Mock Exam 2

CANDIDATE NAME

CENTRE NUMBER

CANDIDATE NUMBER

CHEMISTRY **9701**

Paper 4 A Level Structured Questions **2 hours 15 minutes**

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 .
- The number of marks for each question or part question is shown in brackets 114
- The Periodic Table is printed in the question paper.
- Important values, constants and standards are printed in the question paper.

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

1

(a) **(i)** What is meant by the term *lattice energy*?

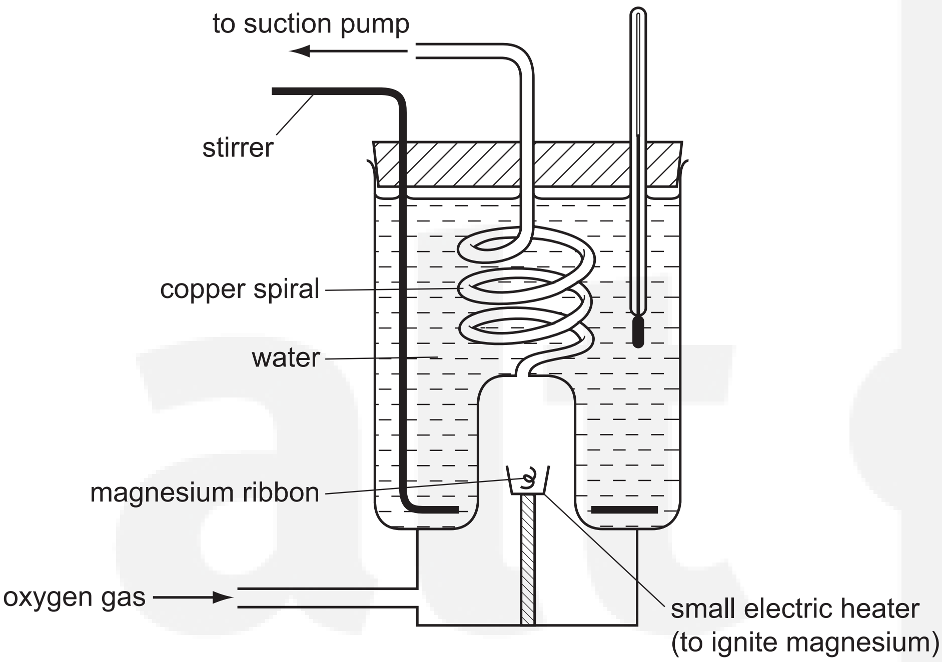
....

....

(ii) Write an equation to represent the lattice energy of MgO.

.... [3]

(b) The apparatus shown in the diagram can be used to measure the enthalpy change of formation of magnesium oxide, $\Delta H_f^\ominus(MgO)$.



List the measurements you would need to make using this apparatus in order to calculate $\Delta H_f^\ominus(MgO)$.

....

....

....

.... [3]

(c) Use the following data, together with appropriate data from the *Data Booklet*, to calculate a value of $\Delta H_f^\ominus$(MgO).

lattice energy of MgO(s)	=	–3791 $kJ\,mol^{-1}$
enthalpy change of atomisation of Mg	=	+148 $kJ\,mol^{-1}$
electron affinity of the oxygen atom	=	–141 $kJ\,mol^{-1}$
electron affinity of the oxygen anion, O^-	=	+798 $kJ\,mol^{-1}$

$\Delta H_f^\ominus$(MgO) = ... $kJ\,mol^{-1}$ [3]

(d) Write equations, including state symbols, for the reactions, if any, of the following two oxides with water. Suggest values for the pH of the resulting solutions.

oxide	equation	pH of resulting solution
Na_2O		
MgO		

[3]

[Total: 12]

2 **(a)** State briefly what is meant by the following terms.

(i) reversible reaction

....

(ii) dynamic equilibrium

....

....

