1 **(a)** Dilute sodium hydroxide, NaOH(aq), is electrolysed.

Identify the gas produced at the anode, and write a half-equation for the reaction involved.

gas produced at the anode ..... O_2 ✓ .....

half-equation .... $4OH^- \rightarrow 2H_2O + O_2 + 4e^-$ .....

[2]

(b) Molten lead bromide, $PbBr_2(l)$, is electrolysed using a current of 2.40 A for 12.0 minutes.

Bromine gas, $Br_2(g)$, is produced at the anode.

(i) Calculate the amount, in mol, of $Br_2(g)$ produced.

$Q = I \cdot t = 2.4 \times 12 \times 60 = 1728\ C$.

$n_e = \frac{Q}{F} = 0.0179\ mol$

$n_{Br_2} = \frac{1}{2} n_e$ amount of $Br_2(g)$ = ... 8.95×10^{-3} ..... mol [2]

(ii) The $Br_2(g)$ is collected and its volume is measured at a pressure of 101 kPa and a temperature of 380 °C.

Use the ideal gas equation to calculate the volume of $Br_2(g)$ collected under these conditions.

Give your answer in dm^3 to **three** significant figures.

Show your working.

$V = \frac{nRT}{P} = \frac{8.95 \times 10^{-3} \times 8.314 \times (380 + 273)}{101 \times 10^3} = 4.81 \times 10^{-4}\ m^3$

$= 0.0681\ dm^3$

volume of $Br_2(g)$ = ... 2.68 ..... dm^3 [1]

(c) In a different experiment, molten sodium chloride, NaC*l*(l), is electrolysed.

36 000 C of charge is transferred. 8.51 g of sodium metal is produced.

Calculate a value for the Avogadro constant, *L*.

Show your working.

Give your answer to **three** significant figures.

$$L = \frac{\text{no. of } e^-}{\text{mole of } e^-} = \frac{36000 / 1.6 \times 10^{-19}}{8.51 / 23} = 6.08 \times 10^{23} \text{ mol}^{-1}$$

L = 6.08×10^{23} mol^{-1} [2]

[Total: 7]

2 **(a)** Define strong acid and weak acid.

strong acid ..... Proton donor that completely dissociated

weak acid ..... Proton donor that partially dissociated. [2]

(b) A 1.00 mol dm^{-3} solution of NaOH(aq) is slowly added to a solution containing ethanedioic acid, HOOCCOOH(aq), until the solution is alkaline.

During the addition of NaOH(aq), two organic conjugate acid–base pairs are formed in the mixture.

Use the formulas of the species involved to identify the **two** different **organic** conjugate acid–base pairs.

pair 1: $HOOCCOOH$ (conjugate acid) $HOOCCOO^-$ (conjugate base)

pair 2: $HOOCCOO^-$ (conjugate acid) $^-OOCCOO^-$ (conjugate base)

[1]

(c) A solution of ethanoic acid, $CH_3COOH(aq)$, mixed with calcium ethanoate, $Ca(CH_3COO)_2(aq)$, acts as a buffer solution.

(i) Write an equation for a reaction that has calcium ethanoate as one of the products.

$2CH_3COOH + Ca(OH)_2 \rightarrow Ca(CH_3COO)_2 + 2H_2O$ [2]

(ii) Define buffer solution.

Solution that resists pH change when a small amount of acid or base are added.

..... [1]

(iii) Write **two** equations to explain how a buffer solution containing $CH_3COOH(aq)$ and $Ca(CH_3COO)_2(aq)$ can control pH.

$CH_3COOH + OH^- \rightarrow CH_3COO^- + H_2O$

$CH_3COO^- + H^+ \rightarrow CH_3COOH$ [2]

(d) The pH of a solution of sodium hydroxide, NaOH, is 11.34.

Calculate the pH of a solution of barium hydroxide, $Ba(OH)_2$, of the same concentration.

pOH of NaOH = 14 - 11.34 = 2.66

$[OH^-] = 10^{-2.66} = 2.19 \times 10^{-3}$ mol·dm^{-3}

$[OH^-]$ in $Ba(OH)_2 = 4.38 \times 10^{-3}$ mol·dm^{-3}

pOH of $Ba(OH)_2 = 2.36$

pH of $Ba(OH)_2$ = 14 - 2.36

pH = 11.64 [3]

(e) (i) Define partition coefficient, K_{pc}.

The ratio of concentration of a solute in two immiscible solvents at equilibrium [1]

(ii) Equal volumes of butan-1-ol, $CH_3CH_2CH_2CH_2OH$, and water are added to a separating funnel. 6.00 g of substance **A** is added to this mixture.

The separating funnel is shaken until all of **A** has dissolved. It is left to stand until no further change takes place.

5.32 g of **A** is found to be dissolved in the aqueous layer.

Calculate the partition coefficient, K_{pc}, of **A** between butan-1-ol and water.

