Confidential

NEW

Department of Examinations - Sri Lanka

G.C.E. (A/L) Examination - 2020

02 - Chemistry

New Syllabus

Marking Scheme

This document has been prepared for the use of Marking Examiners. Some changes would be made according to the views presented at the Chief Examiners' meeting.

Amendments to be included

ශ්‍රී ලංකා විභාග දෙපාර්තමේන්තුව

Department of Examinations – Sri Lanka

අ.පො.ස.(උ.පෙළ)විභාගය/G.C.E. (A/L)- 2020

නව නිර්දේශය/ New Syllabus

විෂයය අංකය **Subject No**	02	විෂයය **Subject**	**Chemistry**

ලකුණු දීමේ පටිපාටිය/Marking Scheme

I පත්‍රය/Paper I

ප්‍රශ්න අංකය **Question No.**	පිළිතුරු අංකය **Answer No.**	ප්‍රශ්න අංකය **Question No.**	පිළිතුරු අංකය **Answer No.**	ප්‍රශ්න අංකය **Question No.**	පිළිතුරු අංකය **Answer No.**	ප්‍රශ්න අංකය **Question No.**	පිළිතුරු අංකය **Answer No.**	ප්‍රශ්න අංකය **Question No.**	පිළිතුරු අංකය **Answer No.**
01.	5	11.	2	21.	3	31.	5	41.	4
02.	3	12.	3	22.	4 or 5	32.	2	42.	1 or 2
03.	4	13.	3	23.	1	33.	5	43.	3
04.	2	14.	2	24.	ALL	34.	4 or 5	44.	4
05.	ALL	15.	ALL	25.	ALL	35.	1	45.	5
06.	1	16.	3	26.	1	36.	5	46.	1
07.	2	17.	1	27.	5	37.	3 or 5	47.	4
08.	3	18.	1	28.	5	38.	4	48.	1
09.	4	19.	2	29.	4	39.	4	49.	3
10.	2	20.	2	30.	2	40.	5	50.	3

✪විශේෂ උපදෙස්/ Special Instructions:
එක් පිළිතුරකට ලකුණු 01 බැගින්/ 01 Mark for each question
මුළු ලකුණු/ Total Marks 01 × 50 = 50

PART A — STRUCTURED ESSAY

Answer all four questions on this paper itself. (Each question carries 10 marks.)

1. (*a*) Write the answers to the questions given below on the dotted lines.

(i) Of the three ions Na^+, Mg^{2+} and F^-, which one has the smallest ionic radius? ......Mg^{2+}......

(ii) Of the three elements C, N and O, which one has the highest second ionization energy? ......O......

(iii) Of the three compounds H_2O, HOCl and OF_2, which one has the most electronegative oxygen atom? ......OF_2......

(iv) Of the three elements Be, C and N, which one will liberate energy when an electron is added to its atom [$Y(g) + e \rightarrow Y^-(g)$; Y = Be, C, N] in the gaseous state? ......C......

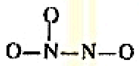
(v) Of the three ionic compounds NaF, KF and KBr, which one has the highest solubility in water? ..KF or KBr..

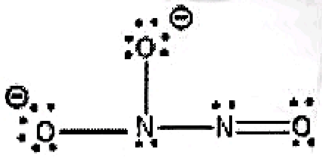
(vi) Of the three compounds HCHO, CH_3F and H_2O_2, which one has the strongest intermolecular forces? ......H_2O_2....

(04 marks X 6 = 24)

1(a): 24 marks

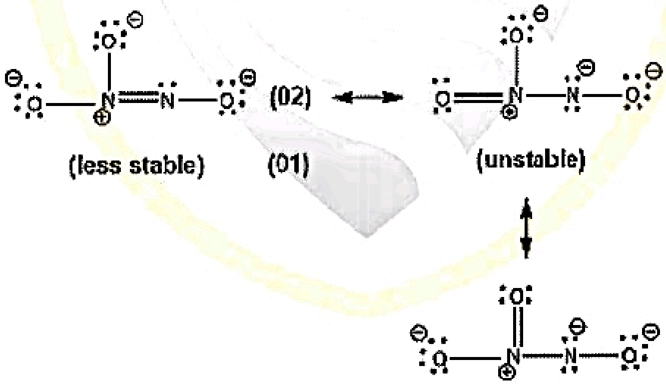
(*b*) (i) Draw the most acceptable Lewis structure for the ion, $N_2O_3^{2-}$. Its skeleton is given below.





(06)

(ii) Draw three more Lewis structures (resonance structures) for this ion. Indicate the relative stabilities of the structures drawn by you, when compared with the most acceptable structure drawn in (i) above, by writing 'less stable' or 'unstable' under these structures.



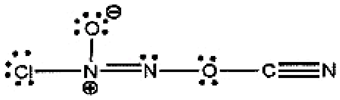
(02) (02)

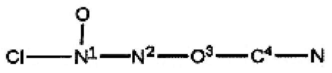
(less stable) (01) **(unstable)** (01)

(02)

(unstable) (01)

(iii) Complete the given table based on the Lewis structure and its labelled skeleton given below.





	N^1	N^2	O^3	C^4
VSEPR pairs around the atom	3	3	4	2
electron pair geometry around the atom	trigonal planar	trigonal planar	tetrahedral	linear
shape around the atom	trigonal planar	angular/ V	angular/ V	linear
hybridization of the atom	sp^2	sp^2	sp^3	sp

(01 X 16 = 16)

- Parts (iv) to (vii) are based on the Lewis structure given in part (iii) above. Labelling of atoms is as in part (iii).

(iv) Identify the atomic/hybrid orbitals involved in the formation of σ bonds between the two atoms given below.

I. $Cl—N^1$ Cl ...3p OR sp^3... N^1 ...sp^2...

II. $N^1—O$ N^1 ...sp^2... O ...2p OR sp^3...

III. $N^1—N^2$ N^1 ...sp^2... N^2 ...sp^2...

IV. $N^2—O^3$ N^2 ...sp^2... O^3 ...sp^3...

V. $O^3—C^4$ O^3 ...sp^3... C^4 ...sp...

VI. $C^4—N$ C^4 ...sp... N ...2p OR sp... **(01 X 12 = 12)**

(v) Identify the atomic orbitals involved in the formation of π bonds between the two atoms given below.

I. $N^1—N^2$ N^1 ...N^1, 2p... N^2 ...N^2, 2p...

II. $C^4—N$ C^4 ...C^4, 2p... N ...N, 2p...

C^4 ...C^4, 2p... N ...N, 2p... **(01 X 6 = 06)**

(vi) State the approximate bond angles around N^1, N^2, O^3 and C^4 atoms.

N^1 ...120° ± 1, 1 N^2 ...115° -118°, O^3 ...104° ± 1, C^4 ...180° ± 1

(01 X 4 = 04)

(vii) Arrange the atoms N^1, N^2, O^3 and C^4 in the increasing order of electronegativity.

...C^4... < ...N^2... < ...N^1... < ...O^3... **(03)**

1(b): 56 marks

(*c*) Consider the following information.

I. The atoms **A** and **B** combine to form a heterodiatomic molecule **AB** that has a σ bond. This is represented as, **A–B**.

II. The electronegativity of **A** is less than that of **B** ($X_A < X_B$).
X = electronegativity of the atom

III. The inter-nuclear distance between **A** and **B** atoms (d_{A-B}) of the **AB** molecule is given by the following equation.

$$d_{A-B} = r_A + r_B - c(X_B - X_A)$$

r = atomic radius, c = 9 pm

Note: d and r are measured in picometres (pm). (1 pm = 10^{-12} m)

Based on the above information, answer the following questions.

(i) What is the name used to identify the type of σ bond between **A** and **B**?

Polar covalent bond ... **(03)**

(ii) Show how fractional charges (δ+ and δ–) are located in the molecule **AB**.

$A^{\delta+}—B^{\delta-}$ ... **(03)**

(iii) Write the equation to calculate the dipole moment (μ) of molecule **AB** and show its direction.

$\mu = d_{AB} \times \delta$, **OR** $\mu = qr$, $\overset{\longrightarrow}{A—B}$ **OR** $\overset{+\!\!\longrightarrow}{A—B}$ **(01 + 01)**

(iv) Calculate the percentage of ionic character of the H–F bond in the HF molecule using the data given below.

Inter-nuclear distance of H_2 (d_{H-H})	= 74 pm	Electronegativity of F	= 4.0
Inter-nuclear distance of F_2 (d_{F-F})	= 144 pm	Dipole moment of HF	= 6.0×10^{-30} C m
Electronegativity of H	= 2.1	Charge of an electron	= 1.6×10^{-19} C

$\mu = d_{HF} \times \delta$, $H^{\delta+}—F^{\delta-}$

$r_H = \frac{d_{H2}}{2} = \frac{74}{2} = 37$ pm (02)

$r_F = \frac{d_{F2}}{2} = \frac{144}{2} = 72$ pm (02)

Therefore, $d_{HF} = 37 + 72 - 9(4.0 - 2.1)$ (01)

$= 109 - 9 \times 1.9$

$= 91.9$ pm (02)

$\mu = d_{HF} \times \delta$, 6.0×10^{-30} C m $= \delta \times 91.9 \times 10^{-12}$ m (01)

$\delta = \frac{6.0 \times 10^{-30}}{91.9 \times 10^{-12}} = 0.65 \times 10^{-19}$ (02)

% Ionic character $= \frac{0.65 \times 10^{-19}}{1.6 \times 10^{-19}} \times 100$ (01)

= 40.6% (01)

OR

$r_H = \frac{d_{H2}}{2} = \frac{74}{2} = 37$ pm (02)

$r_F = \frac{d_{F2}}{2} = \frac{144}{2} = 72$ pm (02)

Therefore, $d_{HF} = 37 + 72 - 9(4.0 - 2.1)$ (01)

$= 109 - 9 \times 1.9$

$= 91.9$ pm (02)

$\mu_{ionic} = 1.6 \times 10^{-19}$ C $\times 91.9 \times 10^{-12}$ m (03)

$= 147.04 \times 10^{-31}$ C m

% Ionic character $= \frac{6 \times 10^{-30}}{147.04 \times 10^{-31}} \times 100$ (01)

= 40.8% (01

2. (*a*) **A**, **B**, **C** and **D** are chlorides of *p*-block elements. These elements have atomic numbers less than 20. A description of the products (**$P_1 - P_9$**) formed when **A** is reacted with a limited amount of water and **B**, **C** and **D** are reacted with excess water are given below.

Compound	Description of products	
A	**P_1**	a compound with a covalent network structure
	P_2	a strong monobasic acid
B	**P_3**	a gas that turns red litmus blue
	P_4	a compound with bleaching properties
C	**P_5**	a tribasic acid
	P_6	a strong monobasic acid
D	**P_7**	a gas that turns acidic $KMnO_4$ solution colourless
	P_8	a colloidal solid
	P_9	a strong monobasic acid

(i) Identify **A**, **B**, **C** and **D** (give the chemical formulae).

A: $SiCl_4$ **B:** NCl_3 **C:** PCl_5 **D:** SCl_2 **(04 x 4)**

(ii) Give balanced chemical equations for the reactions of **A**, **B**, **C** and **D** with water to give products **P_1** to **P_9**.

$SiCl_4 + 2H_2O \rightarrow SiO_2\ (P_1) + 4HCl\ (P_2)$ **(05)**

$NCl_3 + 3H_2O \rightarrow NH_3\ (P_3) + 3HOCl\ (P_4)$ **(05)**

$PCl_5 + 4H_2O \rightarrow H_3PO_4\ (P_5) + 5HCl\ (P_6)$ **(05)**

$2SCl_2 + 2H_2O \rightarrow SO_2\ (P_7) + S\ (P_8) + 4HCl\ (P_9)$ **(05)**

Note: Award marks if correct balanced equations are given.

