GradeMax

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CANDIDATE NAME

CENTRE NUMBER

CANDIDATE NUMBER

8738073913

CHEMISTRY **9701/41**

Paper 4 A Level Structured Questions **May/June 2026**

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. Do **not** use correction fluid or tape.
- 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.

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[Turn over

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1 **(a)** Write the equation to represent the lattice energy, ΔH_{latt}, of calcium sulfide, CaS.

Include state symbols.

..... [2]

(b) Explain why the value of ΔH_{latt} of CaS is negative.

.....

..... [1]

(c) State the order of the ΔH_{latt} values of CaS, MgO and KC*l*, from most negative to least negative.

Explain your answer.

....
most negative least negative

explanation .....

.....

.....

.....

.....

.....

[3]

(d) The enthalpy change of formation, ΔH_f, of $Cl^-(g)$ or $Mg^{2+}(g)$ is the energy change when one mole of gaseous ions forms from the element in its standard state at 298 K.

enthalpy change of formation of chloride ions, $Cl^-(g) = -243\,kJ\,mol^{-1}$

enthalpy change of formation of magnesium ions, $Mg^{2+}(g) = +2336\,kJ\,mol^{-1}$

(i) The enthalpy change of formation of $Cl^-(g)$ can be calculated using two energy changes only.

Identify the **two** energy changes.

.....

..... [1]

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(ii) The lattice energy of magnesium chloride, $MgCl_2$, is –2493 kJ mol^{-1}.

Use this value, and other data given, to calculate the enthalpy change of formation, in kJ mol^{-1}, of $MgCl_2$(s).

ΔH_f of $MgCl_2$(s) = ... kJ mol^{-1} [2]

(e) Magnesium carbonate, $MgCO_3$, decomposes when heated.

$MgCO_3 \rightarrow MgO + CO_2$ $\quad \Delta S = +175\,J\,K^{-1}\,mol^{-1}$, $\Delta H = +117\,kJ\,mol^{-1}$

Predict whether the decomposition of $MgCO_3$ is feasible at 600 °C.

Use a calculation to explain your answer.

feasibility .....

explanation .....

.....

[3]

(f) Calcium carbonate, $CaCO_3$, also decomposes when heated.

State whether the decomposition of $CaCO_3$ occurs at a higher or lower temperature than that of $MgCO_3$. Explain your answer.

.....

.....

.....

..... [2]

[Total: 14]

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2 **(a)** **(i)** Define pH mathematically.

pH = ... [1]

(ii) Define K_w mathematically.

K_w = ... [1]

(b) Solution **A** is 100 cm^3 of an aqueous solution of 0.105 mol dm^{-3} butanoic acid, $CH_3CH_2CH_2COOH$. **A** has pH 2.90 at 298 K.

(i) Calculate the concentration, in mol dm^{-3}, of $H^+(aq)$ in **A**.

$[H^+]$ in **A** = ... mol dm^{-3} [1]

(ii) Calculate the value of K_a of $CH_3CH_2CH_2COOH$ at 298 K.

K_a of $CH_3CH_2CH_2COOH$ = ... [1]

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(c) Solution **B** is 100 cm^3 of an aqueous solution containing 0.450 $mol\,dm^{-3}$ $CH_3CH_2CH_2COOH$.

Solution **C** is 200 cm^3 of an aqueous solution containing sodium butanoate, $CH_3CH_2CH_2COONa$.

B is added to **C** to produce 300 cm^3 of solution **D**. The concentration of H^+ ions in **D** is 6.31×10^{-5} $mol\,dm^{-3}$.

(i) Calculate the concentration of $CH_3CH_2CH_2COONa$ in **C**.

(If you were unable to calculate an answer in **2(b)(ii)**, then use 3.00×10^{-5} as the value of K_a of $CH_3CH_2CH_2COOH$. This is **not** the correct answer.)

[$CH_3CH_2CH_2COONa$] in **C** = ... $mol\,dm^{-3}$ [3]

(ii) Write an equation for the reaction when $H_2SO_4(aq)$ is added to **D**.

..... [1]

(iii) Write an equation for the reaction when KOH(aq) is added to **D**.

..... [1]

(d) Predict the relative acidities of 2,2-dichlorobutanoic acid, $CH_3CH_2CCl_2COOH$, and butanoic acid, $CH_3CH_2CH_2COOH$.