Your answer should be less than 1.00.

$$K_{pc} = \frac{n_A \text{ in butan-1-ol} / V_b}{n_A \text{ in aqueous} / V_{H_2O}} = \frac{(6 - 5.32)/1}{5.32/1} = 0.128$$

K_{pc} = 0.128 [1]

(iii) A similar experiment is performed to find the partition coefficient, K_{pc}, of **A** between cyclohexane, C_6H_{12}, and water.

Predict whether this K_{pc} is greater than, equal to, or less than your answer to **2(e)(ii)**.

Explain your answer.

K_{pc} of **A** between C_6H_{12} and water is less than my answer to **2(e)(ii)**.

explanation A is a polar molecule as it dissolved more in aqueous than butan-1-ol. C_6H_{12} is a non-polar solvent compared to butan-1-ol, dissolves A less. [3]

[Total: 16]

3 Nitrogen dioxide reacts with fluorine as shown.

$$2NO_2(g) + F_2(g) \rightarrow 2NO_2F(g)$$

The rate equation for this reaction is shown.

$$\text{rate} = k[NO_2][F_2]$$

(a) Complete Table 3.1.

Table 3.1

order of the reaction with respect to $[NO_2]$	1st
order of the reaction with respect to $[F_2]$	1st
overall order of the reaction	2nd

[1]

(b) Table 3.2 shows data from three experiments. The table is incomplete.

Table 3.2

experiment	$[NO_2]$ / mol dm^{-3}	$[F_2]$ / mol dm^{-3}	rate / mol dm^{-3} s^{-1}
1	0.0250	0.0300	3.45×10^{-6}
2	0.0250	0.1200	1.38×10^{-5}
3	0.0125	0.1200	6.90×10^{-6}

(i) Complete Table 3.2, stating the concentration of F_2 in experiment 2 and the rate of the reaction in experiment 3. [2]

(ii) Calculate the rate constant, *k*, under these conditions. Include the units of *k*.

$$k = \frac{\text{rate}}{[NO_2][F_2]} = \frac{3.45 \times 10^{-6}}{0.025 \times 0.03} = 4.6 \times 10^{-3} \text{ mol}^{-1}\text{ dm}^3\text{ s}^{-1}$$

k = 4.6×10^{-3}

units = $\text{mol}^{-1}\text{ dm}^3\text{ s}^{-1}$

[2]

(c) The experiment is performed again using a large excess of NO_2.

Under these conditions, the reaction behaves as if it is overall first order. The rate equation is shown.

$$\text{rate} = k'[F_2]$$

When the initial value of $[F_2]$ is 4.00×10^{-5} mol dm^{-3} and the rate of the reaction is measured in mol dm^{-3} s^{-1}, the value of k' is 0.0101.

Calculate the half-life of the reaction, $t_{\frac{1}{2}}$, under these conditions.

$t_{1/2} = \frac{\ln 2}{k} = 68.61$ s

$t_{\frac{1}{2}}$ = 68.61 s [1]

(d) Suggest a two-step mechanism for the reaction between nitrogen dioxide and fluorine.

Identify which of the two steps is the slower step.

$$2NO_2(g) + F_2(g) \rightarrow 2NO_2F(g)$$

$$\text{rate} = k[NO_2][F_2]$$

step 1 $NO_2 + F_2 \rightarrow NO_2F_2$

step 2 $NO_2F_2 + NO_2 \rightarrow 2NO_2F$

slower step step 1

[2]

[Total: 8]

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

The energy change when each of 1 mole of gaseous atoms gains 1 electron. [1]

(ii) Describe the trend in the first electron affinities of chlorine, bromine and iodine.

Explain your answer.

Less negative from Cl to Br to I.

Larger radius down the group, weaker attraction between the nuclei and the incoming electron, less energy released. [2]

(b) The lattice enthalpy of potassium bromide, KBr, is $-670\,kJ\,mol^{-1}$.

Predict values, in $kJ\,mol^{-1}$, for the lattice enthalpies of sodium chloride, NaCl, and magnesium oxide, MgO. No calculations are needed.

Explain your predictions.

lattice enthalpy of NaCl = − low $kJ\,mol^{-1}$

explanation Na^+ has higher charge density than K^+ due to smaller radius, same as Cl^- to Br^-. Stronger attraction between Na^+ & Cl^-.

lattice enthalpy of MgO = − low $kJ\,mol^{-1}$

explanation Mg^{2+} has higher charge density than Na^+ due to greater charge, same as O^{2-} to Cl^-. Stronger attraction between Mg^{2+} & O^{2-}

[4]

(c) Magnesium reacts with chlorine as shown.

$$Mg(s) + Cl_2(g) \rightarrow MgCl_2(s) \qquad \Delta S^{\ominus} = -198.3\,J\,mol^{-1}\,K^{-1}$$

(i) Define entropy.

The possible arrangement of particles & energy in a system. [1]

(ii) Explain why the sign of the entropy change for this reaction is negative.

Gas molecules is fewer on the RHS.