[2]

(b) Water ionises to a small extent as follows.

$$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq) \qquad \Delta H = +58\,kJ\,mol^{-1}$$

(i) Write an expression for K_c for this reaction.

....

(ii) Write down the expression for K_w, the ionic product of water, and explain how this can be derived from your K_c expression in **(i)**.

....

....

(iii) State and explain how the value of K_w for hot water will differ from its value for cold water.

....

....

[3]

(c) K_w can be used to calculate the pH of solutions of strong and weak bases.

(i) Use the value of K_w in the *Data Booklet* to calculate the pH of $0.050\,mol\,dm^{-3}$ NaOH.

pH = ...

Ammonia ionises slightly in water as follows.

$$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

The following expression applies to this equilibrium.

$$[H_2O] \times K_c = [NH_4^+][OH^-]/[NH_3] = 1.8 \times 10^{-5}\,mol\,dm^{-3}$$

(ii) Calculate $[OH^-(aq)]$ in a 0.050 mol dm^{-3} solution of NH_3. You may assume that only a small fraction of the NH_3 ionises, so that $[NH_3]$ at equilibrium remains at 0.050 mol dm^{-3}.

$[OH^-(aq)]$ = ...

(iii) Use the value of K_w in the *Data Booklet*, and your answer in **(ii)**, to calculate $[H^+(aq)]$ in 0.050 mol dm^{-3} NH_3(aq).

$[H^+(aq)]$ = ...

(iv) Calculate the pH of this solution.

pH = ...

[6]

[Total: 11]

3 Substances **P** and **Q** react in solution at a constant temperature.
The initial rate of reaction was studied in three experiments by measuring the change in concentration of **P** over the first five seconds of the reaction.
The data obtained are shown in **Table 1**.

Table 1

Experiment	Time after mixing / s	Concentration / mol dm^{-3}	
		P	Q
1	0	1.00×10^{-2}	1.25×10^{-2}
	5.0	0.92×10^{-2}	not measured
2	0	2.00×10^{-2}	1.25×10^{-2}
	5.0	1.84×10^{-2}	not measured
3	0	0.50×10^{-2}	2.50×10^{-2}
	5.0	0.34×10^{-2}	not measured

(a) (i) Complete **Table 2** to show the initial rate of reaction of **P** in each experiment.

[1 mark]

Table 2

Experiment	Initial rate / mol dm^{-3} s^{-1}
1	1.6×10^{-4}
2	
3	

(ii) Determine the order of reaction with respect to **P** and the order of reaction with respect to **Q**.

[2 marks]

Order with respect to **P** ______________________

Order with respect to **Q** ______________________

(iii)

A reaction between substances **R** and **S** was second order with respect to **R** and second order with respect to **S**.
At a given temperature, the initial rate of reaction was 1.20×10^{-3} mol dm^{-3} s^{-1} when the initial concentration of **R** was 1.00×10^{-2} mol dm^{-3} and the initial concentration of **S** was 2.45×10^{-2} mol dm^{-3}

Calculate a value for the rate constant, *k*, for the reaction at this temperature.
Give the units for *k*

[3 marks]

k ______________________ Units ______________________

(b) At 800 K, nitrogen monoxide reacts with hydrogen according to the following equation.

equation **I** $2H_2(g) + 2NO(g) \rightarrow 2H_2O(g) + N_2(g)$

The following table shows how the initial rate of this reaction depends on the partial pressures of the reagents.

experiment	$p(H_2)$ / atm	p(NO) / atm	initial rate / atm s^{-1}
1	0.64	1.60	1.50×10^{-7}
2	0.64	0.80	3.75×10^{-8}
3	0.32	1.60	7.50×10^{-8}

(i) Find the order of the reaction with respect to each reactant, explaining how you arrive at your answer.

....

....

....

....

....

(ii) Write down the rate equation and the units of the rate constant.

....