Explain your answer.

stronger acid .....

explanation .....

.....

.....

.....

[2]

[Total: 11]

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3 Nitrogen monoxide reacts with hydrogen to produce nitrogen and water.

$$2NO + 2H_2 \rightarrow N_2 + 2H_2O$$

The rate equation for this reaction is shown.

$$\text{rate} = k[NO]^2[H_2]$$

Two experiments are carried out to investigate this reaction.

(a) Complete Table 3.1.

Table 3.1

order with respect to [NO]	
order with respect to [H_2]	
overall order	

[1]

(b) In experiment 1, the rate of the reaction is 2.80×10^{-10} mol dm^{-3} s^{-1} when [NO] is 5.00×10^{-2} mol dm^{-3} and [H_2] is 8.00×10^{-2} mol dm^{-3}.

Calculate the value of the rate constant, k, in experiment 1. State the units of k.

k = ...

units = ...

[2]

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(c) Experiment 2 is carried out under different conditions from experiment 1. The value of *k* for experiment 2 is 2.13×10^{-5}.

In experiment 2, a large excess of NO is used. The initial value of $[H_2]$ is $1.20 \times 10^{-3}\,\text{mol}\,\text{dm}^{-3}$.

(i) A graph of $[H_2]$ against time for experiment 2 shows that the reaction has a constant half-life.

Explain why the graph shows a constant half-life, referring to:

- the overall order of the reaction under these conditions
- the reason why this is the overall order under these conditions.

.....

.....

..... [1]

(ii) Calculate the half-life, in s, of the reaction in experiment 2 and state the time taken, in s, for the value of $[H_2]$ to fall to $7.50 \times 10^{-5}\,\text{mol}\,\text{dm}^{-3}$.

half-life = ... s

time taken for $[H_2]$ to fall to $7.50 \times 10^{-5}\,\text{mol}\,\text{dm}^{-3}$ = ... s
[2]

(d) The overall reaction of nitrogen monoxide with hydrogen has a three-step mechanism.

$$2NO + 2H_2 \rightarrow N_2 + 2H_2O$$

Part of this mechanism is shown.

step 1 $2NO \rightarrow N_2O_2$

step 2 ..... $\rightarrow$ .....

step 3 $N_2O + H_2 \rightarrow N_2 + H_2O$

(i) Complete the mechanism by writing an equation for step 2. [2]

(ii) It can be deduced that step 1 is **not** the rate-determining step of the reaction.

Explain why.

.....

..... [1]

[Total: 9]

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4 Some electrode potentials are given in Table 4.1.

Table 4.1

electrode reaction	$E^{\ominus}$ / V
$Cl_2 + 2e^- \rightleftharpoons 2Cl^-$	+1.36
$Cu^{2+} + 2e^- \rightleftharpoons Cu$	+0.34
$Fe(OH)_3 + e^- \rightleftharpoons Fe(OH)_2 + OH^-$	–0.56
$Fe^{3+} + e^- \rightleftharpoons Fe^{2+}$	+0.77
$V^{2+} + 2e^- \rightleftharpoons V$	–1.13
$V^{3+} + e^- \rightleftharpoons V^{2+}$	–0.26

(a) Complete the equation that can be used to calculate the standard Gibbs free energy change, $\Delta G^{\ominus}$, for a cell reaction using the standard cell potential, $E^{\ominus}_{cell}$.

$\Delta G^{\ominus}$ =

[1]

(b) An electrochemical cell is set up using a V^{3+}/V^{2+} electrode and a Cu^{2+}/Cu electrode, both under standard conditions.

Write an equation for the cell reaction that occurs and calculate the value for $E^{\ominus}_{cell}$.

equation .....

$E^{\ominus}_{cell}$ = ... V

[2]

(c) Identify **two** atoms or ions from Table 4.1 that will reduce Fe^{3+} to Fe^{2+} under neutral conditions, but will **not** reduce $Fe(OH)_3$ to $Fe(OH)_2$ under alkaline conditions.

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

(d) Identify the strongest oxidising agent and the strongest reducing agent in Table 4.1.

strongest oxidising agent .....

strongest reducing agent .....