[1]

(iii) Predict whether the reaction between magnesium and chlorine becomes more or less spontaneous as temperature increases.

Explain your answer.

The reaction becomes less spontaneous.

explanation $\Delta G^{\theta} = \Delta H - T\Delta S^{\theta}$ becomes more positive as ΔS^{θ} is negative, $-T\Delta S^{\theta}$ gets more positive as T increases.

[2]

[Total: 11]

5 (a) The Group 2 nitrates undergo thermal decomposition.

(i) Write an equation for the thermal decomposition of anhydrous calcium nitrate.

$Ca(NO_3)_2 \rightarrow CaO + 2NO_2 + \frac{1}{2}O_2$ [1]

(ii) Describe the trend in thermal stability of the nitrate compounds going down Group 2.

Explain your answer.

trend Increases

explanation Charge density of cations decreases down the group due to increasing ionic radius. Less polarisation of the nitrate. More energy required to decompose

[2]

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(b) (i) A spatula measure of magnesium hydroxide, $Mg(OH)_2(s)$, is stirred into a beaker of $H_2SO_4(aq)$. A solution is formed with no solid remaining.

A spatula measure of barium hydroxide, $Ba(OH)_2(s)$, is stirred into a different beaker of $H_2SO_4(aq)$. A permanent precipitate is seen.

Explain these observations.

The white ppt is $BaSO_4$.
which has much lower solubity than $MgSO_4$.

[1]

(ii) A spatula measure of $Mg(OH)_2(s)$ is stirred into a beaker of water. Very little of the solid dissolves.

A spatula measure of $Ba(OH)_2(s)$ is stirred into a different beaker of water. A solution is formed with no solid remaining.

Explain these observations in terms of the energy changes involved.

$Mg(OH)_2$ is less soluble than $Ba(OH)_2$

$\Delta H^{\ominus}_{latt}$ & $\Delta H^{\ominus}_{hyd}$ both become less negative of $Ba(OH)_2$.
$\Delta H^{\ominus}_{latt}$ changes more.
$\Delta H^{\ominus}_{sol}$ become more negative of $Ba(OH)_2$ [3]

[Total: 7]

6 Transition elements can form complex ions.

(a) Define complex.

Central atom/ion surrounded by coordinately bonded ligands. [1]

(b) Rhodium ions, Rh^{3+}, form ten different octahedral complexes with chloride and ammonia ligands, including isomers.

These complexes have the formula $[Rh(NH_3)_xCl_y]^n$ where *x* and *y* can be any integer from zero to six, and *n* represents a charge between 3– and 3+.

(i) Complexes **B** and **C** both contain Rh^{3+}, chloride and ammonia ligands.

B has a 2– charge. **C** has a 1+ charge.

State the values of *x* and *y* in **B** and in **C**.

x in **B** = 1 *y* in **B** = 5

x in **C** = 4 *y* in **C** = 2

[2]

(ii) Complex **D**, $[Rh(NH_3)_3Cl_3]$, is uncharged. It exists as a pair of isomers.

State the coordination number of Rh^{3+} in **D**.

6 [1]

(iii) Complete the three-dimensional diagrams in Figure 6.1 to show the two isomers of **D**, $[Rh(NH_3)_3Cl_3]$.

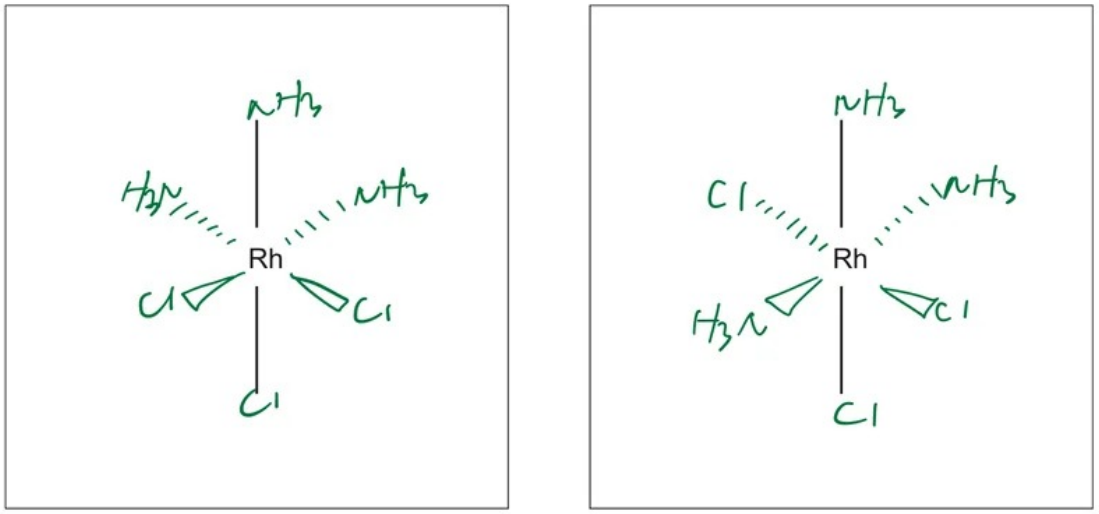


Figure 6.1

[2]

(iv) Complete Table 6.1 by placing **one** tick (✓) in **each** row to indicate whether the type of isomerism is shown in **D**.

