Department of Examinations – Sri Lanka

## G.C.E. (A/L) Examination – 2024

# 02 - Chemistry

## Marking Scheme

This 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**

# G.C.E. (A/L) Examination - 2024

# 02 - Chemistry

## Distribution of Marks

**Paper I** : 1 X 50 = 50

**Paper II** :

Part A : 100 X 4 = 400

Part B : 150 X 2 = 300

Part C : 150 X 2 = 300

**Total** = 1000

**Paper II - Final Marks** = 100

# ශ්‍රී ලංකා විභාග දෙපාර්තමේන්තුව

# Department of Examinations – Sri Lanka

## අ.පො.ස.(උ.පෙළ)විභාගය/G.C.E. (A/L) - 2024

| විෂය 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. | 3 | 21. | 4 | 31. | 4/5 | 41. | 1 |
| 02. | 2 | 12. | 2 | 22. | 3 | 32. | 5 | 42. | 1 |
| 03. | 4 | 13. | 3 | 23. | 4 | 33. | 3 | 43. | 1 |
| 04. | 4 | 14. | 1 | 24. | 1 | 34. | 3 | 44. | 1 |
| 05. | 2 | 15. | 3 | 25. | 1 | 35. | 3 | 45. | 2 |
| 06. | 4 | 16. | 2 | 26. | 4 | 36. | 4 | 46. | 3 |
| 07. | 5 | 17. | 4 | 27. | 2 | 37. | 5 | 47. | 4 |
| 08. | 3 | 18. | 5/2 | 28. | 5 | 38. | 1 | 48. | 3 |
| 09. | 3 | 19. | 5 | 29. | (all) | 39. | 2 | 49. | 1 |
| 10. | 5 | 20. | 2 | 30. | 5 | 40. | 2 | 50. | 1 |

✪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* **100** *marks.*)

1. (*a*) State whether the following statements are **true** or **false** on the dotted lines. Reasons **not** required.

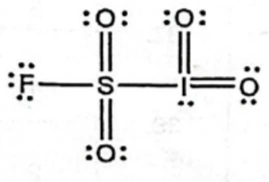
| | | |
|---|---|---|
| (i) | Particles in both cathode rays and $\beta$ rays have the same charge to mass ratio (e/m). | true |
| (ii) | In a copper (Cu) atom there are 6 electrons having magnetic quantum number, $m_l = -1$. | true |
| (iii) | The $F_2ClO^+$ ion has a trigonal planar shape. | false |
| (iv) | Sulphur (S) has the **lowest** first ionization energy among the elements F, S and Cl. | true |
| (v) | Rules related to polarizing power of cations and polarizability of anions, predict that the melting point of LiCl is **higher** than that of KF. | false |
| (vi) | In nitrous acid ($HNO_2$) the two N — O bonds are equal in length. | false |
| (vii) | The number of Lewis dot-dash structures (resonance structures) that can be drawn for the ion $CN_2^{2-}$ is 3. | true |
| (viii) | The boiling point of hexane is **higher** than that of 2,2-dimethylbutane. | true |

**(04 marks X 8 = 32 marks)**

**1(a): 32 marks**

(*b*) (i) Draw the **most** acceptable Lewis dot-dash structure for the molecule $ISO_4F$. Its skeleton is given below.

accept S>I



electronegativity of S and I are same.

(S=I)

S=+5

I= +6

**(06 marks)**

(ii) Give oxidation numbers of the S and I atoms in the structure drawn in (i) above.

S +5 or +V, I +4 or +IV

S<I

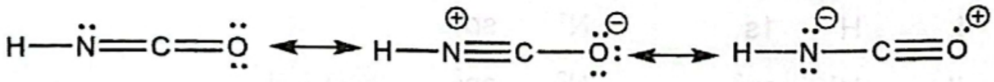
S=+6 I+3

(S>I S>~~I~~ S=+~~6~~ I=+5)

**(01) + (01)**

**Award marks for (ii) only of the Lewis structure in (i) is correct.**

(iii) An acceptable (stable) Lewis dot-dash structure for the HNCO molecule is given below. Draw **two** more Lewis dot-dash structures (resonance structures) for this molecule and indicate their stabilities relative to the structure given by writing **stable** or **less stable** or **unstable** under these structures.



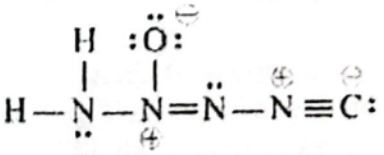
$H-\ddot{N}=C=\ddot{O} \longleftrightarrow H-\overset{\oplus}{N}\equiv C-\overset{\ominus}{O} \longleftrightarrow H-\overset{\ominus}{N}-C\equiv\overset{\oplus}{O}$

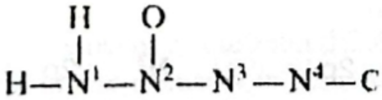
(less stable) (unstable)

**(02 marks structure) + (01 mark stability)**

**(06 marks)**

(iv) Complete the table based on the Lewis dot-dash structure and its labelled skeleton given below.





|  |  | $N^1$ | $N^2$ | $N^3$ | $N^4$ |
|---|---|---|---|---|---|
| I | The number of VSEPR pairs around the atom | 4 | 3 | 3 | 2 |
| II | electron pair geometry around the atom | tetrahedral | trigonal planar | trigonal planar | linear |
| III | Shape around the atom | pyramidal / trigonal pyramidal | trigonal planar | angular/ V / bent | linear |
| IV | Hybridization of the atom | $sp^3$ | $sp^2$ | $sp^2$ | $sp$ |

**(01 mark X 16 = 16 marks)**

- Parts (v) to (viii) are based on the Lewis dot-dash structure given in part (iv) abo Labelling of atoms is as in part (iv).

(v) Identify atomic/hybrid orbitals involved in the formation of $\sigma$ bonds between the t atoms given below.

| | | | | |
|---|---|---|---|---|
| I. | H | 1s | $N^1$ | $sp^3$ |
| II. | $N^1$ | $sp^3$ | $N^2$ | $sp^2$ |
| III. | $N^2$ | $sp^2$ | O | $2p / sp^3$ |
| IV. | $N^2$ | $sp^2$ | $N^3$ | $sp^2$ |
| V. | $N^3$ | $sp^2$ | $N^4$ | sp |
| VI. | $N^4$ | sp | C | 2p / sp |

**(01 mark X 12 = 12 marks)**

(vi) Identify the atomic orbitals involved in the formation of $\pi$ bonds between the two atom given below.

| | | | | |
|---|---|---|---|---|
| I. | $N^2$ | 2p | $N^3$ | 2p |
| II. | $N^4$ | 2p | C | 2p |
| | $N^4$ | 2p | C | 2p |

**(01 mark X 6 = 06 marks)**

(vii) State approximate bond angles around the $N^1$, $N^2$, $N^3$ and $N^4$ atoms.

$N^1$ (107° ± 1) $N^2$ (120° ± 1)
$N^3$ (117° ± 2) $N^4$ (180° ± 1)

**(01 mark X 4 = 04 marks)**

(viii) Arrange the atoms $N^1$, $N^2$, $N^3$ and $N^4$ in **increasing** order of their electronegativities.

$N^1$ < $N^3$ < $N^2$ < $N^4$

**(04 marks)**

**1(b): 56 marks**

Arrange the following species in the **increasing** order of the property indicated in parenthesis. (Reasons are **not** required)

(i) B, O, F, S, Na, Mg (electronegativity)

Na < Mg < B < S < O < F **(06 marks)**

(ii) $K^+$, $Mg^{2+}$, $Ca^{2+}$, $Al^{3+}$, $Cl^-$, $S^{2-}$ (ionic radius)

$Al^{3+} < Mg^{2+} < Ca^{2+} < K^+ < Cl^- < S^{2-}$ **(06 marks)**

**1(c): 12 marks**

**2.** (*a*) (i) I. **X** is an orange coloured ionic compound. It is composed of three elements in the ratio 7:2:2 (not in the order of writing the chemical formula). Of these, two are metals that belong to the same row of the Periodic Table. One of these two metals belongs to the *s*-block and the other to the *d*-block. The *d*-block metal is widely used for electroplating.

I. **X:** $K_2Cr_2O_7$

II. **Y** is a mineral acid. It is composed of three elements in the ratio 1:2:4 (not in the order of writing the chemical formula). One of the elements in **Y** is also found in **X**. **Y** is used in the manufacture of phosphate fertilizer.

II. **Y:** $H_2SO_4$

III. **Z** is a tri-atomic gas with a pungent smell. It has a V-shape. It is used in the manufacture of **Y**.

III. **Z:** $SO_2$

**(06 marks x 3 = 18 marks)**

(ii) Write the oxidation numbers and the electronic configurations of the two metals in **X**.

metal K oxidation number +I electronic configuration $1s^22s^22p^63s^23p^6$

or $1s^22s^22p^63s^23p^64s^1$

metal Cr oxidation number +VI electronic configuration $1s^22s^22p^63s^23p^6$

or $1s^22s^22p^63s^23p^63d^54s^1$

**(02 marks x 6 = 12 marks)**

(iii) I. Name the process by which **Y** is manufactured using **Z**.