(iii) Write balanced chemical equations for the following reactions.

I. P_1 with NaOH(aq)

$SiO_2 + 2NaOH \rightarrow Na_2SiO_3 + H_2O$ (04)

II. P_3 with Mg

$3Mg + 2NH_3 \rightarrow Mg_3N_2 + 3H_2$ (04)

III. P_7 with acidic $K_2Cr_2O_7$

$3(SO_2 + 2H_2O \rightarrow SO_4^{2-} + 4H^+ + 2e)$

$Cr_2O_7^{2-} + 14H^+ + 6e \rightarrow 2Cr^{3+} + 7H_2O$

$3SO_2 + Cr_2O_7^{2-} + 2H^+ \rightarrow 2Cr^{3+} + 3SO_4^{2-} + H_2O$ (06)

If only half reactions are given – part marks (02 + 02)

2(a): 50 marks

(*b*) A student is provided with bottles labelled **P, Q, R, S, T** and **U** containing aqueous solutions of $Al_2(SO_4)_3$, H_2SO_4, $Na_2S_2O_3$, $BaCl_2$, $Pb(Ac)_2$ and KOH **(not in order)**. Some useful observations for their identification on mixing two solutions at a time are given below. (Ac - Acetate ion)

	Solutions mixed	Observations
I	T + R	a clear colourless solution
II	P + R	a white precipitate
III	T + S	a gelatinous white precipitate
IV	U + R	a white precipitate
V	P + Q	a white precipitate, turns black on heating
VI	P + U	a white precipitate, dissolves on heating

(i) Identify **P** to **U**.

P: $Pb(Ac)_2$ Q: $Na_2S_2O_3$ R: H_2SO_4

S: $Al_2(SO_4)_3$ OR KOH T: KOH OR $Al_2(SO_4)_3$ U: $BaCl_2$

(05 X 6 = 30)

(ii) Give balanced chemical equations for each of the reactions **I** to **VI**.

I. $2KOH + H_2SO_4 \rightarrow K_2SO_4 + 2H_2O$ **OR** (03)

$Al_2(SO_4)_3 + H_2SO_4 \rightarrow$ No reaction

II. $Pb(Ac)_2 + H_2SO_4 \rightarrow PbSO_4\downarrow + 2HAc$ (03)

III. $6KOH + Al_2(SO_4)_3 \rightarrow 2Al(OH)_3\downarrow + 3K_2SO_4$ (03)

IV. $BaCl_2 + H_2SO_4 \rightarrow BaSO_4\downarrow + 2HCl$ (03)

V. Formation of white ppt

$Pb(Ac)_2 + Na_2S_2O_3 \rightarrow PbS_2O_3\downarrow + 2NaAc$ (03)

Turning black on heating

$PbS_2O_3 + H_2O \rightarrow PbS\downarrow + H_2SO_4$ (02)

VI. $Pb(Ac)_2 + BaCl_2 \rightarrow PbCl_2\downarrow + Ba(Ac)_2$ (03)

Note: Precipitates have to be shown by ↓ or as (s). If not, deduct (01) mark.

2(b): 50 marks

3. (*a*) A saturated aqueous solution of a sparingly soluble salt $AB_2(s)$ was prepared by stirring an excess amount of $AB_2(s)$ in 1.0 dm^3 of distilled water at 25 °C. The amount of $A^{2+}(aq)$ ions present in this saturated aqueous solution was found to be 2.0×10^{-3} mol.

(i) Write the equilibrium related to the dissolution of $AB_2(s)$ in the above system at 25 °C.

$AB_2(s) \rightleftharpoons A^{2+}(aq) + 2B^-(aq)$ **(05)**

(ii) Write the expression for the equilibrium constant for the equilibrium written in (i) above at 25 °C.

$K_{sp} = [A^{2+}(aq)][B^-(aq)]^2$ **(05)**

$K_C = \dfrac{[A^{2+}(aq)][B^-(aq)]^2}{[AB_2(s)]}$

Note: If only K_c is given award (03 marks)

(iii) Calculate the value of the equilibrium constant stated in (ii) above at 25 °C.

$[A^{2+}(aq)] = 2.0 \times 10^{-3} \text{mol dm}^{-3}$ **(04+01)**

$[B^{-}(aq)] = 2[A^{2+}(aq)] = 4.0 \times 10^{-3} \text{mol dm}^{-3}$ **(04+01)**

$K_{sp} = 2.0 \times 10^{-3} \text{mol dm}^{-3} \times (4.0 \times 10^{-3} \text{mol dm}^{-3})^2$ **(05)**

$\mathbf{K_{sp} = 3.2 \times 10^{-8} mol^3 dm^{-9}}$ **(05)**

(iv) Another saturated aqueous solution of AB_2 was prepared by stirring an excess amount of $AB_2(s)$ in 2.0 dm^3 of distilled water at 25 °C. Giving reasons, predict the value of the equilibrium constant for this system.

$K_{sp} = 3.2 \times 10^{-8}$ $\text{mol}^3 \text{dm}^{-9}$ **(05)**

K_{sp} is a constant at constant temperature **(05)**

and does not depends on the volume **(05)**

(v) A small amount of the strong electrolyte NaB(s) is added to a saturated aqueous solution of AB_2 at 25 °C. Giving reasons, predict whether the concentration of $A^{2+}(aq)$ is increased or decreased.

Common-ion $B^{-}(aq)$ is added **(05)**

∴ More $AB_2(s)$ is formed to keep the K_{sp} constant **or** reverse reaction takes place **(05)**

$[A^{2+}(aq)]$, ***decreases*** **(05)**

3(a): 60 marks

(b) In an aqueous solution, propanoic acid (C_2H_5COOH) ionizes as given below.

$$C_2H_5COOH(aq) + H_2O(l) \rightleftharpoons C_2H_5COO^{-}(aq) + H_3O^{+}(aq)$$

At 25 °C, K_a (propanoic acid) = 1.0×10^{-5}

(i) Write the expression for the equilibrium constant for the above reaction at 25 °C.

$$K_a = \frac{[C_2H_5COO^{-}(aq)][H_3O^{+}(aq)]}{[C_2H_5COOH\ (aq)]}$$ **(05)**

(ii) 100.0 cm^3 of an aqueous solution of $C_2H_5COOH(aq)$ was prepared by dissolving 0.74 cm^3 of C_2H_5COOH in distilled water at 25 °C. Calculate the pH of the solution at 25 °C. (C = 12; O = 16; H = 1; consider the density of C_2H_5COOH as 1.0 g cm^{-3})

mass of $C_2H_5COOH(aq) = 0.74 \text{ cm}^3 \times 1.00 \text{ g cm}^{-3} = 0.74$ g

moles of $C_2H_5COOH(aq)$ in 100 cm^3 = 0.74 g/ 74 g mol^{-1} = 0.01 mol **(05)**

∴ $[C_2H_5COOH(aq)] = 0.10 \text{ mol dm}^{-3}$ **(05)**

Consider the equilibrium:

$$C_2H_5COOH(aq) + H_2O(l) \rightleftharpoons C_2H_5COO^{-}(aq) + H_3O^{+}(aq)$$

Initial	*0.10*	*0*	*0*	*mol dm⁻³*	
Change	*-x*	*x*	*x*	*mol dm⁻³*	
At eqm	*0.10-x*	*x*	*x*	*mol dm⁻³*	**(05)**

$$K_a = \frac{[C_2H_5COO^{-}(aq)][H_3O^{+}(aq)]}{[C_2H_5COOH\ (aq)]} = \frac{x.x}{0.10-x} = 1.0 \times 10^{-5}$$ **(02)**

$$\frac{x^2}{0.10} = 1.0 \times 10^{-5} \quad (0.10 - x \sim 0.1)$$ **(03)**

$x^2 = 1.0 \times 10^{-6}$

$x = 1.0 \times 10^{-3}\ mol\ dm^{-3} = H_3O^{+}(aq)]$ **(05)**

$pH = -log\ [H_3O^{+}(aq)] = 1.0 \times 10^{-3}$ **(05)**

pH = 3.0 **(05)**

Note : Students may take –log of both sides of $K_a = \frac{[C_2H_5COO^{-}(aq)][H_3O^{+}(aq)]}{[C_2H_5COOH\ (aq)]}$ and calculate pH.

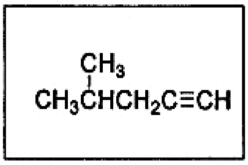
Award marks appropriately.

3(b): 40 marks

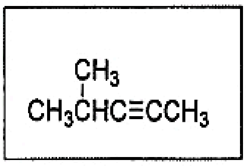
4. (*a*) **A, B, C** and **D** are structural isomers having the molecular formula C_6H_{10}. None of them show optical isomerism. All four isomers, **A, B, C** and **D** when treated with $HgSO_4$/dil. H_2SO_4 give products which react with 2,4-dinitrophenylhydrazine (2,4-DNP) to give coloured precipitates.

Only **A** gives a precipitate with ammonical $AgNO_3$. **A** has only one position isomer, which is **B**. **B** is a chain isomer of **C**. **C** reacts with $HgSO_4$/dil. H_2SO_4 to give two products **E** and **F**. **D** reacts with $HgSO_4$/dil. H_2SO_4 to give only one product, which is **E**.

(i) Draw the structures of **A, B, C, D, E** and **F** in the boxes given below.


$CH_3\overset{CH_3}{\overset{|}{C}}HCH_2C\equiv CH$

A


$CH_3\overset{CH_3}{\overset{|}{C}}HC\equiv CCH_3$

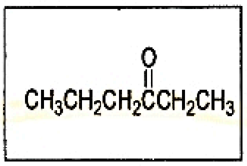
B

$CH_3CH_2CH_2C\equiv CCH_3$

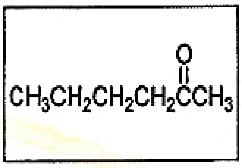
C

$CH_3CH_2C\equiv CCH_2CH_3$

D


$CH_3CH_2CH_2\overset{O}{\overset{\|}{C}}CH_2CH_3$

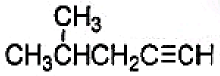
E


$CH_3CH_2CH_2CH_2\overset{O}{\overset{\|}{C}}CH_3$

F

(06 x 6 = 36)

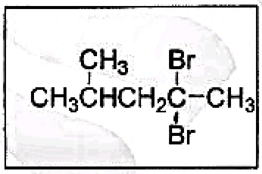
(ii) Which of the compounds **A, B, C** and **D** gives a product that does not show diastereoisomerism when reacted separately with H_2 / Pd-$BaSO_4$ / quinoline?


$CH_3\overset{CH_3}{\overset{|}{C}}HCH_2C\equiv CH$

(05)

or Appropriate letter (**A**, **B**, **C** or **D**) identifying the correct structure

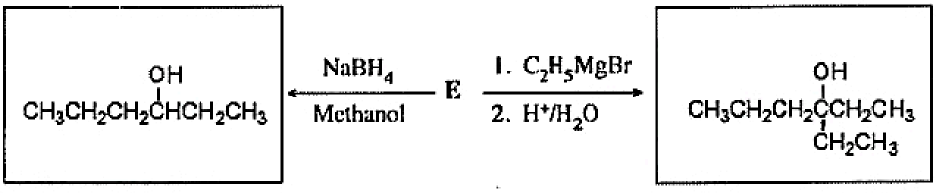
(iii) Draw, in the box given below, the structure of the product **G** obtained when **A** is reacted with excess HBr.


