

Section A

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

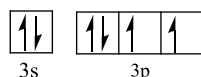
- 1 The periodic table is an arrangement of the chemical elements, organised on the basis of their atomic numbers, electron configurations and chemical properties.

(a) In 1649, Hennig Brand discovered a new element with his experiment on distilled human urine that resulted in the production of a glowing white substance, which he named as phosphorus.

(i) State the electron configuration of phosphorus.



(ii) Explain the difference in ionisation energy between phosphorus and sulfur.



In Sulfur, the electrons in the doubly filled 3p orbital experience inter-electronic repulsion. This factor outweighs the effect of increase in nuclear charge from P to S, resulting in a lower effective nuclear charge and less energy is required to remove the electron.

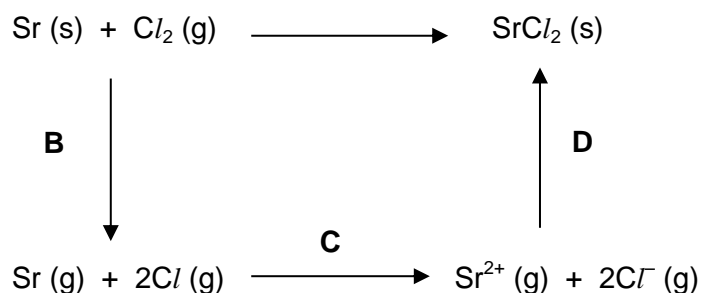
[3]

(b) In 1817, Johann Wolfgang Döbereiner began to formulate one of the earliest attempts to classify the elements in the Periodic Table. He found that he could group some of the elements into groups of three. He termed these groups 'triads'. One of the triads that were classified by him is: calcium, strontium and barium.

(i) Describe the trend in atomic radius from calcium to barium.

The number of protons increases down the group, hence nuclear charge increases. The number of quantum shells increases down the group, hence shielding effect increases. The increase in shielding effect outweighs the increase in nuclear charge. Thus, effective nuclear charge decreases and the attraction between the nucleus and valence electrons are weaker hence atomic radius increases.

The energy cycle below shows how strontium chloride is formed from strontium.



- (ii) Using the data given below and relevant data from the *Data Booklet*, prove that the enthalpy changes represented by **B** and **C** is $+408 \text{ kJ mol}^{-1}$ and $+910 \text{ kJ mol}^{-1}$ respectively.

	$\Delta H^\circ / \text{kJ mol}^{-1}$
$\text{Sr (s)} \rightarrow \text{Sr (g)}$	+164
$\text{Cl (g)} \rightarrow \text{Cl}^- \text{ (g)}$	-349
$\text{Sr (s)} + \text{Cl}_2 \text{ (g)} \rightarrow \text{SrCl}_2 \text{ (s)}$	-829

$$B = 164 + 244 = +408 \text{ kJ mol}^{-1}$$

$$C = 548 + 1060 + 2(-349) = +910 \text{ kJ mol}^{-1}$$

- (iii) Hence, using the energy cycle and the data given above, calculate the lattice energy of SrCl_2 .

$$A = B + C + D$$

$$LE = A - B - C$$

$$= -829 - 408 - 910$$

$$= -2147 \text{ kJ mol}^{-1}$$

- (iv) Explain the difference in lattice energy between SrCl_2 and RbCl .

$$\text{Lattice Energy} \propto \left| \frac{q^+ q^-}{r_+ + r_-} \right|$$

Sr^{2+} has a higher charge and smaller ionic radius than Rb^+ or Sr^{2+} has a higher charge density. Hence the lattice energy of SrCl_2 is higher in magnitude / more exothermic as compared to RbBr .

[9]

[Total:12]

- 2 (a) A 2.35 g mixture of Na_2O , Al_2O_3 and SiO_2 was analysed to determine the

percentage by mass of each oxide present in the mixture. The mixture was first dissolved in water and the solution was filtered. The residue which then contained two of the oxides was then left to stand to evaporate. After some time, the residue was weighed and the mass was found to be 1.93 g. 100 cm³ of 0.200 mol dm⁻³ hydrochloric acid was added to the residue. The excess acid required 5.20 cm³ of 0.0500 mol dm⁻³ sodium hydroxide for neutralisation.

- (i) Identify the oxide(s) present in the residue and filtrate.