Contact Process

**(02 marks)**

II. When the gas formed on reaction of **Z** with $O_2(g)$ is dissolved in a concentrate solution of **Y**, the compound **P** is formed. When compound **P** reacts with water **Y** is obtained again. Write the name and the chemical formula of compound **P**.

name Oleum / pyrosufluric acid / fuming sulfuric acid / disulfuric acid

chemical formula (P) $H_2S_2O_7$

**(04 marks x 2 = 08 marks)**

(iv) Write the balanced chemical equation for the reaction taking place when **X**, **Y** and are reacted together.

$$K_2Cr_2O_7(aq) + H_2SO_4(aq) + 3SO_2(g) \rightarrow K_2SO_4(aq) + Cr_2(SO_4)_3(aq) + H_2O(l)$$

**(10 marks)**

or

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

**(06 marks)**

Physical states are not required.

**2(a): 50 marks**

(*b*) A student is provided with eight bottles labelled **A, B, C, D, E, F, G** and **H** with aqueous solutions of $BaCl_2$, NaI, $Pb(NO_3)_2$, dil. HCl, $Al_2(SO_4)_3$, $AgNO_3$, conc. $NH_4OH$ and dil. $NH_4OH$ (not in order). Some useful observations for their identification on mixing two solutions at a time are given below.

| | Solutions Mixed | Observation |
|---|---|---|
| I. | **A** + **C** | a yellow precipitate soluble in hot water |
| II. | **B** + **C** | a yellow precipitate insoluble in **H** |
| III. | **A** + **E** | a white precipitate soluble in hot water |
| IV. | **B** + **E** | a white precipitate soluble in **D** |
| V. | **E** + **F** | a white precipitate insoluble in **G** |
| VI. | **A** + **F** | a white precipitate insoluble in **G** |
| VII. | **D** + **G** | a colourless solution |
| VIII. | **H** + **G** | a colourless solution |

(i) Identify **A** to **H**.

A $Pb(NO_3)_2$

B $AgNO_3$

C NaI

D dil $NH_4OH$

E $BaCl_2$

F $Al_2(SO_4)_3$

G dil HCl

H conc $NH_4OH$

**(04 marks x 8 = 32 marks)**

(ii) Give balanced chemical equations for the formation of precipitates, in each of the reactions I to VI. Use the symbol ↓ to indicate precipitates.

I. $Pb(NO_3)_2 + 2NaI \rightarrow PbI_2\downarrow + 2NaNO_3$

II. $AgNO_3 + NaI \rightarrow AgI\downarrow + NaNO_3$ $PbI_2$ × no marks

III. $Pb(NO_3)_2 + BaCl_2 \rightarrow PbCl_2\downarrow + Ba(NO_3)_2$

IV. $2AgNO_3 + BaCl_2 \rightarrow 2AgCl\downarrow + Ba(NO_3)_2$

V. $3BaCl_2 + Al_2(SO_4)_3 \rightarrow 3BaSO_4\downarrow + 2AlCl_3$

VI. $3Pb(NO_3)_2 + Al_2(SO_4)_3 \rightarrow 3PbSO_4\downarrow + 2Al(NO_3)_3$

**(03 marks x 6 = 18 marks)**

**Note:** Deduct **01 mark** if precipitates are not indicated the using symbol ↓

**2(b): 50 marks**

**3.** (*a*) At temperature 25 °C, dissociation constants of $H_2CO_3(aq)$ acid are,

$$K_1 = 4.5 \times 10^{-7}\ \text{mol dm}^{-3} \text{ and } K_2 = 4.7 \times 10^{-11}\ \text{mol dm}^{-3}$$

(i) Write the equilibrium reactions for the first and second dissociations of $H_2CO_3(aq)$.

**i.** **NOTE: PHYSICAL STATES ARE NECESSARY**

**The symbol of equilibrium ⇌ also needed for all the reactions**

1st dissociation: $H_2CO_3(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + HCO_3^-(aq)$ …… **(05)**

**OR** $H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$

2nd dissociation: $HCO_3^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CO_3^{2-}(aq)$ … **(05)**

**OR** $HCO_3^-(aq) \rightleftharpoons H^+(aq) + CO_3^{2-}(aq)$

(ii) Considering the first dissociation, calculate the concentrations of $H_3O^+(aq)$ and $HCO_3^-(aq)$ in 0.05 mol dm$^{-3}$ $H_2CO_3(aq)$ solution at 25 °C.

**ii.** $K_1 = \dfrac{[H_3O^+(aq)][HCO_3^-(aq)]}{[H_2CO_3(aq)]}$ **(05)**

$$H_2CO_3(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + HCO_3^-(aq)$$

| | | | | |
|---|---|---|---|---|
| Initial con. | 0.05 | 0 | 0 mol dm$^{-3}$ | |
| Change con. | $-x$ | $x$ | $x$ mol dm$^{-3}$ | |
| Equi. con. | $0.05 - x$ | $x$ | $x$ mol dm$^{-3}$ | 04 ~~(05)~~ |

This step only also correct ⇒

$K_1 = 4.50 \times 10^{-7} = \dfrac{x.x}{0.05 - x} \approx \dfrac{x^2}{0.05}$ **(05)**

$x^2 = 225 \times 10^{-10}$

$x = 1.5 \times 10^{-4}\ \text{mol dm}^{-3}$ **(04 + 01)**

$[H_3O^+(aq)] = [HCO_3^-(aq)] = 1.5 \times 10^{-4}\ \text{mol dm}^{-3}$ **(04 + 01)**

(iii) Considering the second dissociation, show that $\left[CO_3^{2-}(aq)\right]$ of the solution is approximately equal to $K_2$. State any assumption/s made.

***iii.*** $K_2 = \dfrac{[H_3O^+(aq)][CO_3^{2-}(aq)]}{[HCO_3^-(aq)]}$ **(05)**

$$HCO_3^-(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CO_3^{2-}(aq)$$

| | | | | |
|---|---|---|---|---|
| Initial con. | $1.5 \times 10^{-4}$ | $1.5 \times 10^{-4}$ | 0 mol dm$^{-3}$ | |
| Change con. | $-y$ | $1.5 \times 10^{-4} + y$ | $y$ mol dm$^{-3}$ | |
| Equi. con. | $1.5 \times 10^{-4} - y$ | $1.5 \times 10^{-4} + y$ | $y$ mol dm$^{-3}$ | **(05)*** |

$K_2 = 4.70 \times 10^{-11} = \dfrac{(1.5 \times 10^{-4} + y).y}{(1.5 \times 10^{-4} - y)} \approx y$ **(05)***

***If student writes in words that the amount dissociated from $HCO_3^-$ is very small and amount accumulated in $H_3O^+$ is very small, therefore concentration change of the two species are negligible, award these 05 + 05 marks.**

$[CO_3^{2-}(aq)] \approx K_2$ **(05)**

Assumption: 2nd dissociation is much less compared to the 1st. **(05)**

**3(a): 60 marks**

(b) You are provided with an aqueous solution containing 0.01 mol dm$^{-3}$ $Al^{3+}(aq)$ ions and 0.01 mol dm$^{-3}$ $Ag^{+}(aq)$ ions at temperature 25 °C. To 1.0 dm$^3$ of this solution, a concentrated solution of $PO_4^{3-}(aq)$ ions was added dropwise with continuous stirring.

At temperature 25 °C,

$K_{sp}(AlPO_4) = 1.3 \times 10^{-20}$ mol$^2$ dm$^{-6}$ and $K_{sp}(Ag_3PO_4) = 8.1 \times 10^{-12}$ mol$^4$ dm$^{-12}$.

(i) Neglecting any volume change that may occur when the $PO_4^{3-}(aq)$ solution is added, state which metal ion ($Al^{3+}$ or $Ag^{+}$) will precipitate first from the mixture. Give reasons for your answer based on a suitable calculation.

i. The precipitates formed are $AlPO_4$ ***and*** $Ag_3PO_4$

*For AlPO₄*

$$AlPO_4(s) \rightleftharpoons Al^{3+}(aq) + PO_4^{3-}(aq) \qquad \textbf{(02)}$$

$$K_{sp} = [Al^{3+}(aq)][PO_4^{3-}(aq)] \qquad \textbf{(02)}$$

$$1.30 \times 10^{-20} = 0.01 \times [PO_4^{3-}(aq)] \qquad \textbf{(04)}$$

$[PO_4^{3-}(aq)] = 1.30 \times 10^{-18}$ mol dm$^{-3}$ ; needed to precipitate $AlPO_4(s)$ **(03+01)**

*For* $Ag_3PO_4$

$$Ag_3PO_4(s) \rightleftharpoons 3Ag^{+}(aq) + PO_4^{3-}(aq) \qquad \textbf{(02)}$$

$$K_{sp} = [Ag^{+}(aq)]^3[PO_4^{3-}(aq)] \qquad \textbf{(02)}$$

$$8.10 \times 10^{-12} = (0.01)^3 \times [PO_4^{3-}(aq)] \qquad \textbf{(04)}$$

$[PO_4^{3-}(aq)] = 8.10 \times 10^{-6}$ mol dm$^{-3}$ ; needed to precipitate $Ag_3PO_4(s)$ **(03+01)**

$$[PO_4^{3-}(aq)]_{AlPO_4(s)} < [PO_4^{3-}(aq)]_{Ag_3PO_4(s)} \qquad \textbf{(04)}$$

$AlPO_4(s)$ precipitates first. **(04)**

(ii) Calculate the concentration of the ion which precipitated first when the second ion starts to precipitate.