The following mechanism has been put forward for this reaction.

step 1	$NO + NO \rightarrow N_2O + O$
step 2	$H_2 + O \rightarrow H_2O$
step 3	$H_2 + N_2O \rightarrow N_2 + H_2O$

(iii) Show how the overall stoichiometric equation **I** can be derived from the three equations for the individual steps given above.

(iv) Suggest which of the three reactions in the mechanism is the rate determining step. Explain your answer.

....

....

[8]

(c) The following information on half-reactions relates to the reaction between HNO_3 and an excess of $FeSO_4$.

$Fe^{3+} + e^- \rightarrow Fe^{2+}$	$E^\ominus = +0.77\,V$
$3H^+ + NO_3^- + 2e^- \rightarrow HNO_2 + H_2O$	$E^\ominus = +0.94\,V$
$HNO_2 + H^+ + e^- \rightarrow NO + H_2O$	$E^\ominus = +0.99\,V$

(i) Suggest the formula of the nitrogen-containing final product of this reaction.

....

(ii) Write an equation for the formation of this nitrogen-containing product.

(iii) Nitrogen monoxide forms a dark brown complex with an excess of $FeSO_4$(aq). What kind of bonding is involved in the complex formation?

....

(iv) Suggest a formula for this complex.

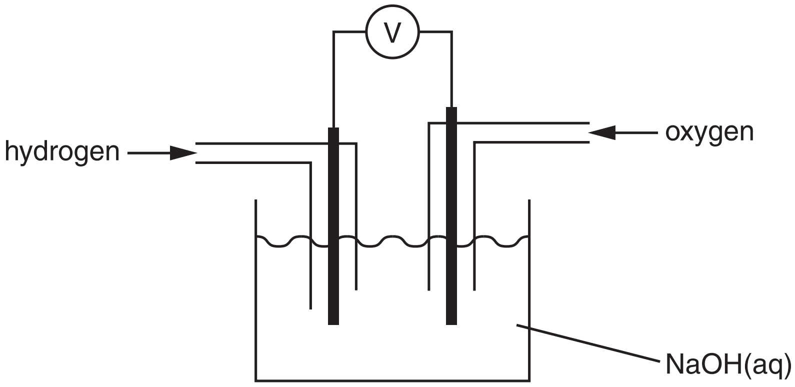
....

[4]

[Total: 18]

4 Although standard electrode potentials are measured for solutions where the concentrations of ions are 1.0 mol dm^{-3}, cells used as sources of battery power tend to operate with more concentrated solutions. This question concerns the electrode reactions involved in the hydrogen-oxygen fuel cell and the lead-acid car battery.

(a) In the hydrogen-oxygen fuel cell, H_2(g) and O_2(g) are fed onto two inert electrodes dipping into NaOH(aq).



The following reactions take place.

left hand electrode (cathode): $H_2(g) + 2OH^-(aq) \rightarrow 2H_2O(l) + 2e^-$

right hand electrode (anode): $O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$

(i) Use the *Data Booklet* to calculate $E^{\ominus}_{cell}$ for this reaction.

....

(ii) Construct an equation for the overall reaction.

....

(iii) By using **one** of the phrases *more positive*, *more negative* or *no change*, deduce the effect of increasing [OH$^-$(aq)] on the electrode potential of

- the left hand electrode ....
- the right hand electrode ....

(iv) Hence deduce whether the overall E_{cell} is likely to *increase*, *decrease* or *remain the same*, when [OH$^-$(aq)] increases. Explain your answer.

....

....

(v) Suggest **one** other reason why a high [NaOH(aq)] is used in the fuel cell.

....

[6]

(b) In the cells of a lead-acid car battery the following reactions take place.

cathode: $Pb(s) \rightarrow Pb^{2+}(aq) + 2e^-$

anode: $PbO_2(s) + 4H^+(aq) + 2e^- \rightarrow Pb^{2+}(aq) + 2H_2O(l)$

(i) Use the *Data Booklet* to calculate $E^{\ominus}_{cell}$ for this reaction.