	Oxide(s)
Residue	Al_2O_3 and SiO_2
Filtrate	Na_2O

- (ii) Identify the oxide that reacts with hydrochloric acid and hence write the balanced equation for this reaction.



- (iii) Calculate the percentage by mass of the three oxides present in the mixture.

$$\text{Mass of } Na_2O = 2.35 - 1.93 = 0.42 \text{ g}$$

$$\% \text{ by mass of } Na_2O = 0.42/2.35 \times 100\% = 17.9\%$$

$$\text{No of moles of remaining HCl} = 5.20 / 1000 \times 0.05 = 0.00026 \text{ mol}$$

$$\text{No of moles of initial HCl added} = 100/1000 \times 0.2 = 0.02 \text{ mol}$$

$$\text{No of moles of HCl that reacted with } Al_2O_3 = 0.02 - 0.00026 = 0.01974 \text{ mol}$$

$$\text{No of moles of } Al_2O_3 = 0.01974/6 = 0.00329 \text{ mol}$$

$$\text{Mass of } Al_2O_3 = 0.00329 \times [(27 \times 2) + (16 \times 3)] = 0.336 \text{ g}$$

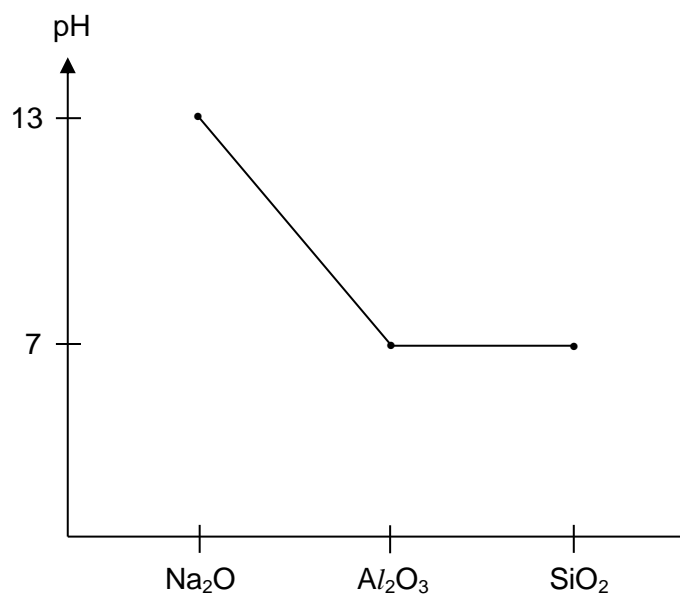
$$\% \text{ by mass of } Al_2O_3 = 0.336/2.35 \times 100\% = 14.3\%$$

$$\text{Mass of } SiO_2 = 1.93 - 0.336 = 1.59 \text{ g}$$

$$\% \text{ by mass of } SiO_2 = 1.59/2.35 \times 100\% = 67.7\%$$

[8]

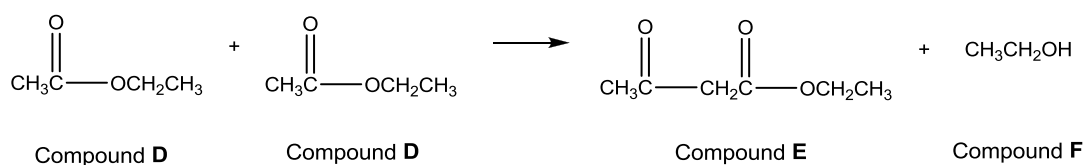
- (b) Using the axes given below, sketch the graph for the pH of Na_2O , Al_2O_3 and SiO_2 when they are dissolved in water.



[2]

[Total: 10]

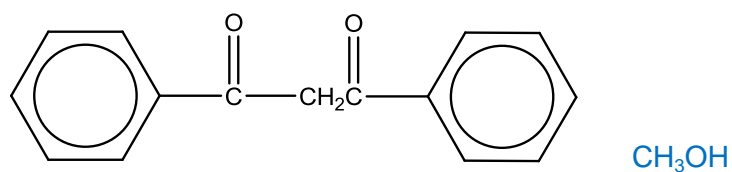
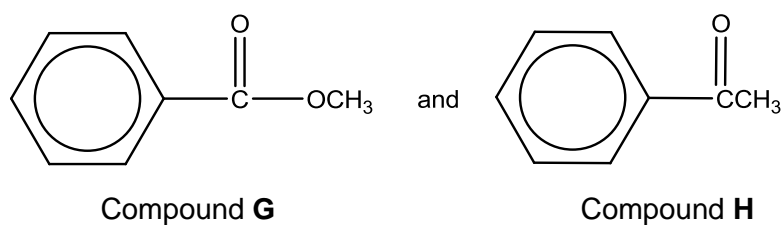
- 3 (a) The following reaction is a carbon-carbon bond forming process that is named after the chemist, Rainer Ludwig Claisen.