[2]

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(e) A dilute solution of NaOH(aq) is electrolysed using inert electrodes.
A steady current of 2.40A is passed for 2.00 hours.

Calculate the mass, in g, of oxygen that is released at the anode.

mass of oxygen = ... g [3]

[Total: 10]

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5 Cobalt is a transition element. It forms a wide range of coloured compounds that contain Co^{2+} ions or Co^{3+} ions.

(a) Explain why a transition element, such as cobalt, has variable oxidation states in its compounds.

.....

..... [1]

(b) Complete the electronic configurations of a Co atom and a Co^{2+} ion.

Co atom: [Ar] .....

Co^{2+} ion: [Ar] .....

[1]

(c) Explain why compounds containing Co^{2+} ions are coloured.

.....

.....

.....

.....

.....

..... [3]

(d) A few drops of water are added to a piece of dry cobalt(II) chloride paper.

Describe the colour change that is seen. Write an equation for the reaction that causes this colour change.

colour change: from ..... to .....

equation .....

[2]

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(e) Copper is a transition element.

A piece of copper is added to $HNO_3(aq)$. All the copper forms $Cu(NO_3)_2(aq)$.

An excess of KI(aq) is added to the $Cu(NO_3)_2(aq)$ in a conical flask. All the copper present forms CuI. The equation for the reaction is shown.

reaction 1 $2Cu(NO_3)_2 + 4I^- \rightarrow 2CuI + I_2 + 4NO_3^-$

The I_2 formed in this reaction is titrated with $0.200\,mol\,dm^{-3}$ $Na_2S_2O_3(aq)$. The end-point of the titration is reached when $37.60\,cm^3$ of $Na_2S_2O_3(aq)$ has been added. The equation for the reaction is shown.

reaction 2 $2S_2O_3^{2-} + I_2 \rightarrow S_4O_6^{2-} + 2I^-$

(i) Describe **two** observations that can be made about the contents of the conical flask after KI(aq) has been added to $Cu(NO_3)_2(aq)$.

observation 1 .....

observation 2 .....

[1]

(ii) Name a suitable indicator for this titration and describe the colour change at the end-point of the titration.

indicator .....

colour change from ..... to .....

[1]

(iii) Name the type of reaction that occurs in both reactions 1 and 2.

..... [1]

(iv) Calculate the mass, in g, of the piece of copper added to $HNO_3(aq)$.

mass of copper = ... g [3]

[Total: 13]

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[Turn over

6 Transition elements form complexes with species called ligands. The ethanedioate ion, $C_2O_4^{2-}$, is a bidentate ligand.

(a) Explain what is meant by bidentate ligand.

.....

..... [2]

(b) One Fe^{3+} ion forms an octahedral complex with three $C_2O_4^{2-}$ ions.

(i) State the formula and charge of this complex.

..... [1]

(ii) This complex shows stereoisomerism.

Draw three-dimensional diagrams to show all the stereoisomers of this complex.

The $C_2O_4^{2-}$ ion can be represented using  .

[2]

(iii) State the type or types of stereoisomerism shown by this complex.

..... [1]

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(c) Hg^{2+} ions and iodide ions, I^-, form a complex with the formula $[HgI_4]^{2-}$.

Write the expression for K_{stab} of $[HgI_4]^{2-}$. State its units.

K_{stab} =

units = ...

[2]

[Total: 8]

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7 **(a)** Phenol, C_6H_6O, can be made from benzene, C_6H_6, in a four-step process, as shown in Figure 7.1.

$$C_6H_6 \xrightarrow{\text{step 1}} C_6H_5NO_2 \xrightarrow{\text{step 2}} C_6H_7N \xrightarrow{\text{step 3}} C_6H_5N_2Cl \xrightarrow{\text{step 4}} C_6H_6O$$

Figure 7.1

(i) State the reagents and conditions for step 1.

..... [1]

(ii) State the reagents and conditions for step 3.

..... [1]

(iii) Name the compound $C_6H_5N_2Cl$ formed in step 3.

..... [1]

(b) Phenol reacts with propanone in the presence of an acid catalyst to form compound **G**, as shown in Figure 7.2.