$[Al^{3+}(aq)]$ left in the solution after precipitation of $AlPO_4(s)$ $= \dfrac{K_{sp(AlPO_4(s))}}{8.10 \times 10^{-6}}$ **(04)**

$[Al^{3+}(aq)]$ left in the solution $= \dfrac{1.30 \times 10^{-20}}{8.10 \times 10^{-6}}$

$= 1.6 \times 10^{-15}$ mol dm$^{-3}$ **(03+01)**

**3(b): 40 marks**

4. (*a*) • The organic compound **A** having the molecular formula $C_5H_{10}O_3$ reacts with excess PCl to give compound **B**, having a relative molecular mass of 155. Compound **A** liberate $CO_2$ with aqueous $Na_2CO_3$. (C = 12.0, H = 1.0, O = 16.0, Cl = 35.5)

(i) Write the functional groups present in compound **A**.

OH / hydroxy/ hydroxyl , COOH / carboxylic acid

Note: no marks if 'acid' is not written

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

• Compound **A** does not exhibit optical isomerism. Compound **A** reacts with pyridinium chlorochromate to give compound **C**. Compound **C** gives a silver mirror with ammoniacal $AgNO_3$. Compound **B** reacts with water to form compound **D**. Compound **D** reacts with alcoholic KOH to give the product **E** which contains a double bond.

(ii) Draw the structures of **A**, **B**, **C**, **D** and **E** in the relevant boxes.

$HOCH_2CH_2CH_2CH_2COOH$

**A**

$ClCH_2CH_2CH_2CH_2COCl$

**B**

$OHCCH_2CH_2CH_2COOH$

**C**

$ClCH_2CH_2CH_2CH_2COOH$

**D**

$H_2C{=}CHCH_2CH_2COOH$

OR

$H_2C{=}CHCH_2CH_2COOK$

**E**

**(07 marks x 5 = 35 marks)**

- Compound F is a structural isomer of A. Compound F reacts with excess $PCl_5$ to give compound G having a relative molecular mass of 155. Compound F does not liberate $CO_2$ with aqueous $Na_2CO_3$. Compound F exhibits optical isomerism. Compound F does not give a turbidity when treated with conc. HCl/anhydrous $ZnCl_2$. Compound F forms a coloured precipitate with 2,4-dinitrophenylhydrazine (2,4-DNP) and gives a silver mirror with ammoniacal $AgNO_3$.

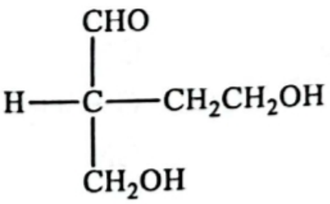
(iii) Write the functional groups present in F.

CHO / aldehyde , OH / hydroxy/ hydroxyl

**Note:** If both are correct, award 09 marks. If only one is correct, award 05 marks only.

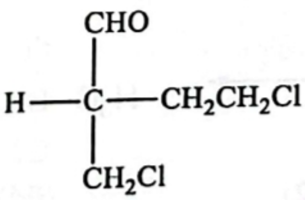
**(05 marks + 04 marks = 09 marks)**

(iv) Draw the structures of F and G in the relevant boxes.



$$\mathrm{H{-}\overset{\overset{CHO}{|}}{\underset{\underset{CH_2OH}{|}}{C}}{-}CH_2CH_2OH}$$

**(F)**



$$\mathrm{H{-}\overset{\overset{CHO}{|}}{\underset{\underset{CH_2Cl}{|}}{C}}{-}CH_2CH_2Cl}$$

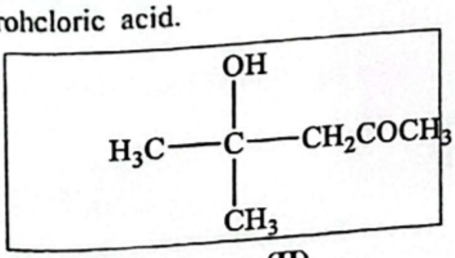
**(G)**

**(07 marks x 2 = 14 marks)**

**4(a): 68 marks**

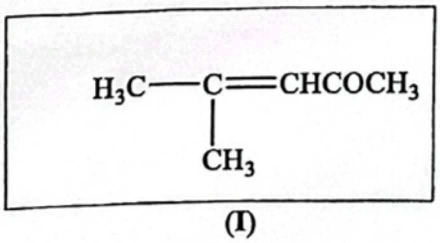
(*b*) (i) Draw the structure of the product H formed in the relevant box when acetone is reacted with dilute aqueous NaOH.

(ii) Draw the structure of the product I formed in the relevant box when H is heated with hydrohcloric acid.



$$\mathrm{H_3C{-}\overset{\overset{OH}{|}}{\underset{\underset{CH_3}{|}}{C}}{-}CH_2COCH_3}$$

**(H)**



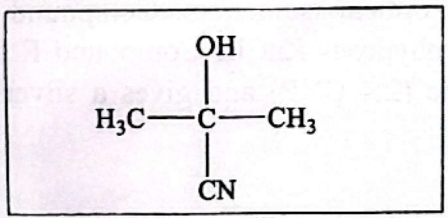
$$\mathrm{H_3C{-}\underset{\underset{CH_3}{|}}{C}{=}CHCOCH_3}$$

**(I)**

**(06 marks x 2 = 12 marks)**

**4(b): 12 marks**

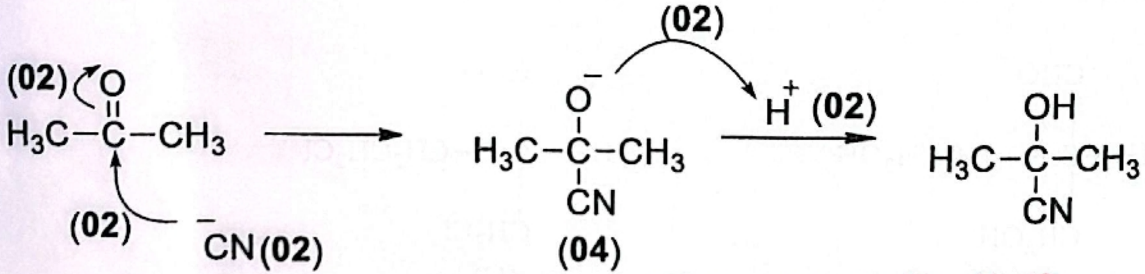
(*c*) (i) Draw the structure of the product **J** formed in the relevant box from the reaction between acetone and HCN.



**(J)**

**(06 marks)**

(ii) Write the mechanism of the above reaction.



Can accept $H_3O^+$
no marks for $H_2O$

**Notes:**

IF HCN is used instead of $^-CN$ deduct the **02** marks allocated for $^-CN$.

**(14 Marks)**

**4(c): 20 marks**

## PART B — ESSAY

*Answer two questions only.* (*Each question carries* **150** *marks.*)

**NOTE: PHYSICAL STATES ARE NECESSARY**

5. (*a*) A mixture of NO(g) and $O_2(g)$ in 2:1 molar ratio respectively, was introduced to a rigid clos container of volume 10 $dm^3$ and allowed to react at temperature *T*. After a certain time, t system reached the equilibrium as given below, at temperature *T*.

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$$

At equilibrium, the following observations were noted.

- The pressure of the gaseous mixture was $32 \times 8.314 \times 10^3$ Pa.
- The total number of moles of the three gases was 0.64.
- The mass of $O_2$ was 6.4 g.

(i) Calculate the concentration of each gaseous species in mol $dm^{-3}$ at equilibrium. (O = 16)

$$2NO(g) + O_2(g) \rightleftharpoons NO_2(g)$$

Moles of $O_2(g) = \frac{6.4\ g}{32\ g\ mol^{-1}} = 0.20$ **(02)**

Con. of $O_2(g) = \frac{0.20\ mol}{10\ dm^3} = 2.0 \times 10^{-2}\ mol\ dm^{-3}$ **(02+01)**

Moles of $NO(g) = 0.40$ (2:1 ratio given) **(02)**

Con. of $NO(g) = \frac{0.40\ mol}{10\ dm^3} = 4.0 \times 10^{-2}\ mol\ dm^{-3}$ **(02+01)**

Moles of $NO_2(g) = 0.64 - (0.40 + 0.20) = 0.04$ **(02)**

Con. of $NO_2(g) = \frac{0.04\ mol}{10\ dm^3} = 4.0 \times 10^{-3}\ mol\ dm^{-3}$ **(02+01)**

(ii) Calculate the equilibrium constant, $K_c$ at temperature *T*.

$K_C = \frac{[NO_2(g)]^2}{[O_2(g)][NO(g)]^2}$ **(05)**

$K_C = \frac{[4.0 \times 10^{-3}\ mol\ dm^{-3}]^2}{[2.0 \times 10^{-2}\ mol\ dm^{-3}][4.0 \times 10^{-2}\ mol\ dm^{-3}]^2}$ **(05)**

$\mathbf{K_C = 0.50\ mol^{-1}\ dm^3}$ ~~**(05)**~~

④+①

(iii) Calculate the value of temperature $T$ (in K) under these conditions. State any assumption/s made. **(03)**

Assuming ideal gas behavior **(02)**

$$PV = nRT$$

$$T = \frac{PV}{nR}$$

$$T = \frac{32 \times 8.314 \times 10^3\ Pa \times 10 \times 10^{-3}\ m^3}{0.64\ mol \times 8.314\ J\ K^{-1}\ mol^{-1}} \quad \textbf{(05)}$$

$$\mathbf{T = 500\ K} \quad \textbf{(04+01)}$$

must

(iv) Calculate the equilibrium constant $K_p$ for the reaction,

$$2NO_2(g) \rightleftharpoons 2NO(g) + O_2(g)$$

at the temperature determined in (iii) above.