$CH_3\overset{CH_3}{\overset{|}{C}}HCH_2\underset{\underset{Br}{|}}{\overset{\overset{Br}{|}}{C}}-CH_3$

G

(05)

(iv) Draw the structures of products **X** and **Y** obtained in the following reactions of **E**, in the appropriate boxes.


$$CH_3CH_2CH_2\overset{OH}{\overset{|}{C}}HCH_2CH_3 \xleftarrow[\text{Methanol}]{NaBH_4} \mathbf{E} \xrightarrow[\text{2. } H^+/H_2O]{\text{1. } C_2H_5MgBr} CH_3CH_2CH_2\underset{\underset{CH_2CH_3}{|}}{\overset{\overset{OH}{|}}{C}}CH_2CH_3$$

X **Y**

(05 x 2 = 10)

Name a test to distinguish between **X** and **Y**.

Lucas test or

anh. $ZnCl_2$ / conc. HCl or

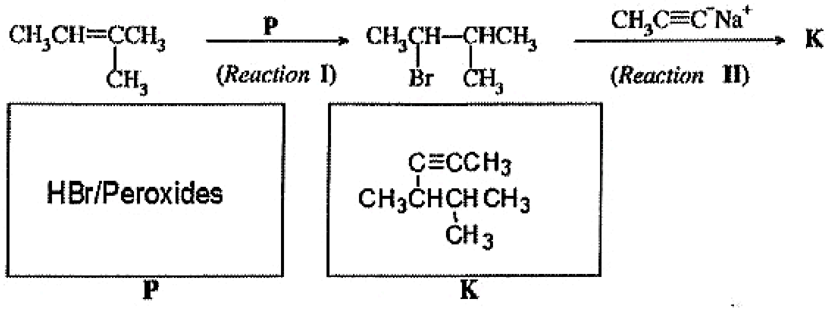
$H^+/K_2Cr_2O_7$ or

$H^+/KMnO_4$

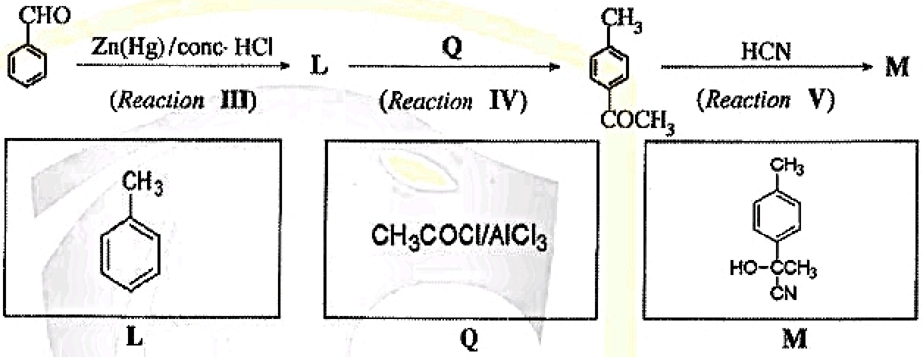
(04)

4(a): 60 marks

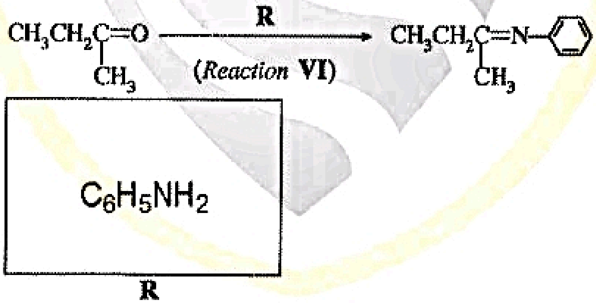
Sequence 1:



Sequence 2:



Sequence 3:



Compounds/reagents **(05 x 6 = 30)**

(ii) Selecting from the reactions **I – VI**, give **one (01)** example for each of the following types of reactions.

Nucleophilic addition ....Reaction V........

Nucleophilic substitution ....Reaction II........

Reactions **(05 x 2 = 10)**

4(b): 40 marks

PART B — ESSAY

5. (*a*) A compound $XY_2Z_2(g)$ undergoes dissociation when heated to temperatures above 300 K as given below.

$$XY_2Z_2(g) \overset{\Delta}{\rightleftharpoons} XY_2(g) + Z_2(g)$$

A sample of 7.5 g of $XY_2Z_2(g)$ was placed in an evacuated 1.00 dm^3 rigid-closed container and the temperature was raised to 480 K.
Molar mass of $XY_2Z_2(g)$ is 150 g mol^{-1}. Use the approximate value of 4000 J mol^{-1} for *RT* at 480 K. Assume ideal gas behaviour for all gases.

(i) Calculate the number of moles of $XY_2Z_2(g)$ in the container before dissociation.

$7.5\ g/150\ g\ mol^{-1} = 5.0 \times 10^{-2}\ mol$ **(05)**

5(a) (i): 05 marks

(ii) When the above system reaches equilibrium at 480 K, the total number of moles in the container was found to be 7.5×10^{-2} mol. Calculate the number of moles of $XY_2Z_2(g)$, $XY_2(g)$ and $Z_2(g)$ in the equilibrium mixture at 480 K.

	$XY_2Z_2(g)$	$\rightleftharpoons$	$XY_2(g)$	+	$Z_2(g)$		
Initial	*0.05*		*0*		*0*	*mol dm^{-3}*	**(05)**
Change	*-x*		*x*		*x*	*mol dm^{-3}*	
At eqm	*0.05-x*		*x*		*x*	*mol dm^{-3}*	**(05)**

Total number of moles $= 0.05+x = 7.5 \times 10^{-2}$ mol **(05)**

$x = 2.5 \times 10^{-2}$ mol **(05)**

$XY_2(g) = Z_2(g) = 2.5 \times 10^{-2}$ mol **(05)**

$XY_2Z_2(g) = 5.0 \times 10^{-2}\ mol - 2.5 \times 10^{-2}\ mol = 2.5 \times 10^{-2}$ mol **(05)**

5(a) (ii): 30 marks

(iii) Calculate the equilibrium constant K_c for the above reaction at 480 K.

$$K_c = \frac{[XY_2(g)\ ][Z_2(g)]}{[XY_2Z_2(g)]}$$ **(05)**

Concentration $= 2.5 \times 10^{-2}\ mol\ dm^{-3}$ **(05)**

$$K_c = \frac{2.5 \times 10^{-2}\ mol\ dm^{-3} \times 2.5 \times 10^{-2}\ mol\ dm^{-3}}{2.5 \times 10^{-2}\ mol\ dm^{-3}}$$ **(05)**

$$\boldsymbol{K_c = 2.5 \times 10^{-2}\ mol\ dm^{-3}}$$ **(05)**

5(a) (iii): 20 marks

(iv) Calculate K_p for the equilibrium at 480 K.

$K_p = K_c\ (RT)^{\Delta n}$ **(05)**

$\Delta n = 1$ **(05)**

$K_p = 2.5 \times 10^{-2}\ mol\ dm^{-3} \times 4 \times 10^{3}\ J\ mol^{-1}$ **(05)**

$\boldsymbol{K_p = 1.0 \times 10^{5}\ Pa}$ **(05)**

iv. Alternative:

Total number of moles at equilibrium $= 7.5 \times 10^{-2}$ mol

$P_{Total} = (7.5 \times 10^{-2}\ \text{mol} \times 4 \times 10^{3}\ \text{J mol}^{-1})/1.0 \times 10^{-3}\ \text{m}^{3}) = 3.0 \times 10^{5}\ \text{Pa})$

Number of moles of $XY_2\,Z_2(g) = XY_2(g) = Z_2(g) =$ *2.5* $\times 10^{-2}$ mol

Mole fractions of $XY_2\,Z_2(g) = XY_2(g) = Z_2(g) =$ *1/3*

$P_i = X_i\, P_{total}$

$P_{XY2\,Z2(g)} = P_{XY2(g)} = P_{Z2(g)} = 1.0 \times 10^{5}$ Pa

$K_p = [P_{XY2(g)} = P_{Z2(g)}]\ /\ P_{XY2\,Z2(g)} = \mathbf{1.0 \times 10^{5}\ Pa}$

5(a): 75 marks

(*b*) For the reaction $XY_2Z_2(g) \rightarrow XY_2(g) + Z_2(g)$ described in (a), Gibbs free energies (G) at 480 K for $XY_2Z_2(g)$, $XY_2(g)$ and $Z_2(g)$ are -60 kJ mol^{-1}, -76 kJ mol^{-1} and -30 kJ mol^{-1}, respectively.

(i) Calculate ΔG (in kJ mol^{-1}) for the reaction at 480 K.

$$XY_2Z_2(g) \quad \rightarrow \quad XY_2(g) \quad + \quad Z_2(g)$$

$\Delta G_{rxn} = G_{products} - G_{reactants}$ **(05)**

$= (-76 + (-30)) - (-60) = \mathbf{-46\ kJ\ mol^{-1}}$ **(04+01)**

Note: No marks if ΔG^{0}_{rxn} is written.

5(b) (i): 10 marks

(ii) The magnitude of ΔS of the above reaction is 150 J K^{-1} mol^{-1} at 480 K. Calculate ΔH for the reaction at 480 K by using the appropriate sign (– or +) of ΔS.

ΔS must be positive (number of gaseous moles is higher in products) **(05)**

5(b) (ii): 05 marks

(iii) By using the sign (– or +) of ΔH obtained in (ii), explain whether this reaction is exothermic or endothermic.

$\Delta G = \Delta H - T\Delta S$ **(05)**

$-46\ kJ\ mol^{-1} = \Delta H - 480\ K \times 150 \times 10^{-3}\ kJ\ K^{-1}\ mol^{-1}$

$\Delta H = -46\ kJ\ mol^{-1} + 72\ kJ\ mol^{-1}$ **(04 +01)**

$\mathbf{\Delta H = +26\ kJ\ mol^{-1}}$ **(04+01)**

5(b) (iii): 15 marks

(iv) Deduce the enthalpy difference for the formation of $XY_2Z_2(g)$ from $XY_2(g)$ and $Z_2(g)$ at 480 K.

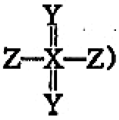
The reaction is endothermic **(05)**

because ΔH is positive **(05)**

5(b) (iv): 10 marks

(v) If the bond enthalpy of the X–Z bond in $XY_2Z_2(g)$ is +250 kJ mol^{-1}, calculate the bond enthalpy of the Z–Z bond.

(Assume that $XY_2Z_2(g)$ has the structure



$$Z{-}\overset{\overset{\displaystyle Y}{\|}}{\underset{\underset{\displaystyle Y}{\|}}{X}}{-}Z$$
)

$\Delta H = -26\ kJ\ mol^{-1}$ (09 +01)

5(b) (v): 10 marks

(vi) If liquid XY_2Z_2 is used instead of gaseous XY_2Z_2, giving reasons, explain whether the value of ΔH obtained for the reaction $XY_2Z_2(l) \rightarrow XY_2(g) + Z_2(g)$ is equal to, or higher or lower than ΔH obtained in (ii).