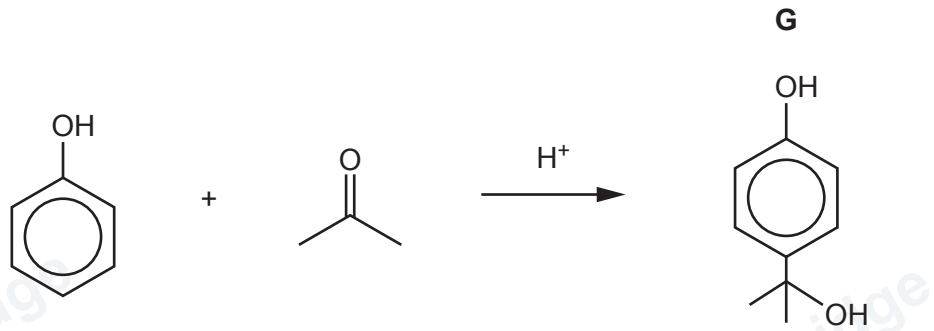

Figure 7.2

(i) Complete Table 7.1 to show the number of sp, sp^2 and sp^3 hybridised carbon atoms in propanone and in **G**.

Table 7.1

	sp	**sp^2**	**sp^3**
propanone			
G			

[1]

(ii) State the number of peaks in the carbon-13 NMR spectrum of **G**.

..... [1]

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(iii) The first stage of the mechanism for the reaction in Figure 7.2 involves the formation of ion **J**.

Complete the mechanism in Figure 7.3 to show the formation of **J** by adding dipoles and curly arrows, as appropriate.

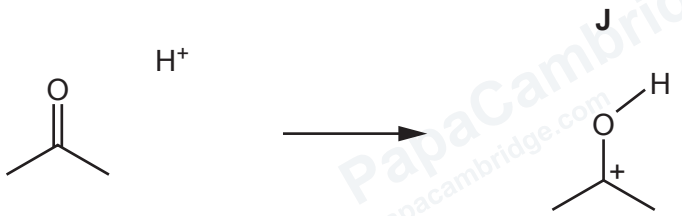

Figure 7.3

[1]

(iv) The next stage of the mechanism involves the reaction between **J** and phenol to form intermediate **K**. A proton is then lost from **K** to produce **G**.

Complete Figure 7.4 to show these stages of the mechanism. Include relevant curly arrows and charges.

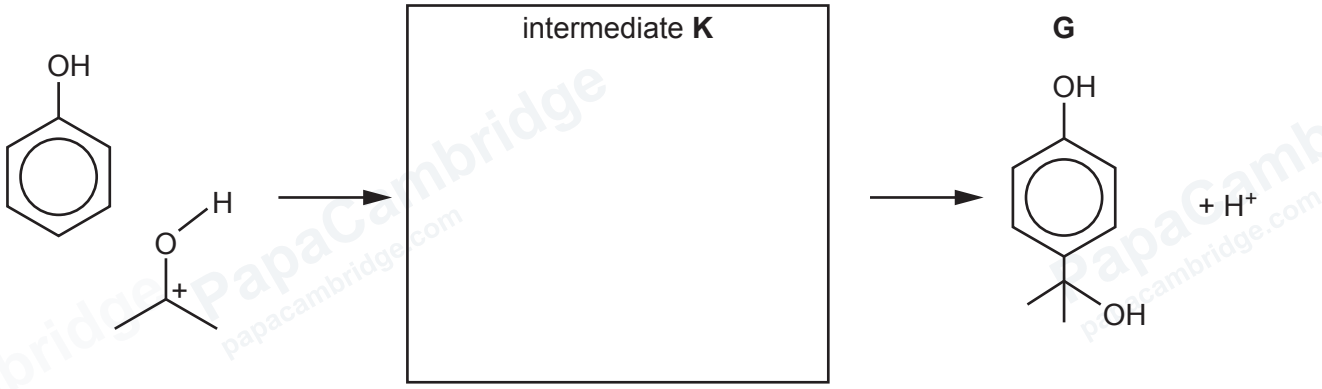

Figure 7.4

[3]

(v) Benzene is mixed with propanone in the presence of $H^+(aq)$.

Predict whether benzene reacts with propanone more readily, as readily or less readily than phenol does under the same conditions.

Explain your answer.

Benzene reacts with propanone ..... than phenol does.

explanation .....

.....

.....