- (i) State the type of reaction.

Condensation

- (ii) Hence, suggest the products formed between the following two compounds.



- (iii) Compound **D** can be produced in the laboratory via an esterification reaction. Name the two reactants and state the reagent and condition for this reaction.

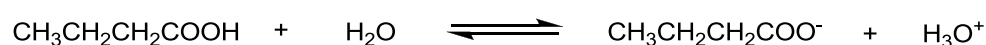
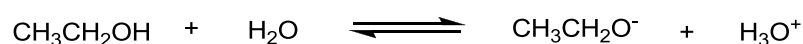
React ethanoic acid and ethanol with conc H_2SO_4 and heat.

OR ethanoyl chloride and ethanol

- (iv) Name the functional groups that are present in compound **E**.

Ketone and Ester

- (v) Explain how the acidity of compound **F** differs from that of butanoic acid.



The electron donating group $-\text{CH}_2\text{CH}_3$ intensifies the negative charge on the ethoxide ion making it less stable and hence ethanol is less acidic.

The negative charge on butanoate ion is delocalised over the two highly electronegative O atoms, making it resonance / more stabilised and hence butanoic acid is more acidic.

- (vi) State a simple chemical test that will react with both compounds **E** and **F**, and state the observation.

Reagents and conditions: I_2 (aq), NaOH (aq), warm

Observation: yellow ppt

OR

Reagents and conditions: KMnO_4 , H_2SO_4 (aq), heat

Observation: Purple KMnO_4 decolourises

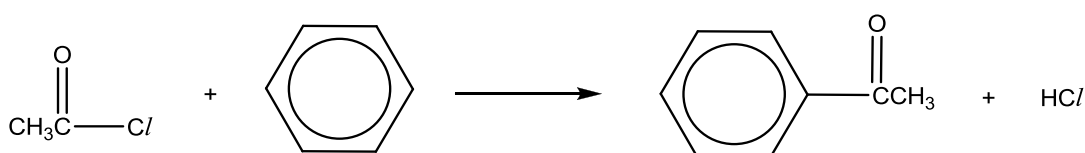
OR

Reagents and conditions: $\text{K}_2\text{Cr}_2\text{O}_7$, H_2SO_4 (aq), heat

Observation: Orange $\text{K}_2\text{Cr}_2\text{O}_7$ turns green

[10]

- (b) Compound **H** is formed from the following reaction. This reaction uses the same condition as when chlorine reacts with benzene



Compound H

- (i) State the type of reaction.

Substitution

- (ii) State the condition used for the above reaction.

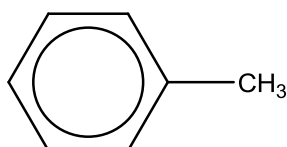
Fe or FeCl₃ or AlCl₃, heat

Benzene in soft drinks is of potential concern due to the carcinogenic nature of the benzene molecule which is formed from benzoic acid. Benzoic acid is often added to drinks as a preservative in the form of its salt, sodium benzoate.

The following reaction scheme shows how sodium benzoate is formed from Compound J.

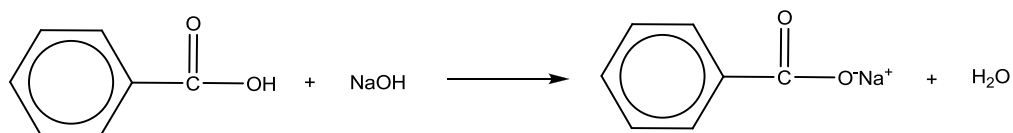


- (iii) Draw the structure of Compound J.

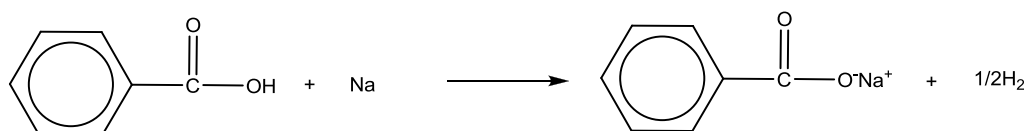


Or any compound with benzylic hydrogen

- (iv) Write the balanced equation for Step 2.