Reaction of concern is

$2NO_2(g) \rightleftharpoons 2NO(g) + O_2(g)$ is the reverse reaction of the initial one **(05)**

If the equilibrium constant is $K_C'$

$$K_C' = \frac{1}{K_C} \quad \textbf{(05)}$$

$$= \frac{1}{0.50} = 2\ mol\ dm^{-3} \quad \textbf{(04+01)}$$

$$K_P = K_C\,(RT)^{\Delta n} \qquad \Delta n = 1 \quad \textbf{(03+02)}$$

$$K_P = 2\ (8.314\ J\ K^{-1}\ mol^{-1} \times 500\ K)$$

$$\mathbf{K_P = 8.314 \times 10^{\cancel{3}}\ Pa} \quad \textbf{(04+01)}$$

$8.314 \times 10^6$

**5(a): 70 marks**

(*b*) Consider the information given below at temperature 298 K.

$$\Delta H_f^{\circ}(NO(g)) = 90\ kJ\ mol^{-1}$$

$$\frac{1}{2}N_2(g) + O_2(g) \rightarrow NO_2(g) \quad \Delta H^{\circ} = 33\ kJ\ mol^{-1}$$

$$4NO_2(g) + O_2(g) \rightarrow 2N_2O_5(g) \quad \Delta H^{\circ} = -102\ kJ\ mol^{-1}$$

b. Information given:

$$\Delta H^{\theta}_{f\ (NO(g))} = 90\ kJ\ mol^{-1} \quad \textbf{(A)}$$

$$\frac{1}{2}N_2(g) + O_2(g) \rightarrow NO_2(g): \quad \Delta H^{\theta} = 33\ kJ\ mol^{-1} \quad \textbf{(B)}$$

$$4NO_2(g) + O_2(g) \rightarrow 2N_2O_5(g): \quad \Delta H^{\theta} = -102\ kJ\ mol^{-1} \quad \textbf{(C)}$$

i. Reaction needed: $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$

From (A), $\Delta H^{\theta}_{f\,(NO(g))}$: $\frac{1}{2}N_2(g) + \frac{1}{2}O_2(g) \rightarrow NO(g)$: $\Delta H^{\theta} = 90\ kJ\ mol^{-1}$..(D) **(05)**

**(B) – (D) :** $\frac{1}{2}O_2(g) + NO(g) \rightarrow NO_2(g)$ ……. **(E)** **(05)**

$\Delta H^{\theta} = (33 - 90) = -57\ kJ\ mol^{-1}$ **(05 +05)**

**(E) × 2 :** $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$ $\boldsymbol{\Delta H^{\theta} = -114\ kJ\ mol^{-1}}$ **(04+01)**

**OR: (B) × 2 – (D) × 2 :** $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$ **(05+05)**

$\Delta H^{\theta} = (66 - 180)\ kJ\ mol^{-1}$ **(05+05)**

$\Delta H^{\theta} = -114\ kJ\ mol^{-1}$ **(04+01)**

**OR**

$$\begin{tikzcd}
2NO(g) + O_2(g) \arrow[rr, "\Delta H^{\theta}"] & & 2NO_2(g) \quad \mathbf{(05)} \\
& N_2(g) + 2O_2(g) \arrow[ul, "\mathbf{(05)}\ \Delta H_1^{\theta}"'] \arrow[ur, "\Delta H_2^{\theta}\ \ \mathbf{(05)}"'] &
\end{tikzcd}$$

From Hess's law: $\Delta H^{\theta} = \Delta H_2^{\theta} - \Delta H_1^{\theta} = (2 \times 33 - 2 \times 90)kJ\ mol^{-1}$ **(05)**

$= -114\ kJ\ mol^{-1}$ **(04 + 01)**

**OR other acceptable method(s)**

ii. Formation reaction of $2N_2O_5(g)$:

$N_2(g) + \frac{5}{2}O_2(g) \rightarrow N_2O_5(g)$: $\Delta H_f^{\theta} = ?$ **(05)**

Information: $\frac{1}{2}N_2(g) + \frac{1}{2}O_2(g) \rightarrow NO(g)$: $\Delta H^{\theta} = 90\ kJ\ mol^{-1}$…..(D)

**(D)×2 :** $N_2(g) + O_2(g) \rightarrow 2NO(g)$: $\Delta H^{\theta} = 180\ kJ\ mol^{-1}$….. (F) **(05+05)**

$2NO(g) + O_2(g) \rightarrow NO_2(g)$ $\Delta H^{\theta} = -114\ kJ\ mol^{-1}$ …. (G)

$4NO_2(g) + O_2(g) \rightarrow 2N_2O_5(g)$: $\Delta H^{\theta} = -102\ kJ\ mol^{-1}$ (C)

**(C) ÷ 2 :** $2NO_2(g) + \frac{1}{2}O_2(g) \rightarrow N_2O_5(g)$: $\Delta H^{\theta} = -51\ kJ\ mol^{-1}$ …..(H) **(05)**

**(F) + (G) + (H):** $N_2(g) + \frac{5}{2}O_2(g) \rightarrow N_2O_5(g)$

$\Delta H^{\theta}_{f\,(N_2O_5(g))} = [180 + (-114) + (-51)]\ kJ\ mol^{-1} = \boldsymbol{15\ kJ\ mol^{-1}}$ **(05+04+01)**

**OR**

$$\begin{tikzcd}
4NO_2(g) + O_2(g) \arrow[rr, "-102"] & & 2N_2O_5(g) \quad (05) \\
& 2N_2(g) + 5O_2(g) \arrow[ul, "(05)\ 4 \times 33"] \arrow[ur, "2\Delta H^{\theta}_{f(N_2O_5(g))}\ (05)"'] &
\end{tikzcd}$$

From Hess's law: $2\Delta H^{\theta}_{f(N_2O_5(g))} = (4 \times 33 - 102)kJ\ mol^{-1}$ **(05 + 05)**

$$\Delta H^{\theta}_{f(N_2O_5(g))} = 15\ kJ\ mol^{-1} \quad \mathbf{(04 + 01)}$$

**OR other acceptable method(s)**

(iii) Using the results obtained in (ii) above, predict the following.

I. the sign of $\Delta S^{\circ}_{f}(N_2O_5(g))$

$$N_2(g) + \frac{5}{2}O_2(g) \rightarrow N_2O_5(g)$$

3.5 moles → 1 mole : number of moles decreased (05)

$\Delta S^{\theta}$ $\Delta H^{\theta}_{S\ (N_2O_5(g))}$ is negative ($< 0$) (05)

II. spontaneity of the reaction for the formation of $N_2O_5(g)$ from $N_2(g)$ and $O_2(g)$

$\Delta G^{\theta} = \Delta H^{\theta} - T\Delta S^{\theta}$ (05)

$= +ve - (+ve)(-ve) = +ve$ (05)

The reaction is non-spontaneous at 298 K (05)

**5(b): 80 marks**

**NOTE: PHYSICAL STATES ARE NECESSARY**

6\. (*a*) According to the kinetic molecular theory of gases, for an ideal gas at temperature $T$, $PV = \frac{1}{3}mN\overline{C^2}$. Here $P$ is the pressure of the gas, $V$ is the volume of the gas, $m$ is the mass of a gas molecule, $N$ is the number of molecules of gas and $\overline{C^2}$ is the mean square speed of the gas.

(i) Show that $\overline{C^2} = \frac{3RT}{M}$ for an ideal gas. $M$ is the molar mass of the gas.

$PV = \frac{1}{3}mN\overline{C^2} = \frac{1}{3}m(nN_A)\overline{C^2}$ : n – moles, $N_A$ – Avogadro no **(04)**

$= \frac{1}{3}nM\overline{C^2}$ : M-molar mass **(04)**

$PV = nRT = \frac{1}{3}nM\overline{C^2}$ **(04)**

$\overline{C^2} = \frac{3RT}{M}$ **(04)**

(ii) **A** and **B** are two ideal gases with molar masses $M_A$ and $M_B$ respectively. Show that the mean square speed of gas **B** $\left(\overline{C_B^2}\right)$ at temperature $T = 300\frac{M_B}{M_A}$, is equal to the mean square speed of gas **A** $\left(\overline{C_A^2}\right)$ at $T = 300$. (Temperatures are given in kelvin)

For gas A: $\overline{C_A^2} = \frac{3RT}{M_A} = \frac{3R \times 300}{M_A}$ (1)

For gas B: $\overline{C_B^2} = \frac{3RT}{M_B} = \frac{3R \times 300(\frac{M_B}{M_A})}{M_B} = \frac{3R \times 300}{M_A}$ (2) **(04+04)**

(1) = (2): $\overline{C_A^2} = \overline{C_B^2}$ **(04)**

(iii) Derive an expression for the ratio between the molar kinetic energies of the two gases A and B at any given temperature $T$.

