e⁻ density the greater the attraction

(a) Compare the relative basicities of ammonia, cyclohexylamine and phenylamine. Explain your reasoning.

cyclohexylamine > ammonia > phenylamine
most basic least basic

Basicity depends on ability of N atom to accept a proton. Electron donating alkyl group increases electron density on N atom in cyclohexylamine. Lone pair of electrons of N atom is delocalised into ring of phenylamine and reduces charge density on N atom.

[3]

(b) Cyclohexylamine reacts with ethanoyl chloride to form the corresponding amide, L.

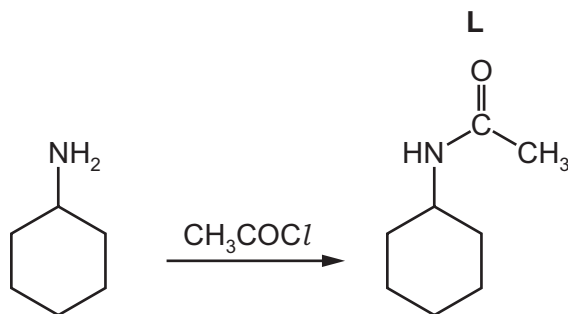


Fig. 9.2

(i) Name the mechanism for the reaction shown in Fig. 9.2.

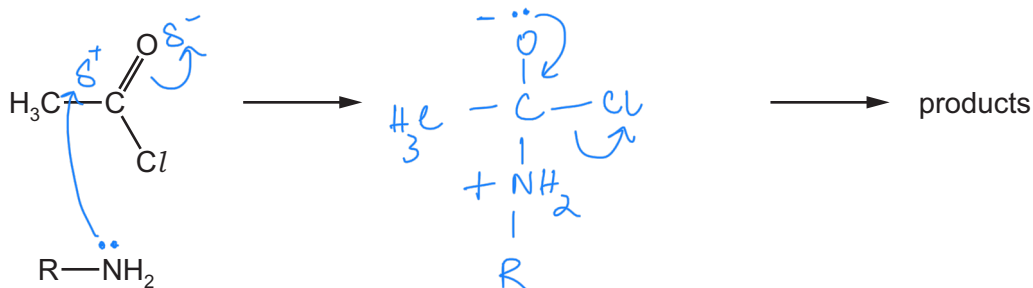
Addition-elimination

[1]

(ii) Complete the mechanism of the reaction between cyclohexylamine and CH_3COCl .

R-NH_2 is used to represent cyclohexylamine.

Include all relevant lone pairs of electrons, curly arrows, charges and partial charges.

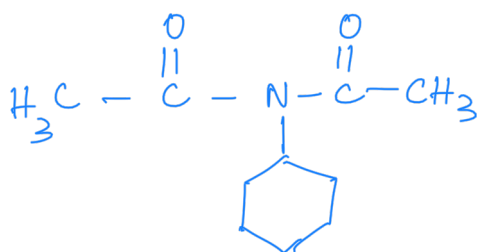


[4]

(iii) The reaction between cyclohexylamine and an excess of CH_3COCl forms compound M. Compound M has the molecular formula $\text{C}_{10}\text{H}_{17}\text{NO}_2$.

Suggest and draw the structure of M.

same as
part 2



[1]

[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 $\text{J g}^{-1} \text{ K}^{-1}$)

The Periodic Table of Elements

		Group																					
1	2																	13	14	15	16	17	18
		1															5	6	7	8	9		2
		H															B	C	N	O	F		He
		hydrogen															boron	carbon	nitrogen	oxygen	fluorine		helium
		1.0															10.8	12.0	14.0	16.0	19.0		4.0
																	13	14	15	16	17		10
																	Al	Si	P	S	Cl		Ne
																	aluminium	silicon	phosphorus	sulfur	chlorine		neon
																	27.0	28.1	31.0	32.1	35.5		20.2
																	31	32	33	34	35		36
																	Ga	Ge	As	Se	Br		Kr
																	gallium	germanium	arsenic	selenium	bromine		krypton
																	69.7	72.6	74.9	79.0	79.9		83.8
																	49	50	51	52	53		54
																	In	Sn	Sb	Te	I		Xe
																	indium	tin	antimony	tellurium	iodine		xenon
																	114.8	118.7	121.8	127.6	126.9		131.3
																	81	82	83	84	85		86
																	Tl	Pb	Bi	Po	At		Rn
																	thallium	lead	bismuth	polonium	astatine		radon
																	204.4	207.2	209.0	—	—		—
																	113	114	115	116	117		118
																	Nh	Fl	Mc	Lv	Ts		Og
																	nihonium	flerovium	moscovium	livermorium	tennessine		oganeson
																	—	—	—	—	—		—

		Group																											
3	4	5	6	7	8	9	10	11	12							13	14	15	16	17	18								
3	4																	5	6	7	8	9	10	11	12				
Li	Be																	B	C	N	O	F							
lithium	beryllium																	boron	carbon	nitrogen	oxygen	fluorine							
6.9	9.0																	10.8	12.0	14.0	16.0	19.0							
																		13	14	15	16	17							
																		Al	Si	P	S	Cl							
																		aluminium	silicon	phosphorus	sulfur	chlorine							
																		27.0	28.1	31.0	32.1	35.5							
																		31	32	33	34	35							
																		Ga	Ge	As	Se	Br							
																		gallium	germanium	arsenic	selenium	bromine							
																		69.7	72.6	74.9	79.0	79.9							
																		49	50	51	52	53							
																		In	Sn	Sb	Te	I							
																		indium	tin	antimony	tellurium	iodine							
																		114.8	118.7	121.8	127.6	126.9							
																		81	82	83	84	85							
																		Tl	Pb	Bi	Po	At							
																		thallium	lead	bismuth	polonium	astatine							
																		204.4	207.2	209.0	—	—							
																		113	114	115	116	117							
																		Nh	Fl	Mc	Lv	Ts							
																		nihonium	flerovium	moscovium	livermorium	tennessine							
																		—	—	—	—	—							

		Group																
13	14	15	16	17	18							13	14	15	16	17	18	
67	68	69	70	71								67	68	69	70	71		
Ho	Er	Tm	Yb	Lu								Ho	Er	Tm	Yb	Lu		
holmium	erbium	thulium	ytterbium	lutetium								holmium	erbium	thulium	ytterbium	lutetium		
164.9	167.3	168.9	173.1	175.0								164.9	167.3	168.9	173.1	175.0		
												99	100	101	102			
												Es	Fm	Md	No			
												einsteinium	fermium	mendelevium	nobelium			
												—	—	—	—			
												—	—	—	—			

		Group																			
3	4	5	6	7	8	9	10	11	12							13	14	15	16	17	18
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	
																91	92	93	94	95	
																Pa	U	Np	Pu	Am	
																protactinium	uranium	neptunium	plutonium	americium	
																231.0	238.0	237.0	239.0	243.0	
																—	—	—	—	—	
																—	—	—	—	—	

lanthanoids

actinoids