....

(ii) Construct an equation for the overall reaction.

....

The electrolyte in a lead-acid cell is $H_2SO_4(aq)$. Most of the $Pb^{2+}(aq)$ ions that are produced at the electrodes are precipitated as the highly insoluble $PbSO_4(s)$.

(iii) Construct an equation for the overall cell reaction in the presence of H_2SO_4.

....

(iv) By considering the effect of decreasing $[Pb^{2+}(aq)]$ on the electrode potentials of the cathode and the anode, deduce the effect of the presence of $H_2SO_4(aq)$ in the electrolyte on the overall E_{cell}.
State whether the E_{cell} will *increase*, *decrease* or *remain the same*.

Overall E_{cell} will ....

Explain your answer.

....

....

[5]

[Total: 11]

5 **(a)** **(i)** What is meant by the term *buffer solution*?

....

....

.... [2]

(ii) Write equations to show how the hydrogencarbonate ion, HCO_3^-, controls the pH of blood.

....

.... [2]

(iii) A solution containing both Na_2HPO_4 and NaH_2PO_4 is commonly used as a buffer solution. The following equilibrium is present in the solution.

$$H_2PO_4^-(aq) \rightleftharpoons HPO_4^{2-}(aq) + H^+(aq) \qquad K_a = 6.2 \times 10^{-8}\,mol\,dm^{-3}$$

Calculate the pH of a buffer solution made by mixing 100 cm^3 of 0.5 $mol\,dm^{-3}$ Na_2HPO_4 and 100 cm^3 of 0.3 $mol\,dm^{-3}$ NaH_2PO_4.

pH = ... [2]

(b) Silver phosphate, Ag_3PO_4, is sparingly soluble in water.

(i) Write an expression for the solubility product, K_{sp}, of Ag_3PO_4, and state its units.

K_{sp} = units: .... [1]

(ii) The numerical value of K_{sp} is 1.25×10^{-20} at 298 K. Use this value to calculate $[Ag^+(aq)]$ in a saturated solution of Ag_3PO_4.

$[Ag^+(aq)]$ = ... $mol\,dm^{-3}$ [3]

(c) The half-equation for the redox reaction between phosphoric(III) acid and phosphoric(V) acid is shown.

$$H_3PO_4(aq) + 2H^+(aq) + 2e^- \rightleftharpoons H_3PO_3(aq) + H_2O(l) \qquad E^\ominus = -0.28\,V$$

Find suitable data from the *Data Booklet* to write an equation for the reaction between H_3PO_3 and Fe^{3+}(aq) ions, and calculate the $E^\ominus_{cell}$ for the reaction.

equation: ....

$E^\ominus_{cell}$ = ... V [2]

[Total: 12]

6

Transition elements have characteristic properties due to their partially-filled d orbitals.

(a) **(i)** Which **two** elements in the first row of the d-block have only one electron in the 4s orbital of their neutral atoms?

....

(ii) The d orbitals in an isolated transition metal atom or ion are described as being degenerate.

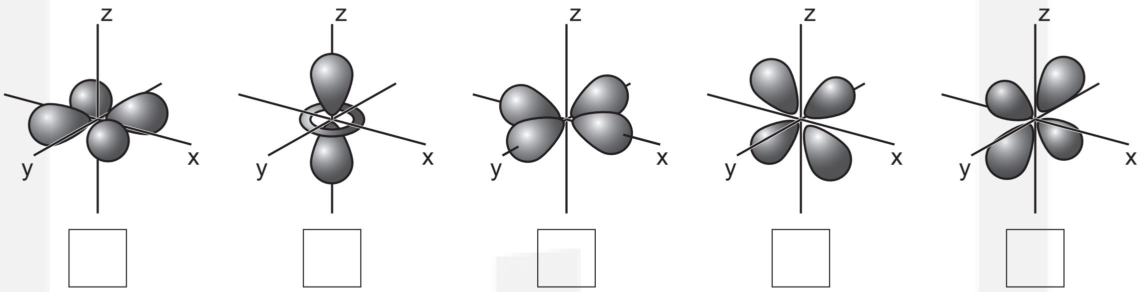
What is meant by the term *degenerate*?