For gas A: $(KE)_A = \frac{3RT_A}{2}$ **(04)**

For gas B: $(KE)_B = \frac{3RT_B}{2}$ **(04)**

As $T_A = T_B$: $(KE)_A = (KE)_B$ **(04)**

OR- Kinetic energy of a gas depends only on the absolute temperature

$(KE)_A = (KE)_B$ **(12)**

**6(a): 40 marks**

[illegible] iii 0/04

(*b*) (i) Define the term 'an elementary reaction'.

Elementary Reaction: A reaction occurs through a single step (without involving an intermediate). **(05)***

(ii) Define the term 'molecularity' of a reaction.

Molecularity: Total number of reacting molecules participating in an elementary reaction or in the rate determining step of a reaction. **(05)**

(iii) For an elementary reaction what is the relationship between 'reaction order' and 'molecularity'?

Elementary reaction : Reaction order = Molecularity **(05)***

(iv) The following table gives the variation of the concentration of the reactant in a reaction with time.

| Time (minutes) | 0 | 10 | 20 | 30 | 40 |
|---|---|---|---|---|---|
| Reactant concentration (mol dm$^{-3}$) | 1.6 | 0.8 | 0.4 | 0.2 | 0.1 |

Reaction order = Molecularity

In 10 minutes time the concentration decreased to half of the initial concentration **(05)**

This is consistent with all the 10 min time intervals **(05)**

I) Reaction is first order **(05)**

II) Half-life ($t_{1/2}$) of the reaction is 10 min **(05)**

*** Note: If student has attempted Q 6 (b), award marks for parts i and iii**

(v) Consider the information given below for two first order reactions ① and ② at a given temperature.

| | Reaction | Reaction rate/ mol dm$^{-3}$ s$^{-1}$ | Rate constant/s$^{-1}$ | Half-life/s |
|---|---|---|---|---|
| ①: | $A \rightarrow P_1$ | $r_A$ | $k_A$ | $(t_{1/2})_A$ |
| ②: | $B \rightarrow P_2$ | $r_B$ | $k_B$ | $(t_{1/2})_B$ |

($P_1$, $P_2$ = Products)

A first order reaction with rate constant, $k$ has a half-life, $t_{1/2} = \frac{0.693}{k}$.

If $r_B = 3r_A$ when $[B] = 2[A]$, show that $2(t_{1/2})_A = 3(t_{1/2})_B$.

As the reactions are first order,

$r_A = k_A[A]$: $k_A = \frac{r_A}{[A]}$ **(03+02)**

$r_B = k_B[B]$: $k_B = \frac{r_B}{[B]}$ **(03+02)**

Given that: [B] = 2[A], $r_B = 3r_A$ and $t_{1/2} = \frac{0.693}{k}$

We can write; $k_A = \frac{r_A}{[A]}$ ……..(I)

$k_B = \frac{3r_A}{2[A]}$ ……(II) **(05)**

(I)÷(II) gives $\frac{k_A}{k_B} = \frac{2}{3}$ **(05+05)**

$$\frac{(t_{1/2})_A}{(t_{1/2})_B} = \frac{0.693/k_A}{0.693/k_B} = \frac{k_B}{k_A} = \frac{3}{2}$$ **(05+05)**

$$2(t_{1/2})_A = 3(t_{1/2})_B$$ **(05)**

**6(b): 75 marks**

(c) At temperature 25 °C, 50.0 cm³ of 0.30 g dm⁻³ iodine aqueous solution was shaken well with 10.0 cm³ of $CCl_4$. When the system reached equilibrium the concentration of iodine in the water layer was found to be 0.02 g dm⁻³.

(i) Calculate the concentration of iodine in the $CCl_4$ layer at equilibrium.

Initial $I_2$ mass in water layer = $0.30\ g\ dm^{-3} \times 50 \times 10^{-3}\ dm^3 = 0.015\ g$ **(03)**

Equilibrium $I_2$ mass in water layer = $0.02\ g\ dm^{-3} \times 50 \times 10^{-3}\ dm^3 = 0.001\ g$ **(03)**

Equilibrium $[I_2]_{H_2O} = \frac{(0.001\ g)}{50 \times 10^{-3} dm^3} = 0.02\ g\ dm^{-3}$

Equilibrium $I_2$ mass in $CCl_4$ layer $= (0.015 - 0.001)g = 0.014\ g$ **(03)**

Equilibrium $[I_2]_{CCl_4} = \frac{(0.014\ g)}{10 \times 10^{-3} dm^3} = \mathbf{1.4\ g\ dm^{-3}}$ **(03+03+01)**

(ii) At temperature 25 °C, calculate the partition co-efficient of $I_2$ between $CCl_4$ and water.

$$K_D = \frac{[I_2]_{CCl_4}}{[I_2]_{H_2O}} = \frac{1.4\ g\ dm^{-3}}{0.02\ g\ dm^{-3}} = \mathbf{70}$$ **(03+03)**

(iii) If the above experiment was done at 25 °C with 20.0 cm³ of $CCl_4$ instead 10.0 cm³, calculate the concentration of iodine in the water layer at equilibrium.

At this stage take $I_2$ mass in $H_2O$ layer as $x$

$$K_D = 70 = \frac{[I_2]_{CCl_4}}{[I_2]_{H_2O}} = \frac{(0.015 - x)/20}{x/50}$$ **(05)**

$$x = 0.0005\ g$$

**(04)**$[I_2]_{H_2O} = \frac{(0.0005\ g)}{50 \times 10^{-3} dm^3} = \mathbf{0.01\ g\ dm^{-3}}$ **(03+01)**

**Alternate answer:**

At this stage take $I_2$ mass in $CCl_4$ layer as $x$

$$K_D = 70 = \frac{[I_2]_{CCl_4}}{[I_2]_{H_2O}} = \frac{x/20}{(0.015-x)/50}$$ (05)

$$x = 0.0145\ g$$ (02)

$I_2$ mass in water layer = 0.0150 – 0.0145 = 0.0005 g (02)

$$[I_2]_{H_2O} = \frac{(0.0005\ g)}{50\times10^{-3}dm^3} = \mathbf{0.01\ g\ dm^{-3}}$$ (03+01)

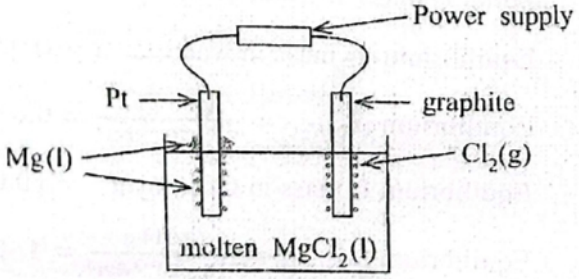
**6(c): 35 marks**

**NOTE: PHYSICAL STATES ARE NECESSARY**

7.(*a*) Mg metal can be extracted by the electrolysis of molten $MgCl_2(l)$ using inert electrodes (examples :Pt, graphite). A simple setup for this is shown in the diagram.

$$E^\circ_{Mg^{2+}(l)/Mg(s)} = -2.37\ V$$

$$E^\circ_{H_2O(l)/H_2(g)} = -0.63\ V$$



Electrolytic cell

(i) Identify the anode and the cathode. Write the half reaction taking place at each electrode.

Electrode | Half-reaction

Anode : C(graphite, s)|$Cl_2$(g)|$MgCl_2$(*l*) $2Cl^-(l) \rightarrow Cl_2(g) + 2e$ (05+05)

Cathode : Pt(s)|Mg(s)|$MgCl_2$(*l*) $Mg^{2+}(l) + 2e \rightarrow Mg(s)$ or $Mg(l)$ (05+05)

**OR** $MgCl_2(l) \rightarrow Mg(s)/(l) + Cl_2(g)$ ~~(05)~~

(ii) Write the overall cell reaction.

Overall cell reaction:

$$Mg^{2+}(l) + 2Cl^-(l) \rightarrow Mg(s)/(l) + Cl_2(g)$$

OR $$MgCl_2(l) \rightarrow Mg(s)/(l) + Cl_2(g)$$ **(05)**

(iii) State the direction of electron flow through the external circuit as the cell operates.

from C(graphite, s)|$Cl_2$(g) anode to Pt(s)|Mg(s) cathode **(05)**

(iv) Explain the following:

I. Molten $MgCl_2(l)$ is used instead of $MgCl_2(s)$ in this extraction process.

Solid or crystalline $MgCl_2(s)$ has no movable ions. Molten state has ionic $Mg^{2+}(l)$ and $Cl^-(l)$. **(05)**

③ (02)

II. A solution of $MgCl_2(aq)$ cannot be used in this extraction process.

Water molecules would reduce to $H_2(g)$ instead of $Mg^{2+}(l)$ **(05)**

3 2

(v) If a 5.37 A current is passed through this cell for one hour and the $Cl_2(g)$ formed is collected at temperature 300 K and pressure 1 atm ($\sim 1.0 \times 10^5$ Pa), calculate the volume

$Q = It$ **(05)**

$= 5.37\ A \times (60 \times 60) = 19300\ C$ **(04+01)**

Moles of electrons = 19300/96500 = 0.2 mol **(05)**

2 mol of electrons ≡ 1 mol of $Cl_2(g)$

Moles of $Cl_2(g)$ produced = 0.10 mol **(05)**

Assuming an ideal gas behavior: PV = nRT **(05)**

$$V = \frac{nRT}{P} = \frac{0.10\ mol \times 8.314\ J\ K^{-1}\ mol^{-1} \times 300\ K}{1 \times 10^5\ Pa}$$ **(05)**

$$= 249.4 \times 10^{-5}\ m^3\ or\ 2.49\ dm^3$$ **(04+01)**

**7(a): 75 marks**

(*b*) (i) **P**, **Q**, **R**, **S** and **T** are coordination compounds of Co(III). They have an octahedral geometry. Give the structural formulae or draw the structures of these coordination compounds, selecting the appropriate species from the list given below.