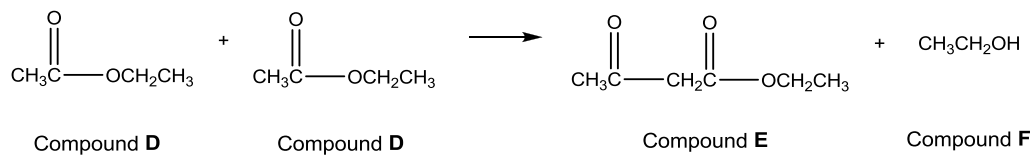


OR



[4]

- (c) (i) Given the data below, calculate the standard enthalpy change of reaction of the following reaction from (a).



Compound	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	$\Delta H_c^\ominus / \text{kJ mol}^{-1}$
D	-480	x
E	-640	-3150
F	-277	-1371

$$\begin{aligned}
 \Delta H_r^\ominus &= \sum n\Delta H_f^\ominus(\text{products}) - \sum n\Delta H_f^\ominus(\text{reactants}) \\
 &= [(-640) + (-277)] - 2(-480) \\
 &= +43 \text{ kJ mol}^{-1}
 \end{aligned}$$

- (ii) Hence, calculate the value of **x**.

$$\begin{aligned}
 \Delta H_r^\ominus &= \sum n\Delta H_c^\ominus(\text{reactants}) - \sum n\Delta H_c^\ominus(\text{products}) \\
 +43 &= 2x - [(-3150) + (-1371)] \\
 x &= -2239
 \end{aligned}$$

[4]

[Total: 18]

Section B

Answer **two** questions from this section on separate answer paper.

4

(a) Bonds broken: 2 X C-H + C=O

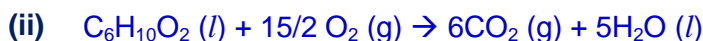
Bonds formed: C=C + 2O-H

$$\begin{aligned}\Delta H_f &= (2 \times 410 + 740) - (610 + 2 \times 460) \\ &= \mathbf{+30 \text{ kJ mol}^{-1}}\end{aligned}$$

[2]

(b)

(i) The energy released/evolved when one mole of substance/compound is completely burned in excess oxygen at 298K and 1 atm.



(iii) Amt of $\text{C}_6\text{H}_{10}\text{O}_2 = 10 \times 0.973 / (6 \times 12.0 + 10 \times 1.0 + 2 \times 16.0)$
 $= 0.085351 \text{ mol}$

$$\begin{aligned}\text{Heat released} &= 200 \times 4.18 \times 1.5 \\ &= 1254 \text{ J}\end{aligned}$$

$$\begin{aligned}\Delta H &= -1254 / 0.085351 \\ &= -14692.3 \text{ J mol}^{-1} = \mathbf{-14.7 \text{ kJ mol}^{-1}} \text{ (3sf)}\end{aligned}$$

(iv) There is heat lost to the surrounding during the experiment. Hence, there was a smaller increase in temperature measured.

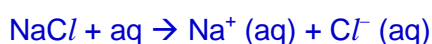
[6]

(c) (i) **X** is AlCl_3 ; **Y** is NaCl ; **Z** is NaOH

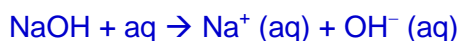


AlCl_3 undergoes hydrolysis in water.

Al^{3+} has a high charge density and can polarise the O-H bond in H_2O , releasing H^+ .

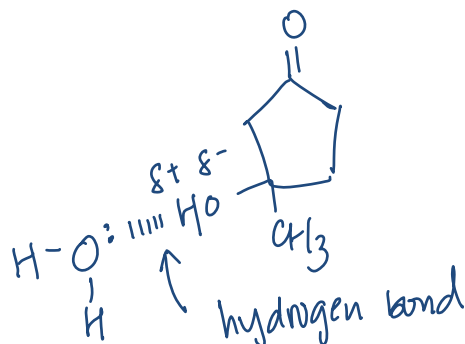


NaCl dissociates in water to give a neutral solution.



NaOH dissociates in water to give OH^- . Hence, the solution is basic.

(ii)



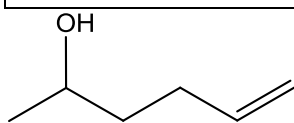
The energy released from formation of hydrogen bond between the intermediate and water is sufficient to overcome the hydrogen bond between water molecules and between the intermediate molecules.