Table 6.1

type of isomerism	shown in D	
	yes	no
stereoisomerism	✓	
optical isomerism		✓
geometrical isomerism	✓	

[1]

(c) Nickel(II) salts dissolve in water to form the $[Ni(H_2O)_6]^{2+}$ complex.

Nickel can also form complex **E**, $[Ni(NH_3)_6]^{2+}$. The expression for K_{stab} of **E** is shown.

$$K_{stab} = \frac{[[Ni(NH_3)_6]^{2+}]}{[[Ni(H_2O)_6]^{2+}][NH_3]^6} = 4.80 \times 10^7 \text{ (units not shown)}$$

(i) Define stability constant, K_{stab}. 分配 Def.

The equilibrium constant of formation of complex from aqueous solution. [1]

(ii) State the units of K_{stab} for **E**.

$mol^{-6}\ dm^{18}$ [1]

(iii) **F** is an aqueous solution containing ammonia, NH_3, **E** and $[Ni(H_2O)_6]^{2+}$.

In solution **F**, $[NH_3] = 0.455\,mol\,dm^{-3}$ and $[\mathbf{E}] = 0.0762\,mol\,dm^{-3}$.

Calculate the concentration, in $mol\,dm^{-3}$, of $[Ni(H_2O)_6]^{2+}$ in **F**.

$$[Ni(H_2O)_6]^{2+} = \frac{[E]}{K_{stab} \cdot [NH_3]^6} = \frac{0.0762}{4.80 \times 10^7 \times 0.455^6}$$

concentration of $[Ni(H_2O)_6]^{2+}$ in **F** = 1.79×10^{-7} $mol\,dm^{-3}$ [2]

(iv) Complete the equation for the reaction between $[Ni(H_2O)_6]^{2+}$ and NH_3 forming **E**.

$[Ni(H_2O)_6]^{2+}$ + 6 NH_3 → ..... $[Ni(NH_3)_6]^{2+}$ + 6 H_2O [1]

(v) Name the type of reaction described in **6(c)(iv)**.

Ligand exchange [1]

[Total: 13]

Turn over

7 **(a)** The molecular formula of benzene is C_6H_6. The six carbon atoms in benzene form a six-membered ring.

(i) State the C–C–H bond angle in benzene and the hybridisation of each carbon atom.

bond angle ..... 120° .....

hybridisation ..... sp^2 .....

[1]

(ii) The bonds between neighbouring carbon atoms in benzene involve two types of orbital overlap, giving σ and π bonds.

Name the orbitals involved, and describe the orbital overlap, in σ and π bonds.

orbitals involved in σ bonds ..... sp^2 .....

orbital overlap in σ bonds ..... head–on .....

orbitals involved in π bonds ..... p .....

orbital overlap in π bonds ..... sideways .....

[2]

(b) Figure 7.1 describes a four-step synthesis of phenol, starting with benzene.