$Co^{3+}$, $K^+$, $NH_3$, $SO_4^{2-}$, $NO_2^-$, $Cl^-$

**Note** : In the above coordination compounds $NO_2^-$ behaves as a monodentate ligand when attached to the metal ion.

**P** – Only neutral ligands are coordinated to the metal ion. On reaction of an aqueous solution of **P** with dil. HCl, reddish-brown fumes are evolved. **P** gives four ions in aqueous solution.

**Q** – Two types of ligands are coordinated to the metal ion. They are neutral ligands and mono-atomic anionic ligands. A white precipitate insoluble in dilute acid is formed on addition of $BaCl_2(aq)$ to an aqueous solution of **Q**. **Q** gives two ions in aqueous solution.

**R** – Two types of ligands are coordinated to the metal ion. They are neutral ligands and multi-atomic anionic ligands. **R** shows geometric isomerism. On reaction of an aqueous solution of **R** with $AgNO_3(aq)$, a white precipitate is formed. This precipitate is soluble in dil. $NH_4OH$. **R** gives two ions in aqueous solution.

**S** – It is a non-ionic compound. An equal number of neutral ligands and multi-atomic anionic ligands are coordinated to the metal ion.

**T** – Only mono-atomic anionic ligands are coordinated to the metal ion. **T** gives four ions in aqueous solution.

**P :** $[Co(NH_3)_6](NO_2)_3$ **(10)**

**Q:** $[Co(NH_3)_5Cl]SO_4$ **(10)**

**R:** $[Co(NH_3)_4(NO_2)_2]Cl$ **(10) ***

**S:** $[Co(NH_3)_3(NO_2)_3]$ **(10)**

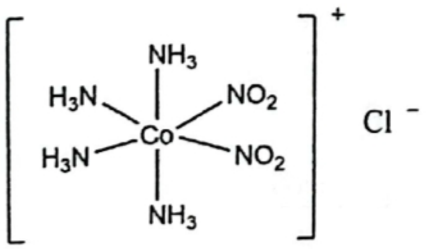
**T:** $K_3[CoCl_6]$ **(10)**

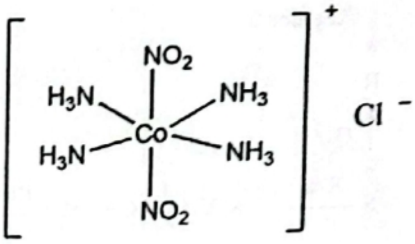
**(7 (b) (i) 50 marks)**

(ii) I. Write the IUPAC name of **T**.

potassium hexachloridocobaltate(III) **(10)**

II. Draw the structures of the geometric isomers of **R**.





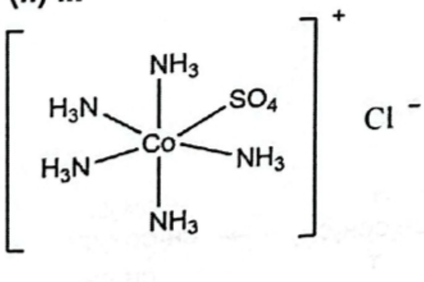
**(05 marks)***

**(If both are correct 05 marks. If only one is correct 03 marks)**

***Note: Although geometric isomerism is commonly taught in A/Levels, students may not be familiar with them in coordinate complexes. Therefore, as a concession, marks will be awarded in the following manner for 7 b (i) R and (ii) II.**

**(i) R:** $[Co(NH_3)_5(SO_4)]Cl$ **(06)**

**(ii) II.**



$SO_4^{2-}$ Consider as monodentate and bidentate.

**(03)**

(iii) X is a coordination compound of Co(III) with an octahedral geometry. The ligands $H_2O$ and $CO_3^{2-}$ are coordinated to the metal ion. On treatment of an aqueous solution of X with $AgNO_3(aq)$ a pale yellow precipitate, soluble in conc. $NH_4OH$ is formed. X gives two ions in aqueous solution. Give the structural formula or draw the structure of X.

Note : $CO_3^{2-}$ coordinates to the metal ion through two oxygen atoms.

$[Co(H_2O)_4(CO_3)]Br$ **(10)**

**7(b): 75 marks**

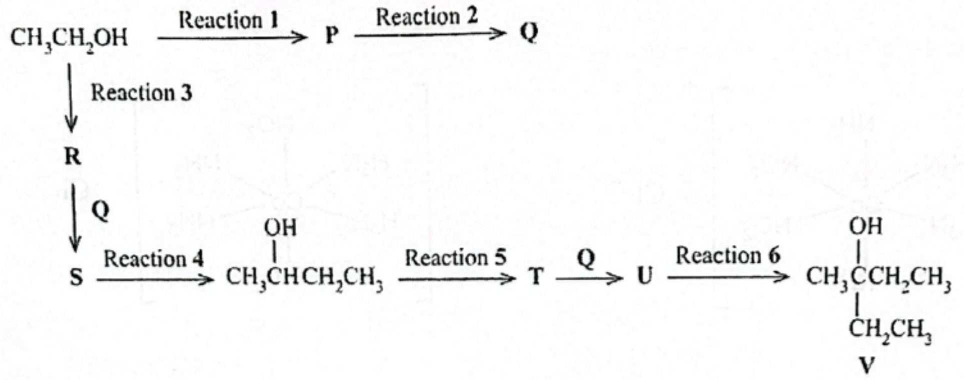
if Q is wrong P to Q dont give 15 marks
if Q is wrong R to S no marks
if S is correct & T is correct
if Q is wrong T to U no marks

## PART C — ESSAY

*Answer **two** questions only.* (*Each question carries* **150** ***marks.***)

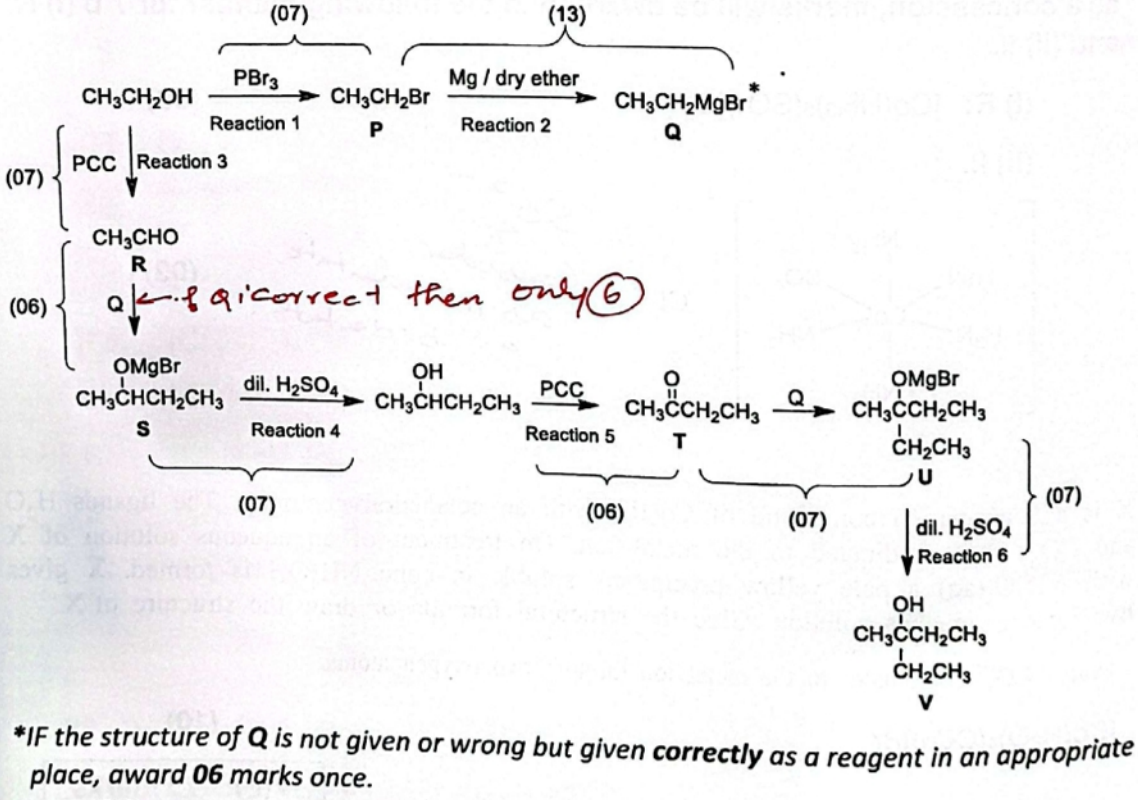
**8.** (*a*) Given below is a reaction scheme for the preparation of compound **V** using ethanol as the only organic starting material.