....

(iii) Sketches of the shapes of the atomic orbitals from the d subshell are shown.

In an octahedral complex, the d orbitals are split into two groups at different energy levels.

On the diagram below, write an 'H' in the box under each of the orbitals at the higher energy level.



[4]

(b) **(i)** Complete the following electronic configurations.

- the cobalt atom, Co $1s^2 2s^2 2p^6$ ....
- the cobalt(II) ion, Co^{2+} $1s^2 2s^2 2p^6$ ....

[1]

(ii) State the colours you would observe when concentrated $HCl(aq)$ is added to an aqueous solution of cobalt(II) nitrate, $Co(NO_3)_2$.
Give the formulae and geometry of the complexes formed.

....

....

....

....

.... [5]

(c) There are two isomers with the formula $Ni(R_3P)_2I_2$, but only one structure with the formula $Co(R_3P)_2I_2$. (R = alkyl, R_3P is a monodentate ligand)

Draw diagrams showing the structure of $Co(R_3P)_2I_2$ and the two isomers of $Ni(R_3P)_2I_2$.

$Ni(R_3P)_2I_2$

$Ni(R_3P)_2I_2$

$Co(R_3P)_2I_2$

[3]

(d) In general, reactions of the compounds of transition elements can be classified under one or more of the following headings.

acid-base
ligand exchange
precipitation
redox

Choose the most suitable heading to describe each of the following reactions, by placing a tick (✓) in the appropriate column in the table below.
Only one tick should be placed against each reaction.

reaction	acid-base	ligand exchange	precipitation	redox
$[Cu(H_2O)_6]^{2+} + 4NH_3 \rightarrow [Cu(NH_3)_4]^{2+} + 6H_2O$				
$[Cu(H_2O)_6]^{2+} + 4HCl \rightarrow [CuCl_4]^{2-} + 4H^+ + 6H_2O$				
$2FeCl_2 + Cl_2 \rightarrow 2FeCl_3$				
$[Fe(H_2O)_6]^{2+} + 2OH^- \rightarrow Fe(OH)_2 + 6H_2O$				
$2Fe(OH)_2 + ½O_2 + H_2O \rightarrow 2Fe(OH)_3$				
$CrO_3 + 2HCl \rightarrow CrO_2Cl_2 + H_2O$				
$Cr(H_2O)_3(OH)_3 + OH^- \rightarrow [Cr(H_2O)_2(OH)_4]^- + H_2O$				
$[Cr(OH)_4]^- + 1½H_2O_2 + OH^- \rightarrow CrO_4^{2-} + 4H_2O$				

[8]

(e) Alloys of aluminium, titanium and vanadium are used in aerospace and marine equipment, and in medicine.

When a powdered sample of one such alloy is heated with an excess of aqueous NaOH, only the aluminium reacts, according to the following equation.

$$2Al(s) + 2OH^-(aq) + 6H_2O(l) \rightarrow 2[Al(OH)_4]^-(aq) + 3H_2(g)$$

Reacting 100 g of alloy in this way produced 8.0 dm^3 of hydrogen, measured under room conditions.

Calculate the percentage by mass of aluminium in the alloy.