[2]

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(c) **G** reacts with $Br_2(aq)$ in the dark. The organic product of this reaction is compound **H**.

(i) Complete the equation for this reaction in Figure 7.5.

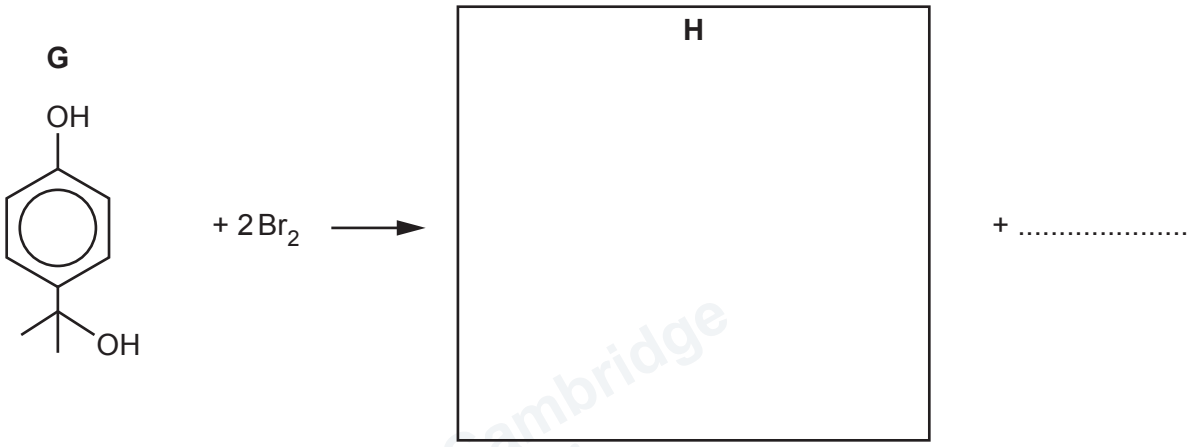

Figure 7.5

[2]

(ii) Name the mechanism for this reaction.

..... [1]

[Total: 14]

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8 Secondary amine **M** can be made by the three-step synthesis shown in Figure 8.1.

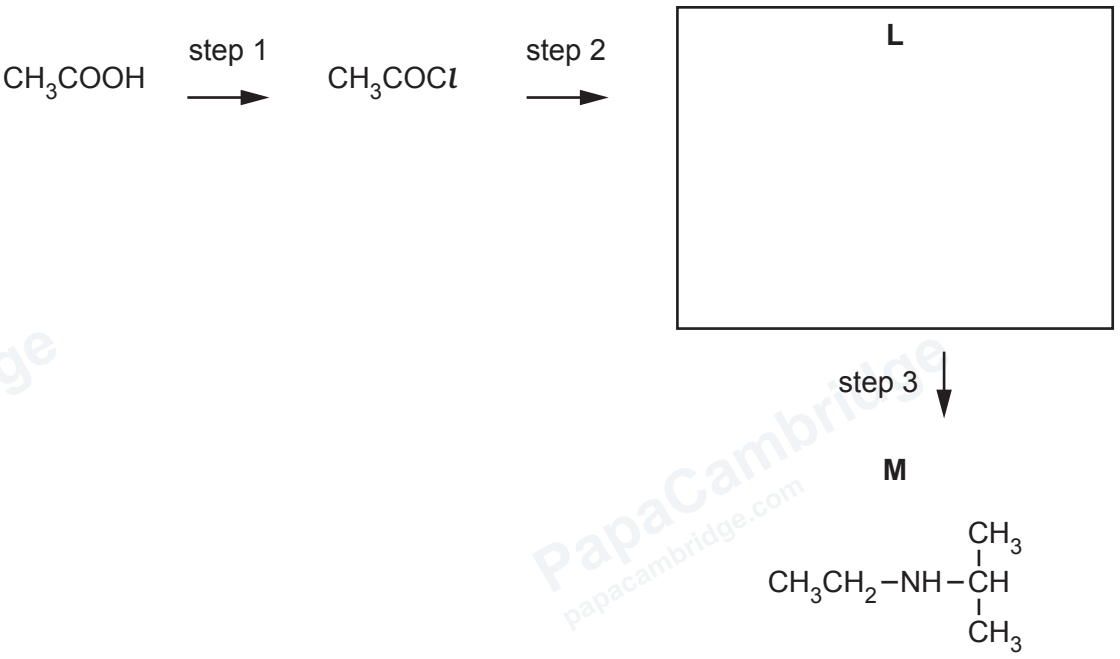

Figure 8.1

(a) (i) Write an equation for the reaction of CH_3COOH with $SOCl_2$ in step 1.