8. (a)



Complete the above reaction scheme by drawing the structures of compounds **P**, **Q**, **R**, **S**, **T** and **U** and writing the appropriate reagents for reactions **1** - **6** selected **only** from those given in the list below.

**Reagents:**
Dilute $H_2SO_4$, Mg/dry ether, $PBr_3$, Pyridinium chlorochromate (PCC)

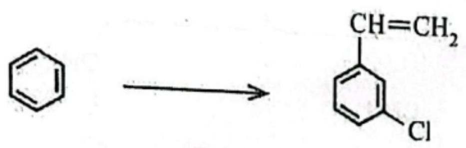


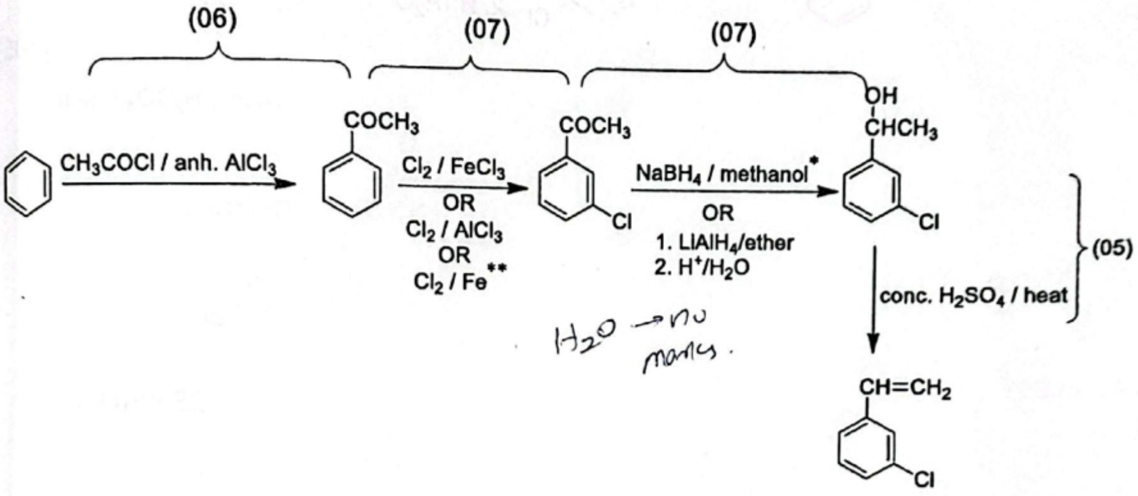
****IF the structure of* **Q** *is not given or wrong but given* **correctly** *as a reagent in an appropriate place, award* **06** *marks once.*

***NOTE:*** *If the structure of* **Q** *is wrong or not given, mark the rest of the answer as given in the marking scheme.*

**8(a): 60 marks**

(*b*) (i) Show how you would carry out the following conversion in not more than **four (04)** steps.





$H_2O$ → no marks.

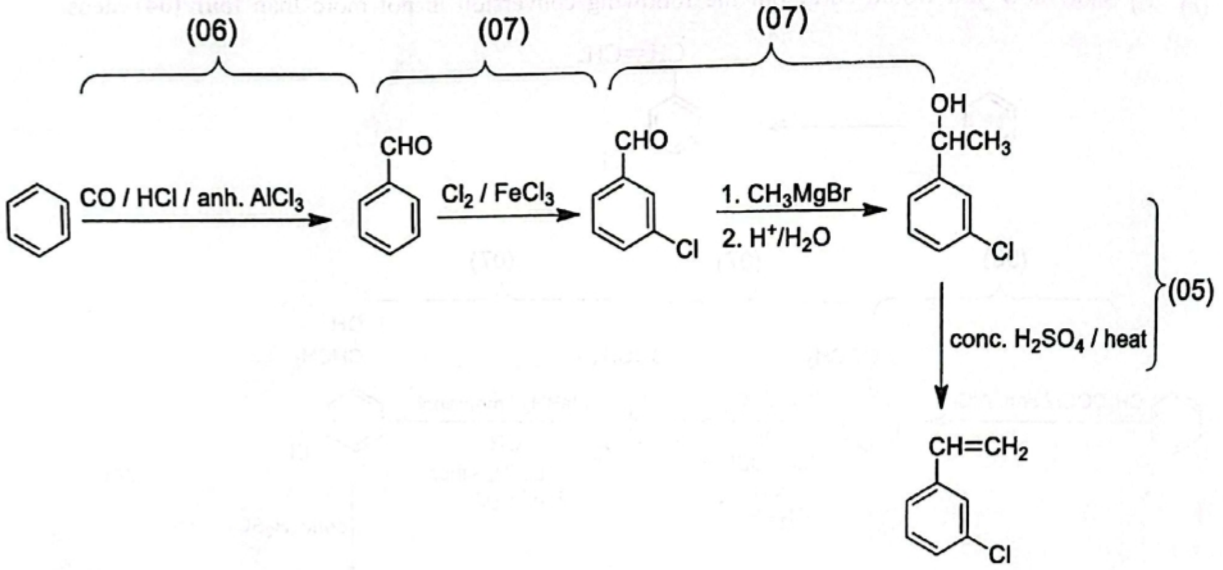
**Methanol is necessary for the reaction. If methanol is not written deduct* ***01*** *mark.*

***This is obsolete and not given in the syllabus or in the teacher guide. But it seems that it has been continuously taught in certain schools. Hence in fairness to the students it is included in the marking scheme.*

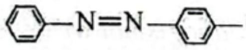
**(25 marks)**

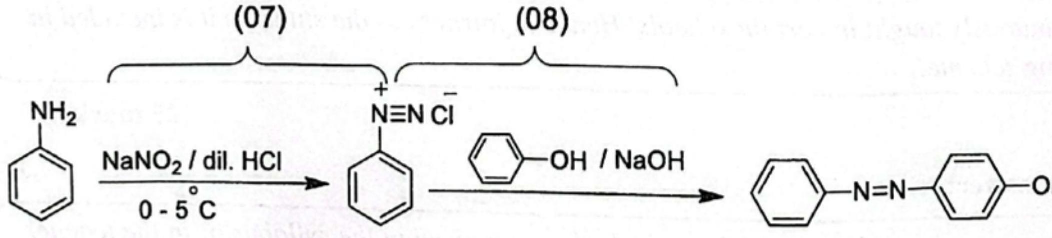
**Alternative answer:**

*Although the conversion of benzene to benzaldehyde is not given in the syllabus or in the teacher guide, it seems that it has been continuously taught in certain schools. Hence in fairness to the students the following alternative answer is included in the marking scheme.*



**(25 marks)**

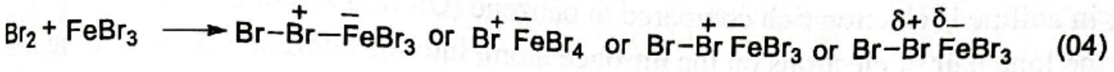
(ii) Propose a method to prepare  from aniline in not more than two (02) steps.



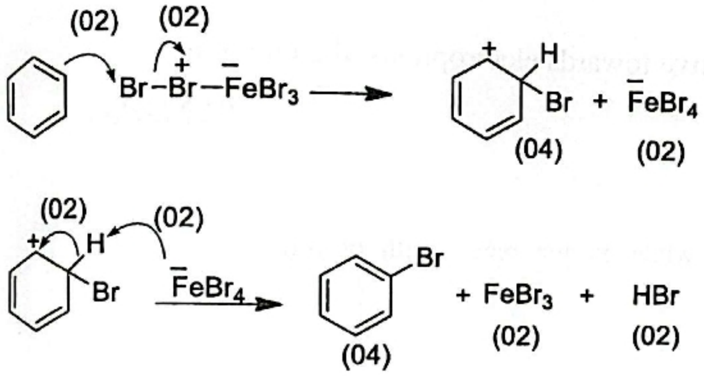
**(15 marks)**

**8(b): 40 marks**

(*c*) (i) Write the product and the mechanism of the reaction that takes place between benzene and bromine in the presence of anhydrous $FeBr_3$.



$Br_2 + FeBr_3 \longrightarrow Br-\overset{+}{Br}-\overset{-}{Fe}Br_3$ or $\overset{+}{Br}\ \overset{-}{Fe}Br_4$ or $Br-\overset{+}{Br}\ \overset{-}{Fe}Br_3$ or $Br-\overset{\delta+}{Br}\ \overset{\delta-}{Fe}Br_3$ (04)

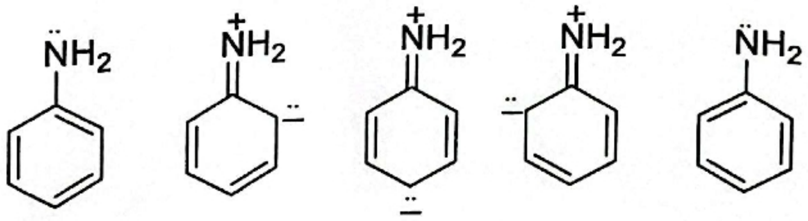


(26 marks)

(ii) Draw the resonance structures of benzene and aniline.