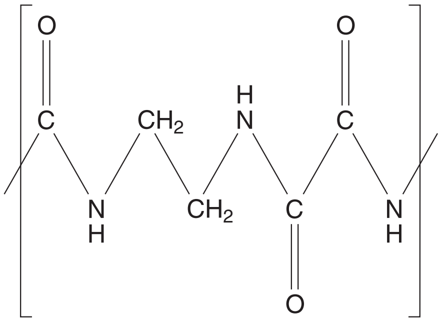
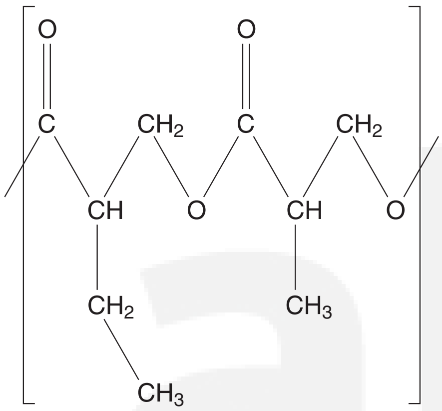
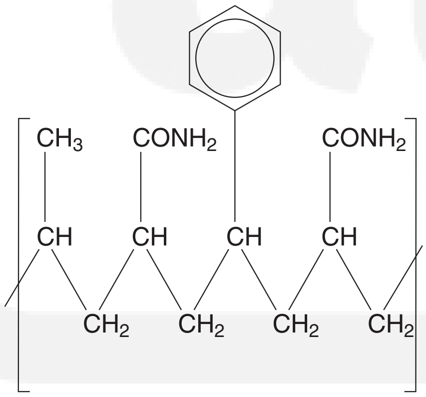
percentage = ... %
[3]

[Total: 24]

7 Each of the following structures is an 8-atom segment of the chain of a commercial polymer.

For each structure,

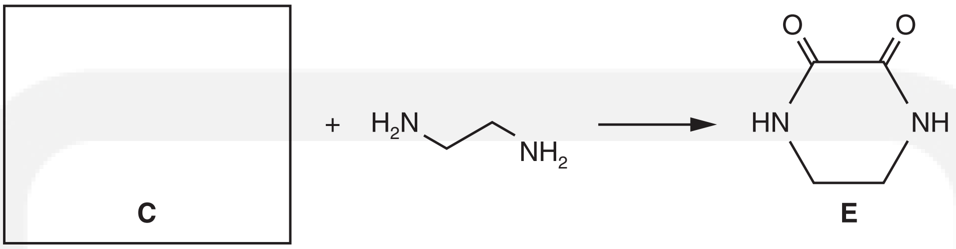
- decide whether it is part of a condensation or an addition polymer, and
- draw the structural formulae of the monomer(s) from which the polymer is made.

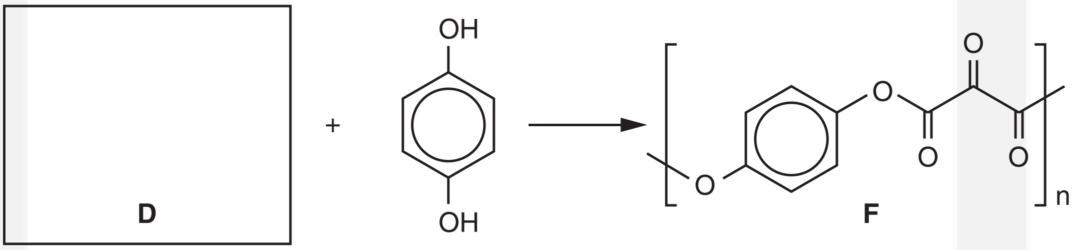
polymer	addition or condensation?	formulae of monomers
		
		
		

[8]

(b)

(i) Suggest suitable acyl chlorides to use in the following reaction. Draw their structures in the boxes provided.





Compound **E** dissolves in, but does not react with, cold water.

(ii) Suggest the major type of intermolecular interaction that occurs between **E** and water.

....

(iii) A solution of the diamine $H_2NCH_2CH_2NH_2$ in water has pH = 11 but a solution of **E** in water has pH = 7. Suggest why this is the case.

....