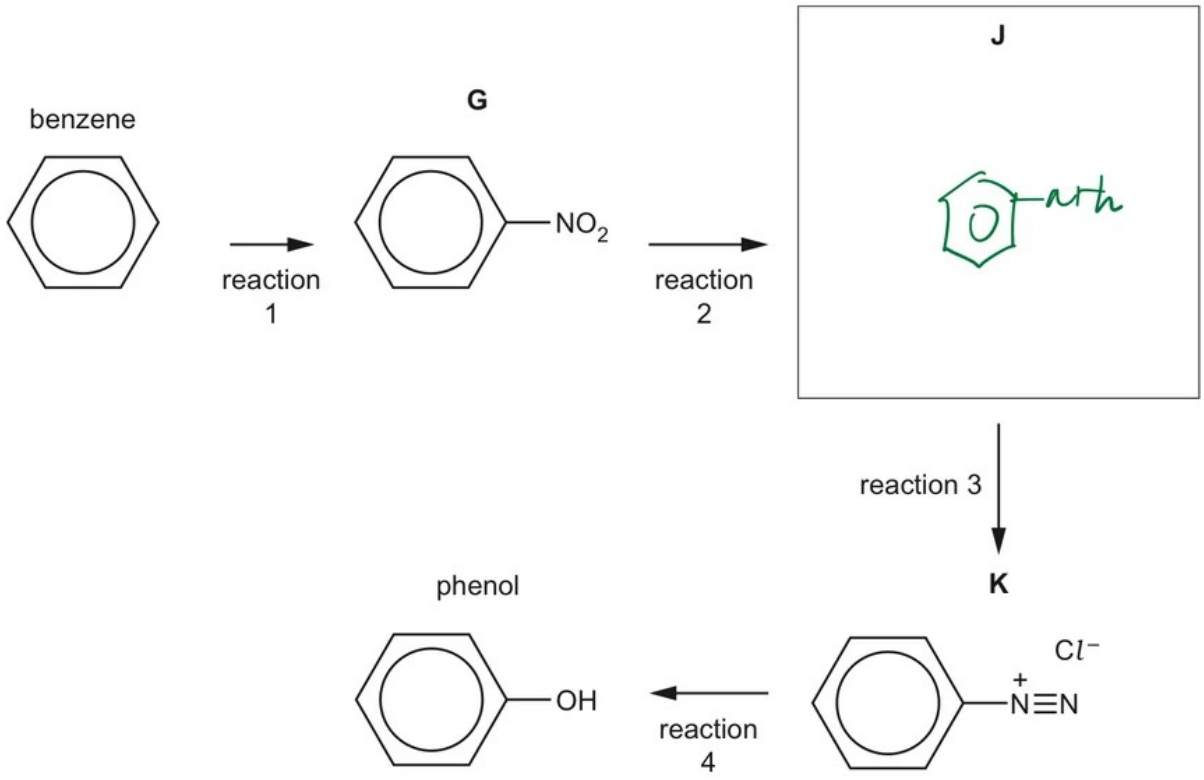


Figure 7.1

(i) State the reagents and conditions for reaction 1 in Figure 7.1.

Conc. HNO_3, conc H_2SO_4, $55°C$ [1]

(ii) The reagents and conditions for reaction 2 are concentrated HC*l* and Sn, heated under reflux.

这不等一下?

Draw the structure of compound **J** in Figure 7.1. [1]

(iii) State the reagents and conditions for reactions 3 and 4 in Figure 7.1.

reaction 3 $NaNO_2$, HCl, $T < 10°C$

reaction 4 HNO, $T > 10°C$

[2]

(c) Benzene reacts with ethanoyl chloride, CH_3COCl, in the presence of an $AlCl_3$ catalyst.

In this reaction, the electrophile is the CH_3C^+O ion.

(i) Complete the mechanism in Figure 7.2 for this reaction.

Include all relevant curly arrows and charges.

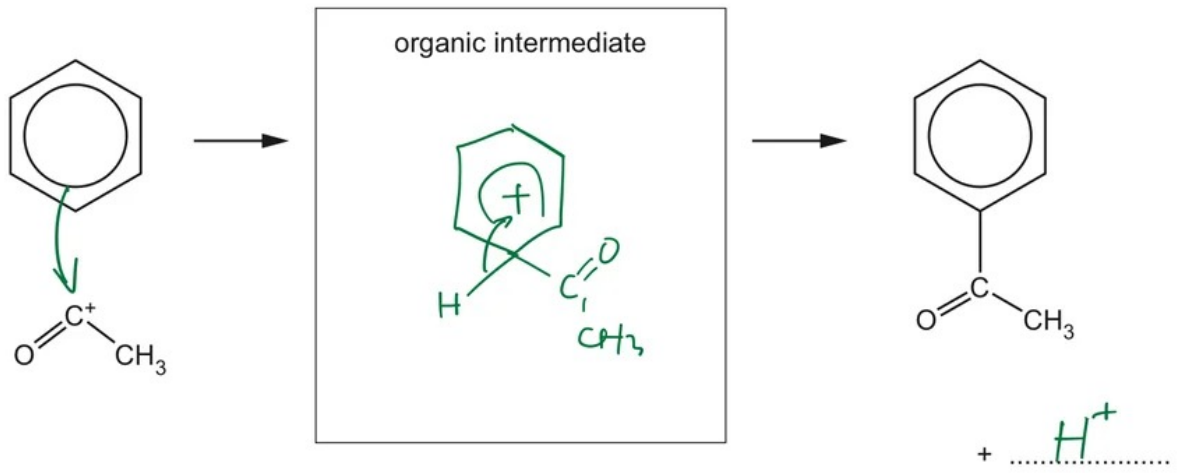


Figure 7.2

[3]

(ii) The product of the reaction shown in Figure 7.2, $C_6H_5COCH_3$, can be oxidised by heating with alkaline $KMnO_4$.

The reaction mixture is then acidified. Benzoic acid, C_6H_5COOH, is produced.

Complete the equation for the overall reaction, where [O] represents one atom of oxygen from the oxidising agent.

$C_6H_5COCH_3$ + 4 [O] → C_6H_5COOH + CO_2 + H_2O [1]

(d) Figure 7.3 describes a two-step synthesis of C_6H_5COOH.

$C_6H_5COCH_3$ is treated with two reagents, firstly reagent **M** and secondly reagent **N**, producing C_6H_5COOH.

Figure 7.3

Identify **M** and **N**, neither contains MnO_4^- or $Cr_2O_7^{2-}$.

reagent **M** ...alkaline I$_2$ (aq)...