..... [1]

(ii) State an alternative reagent that reacts with CH_3COOH to produce CH_3COCl in step 1.

..... [1]

(iii) Compound **L** is an amide.

Draw the structure of **L** in Figure 8.1. [1]

(iv) Draw the structure of the reagent added to CH_3COCl in step 2.

[1]

(v) Name the mechanism of the reaction forming **L** in step 2.

..... [1]

(vi) Suggest a reagent for step 3.

..... [1]

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(b) The proton (^{1}H) NMR spectrum of **M** dissolved in D_2O is obtained. Four of the proton environments, **r**, **s**, **t** and **u**, are labelled on the structure of **M** in Figure 8.2.

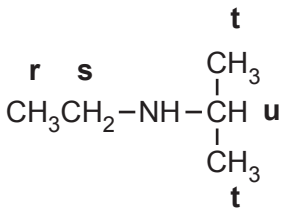

Figure 8.2

(i) Complete Table 8.1 to identify the splitting patterns for proton environments **r**, **s**, **t** and **u**.

Table 8.1

proton environment	name of splitting pattern
r	
s	
t	
u	

[2]

(ii) The proton (^{1}H) NMR spectrum of **M** dissolved in $CDCl_3$ is obtained.

State and explain how this spectrum differs from the proton (^{1}H) NMR spectrum of **M** dissolved in D_2O.

.....

.....

.....

..... [2]

[Total: 10]

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9 An amino acid is a compound that has both an amine group and a carboxyl group.

(a) The structures of three amino acids, **P**, **Q** and **R**, are shown in Figure 9.1.

P	**Q**	**R**
$NH_2CH(CH_3)COOH$	$NH_2C(CH_3)CHCOOH$	NH_2CH_2COOH

Figure 9.1

Two of the amino acids in Figure 9.1 show stereoisomerism.

Draw the **two** stereoisomers of each of these amino acids in Figure 9.2. Name the type of stereoisomerism shown for each pair of stereoisomers. Use three-dimensional bonds where appropriate.

type of stereoisomerism	

type of stereoisomerism	

Figure 9.2

[3]

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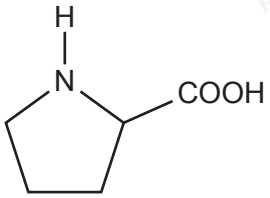
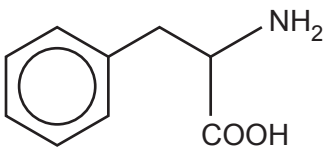
(b) The structures of amino acids **T** and **U** and their isoelectric points are shown in Table 9.1.

Table 9.1

	T	**U**
structure		
isoelectric point	6.3	5.5

(i) Explain what is meant by isoelectric point.

.....

..... [1]

(ii) Complete Table 9.2 to show the predominant species formed by amino acids **T** and **U** at the pH values shown.

Table 9.2

	pH 4.0	**pH 5.5**	**pH 8.0**
T			
U			

[3]

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(c) Amino acids **P**, $NH_2CH(CH_3)COOH$, and **R**, NH_2CH_2COOH, can form tripeptide **W**, $C_8H_{15}N_3O_4$. The structure of tripeptide **W** can be represented as **P–R–P**.

(i) Draw the structure of **W**. The peptide functional groups formed should be displayed.

[2]

(ii) **W** reacts under suitable conditions to form two molecules of **P** and one molecule of **R**.

Name the type of reaction.

..... [1]

(iii) Amino acids **P** and **R** can also form a number of polymers. One of these polymers, **X**, has a structure that can be represented as –[P–R–]_n.

Name the type of polymerisation involved in the formation of **X**.

..... [1]

[Total: 11]

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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	$c = 4.18\,\text{kJ kg}^{-1}\,\text{K}^{-1}$ ($4.18\,\text{J g}^{-1}\,\text{K}^{-1}$)

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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 –

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