$\Delta H_{rxn} = \Delta H_{bonds\,formed} - \Delta H_{bonds\,broken}$ (05)

$\Delta H_{rxn} = \Delta H_{Z-Z} - 2\,\Delta H_{X-Z}$ (05)

$26\ kJ\ mol^{-1} = \Delta H_{Z-Z} - 2 \times 250\ kJ\ mol^{-1}$

$\boldsymbol{\Delta H_{Z-Z} = 526\ kJ\ mol^{-1}}$ (04+01)

(OR students may solve through an appropriate thermo cycle)

Higher (05)

It is necessary to supply energy to convert liquid to gas first (05)

(**or** $XY_2Z_2\,(l) \rightarrow XY_2Z_2(g)$ needs an extra energy)

5(b) (vi): 25 marks

5(b): 75 marks

6. (*a*) Consider the reaction given below occurring in a closed container at a given temperature *T*.

$$2N_2O_5(g) \rightarrow 4NO_2(g) + O_2(g)$$

(i) Write three expressions for the rate of reaction relevant to each of the compounds appearing in the reaction.

$$Rate = -\frac{\Delta[N_2O_5(g)]}{2\,\Delta t} = \frac{\Delta[NO_2(g)]}{4\,\Delta t} = \frac{\Delta[O_2(g)]}{\Delta t}$$ (05)

6(a) (i): 05 marks

(ii) This reaction was carried out at temperature *T* with an initial concentration of 0.10 mol dm^{-3} of $N_2O_5(g)$. It was found that 40% of the initial amount was decomposed after a period of 400 s.

I. Calculate the average rate of decomposition of $N_2O_5(g)$ in this time interval.

Decomposed amount = 0.10 mol dm^{-3} ×40/100 = 4.0×10^{-2} mol dm^{-3} (05)

Remaining concentration after 400 s = 6.0×10^{-2} mol dm^{-3} (05)

$$Average\ Rate = \frac{-(0.06 - 0.10)\ mol\ dm^{-3}}{(400-0)s} = 1.0 \times 10^{-4}\ mol\ dm^{-3}\ s^{-1}$$ (05)

II. Calculate average rates of formation of $NO_2(g)$ and $O_2(g)$.

$$\frac{\Delta[N_2O_5(g)]}{2\,\Delta t} = \frac{\Delta[NO_2(g)]}{4\,\Delta t}$$

$$\frac{\Delta[NO_2(g)]}{4\,\Delta t} = 2.0 \times 10^{-4}\ mol\ dm^{-3}\ s^{-1}$$ (02)

$$\frac{\Delta[O_2(g)]}{\Delta t} = \frac{\Delta[N_2O_5(g)]}{2\,\Delta t} = 5.0 \times 10^{-5}\ mol\ dm^{-3}\ s^{-1}$$ (03)

6(a) (ii): 20 marks

(iii) In another experiment, initial rates were measured for this reaction at 300 K and the results are given below.

$[N_2O_5(g)]$ / mol dm^{-3}	0.01	0.02	0.03
Initial rate / mol dm^{-3} s^{-1}	6.930×10^{-5}	1.386×10^{-4}	2.079×10^{-4}

Derive the rate law for the reaction at 300 K.

When the concentration were increased two and three times, rate increased two and three times, respectively. (05)

∴ Reaction is first order (05)

∴ Rate law : Rate = $k\ [N_2O_5(g)]$ (05)

*(OR $R_1/R_2 = 1/2$ ::::*reaction is first order*)*

6(a) (iii): 15 marks

(iv) Another experiment was carried out at 300 K with an initial concentration of 0.64 mol dm^{-3} of $N_2O_5(g)$. It was found that the concentration of $N_2O_5(g)$ which remained after a period of 500 s was 2.0×10^{-2} mol dm^{-3}.

I. Calculate the half-life ($t_{1/2}$) of the reaction at 300 K.

Order of concentration change = $0.64/2.0 \times 10^{-2} = 32 = (2)^5$ (05)

∴ Fraction of initial $N_2O_5(g)$ = $(1/2)^5$ (05)

That is, 5 half-lives passed to reach this concentration (05)

∴ **$t_{1/2}$ = 500 s/5 = 100 s** (05)

II. Calculate the rate constant of the reaction at 300 K.

from iii,

Rate = $k\ [N_2O_5(g)] = 6.93 \times 10^{-5}\ mol\ dm^{-3}\ s^{-1} = k\ \ 0.01\ mol\ dm^{-3}$ (05)

$k = 6.93 \times 10^{-3}\ s^{-1}$ (04+01)

OR

Reaction is first order

For first order reaction: $t_{1/2} = 0.693 / k$ (05)

∴ $k = 0.693/100\ s = 6.93 \times 10^{-3}\ s^{-1}$ (05)

6(a) (iv): 30 marks

(v) This reaction proceeds through a mechanism involving the following elementary steps.

Step 1 : $N_2O_5(g) \rightleftharpoons NO_3(g) + NO_2(g)$: Fast

Step 2 : $NO_3(g) + NO_2(g) \rightarrow 2NO_2(g) + O(g)$: Slow

Step 3 : $N_2O_5(g) + O(g) \rightarrow 2NO_2(g) + O_2(g)$: Fast

Show that the above mechanism is consistent with the rate law of the reaction. (8.0 *marks*)

Step 1: $N_2O_5(g) \rightleftharpoons NO_3(g) + NO_2(g)$; *fast*

Step 2: $NO_3(g) + NO_2(g) \rightarrow 2NO_2(g) + O(g)$; *slow*

Step 3: $N_2O_5(g) + O(g) \rightarrow 2NO_2(g) + O_2(g)$; *fast*

From step 2 (Slow-step);

Rate= $k[NO_3(g)]\,[NO_2(g)]$ **(05)**

For step 1 (equilibrium)

$K_{eq} = \{ [NO_3(g)]\,[NO_2(g)]\} / [N_2O_5(g)]$ **(05)**

We get, $K_{eq}\,[N_2O_5(g)] = \{[NO_3(g)]\,[NO_2(g)]\}$

$\therefore$ Rate= $k\,K_{eq}\,[N_2O_5(g)] = k'[N_2O_5(g)]$ **(05)**

This is a first order reaction which follows the rate low derived **(05)**

6(a) (v): 20 marks

6(a): 90 marks

(*b*) An ideal binary-liquid mixture was prepared by mixing two liquids of A and B in a closed evacuated container at temperature *T*. After establishing the equilibrium at temperature *T*, partial pressures of A and B in the vapour phase are P_A and P_B, respectively. At temperature *T*, the saturated vapour pressures of A and B are P_A° and P_B°, respectively. Mole fractions of A and B in solution are X_A and X_B, respectively.

(i) Show that $P_A = P_A^\circ X_A$

(Consider that the rates of vaporization and condensation are equal at equilibrium.)

Consider the above described vapor – liquid equilibrium of an ideal solution with components **A** and **B**. As the rate of evaporation equals the rate of condensation, we can write:

$$A_{(l)} \underset{r_c}{\overset{r_v}{\rightleftharpoons}} A_{(g)} \;\ldots\ldots\ldots (1)$$ **(05)**

r_v *and* r_c are the rates of vaporization and condensation, respectively of the component A.

Considering (1), we can write;

$$r_v = k\,[A_{(l)}] = k_1 X_A$$ **(05)**

X_A is the mole fraction of A in solution

Likewise,

$$r_v' = k'[A_{(g)}] = k_2 P_A \qquad \textbf{(05)}$$

P_A is the partial pressure of A in vapor phase.

At equilibrium

$$r_v = r_v'$$

$$k_2 P_A = k_1 X_A \qquad \textbf{(05)}$$

$$\therefore\ P_A = \frac{k_1}{k_2} X_A \ \ or\ \ \therefore\ P_A = k\,X_A \qquad \textbf{(05)}$$

when $X_A = 1$, $P_A = P_A^0$ = saturated vapor pressure of A

$$\therefore\ k = P_A^0 \qquad \textbf{(05)}$$

$$\therefore\ P_A = P_A^0\, X_A \qquad \textbf{(05)}$$

6(b) (i): 35 marks

(ii) In the above system at 300 K, the total pressure was 5.0×10^4 Pa. The saturated vapour pressures of pure A and B at 300 K, are 7.0×10^4 Pa and 3.0×10^4 Pa, respectively.

I. Calculate the mole fraction of A in the liquid phase of the equilibrium mixture.

II. Calculate the vapour pressure of A in the equilibrium mixture.

(I) $P_{total} = P_A + P_B$ **(05)**

$$= X_A P^0_A + X_B P^0_B = X_A P^0_A + (1 - X_B)P^0_B \qquad \textbf{(05)}$$

$$\therefore\ X_A = \frac{P_{total} - P_B^0}{P_A^0 - P_B^0} \qquad \textbf{(05)}$$

$$= \frac{5 \times 10^4 - 3 \times 10^4}{7 \times 10^4 - 3 \times 10^4} = \frac{1}{2} \qquad \textbf{(05)}$$

(II) $\therefore\ P_A = P_A^0\, X_A = \frac{1}{2} \times 7 \times 10^4\ Pa = 3.5 \times 10^4\ Pa$ **(05)**

6(b) (ii): 25 marks

6(b): 60 marks

7. (a) (i) To compare the properties of Electrolytic and Galvanic cells, copy and complete the following table using the given terms.

Terms: anode, cathode, positive, negative, spontaneous, non-spontaneous.

		Electrolytic cell	Galvanic cell
A.	Oxidation half reaction takes place at	Anode	Anode
B.	Reduction half reaction takes place at	Cathode	cathode
C.	Sign of E^0_{cell}	-ve	+ve
D.	Electron flow	**From anode to cathode**	**From anode to cathode**
E.	Spontaneity of reaction	Non-spontaneous	spontaneous

(2 ×10 = 20 marks)

7(a) (i): 20 marks

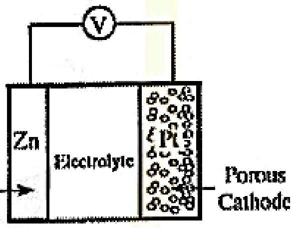
(ii) An electrochemical cell was constructed at 300 K by using a Zn(s) anode, an aqueous alkaline electrolyte and a porous Pt cathode which facilitates the collection of oxygen $O_2(g)$ from air as shown below. As the cell operates ZnO(s) is produced.