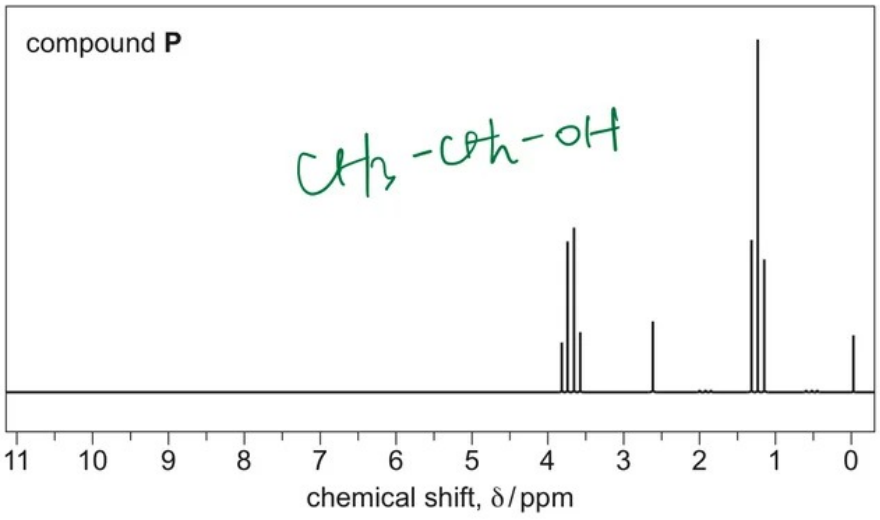
reagent **N** ...dilute HCl (aq)...

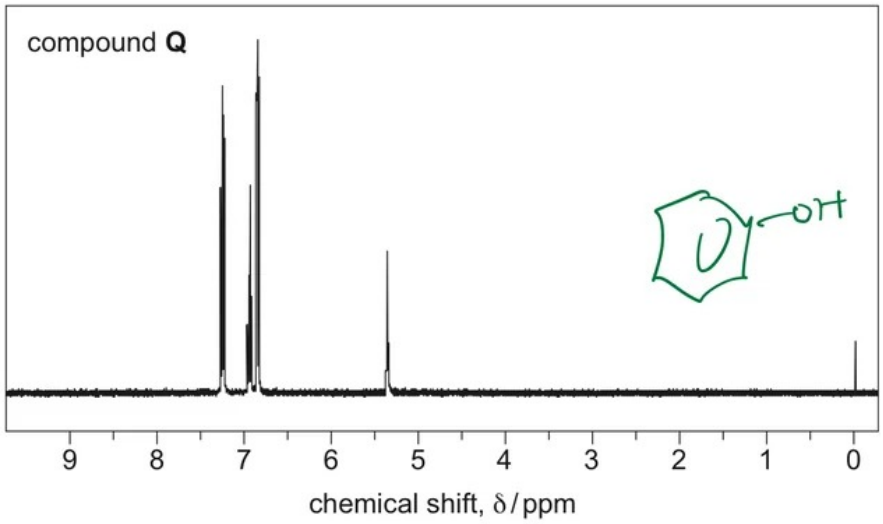
[2]

[Total: 13]

Turn over

8 The proton (^{1}H) NMR spectra of three compounds, **P**, **Q** and **R**, are shown in Figure 8.1. The solvent used is $CDCl_3$ in each case.