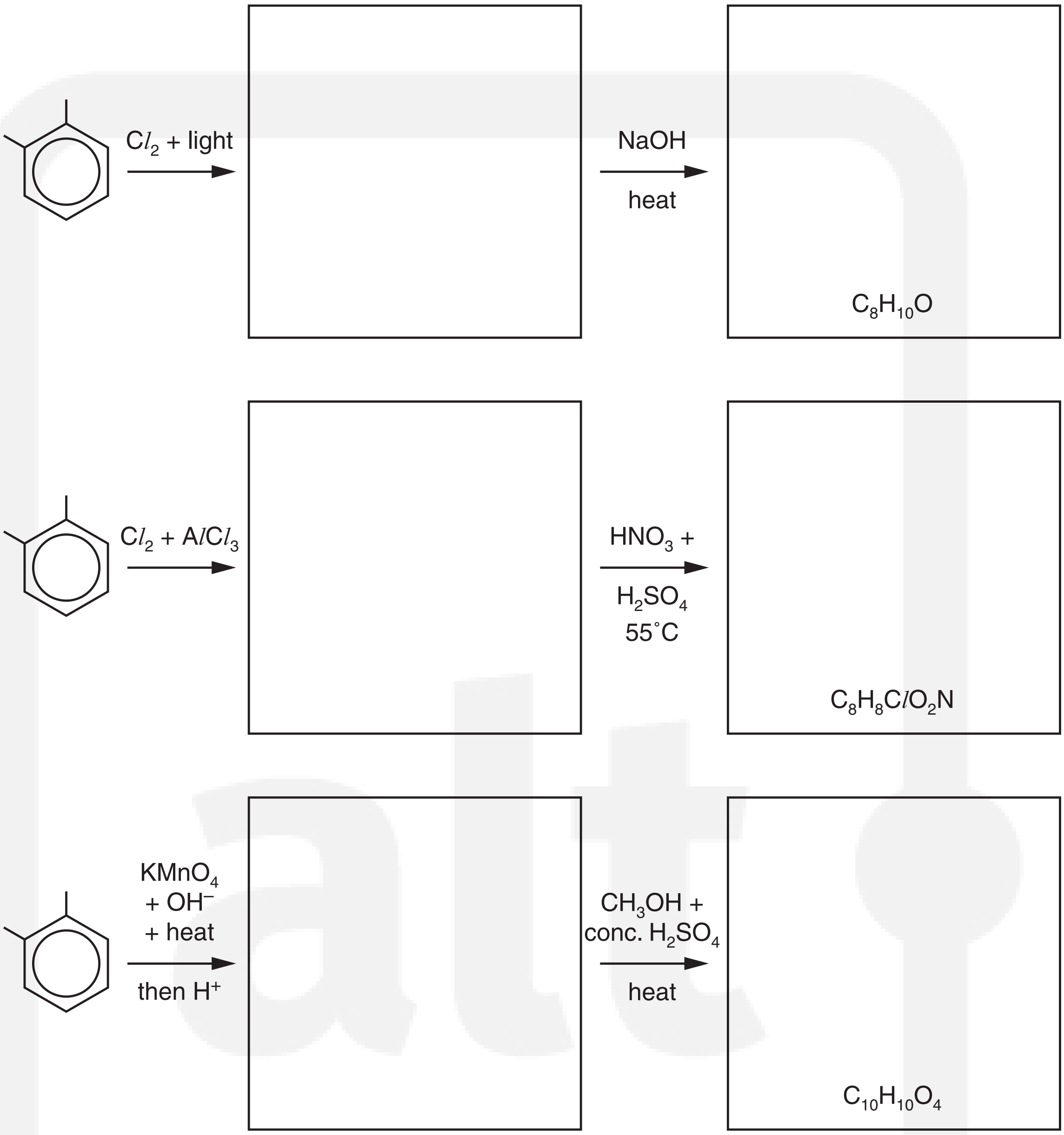
....

(iv) What type of polymer is compound **F**?

....