You are given that

$E^0_{ZnO(s)|Zn(s)|OH^-(aq)} = -1.31$ V and $E^0_{O_2(g)|OH^-(aq)} = +0.34$ V

Zn = 65 g mol^{-1}, O = 16 g mol^{-1} and

1 F = 96,500 C



I. Write the half-reactions occurring at anode and cathode.

anode : $Zn(s) + 2\,OH^-(aq) \rightarrow ZnO(s) + H_2O(l) + 2e$ **(05)**

Cathode ; $O_2(g) + 2\,H_2O(l) + 4e \rightarrow 4\,OH^-(aq)$ **(05)**

II. Write the overall cell reaction.

$2\,Zn(s) + O_2(g) \rightarrow 2ZnO(s)$ **(05)**

III. Calculate the cell potential E°_{cell} at 300 K.

$E^0_{cell} = E^0_R - E^0_L = E^0_{cathode} - E^0_{anode}$ **(05)**

$= 0.34\text{ V} - (-1.31\text{ V}) = 1.65\text{V}$ **(04+01)**

IV. State the direction of migration of $OH^-(aq)$ ions between the electrodes.

From anode to cathode (from Zn electrode to oxygen electrode) **(05)**

V. When the cell operates for a period of 800 s at 300 K, 2 mol of $O_2(g)$ are consumed.

A. Calculate the number of moles of electrons passing through the cell.

$$2 \text{ mol } O_2(g) \times \frac{4\ mol\ ens}{1\ mol\ O_2(g)} = 8 \text{ moles of electrons}$$ **(05)**

B. Calculate the mass of ZnO(s) formed.

$$\text{Mass of ZnO(s)} = \frac{8\ mol\ ens \times 96500\ C}{1\ mol\ \ e \times 800\ s} \times \frac{1\ \ mol\ e}{96500\ C} \times \frac{2\ \ mol\ ZnO(s)}{4\ mol\ en} \times \frac{81\ \ g}{1\ mol\ ZnO}$$ **(05)**

$= 324$ g **(04+01)**

OR

Mass of ZnO $= 4\ mol \times 81\ g\ mol$ **(05)**

$= 324$ g **(04+01)**

C. Calculate the current passing through the cell.

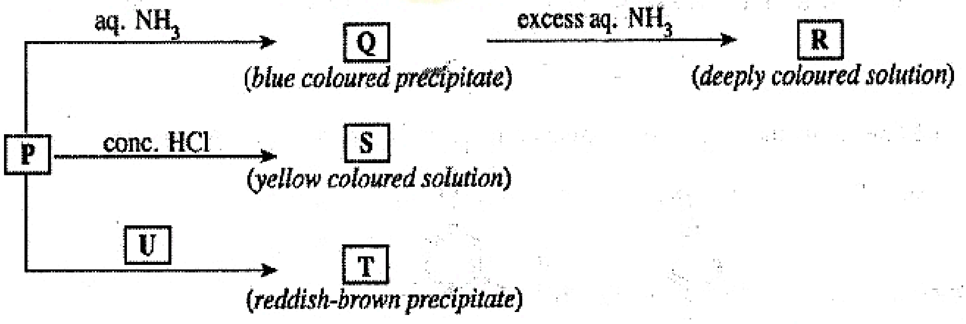
$I = q/t$ **(05)**

$$= \frac{8\ \ mol\ ens \times 96500\ C}{1\ mol\ \ e \times 800\ s} = 965\ A$$ **(05)**

7(a) (i): 55 marks

7(a): 75 marks

(*b*) A coloured complex ion **P** is formed when the salt $M(NO_3)_n$ is dissolved in distilled water. **M** is a transition element belonging to the 3*d* block. **P** undergoes the following reactions.



T and **U** are coordination compounds each containing four elements. **P**, **R** and **S** are complex ions.

(i) Identify the metal **M**. Give the oxidation state of **M** in complex ion **P**.

M = Cu **(10)**

Oxidation state: +2 **OR** Cu^{2+} **(03)**

7(b) (i): 13 marks

(ii) Give the value of n in $M(NO_3)_n$.

$n = 2$ (03)

7(b) (ii): 03 marks

(iii) Write the complete electronic configuration of **M** in complex ion **P**.

$1s^2 2s^2 2p^6 3s^2 3p^6 3d^9$ (03)

7(b) (iii): 03 marks

(iv) Write the chemical formulae of **P**, **Q**, **R**, **S**, **T** and **U**.

P: $[Cu(H_2O)_6]^{2+}$ (04)

Q: $Cu(OH)_2$ (04)

R: $[Cu(NH_3)_4]^{2+}$ (04)

S: $[CuCl_4]^{2-}$ (04)

T: $Cu_2[Fe(CN)_6]$

U: $K_4[Fe(CN)_6]$

7(b) (iv): 16 marks

(v) Give the IUPAC names of **P**, **R**, **S**, **T** and **U**.

P: hexaaquacopper(II) ion (03)

R: tetraamminecopper(II) ion (03)

S: tetrachloridocuprate(II) ion (03)

T: copper hexacyanoferrate(II)

U: potassium hexacyanoferrate(II)

7(b) (v): 12 marks

(vi) What is the colour of **P**?

pale blue (04)

7(b) (vi): 04 marks

(vii) What would you expect to observe in I and II given below?

I. When H_2S gas is passed into an acidic solution containing **P** at room temperature

black precipitate (06)

II. When the mixture obtained in I above is heated with dilute HNO_3 after the removal of dissolved H_2S

pale blue solution (04)
solution is turbid/ pale yellow or milky/ white precipitate (02)
or
turbid pale blue solution (06)

7(b) (vii): 12 marks

(viii) Briefly describe a method with the aid of balanced chemical equations for determining the concentration of M^{n+} present in an aqueous solution, using the following chemicals. KI, $Na_2S_2O_3$ and starch.

Add excess KI **(01)**
to an aqueous solution of volume V_1 cm³ containing M^{n+} **(01)**
Here, $M^{n+} = Cu^{2+}$
Titrate the liberated I_2 **(01)**
with $Na_2S_2O_3$ whose concentration is known (M mol dm⁻³) **(01)**
with starch as the indicator **(01)**

$2Cu^{2+} + 2I^- \rightarrow 2Cu^+ + I_2$ ----------------(1) **(01)**

$I_2 + 2S_2O_3^{2-} \rightarrow S_4O_6^{2-} + 2I^-$ ----------------(2) **(01)**

$2Cu^{2+} + 2S_2O_3^{2-} \rightarrow S_4O_6^{2-} + 2Cu^+$ ----------------(3) **(02)**

OR

$2Cu^{2+} + 4I^- \rightarrow 2CuI\downarrow + I_2$ ----------------(1a) **(01)**

$I_2 + 2S_2O_3^{2-} \rightarrow S_4O_6^{2-} + 2I^-$ ----------------(2a) **(01)**

$2Cu^{2+} + 2S_2O_3^{2-} \rightarrow 2CuI\downarrow + S_4O_6^{2-}$ ----------------(3a) **(02)**

Note: If correct overall equation is given, award the part marks for half equations as well.

From both (3) or (3a) $Cu^{2+} \equiv S_2O_3^{2-}$ **(01)**

Let the burette reading of $S_2O_3^{2-}$ be V_2 cm³ **(01)**

Therefore, moles of $S_2O_3^{2-}$ $= \frac{V_2}{1000} \times M$ **(01)**

Therefore, moles of Cu^{2+} $= \frac{V_2}{1000} \times M$ **(01)**

Therefore, $[Cu^{2+}]$ $= \frac{V_2}{1000} \times M \times \frac{1000}{V_1}$ **(01)**

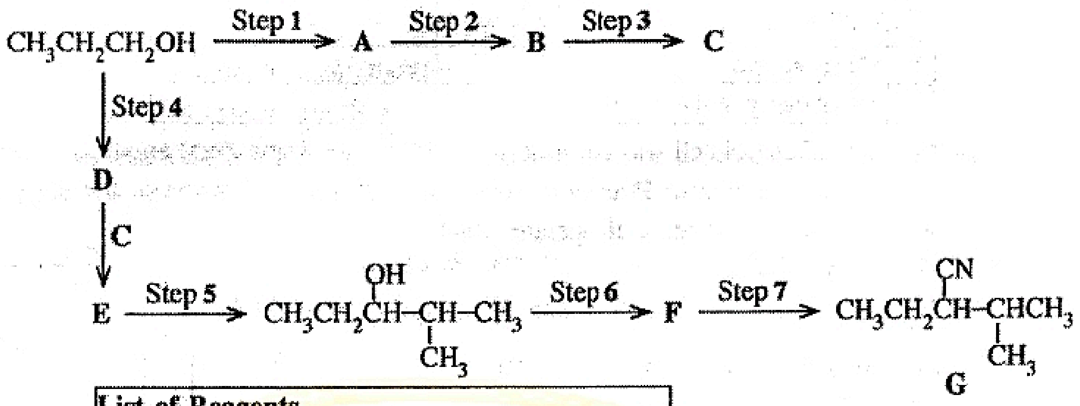
$= \frac{MV_2}{V_1}$ mol dm⁻³ **(01)**

Note: The above explanation could be given in words.

7(b)(viii) : 15 marks

7(b): 75 marks

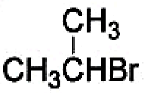
8. (*a*) (i) Given below is a reaction scheme for the synthesis of compound **G** using $CH_3CH_2CH_2OH$ as the only organic starting compound.
Complete the reaction scheme by drawing the structures of compounds **A, B, C, D, E** and **F** and writing the appropriate reagents for steps **1 – 7**, selected only from those given in the list.

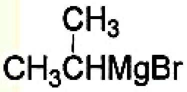


List of Reagents
HBr, PBr_3, pyridiniumchlorochromate (PCC), Mg / dry ether, KCN, conc. H_2SO_4, dil. H_2SO_4

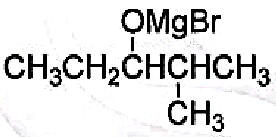
Compounds, A - F

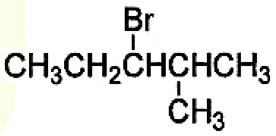
A = $CH_3CH{=}CH_2$

B = 
$CH_3\overset{CH_3}{\overset{|}{C}}HBr$

C = 
$CH_3\overset{CH_3}{\overset{|}{C}}HMgBr$

D = CH_3CH_2CHO

E = 
$CH_3CH_2\overset{OMgBr}{\overset{|}{C}}H\underset{\underset{CH_3}{|}}{C}HCH_3$

F = 
$CH_3CH_2\overset{Br}{\overset{|}{C}}H\underset{\underset{CH_3}{|}}{C}HCH_3$

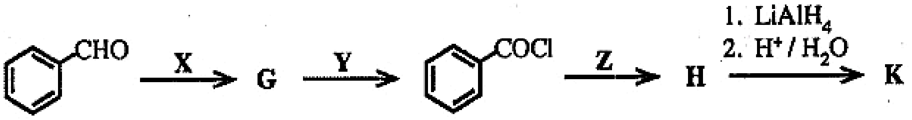
Reagents:

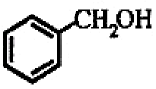
Step 1 = conc.H_2SO_4
Step 2 = HBr
Step 3 = Mg / dry ether
Step 4 = PCC
Step 5 = dil.H_2SO_4
Step 6 = PBr_3
Step 7 = KCN

Compounds/Reagents **(04 x 13 = 52 marks)**

8(a) (i): 52 marks

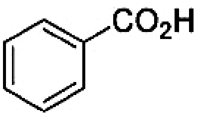
(ii) Consider the following series of reactions.
Draw the structures of compounds **G, H** and **K**. Give the reagents **X, Y** and **Z**.



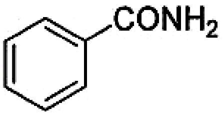
Note that **K** gives benzyl alcohol () when reacted with $NaNO_2$ / dil. HCl.