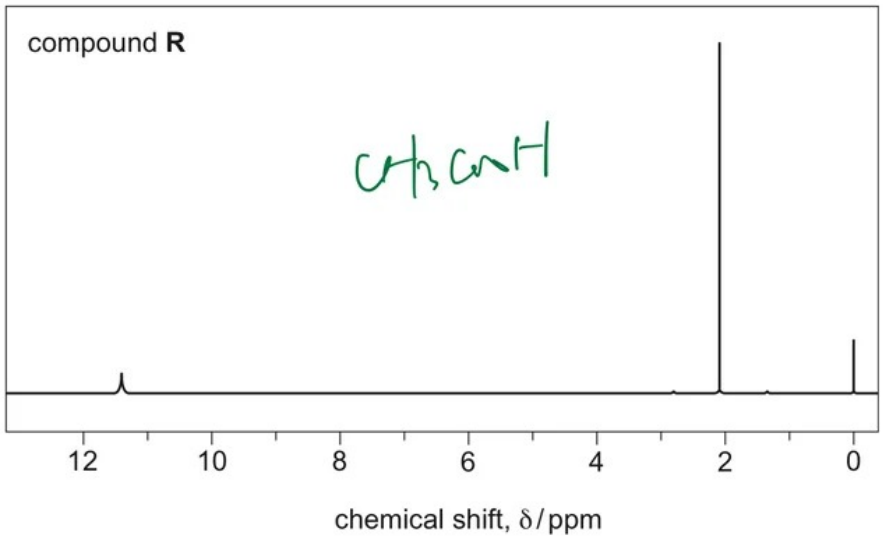


Figure 8.1

Table 8.1

environment of proton	example	chemical shift range δ / ppm
alkane	–C**H**$_3$, –C**H**$_2$–, >C**H**–	0.9–1.7
alkyl next to C=O	C**H**$_3$–C=O, –C**H**$_2$–C=O, >C**H**–C=O	2.2–3.0
alkyl next to aromatic ring	C**H**$_3$–Ar, –C**H**$_2$–Ar, >C**H**–Ar	2.3–3.0
alkyl next to electronegative atom	C**H**$_3$–O, –C**H**$_2$–O, –C**H**$_2$–Cl	3.2–4.0
attached to alkene	=C**H**R	4.5–6.0
attached to aromatic ring	**H**–Ar	6.0–9.0
aldehyde	**H**COR	9.3–10.5
alcohol	RO**H**	0.5–6.0
phenol	Ar–O**H**	4.5–7.0
carboxylic acid	RCOO**H**	9.0–13.0
alkyl amine	R–N**H**–	1.0–5.0
aryl amine	Ar–N**H**$_2$	3.0–6.0
amide	RCON**H**R	5.0–12.0

(a) Identify the substance responsible for the peak at δ = 0 ppm on each spectrum.

TMS ..... [1]

(b) **P**, **Q** and **R** are phenol, ethanol and ethanoic acid, but not necessarily in this order.

(i) Identify which compound is phenol.

Explain your answer, identifying the protons responsible for the peaks in the relevant spectrum.

phenol is compound Q .....

explanation ..... Peaks within 6.0 – 9.0 indicate H–Ar .....

.....

.....

[2]

(ii) The spectrum of **P** has peaks at δ = 1.2 ppm and δ = 3.7 ppm.

Name the splitting pattern of each of these peaks and give a reason why the peaks are split in this way.

splitting pattern of the peak at δ = 1.2 ppm ..... triplet .....

reason for this splitting pattern ..... 2 H atoms on the adjacent C. .....

splitting pattern of the peak at δ = 3.7 ppm ..... quartet .....

reason for this splitting pattern ..... 3 H atoms on the adjacent C. .....

[2]

(c) The spectrum of **Q** dissolved in D_2O is obtained.

Describe how this spectrum differs from the spectrum of **Q** shown in Figure 8.1.

Explain your answer.

difference ..... peak at δ = 5.3 ppm disappears. .....

explanation ..... H on –OH is replaced by D .....

[1]

(d) Compare the acidities of phenol, ethanol and ethanoic acid.

Explain your answer.

ethanoic acid ..... phenol ..... ethanol .....

most acidic least acidic

explanation The acidity increases as bond strength of O–H decreases, easier to donate a proton.

- In ethanoic acid, the C=O is electron-withdrawing group, weaken O–H the most.
- In phenol, the lone pair on O delocalised into the ring, weaken O–H

[4]

- In ethanol, the ethyl group is electron-donating group, strengthen O–H.

[Total: 10]

9 **(a)** Using a gel buffered at pH 7.6, electrophoresis is performed on a mixture of three amino acids: asparagine, histidine and lysine.

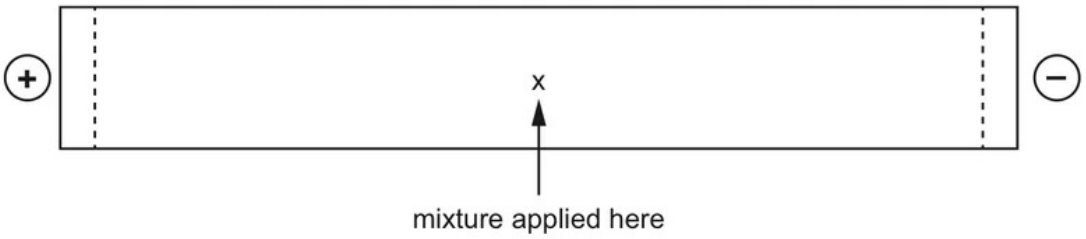


Figure 9.1

The isoelectric points of these amino acids are given in Table 9.1.

Table 9.1

amino acid	isoelectric point
asparagine	5.4
histidine	7.6
lysine	9.7

Describe the direction of movement of each amino acid during the electrophoresis.

Explain your answers.

asparagine ..... Positive terminal as the pH is higher than 5.4 .....

histidine ..... No move as the pH is equal to 7.6 .....

lysine ..... Negative terminal as the pH is lower than 9.7. .....

[3]

(b) Serine, $H_2NCH(CH_2OH)COOH$, is an amino acid. It exists as a pair of optical isomers.

(i) Draw diagrams in Figure 9.2 to show the three-dimensional structures of the two optical isomers of serine.