[6]

(d)

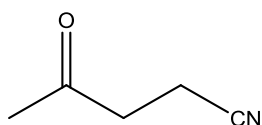
(i)

Observation	Deduction
Decolourises aqueous bromine.	E undergoes addition E is an alkene
Forms yellow ppt with alkaline I_2 (aq)	E undergoes oxidation E has the following structure <div style="text-align: center;">$\begin{array}{c} \text{OH} \\ \\ \text{CH}_3 - \text{C} - \text{---} \\ \\ \text{H} \end{array} \quad \text{or} \quad \begin{array}{c} \text{O} \\ \\ \text{CH}_3 - \text{C} - \text{---} \end{array}$</div>
Reacts with acidified KMnO_4 to form G and CO_2	E undergoes oxidation E is an terminal alkene



compound **E**

(ii)



I : Ethanolic KCN, heat

II: H_2SO_4 (aq), heat

[6]

[Total: 20]

5

(a) (i) Elimination

- (ii) For chloroethane white ppt formed
For bromoethane: cream ppt formed
For iodoethane: yellow ppt formed



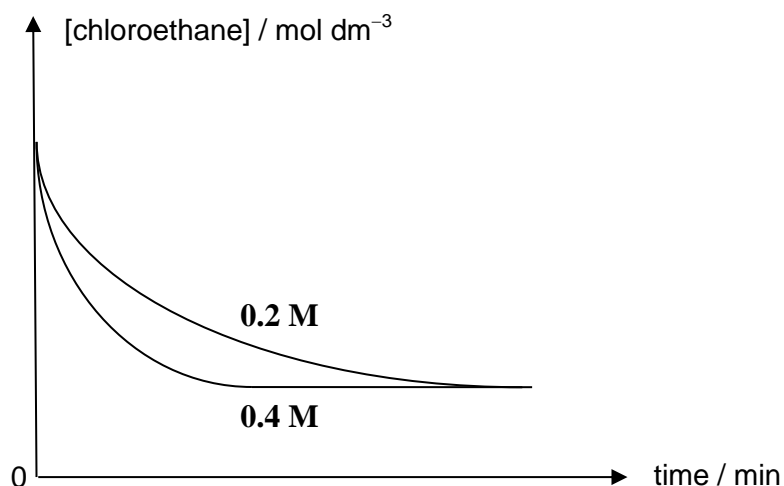
- (iii) The reactivity increases from chloroethane, bromoethane to iodoethane.
As the atomic size increases from Cl to I, the bond length increases from C-Cl to C-I. Hence, the bond strength decreases from C-Cl to C-I and I^- is formed first thus time taken for the ppt of AgX to form decreases from AgCl to AgI.

[5]

(b)

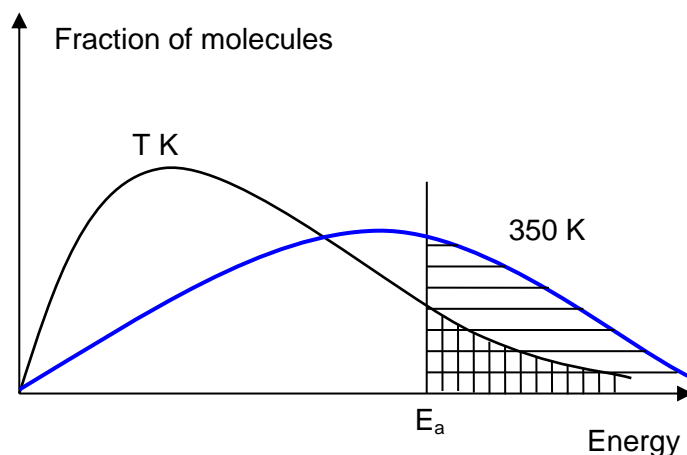
- (i) Two half lives clearly marked out on the graph.
Since half life is (approximately) constant at 40 min (range: 38 – 42 min), first order wrt chloroethane

(ii)



- (iii) rate = $k [\text{KOH}] [\text{chloroethane}]$
 k has units of $\text{mol}^{-1} \text{dm}^3 \text{min}^{-1}$

(iv)

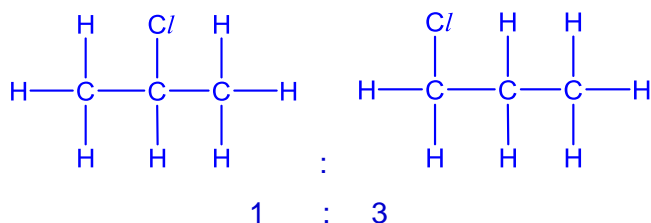


Rate of reaction increases.