Compounds **G, H** and **K**

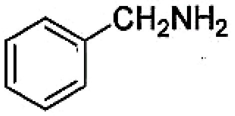
G =



H =



K =



Reagents

X = $H^+ / K_2Cr_2O_7$ / or $H^+ / KMnO_4$ or H^+/CrO_3

Y = PCl_5 or PCl_3

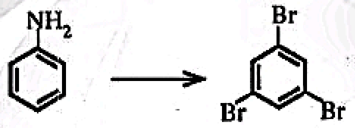
Z = NH_3

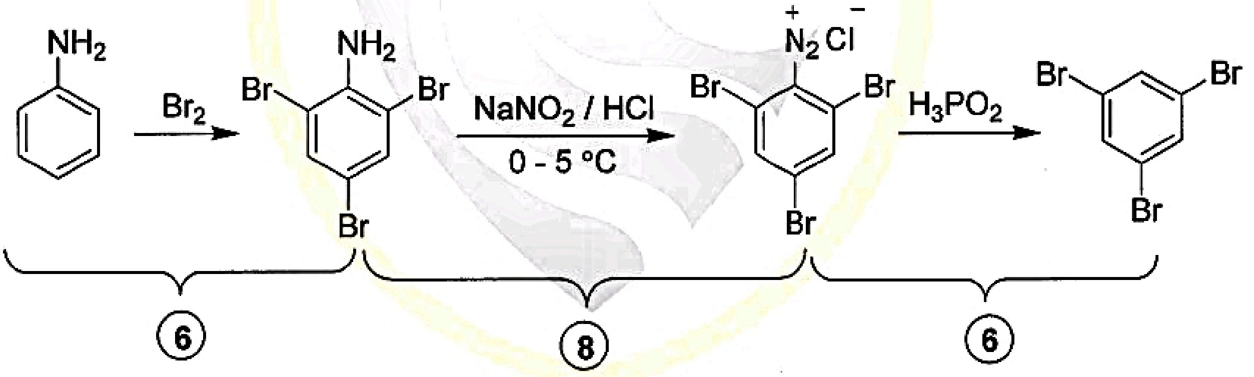
Compounds/Reagents **(04 x 6 = 24 marks)**

8(a) (ii): 24 marks

8(a): 76 marks

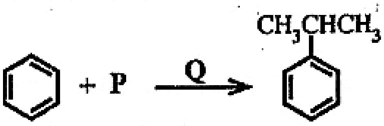
(*b*) (i) Show how the following conversion could be carried out in **not more than three** steps





8(b) (i) 20 marks

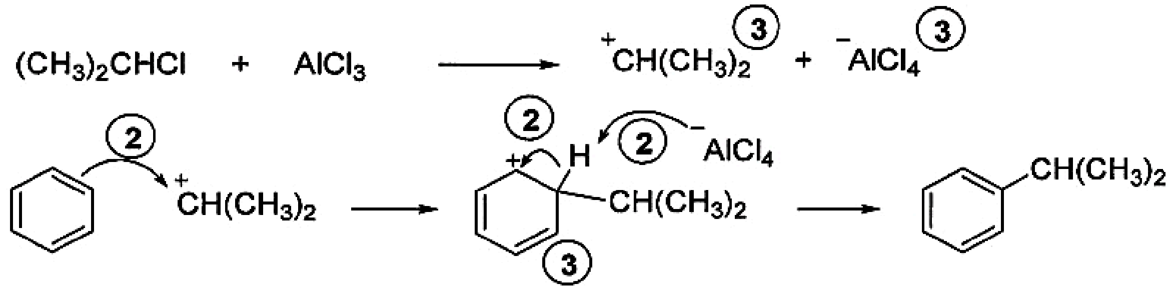
(ii) Consider the following reaction.



Identify the chemical substances **P** and **Q** necessary to carry out this reaction.
Write the mechanism of this reaction.

P + Q = $(CH_3)_2CHCl$ + $AlCl_3$ ⑤

P + Q = **(05)**

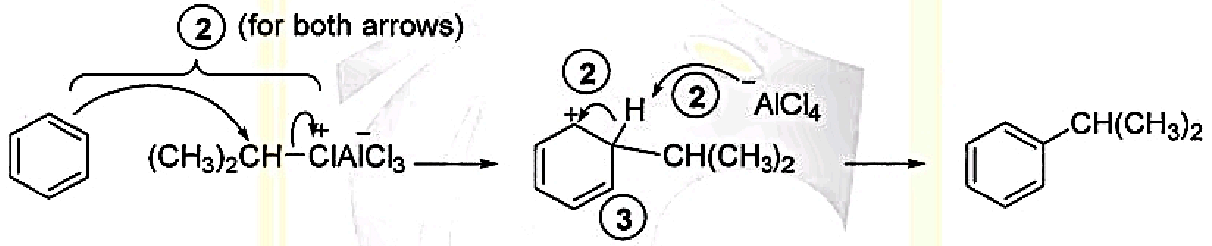


Intermediates **03 x 3 = 09**

Arrows **02 x 3 = 06**

Alternative answer:

IF the student has written the electrophile as R–Cl molecule polarized by coordinating to AlCl₃, only the marks allocated for the last two steps may be awarded as given below.



02+02+02+03 = 09

The electrophile may be written as:

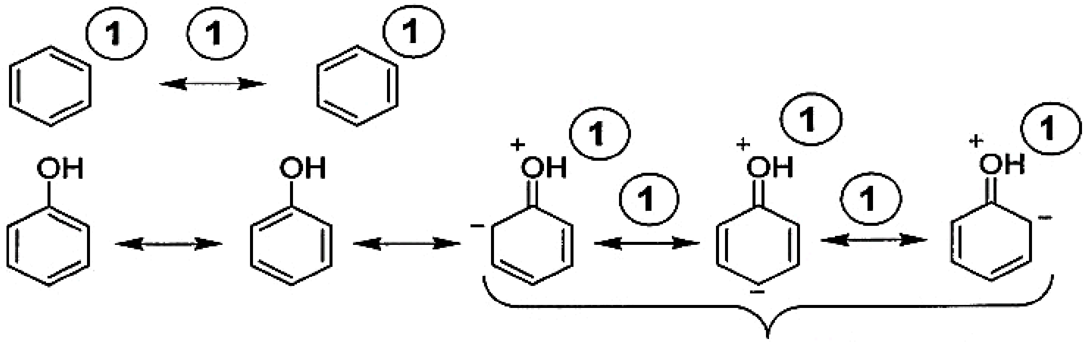
$(CH_3)_2CH-\overset{+}{Cl}\overset{-}{AlCl_3}$ or $(CH_3)_2CH-\overset{+}{Cl}-\overset{-}{AlCl_3}$ or $(CH_3)_2CH-\overset{\delta+}{Cl}\text{--}\overset{\delta-}{AlCl_3}$

8(b)(ii): 20 marks

8(b): 40 marks

(*c*) (i) **Explain why phenol is more reactive in electrophilic substitution reactions than benzene, by considering their resonance hybrids.**

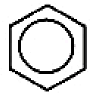
Structures of benzene and phenol can be illustrated as follows.



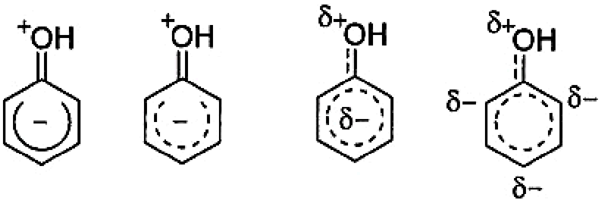
Consider these only for marking

Resonance structures and Double headed arrows **01** x 8 = **08**

OR



Alternative to the resonance hybrid of benzene ③



Any one structure ⑤

Alternative to the resonance hybrid of phenol

The benzene ring of phenol is more reactive towards electrophiles than benzene itself because:

The benzene ring in phenol is electron rich compared to benzene due to the

Delocalization of lone pair of electrons on the oxygen atom

Over the benzene ring of phenol

04 x 3 = 12

8(c)(i): 20 marks

(ii) Illustrate the difference in reactivity between phenol and benzene as given in (i) above by means of a suitable reaction.

Phenol **reacts with bromine at room temperature/ decolorizes bromine / gives a white precipitate with bromine water**

Benzene **does not react with bromine at room temperature / does not decolorize bromine / does not give a white precipitate with bromine water**

OR

Benzene reacts with bromine **(only) in the presence of a Lewis catalyst**

Reaction of phenol with bromine occurs **even in the absence of Lewis catalyst**

OR

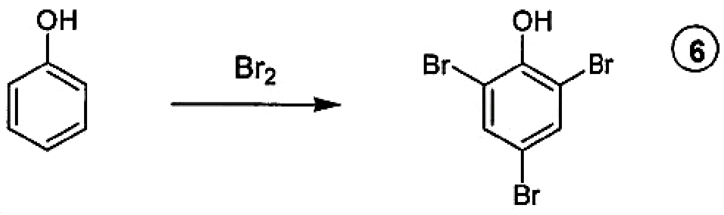
Nitration of phenol takes place at **room temperature** / at **20 °C / without heating with dilute HNO_3 (20% HNO_3)**.

Benzene **does not react with dilute HNO_3**

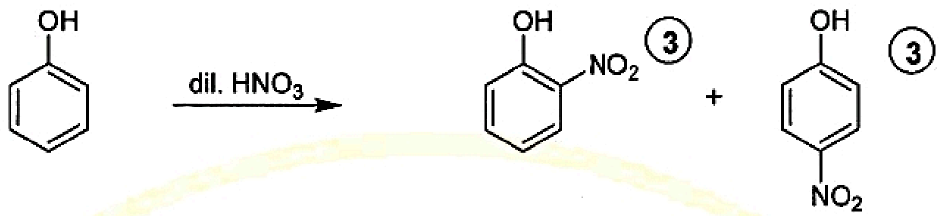
04 x 2 = 08

8(c): (ii) 08 marks

(iii) Draw the structure(s) of product(s) you described in the reaction in (ii) above.



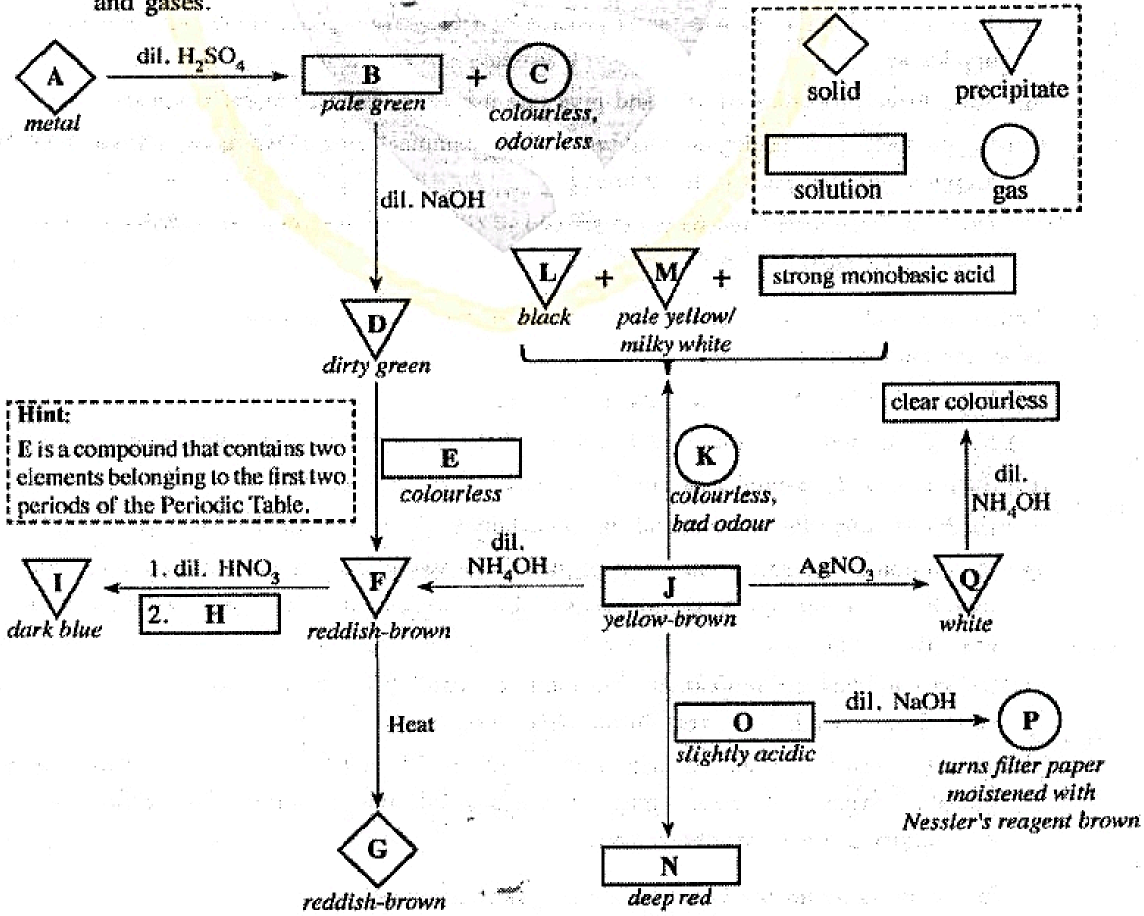
OR



8(c) (iii): 06 marks

$\boxed{\textbf{8(c): 34 marks}}$

9. (*a*) (i) Write the chemical formulae of the substances **A** – **Q** given in the flow chart below.
(**Note:** Chemical equations and reasons are not expected for the identification of substances **A** – **Q**.)
The symbols given in the box (dash lines) are used to represent solids, precipitates, solutions and gases.