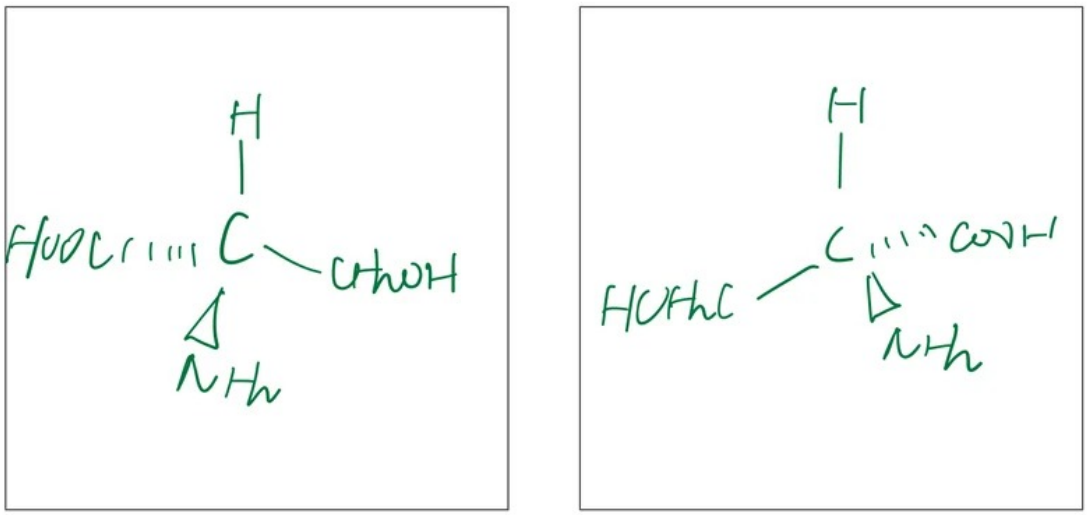


Figure 9.2

[1]

(ii) Give the name for a mixture containing equal amounts of the two optical isomers.

Racemic mixture ..... [1]

(iii) Describe **two** properties that are different for the two optical isomers.

- different direction that rotate plane of polarised light
- different biological activity ..... [2]

(iv) Serine is treated with an excess of phosphorus pentachloride, PCl_5.

The phosphorus-containing product of this reaction is $POCl_3$. ? 这种怎么说我？

Complete the equation for this reaction. Use the structural formula of the organic product.

$H_2NCH(CH_2OH)COOH$ + ... 2 ..... PCl_5 → $HN\,CH(CH_2Cl)COCl$ + $2POCl_3$ + $2HCl$ [2]

[Total: 9]

10 ClOCCOCl can be used to make many polymers.

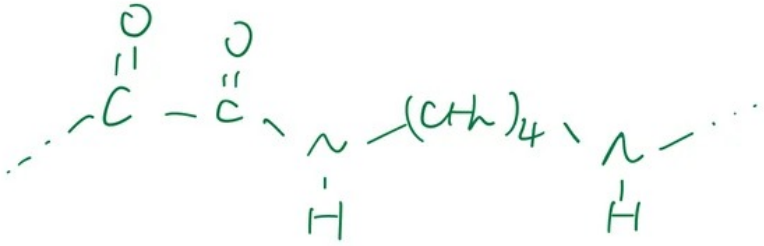
(a) Suggest the name of ClOCCOCl.

Ethanedioyl dichloride [1]

(b) **(i)** ClOCCOCl reacts with $H_2N(CH_2)_4NH_2$ to form a polymer.

Draw a section of the polymer showing only **one** repeat unit.

Any functional groups should be fully displayed.



[2]

(ii) State the type of polymerisation involved and the linkage between the monomers.

type of polymerisation Condensation

linkage Amide [1]

(c) When $H_2NCO(CH_2)_2CONH_2$ reacts with a suitable reagent, $H_2N(CH_2)_4NH_2$ forms.

Identify this reagent.

$LiAlH_4$ [1]

(d) 1,4-dibromobutane can be used to form $H_2N(CH_2)_4NH_2$.

Describe the reagents and conditions used.

NH_3 in ethanol heat under pressure.

[1]

[Total: 6]

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Important values, constants and standards

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

The Periodic Table of Elements

Group																	
1	2											13	14	15	16	17	18
							1 H hydrogen 1.0										2 He helium 4.0
3 Li lithium 6.9	4 Be beryllium 9.0											5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2
11 Na sodium 23.0	12 Mg magnesium 24.3	3	4	5	6	7	8	9	10	11	12	13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium –	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs caesium 132.9	56 Ba barium 137.3	57–71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium –	85 At astatine –	86 Rn radon –
87 Fr francium –	88 Ra radium –	89–103 actinoids	104 Rf rutherfordium –	105 Db dubnium –	106 Sg seaborgium –	107 Bh bohrium –	108 Hs hassium –	109 Mt meitnerium –	110 Ds darmstadtium –	111 Rg roentgenium –	112 Cn copernicium –	113 Nh nihonium –	114 Fl flerovium –	115 Mc moscovium –	116 Lv livermorium –	117 Ts tennessine –	118 Og oganesson –

Key

atomic number
atomic symbol
name
relative atomic mass

lanthanoids	57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.2	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
actinoids	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 –