When temperature increases, the reactants gain kinetic energy and the fraction of reactants having energy equal to or higher than the activation energy increases. This increases the chances/frequency of effective collision.

[9]

(c)



[2]

(d) Melting point: $\text{Cl}_2 < \text{Mg} < \text{Si}$

Mg has a giant metallic lattice structure held by electrostatic forces of attraction between Mg^{2+} and the sea of delocalised electrons. A lot of energy is required to break these strong bonds.

Si has a giant covalent structure held by strong covalent bonds between Si atoms. An even larger amount of energy is required to break these strong bonds.

Cl_2 is a non-polar simple covalent molecule held by weak induced dipole-induced dipole interactions. Less energy is required to break these weak bonds.

[4]

[Total: 20]

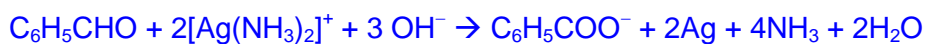
6

(a) (i) Trace amount of KCN/NaCN/NaOH, 10-20°C

(ii) Test: Tollen's Reagent, warm

For cyanohydrin: no silver mirror

For benzaldehyde: silver mirror formed

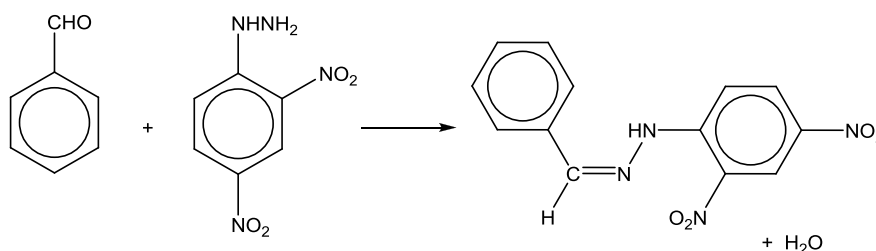


OR

Test: 2,4-dinitrophenylhydrazine, warm

For cyanohydrin: no orange ppt formed

For benzaldehyde: orange ppt formed



[4]

(b) (i) $K_c = [\text{cyanohydrin}] / [\text{benzaldehyde}] [\text{HCN}]$
units for K_c is $\text{mol}^{-1} \text{dm}^3$

(ii) Amt of benzaldehyde = $8 \times 1.04 / (12.0 \times 7 + 16.0 + 1.0 \times 6)$
= **0.0785 mol** (3sf)

(iii)

	benzaldehyde	HCN	\rightleftharpoons	cyanohydrin
I (mol)	0.0785	0.08		0
C (mol)	- 0.02	- 0.02		+ 0.02
E (mol)	0.0585	0.06		0.02
E (mol dm^{-3})	0.02925	0.03		0.01

$$K_c = 0.01 / (0.03 \times 0.02925) = \mathbf{11.4 \text{ mol}^{-1} \text{dm}^3} \text{ (3sf)}$$

[6]

(c) (i) Draw a 'dot-and-cross' diagram to show the bonding in hydrogen cyanide, stating its shape.



Linear

- (ii) HCN is a polar simple covalent molecule held by permanent dipole-permanent dipole interactions (pd-pd). H₂O is a polar simple covalent molecule held by hydrogen bonds. Since pd-pd is weaker than h-bonds, less energy is required to break them. Hence, HCN has a lower boiling point.

[4]

(d)



HCN is a weak acid because it undergoes partial dissociation.

(ii) $[\text{H}^+] = 10^{-2.48} = 3.31 \times 10^{-3} \text{ mol dm}^{-3}$ (3sf)

- (iii) The reaction to form ferricyanide ion decreases the amount of CN⁻ in the solution. By Le Chatelier's Principle, it will result in a shift of the equilibrium towards the right to increase [CN⁻]. Hence, more H⁺ is in the solution and the pH is lowered.

- (iv) KCN or NaCN OR limited KOH or limited NaOH



Large amount of CN⁻ reacts with the added H⁺. Hence, keeping the pH of the solution almost constant.

[6]

[Total: 20]