A: Fe

B: $FeSO_4$ **or** $[Fe(H_2O)_6]SO_4$ **or** $[Fe(H_2O)_6]^{2+}$

C: H_2

D: $Fe(OH)_2$

E: H_2O_2

F: $Fe(OH)_3$

G: Fe_2O_3

H: $K_4[Fe(CN)_6]$

I: $Fe_4[Fe(CN)_6]_3$ **or** $KFe[Fe(CN)_6]$

J: $FeCl_3$

K: H_2S

L: FeS

M: S **or** S_8

N: $Fe(SCN)_3$ **or** $[Fe(SCN)(H_2O)_5]^{2+}$ **or** $[Fe(SCN)]^{2+}$

O: NH_4SCN

P: NH_3

Q: AgCl

(04 marks x 17 = 68 marks)

9 (a) (i) : 68 marks

(ii) Write the complete electronic configuration of **A**.

$1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 4s^2$ **(02)**

(iii) State the function of **E** in the conversion of **D** to **F**. Give the relevant balanced chemical equations for the stated function.

E: H_2O_2 function – oxidizing agent **(02)**

$2(Fe(OH)_2 + H_2O \rightarrow Fe(OH)_3 + H^+ + e)$
$H_2O_2 + 2H^+ + 2e \rightarrow 2H_2O$

$2Fe(OH)_2 + H_2O_2 \rightarrow 2Fe(OH)_3$ **(03)**

OR

$2(Fe^{2+} \rightarrow Fe^{3+} + e)$
$H_2O_2 + 2H^+ + 2e \rightarrow 2H_2O$

$2Fe^{2+} + H_2O_2 + 2H^+ \rightarrow 2Fe^{3+} + 2H_2O$ **(03)**

(Half reactions (01) each if written)

9 (a) (ii & iii) marks :07

9 (a) 75 marks

(*b*) The solid **X** contains only Cu_2S and CuS. The following procedure was used to determine the percentage of Cu_2S in **X**.

Procedure

A 1.00 g portion of solid **X** was treated with 100.00 cm^3 of 0.16 mol dm^{-3} $KMnO_4$ in dilute H_2SO_4 medium. This reaction gave Mn^{2+}, Cu^{2+} and SO_4^{2-} as products. Thereafter, the excess $KMnO_4$ in this solution was titrated with 0.15 mol dm^{-3} Fe^{2+} solution. The volume required for the titration was 35.00 cm^3.

(i) Write the balanced ionic equations for the reactions taking place in the above procedure.

Reaction of Cu_2S with MnO_4^-

$2Cu^+ \rightarrow 2Cu^{2+} + 2e$ ---------(1) **(03)**

$S^{2-} + 4H_2O \rightarrow SO_4^{2-} + 8H^+ + 8e$ ---------(2) **(03)**

OR

(1) + (2)

$2Cu^+ + S^{2-} + 4H_2O \rightarrow 2Cu^{2+} + SO_4^{2-} + 8H^+ + 10e$ -----(3)

$2(MnO_4^- + 8H^+ + 5e \rightarrow Mn^{2+} + 4H_2O)$ ------(4) **(03)**

(3) + (4)

$2Cu^+ + S^{2-} + 2MnO_4^- + 8H^+ \rightarrow 2Cu^{2+} + SO_4^{2-} + 2Mn^{2+} + 4H_2O$ **(05)**

OR

$Cu_2S + 2MnO_4^- + 8H^+ \rightarrow 2Cu^{2+} + SO_4^{2-} + 2Mn^{2+} + 4H_2O$

(If only this equation is written award the full 14 marks)

Reaction of CuS with MnO_4^-

$5(S^{2-} + 4H_2O \rightarrow SO_4^{2-} + 8H^+ + 8e)$ ---------(5)

$8(MnO_4^- + 8H^+ + 5e \rightarrow Mn^{2+} + 4H_2O)$ ---------(6)

(5)+ (6)

$5S^{2-} + 8MnO_4^- + 24H^+ \rightarrow 5SO_4^{2-} + 8Mn^{2+} + 12H_2O$ **(05)**

OR

$5CuS + 8MnO_4^- + 24H^+ \rightarrow 5CuSO_4 + 8Mn^{2+} + 12H_2O$

Reaction of Fe^{2+} with MnO_4

$5(Fe^{2+} \rightarrow Fe^{3+} + e)$ ------------(7) **(03)**

$MnO_4^- + 8H^+ + 5e \rightarrow Mn^{2+} + 4H_2O$ ------------(8)

(7) + (8)

$5Fe^{2+} + MnO_4^- + 8H^+ \rightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$ **(05)**

9 (b)(i) : 27 marks

OR

Reaction of Cu^+ with MnO_4^-

$5(Cu^+ \rightarrow Cu^{2+} + e)$ --------------------(1a) **(03)**

$MnO_4^- + 8H^+ + 5e \rightarrow Mn^{2+} + 4H_2O$ --------------------(2a) **(03)**

(1a) + (2a)

$5Cu^+ + MnO_4^- + 8H^+ \rightarrow 5Cu^{2+} + Mn^{2+} + 4H_2O$ **(05)**

Reaction of S^{2-} with MnO_4^-

$5(S^{2-} + 4H_2O \rightarrow SO_4^{2-} + 8H^+ + 8e)$ ------------(5) **(03)**

$8(MnO_4^- + 8H^+ + 5e \rightarrow Mn^{2+} + 4H_2O)$ ------------(6)

(5)+ (6)

$5S^{2-} + 8MnO_4^- + 24H^+ \rightarrow 5SO_4^{2-} + 8Mn^{2+} + 12H_2O$ **(05)**

Reaction of Fe^{2+} with MnO_4^-

$5(Fe^{2+} \rightarrow Fe^{3+} + e)$ ------------(7) **(03)**

$MnO_4^- + 8H^+ + 5e \rightarrow Mn^{2+} + 4H_2O$ ------------(8)

(7) + (8)

$5Fe^{2+} + MnO_4^- + 8H^+ \rightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$ **(05)**

Note: If only the overall reaction is written correctly, award the marks due to the half reactions as well.

b (b)(i): 27 marks

(ii) Based on the answers to (i) above, determine the molar ratio between,

I. Cu_2S and $KMnO_4$
II. CuS and $KMnO_4$
III. Fe^{2+} and $KMnO_4$

Molar ratios

$\frac{Cu_2S}{MnO_4^-} = \frac{1}{2}$ $\frac{CuS}{MnO_4^-} = \frac{5}{8}$ $\frac{Fe^{2+}}{MnO_4^-} = \frac{5}{1}$ **(05 x 3)**

OR

$Cu_2S : MnO_4^- = 1 : 2$ $CuS : MnO_4^- = 5 : 8$ $Fe^{2+} : MnO_4^- = 5 : 1$

9 (b)(ii): 15 marks

(iii) Calculate the percentage by weight of Cu_2S in **X**. (Cu = 63.5, S = 32)

Let the number of moles of Cu_2S and CuS be n_1 and n_2 respectively in the 1.0 g of sample **X**

Molar mass of Cu_2S = (2 x 63.5) + 32 = 159 **(02)**

Molar mass of CuS = 63.5 + 32 = 95.5 **(02)**

$159n_1 + 95.5n_2 = 1.0$ ------------(9) **(02)**

Moles of Fe^{2+} reacted $= \frac{0.15}{1000} \times 35.0$ **(02)**

Moles of MnO_4^- $= \frac{0.15}{1000} \times 35.0 \times \frac{1}{5}$ **(02)**

Moles of MnO_4^- reacted with Cu_2S and CuS

$= \frac{0.16}{1000} \times 100.0 - \frac{0.15}{1000} \times 35.0 \times \frac{1}{5}$ **(02)**

= 0.016 – 0.001 **(02)**

= 0.015 mol **(02)**

Based on molar ratios

$2n_1 + \frac{8}{5}n_2 = 0.015$ ------------(10) **(02)**

(9) + (10)

$2n_1 + \frac{8}{5}\,\frac{(1-159\,n1)}{95.5} = 0.015$ **(02)**

$2 \times 5 \times 95.5\, n_1 + 8(1-159n_1) = 0.015 \times 95.5 \times 5$ **(02)**

$955n_1 + 8 - 1272n_1 = 7.1625$

$317n_1 = 0.84$

$n_1 = 0.0027$ **(02)**

Weight of Cu_2S = 0.0027 x 159 g **(02)**

= 0.43 g **(02)**

% Cu_2S $= \frac{0.43}{1.0} \times 100$ **(02)**

= **43%** **(03)**

9 (b)(iii) : 33 marks

OR

Moles of Fe^{2+} $= \frac{0.15}{1000} \times 35.0$ **(02)**

Moles of MnO_4^- remaining $= \frac{0.15}{1000} \times 35.0 \times \frac{1}{5}$ **(02)**

Moles of MnO_4^- added $= \frac{0.16}{1000} \times 100.0$ **(02)**

Moles of MnO_4^- reacted with Cu_2S and CuS

$= \frac{0.16}{1000} \times 100.0 - \frac{0.15}{1000} \times 35.0 \times \frac{1}{5}$ **(02)**

= 0.016 – 0.001 **(02)**

= 0.015 mol **(02)**

Consider the masses of Cu_2S and CuS to be p and q respectively.