[5]

(c) Predict the products of the following reactions and draw their structures in the boxes provided. Note that the molecular formula of the final product is given in each case.



[6]

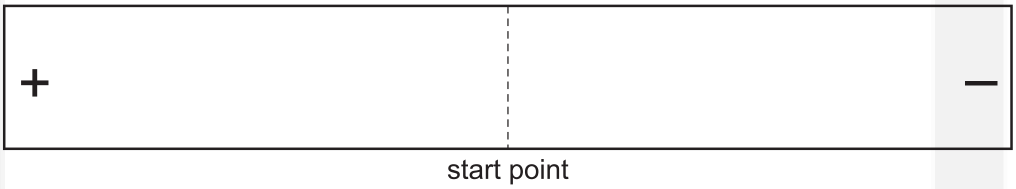
[Total: 19]

8 The analysis of a protein may be carried out by breaking it down into its amino acids. These can then be separated by a process called electrophoresis.

(a) The structures of glycine, lysine and glutamic acid at pH 7 are shown.

glycine	$H_3N^+CH_2CO_2^-$
lysine	$H_3N^+CH(CH_2CH_2CH_2CH_2NH_3^+)CO_2^-$
glutamic acid	$H_3N^+CH(CH_2CH_2CO_2^-)CO_2^-$

Draw and label three circles on the chart below to indicate the likely position of each of these amino acids after electrophoresis of a solution containing these amino acids in a buffer at pH 7.



[3]

(b) The protein fibroin can be broken down into amino acids using an enzyme.

A student uses thin-layer chromatography (TLC) to identify these amino acids.

The student identifies two of the amino acids as alanine and serine.

Use **Figure 3** to calculate the R_f value of the unknown amino acid.
Show your working.

(i) Use your R_f value and **Table 1** to identify the unknown amino acid.

[2 marks]

Figure 3

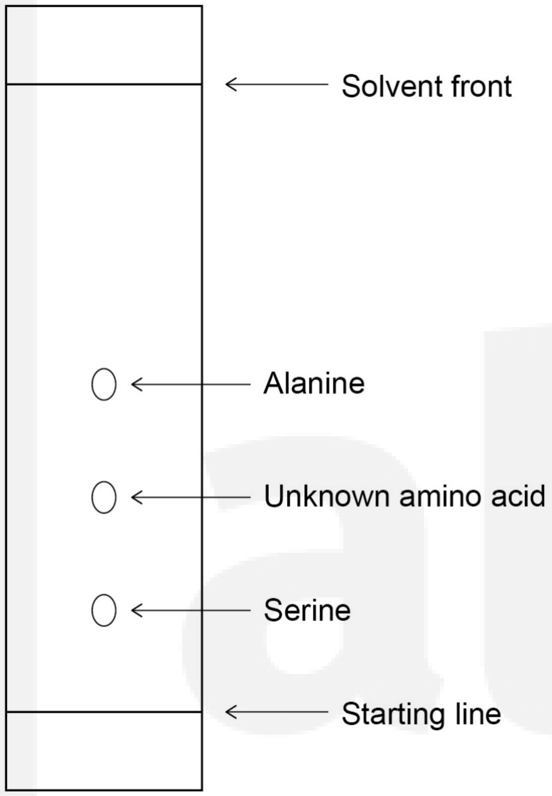


Table 1

Amino acid	**R_f value**
tyrosine	0.25
glycine	0.34
valine	0.64
leucine	0.73

R_f value ____________________

Identity ____________________

(ii) The amino acids cannot be seen as they move during the experiment.

State how the amino acids can be made visible at the end of the experiment.

[1 mark]

(iii) State why each amino acid has a different R_f value.

[1 mark]

[Total: 7]

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

Key

atomic number atomic symbol name relative atomic mass

Group 1	2	3	4	5	6	7	8	9	10	11	12	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											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 –

lanthanoids	57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.4	61 Pm promethium –	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.1	71 Lu lutetium 175.0
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 –