$p + q = 1.0$ g --------------(9a) **(02)**

Molar mass of $Cu_2S = (2 \times 63.5) + 32 = 159$ **(02)**

Molar mass of CuS $= 63.5 + 32 = 95.5$ **(02)**

$\frac{2p}{159} + \frac{8q}{95.5 \times 5} = 0.015$ --------------(10a) **(02)**

From (9a) & (10a)

$\frac{2p}{159} + \frac{8(1-p)}{95.5 \times 5} = 0.015$ **(02)**

$2p \times 5 \times 95.5 + 8 \times 159(1-p) = 0.015 \times 5 \times 159 \times 95.5$ **(02)**

$955p - 1272p = 1138.84 - 1272$ **(02)**

$317p = 133.16$

$p = \frac{133.16}{317} = 0.42$ **(02)**

% Cu_2S $= \frac{0.42}{1000} \times 100.0$ **(02)**

= 42% **(03)**

9 (b)(iii) : 33 marks

OR

Let the number of moles of Cu_2S and CuS be n_1 and n_2 respectively in the 1.0 g of **X**

$5Cu^+ + MnO_4^- + 8H^+ \rightarrow 5Cu^{2+} + Mn^{2+} + 4H_2O$

$5S^{2-} + 8MnO_4^- + 24H^+ \rightarrow 5SO_4^{2-} + 8Mn^{2+} + 12H_2O$

$5Fe^{2+} + MnO_4^- + 8H^+ \rightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O$

Moles of MnO_4^- added $= \frac{0.16}{1000} \times 100.0 = 0.016$ **(02)**

Moles of Fe^{2+} reacted $= \frac{0.15}{1000} \times 35.0 = 0.005$ **(02)**

Moles of MnO_4^- remaining $= \frac{0.15}{1000} \times 35.0 \times \frac{1}{5} = 0.001$ **(02)**

Moles of MnO_4^- reacted $= 0.016 - 0.001 = 0.015$ **(02)**

Molar mass of $Cu_2S = (2 \times 63.5) + 32 = 159$ **(02)**

Molar mass of CuS $= 63.5 + 32 = 95.5$ **(02)**

$159n_1 + 95.5n_2 = 1$ -----------------(1) **(02)**

Moles of $Cu^+ = 2n_1$

Therefore, moles of MnO_4^- reacted $= \frac{2n_1}{5}$

Moles of $S^{2-} = n_1 + n_2$ **(02)**

Therefore, moles of MnO_4^- reacted with $S^{2-} = \frac{8(n_1 + n_2)}{5}$

Therefore, total moles of MnO_4^- reacted $= \frac{10n_1 + 8n_2}{5}$ **(02)**

$\frac{(10n_1 + 8n_2)}{5}$ mol $= 0.015$ mol **(02)**

$10n_1 + 8n_2 = 0.075$ mol ---------------(2) **(02)**

(1) x 8 – (2) x 95.5

$1272\ n_1 - 955\ n_1 = 8 - 7.14$ **(02)**

$317n_1 = 0.86$ Therefore, $n_1 = \frac{0.86}{317}$

Therefore, moles of Cu_2S in 1 g $= \frac{0.86}{317}$ **(02)**

Mass of Cu_2S $= 0.86 \times 159$ g **(02)**

% of Cu_2S $= \frac{0.86}{317} \times 159 \times 100\%$ **(02)**

$=$ **43%** **(03)**

9 (b)(iii): 33 marks

9(b): 75 marks

10. *(a)* The following questions are based on the properties of titanium dioxide (TiO_2) and its manufacture carried out by the "Chloride Process".

(i) Name the raw materials used in this process.

Rutile **(02)**

Coke **(02)**

Cl_2 **(02)**

O_2 **(02)**

10 (a) (i): 08 marks

(ii) Briefly describe the manufacturing process of TiO_2 giving balanced chemical equations where applicable.

<u>Chlorination</u>

Removal of water at 200 °C / 300 °C **(02)**

Heating of rutile and coke mixture at 900 °C / 950 °C **(02)**

$TiO_2(s) + C(s) \rightarrow Ti\ (s) + CO_2\ (g)$ -------(A) **(03)**

Stream of chlorine is passed over mixture of rutile and coke **(02)**

$Ti(s) + 2Cl_2(g) \rightarrow TiCl_4(g)$ -------(B) **(03)**

OR

Reactions (A) and (B) can be combined.

$TiO_2(s) + C(s) + 2Cl_2 \rightarrow TiCl_4(g) + CO_2(g)$ **(06)**

For three descriptions above **(02 x 3)**

After removal of dust particles, $TiCl_4$ gaseous mixture is cooled and liquid $TiCl_4$ is separated. **(02)**

Oxidation

$TiCl_4$ is reacted with oxygen and TiO_2 is regenerated.

$TiCl_4(g) + O_2(g) \rightarrow TiO_2(s) + 2Cl_2(g)$ **(03)**

Cl_2 is re-used in chlorination. **(02)**

10 (a) (ii): 19 marks

(iii) State **three** properties of TiO_2 and give one use each, relevant to each property.

- White colour – as a pigment in paint, plastic goods and paper, paper
- High refractive index – as a pigment
- Chemically inert – as a pigment in medicine and toothpaste
- Prevents the reach of UV rays to skin – produce substances to prevent sunburn

Any three properties **(02 x 3 = 06)**

One use for each property **(02 x 3 = 06)**

10 (a) (iii): 12 marks

(iv) If you were to consider establishing a TiO_2 manufacturing plant in Sri Lanka, state **three** requirements that need to be fulfilled.

- Availability of raw material
- Capitol
- Labour force
- Technology
- Storage conditions
- Minimize environmental pollution
- Transport facilities
- Waste product management

Any three **(02 x 3 = 06)**

10 (a) (iv): 06 marks

(v) Does the manufacturing process described in (ii) above contribute to global warming? Justify your answer.

Yes. **(02)**

CO_2 is produced and given out to the environment in the oxidation of coke **(03)**

10 (a) (v): 05 marks

10(a): 50 marks

(*b*) Currently, global warming due to change in greenhouse effect is significantly greater than that before the industrial revolution.

(i) Explain briefly what is meant by greenhouse effect.

Heating of earth (01) by **infrared absorbing gases (01) in the atmosphere** by **trapping energy (IR radiation) (02) reradiated from the earth surface (02).**

10 (b) (i): 06 marks

(ii) Identify the major environmental problem that occurs due to global warming.

Climate change **(03)**

10 (b) (ii): 03 marks

(iii) State **two main** natural gases that contribute to global warming.

CO_2, CH_4, and N_2O any two **(03 + 03)**

10 (b) (iii): 06 marks

(iv) Explain briefly how microorganisms contribute to the release of the gases you stated in (iii).

CO_2- Action of aerobic bacteria on organic substances/ plant materials/ and animal materials

CH_4- Action of anaerobic bacteria on organic substances/ materials

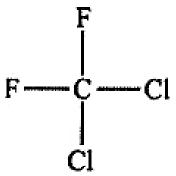
N_2O- Action denitrifying bacteria on ammonia/ nitrogen fertilizers(urea)/ and nitrogen containing substances.

Any two (04 + 04)

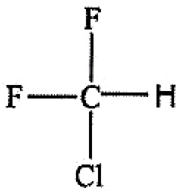
10 (b) (iv): 08 marks

(v) In addition to the gases you stated in (iii), name **two** classes of synthetic volatile compounds that directly contribute to the global warming, and selecting one compound from each class, draw their structures.

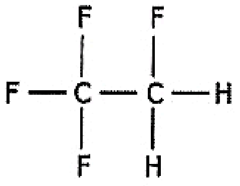
CFC, HFC, HCFC



CFC,



HFC,



HCFC

Any two (03 for class +03 for the structure)

(03 x 4 =12 marks)

No marks for the structure if the class is wrong

Note In addition to these compounds award marks for the following structures on each class.

CFC - Any saturated organic compound that contain one or two carbon atoms with only Cl and F atom

HCFC - Any saturated organic compound that contain one or two carbon atoms with only one hydrogen atom and others are Cl and F atoms

HFC - Any saturated organic compound that contain one or two carbon atoms with only one hydrogen atom and others are F atoms.

10 (b) (v): 12 marks

(vi) Select **one** class of compounds from the two classes you stated in (v) that contributes to the catalytic degradation of ozone in the upper atmosphere.

CFC or HCFC (must be selected from (v) to get marks)

10 (b) (vi): 03 marks

(vii) The slow down of industrial activities due to the Covid-19 pandemic temporarily eased the global environmental issues in many countries. Justify this statement by using **two** main global environmental issues you have learnt.

<u>Reduction of Global warming</u> **(01)**: Due to the **reduction of emission of CO_2 (01)** because of **reduction of fossil fuel burning (02)** due to **limitation of industrial activities (01) and transportation (01)**.

<u>Reduction of acid rain</u> **(01) : Reduction of emission of SO_2 (01)** into the atmosphere due to decrease of **burning of coal and diesel (01+01)** for power **generation and transportation (01+01)** respectively .

or

<u>Reduction of acid rain</u> **(01)** Reduction of emission of **NO_2/NO into the atmosphere (01)** due to **decrease of fuel burning (01)** in **internal combustion engine (01)** of vehicles caused by limitation of **transportation (02)**.

<u>Reduction of Photochemical smog</u> **(01)**. Reduction of emission **of NO** and **volatile hydrocarbons (01+01)** into the atmosphere from internal combustion engines/vehicles **(01)** due to limitation of transportation **(02)**.

Any two (06 x 2 = 12 marks)

10 (b) (vii): 12 marks

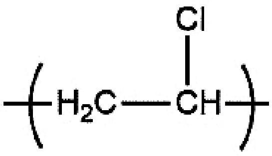
10(b): 50 marks

(*c*) The following questions are based on the polymers given below.

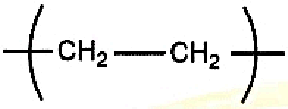
Polyvinyl chloride (PVC), Polyethylene (PE), Polystyrene (PS), Bakelite, Nylon 6.6, Polyethylene terephthalate (PET), Gutta percha

(i) Draw the repeating units of fo f the above polymers.

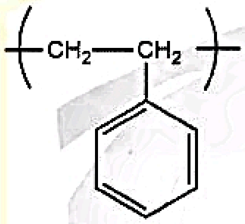
PVC



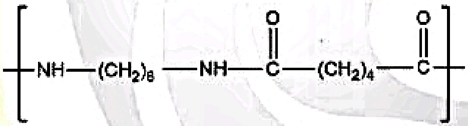
PE



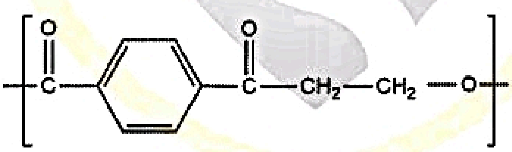
PS



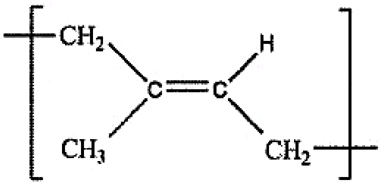
Nylon 6,6



PET



Gutta percha



Brackets are not required for award of marks.

Any four **(02 x 4 = 08)**

10 (c) (i): 08 marks

(ii) Categorize each of the above seven (7) polymers as either,

I. natural or synthetic polymers.
II. addition or condensation polymers.

	I - natural/synthetic	II - addition/condensation
PVC	synthetic	addition
PE	synthetic	addition
PS	synthetic	addition
Bakelite	synthetic	condensation
Nylon 6,6	synthetic	condensation
PET	synthetic	condensation
Gutta percha	natural	addition

For I – Any 6 **(02 x 6 = 12)**

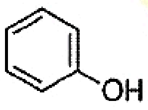
For II – Any 6 **(02 x 6 = 12)**

10 (c) (ii): 24 marks

(iii) Name the two monomers used in the formation of bakelite.

phenol and formaldehyde

OR



and HCHO

(02 x 2 = 04)

10 (c) (iii): 04 marks

(iv) Polymers can be grouped into two categories based on their thermal properties. State these two categories. Write to which of these categories PVC and bakelite belong.

Thermoset polymers **(02)**

Thermoplastic polymers **(02)**

Bakelite – thermoset polymer **(02)**

PVC – thermoplastic polymer **(02)**

10 (c) (iv): 08 marks

(v) Give **one** use each for **three** of the polymers given in the above list.

PVC	pipes to supply water, seat cover, electric wire covers
PE	food wrapping, garbage bags
PS	stylofoam cups, rigiform, insulating materials, packing materials
Bakelite	heat resistant parts for electric utensils, insulating materials
Nylon 6,6	clothes, fishing nets & lines, tyre threads
PET	bottles
Gutta percha	insulation, permanent tooth fillings, golf balls

Any three **(02 x 3 = 06)**

10(c) (v): 06 marks

10(c): 50 marks