Resonance structures of benzene

Resonance structures of aniline



Note: **IF** the lone pair is not written, deduct **02** marks once.

(02 marks x 7 = 14 marks)

(iii) Considering the above resonance structures, explain why the benzene nucleus in aniline is more reactive towards electrophilic substitution reactions than benzene itself.

The benzene ring in aniline is electron rich compared to benzene (03 marks) due to the delocalization of the lone pair of electrons on the nitrogen atom, into the benzene ring in aniline (03 marks).

Therefore, benzene ring in aniline is more reactive towards electrophiles, than benzene.

**(06 Marks)**

(iv) Draw the structure of the product formed when aniline reacts with bromine.

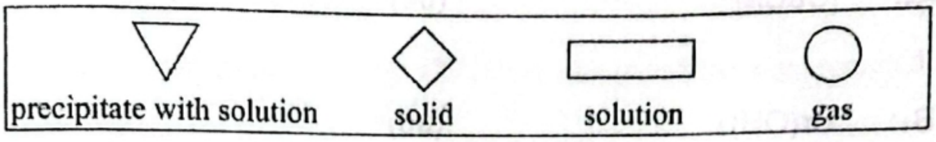
**(04 marks)**

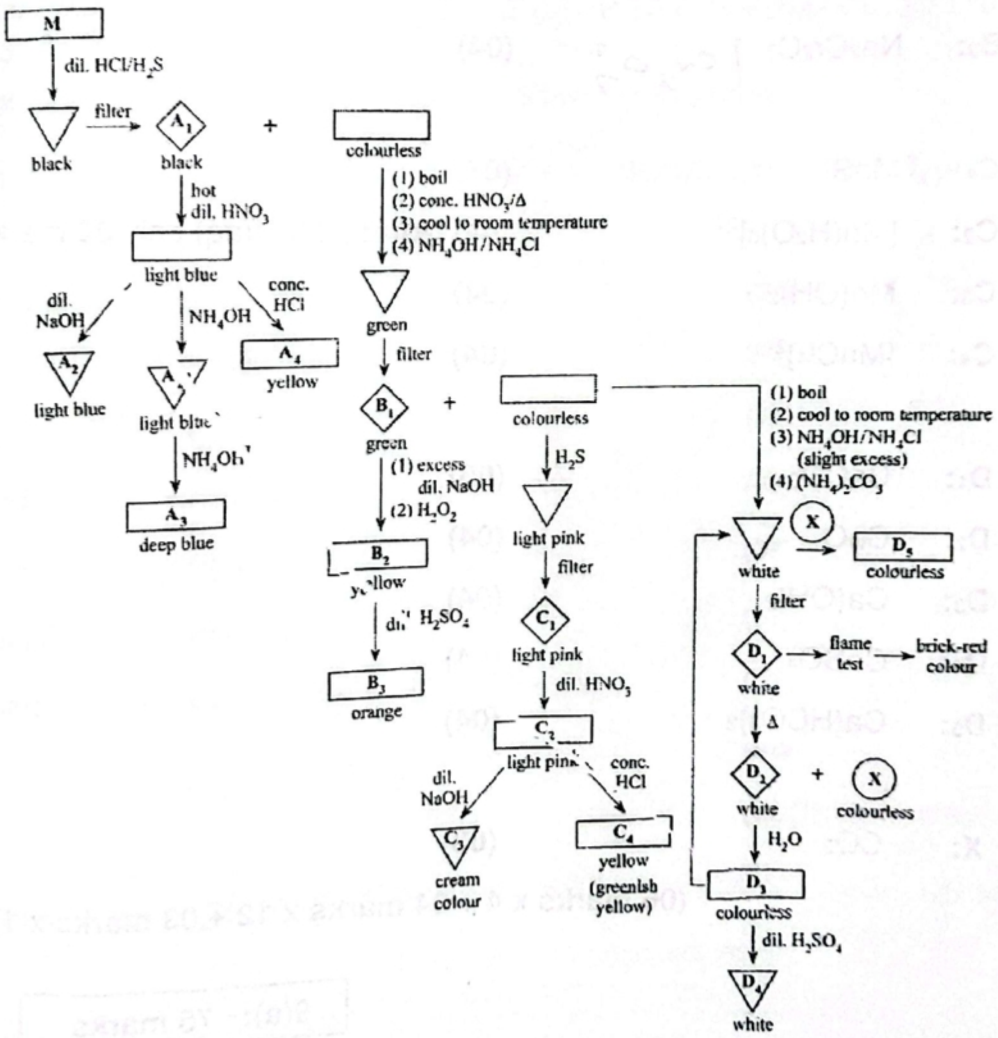
**8(c): 50 marks**

9. (*a*) The following question is based on the qualitative analysis of cations.

An aqueous solution **M** contains one cation of each of the metals **A**, **B**, **C** and **D**. **M** is analysed according to the scheme given below.

The symbols given in the box are used to represent precipitate with solution, solids, solutions and gases.





$A_1$–$A_4$, $B_1$–$B_3$, $C_1$–$C_4$ and $D_1$–$D_5$ are compounds/species of the four cations of metals **A**, **B**, **C** and **D**. **X** is a gas.

Identify $A_1$, $A_2$, $A_3$, $A_4$, $B_1$, $B_2$, $B_3$, $C_1$, $C_2$, $C_3$, $C_4$, $D_1$, $D_2$, $D_3$, $D_4$, $D_5$, and X.

(Note : Write only chemical formulae. Chemical equations and reasons are not required.)

**A$_1$:** CuS (06)
**A$_2$:** $Cu(OH)_2$ (04)
**A$_3$:** $[Cu(NH_3)_4]^{2+}$ (04)
**A$_4$:** $[CuCl_4]^{2-}$ (04)

**B$_1$:** $Cr(OH)_3$ (06)
**B$_2$:** $Na_2CrO_4$ | $CrO_4^{2-}$ (04)
**B$_3$:** $Na_2Cr_2O_7$ | $Cr_2O_7^{2-}$ (04)

**C$_1$:** MnS (06)
**C$_2$:** $[Mn(H_2O)_6]^{2+}$ (04) **Note:** If $Mn^{2+}(aq)$ only **02 marks**
**C$_3$:** $Mn(OH)_2$ (04)
**C$_4$:** $[MnCl_4]^{2-}$ (04)

**D$_1$:** $CaCO_3$ (06)
**D$_2$:** CaO (04)
**D$_3$:** $Ca(OH)_2$ (04)
**D$_4$:** $CaSO_4$ (04)
**D$_5$:** $Ca(HCO_3)_2$ (04)

**X:** $CO_2$ (03)

**(06 marks x 4 + 04 marks x 12 + 03 marks x 1)**

**9(a): 75 marks**

(*b*) The main compound present in iron pyrite is $FeS_2$. A 1.50 g sample of iron pyrite was oxidized under laboratory conditions and all the sulphur in $FeS_2$ was converted to $SO_4^{2-}$. The resultant $SO_4^{2-}$ was precipitated as $BaSO_4$. The dry weight of $BaSO_4$ obtained was 4.66 g.

(i) Calculate the weight percentage of $FeS_2$ present in iron pyrite.

$H_2SO_4$ that was produced in this reaction after 120 hours was quantitatively separated and precipitated as $BaSO_4$. The dry weight of $BaSO_4$ obtained was 31.13 g.

$FeS_2$ in 20.0 g of iron pyrite was subjected to oxidation by soil microbes under natural conditions for 120 hours.

This oxidation reaction is represented in the following equation.

$$4FeS_2(s) + 15O_2(g) + 14H_2O(l) \xrightarrow{\text{soil microbes}} 4Fe(OH)_3(s) + 8H_2SO_4(aq)$$

$BaSO_4$ - Molar mass = $137 + 32 + 64 = 233\ g\ mol^{-1}$ **(03)**

$FeS_2$ - Molar mass = $56 + 64 = 120\ g\ mol^{-1}$ **(03)**

Moles of $BaSO_4 = \frac{4.66}{233} = 0.02$ mol **(03)**

1 mole of $FeS_2$ gives 2 moles $BaSO_4$ **(03)**

$\therefore$ moles of $FeS_2 = \frac{0.02}{2} = 0.01$ mol **(03)**

$\therefore$ weight of $FeS_2 = 0.01 \times 120 = 1.20$ g **(03)**

$\therefore$ weight percentage of $FeS_2$ in iron pyrite $= \frac{1.20}{1.50} \times 100$ **(03)**

$= 80\%$ **(04)**

**(9b(i): 25 marks)**

(ii) Calculate the percentage conversion of $FeS_2$ in iron pyrite to $SO_4^{2-}$ after 120 hours by soil microbes.

**Note :** $$\text{Percentage conversion} = \frac{\text{Experimentally obtained mass using soil microbes}}{\text{Theoretical mass}} \times 100$$

4 moles $FeS_2 \rightarrow$ 8 moles $H_2SO_4 \rightarrow$ 8 moles $BaSO_4$

Amount of $FeS_2$ in 20.0 g of iron pyrite $= 20.0 \times \frac{80}{100}$ **(03)**

$= 16.0$ g **(03)**

40.8
4896

40.82
48984

4898g → 6.1426g

Calculation of theoretical mass of $BaSO_4$

According to the equation

4 moles $FeS_2$ gives 8 moles of $BaSO_4$ **(03)**

∴ 4 x 120 g $FeS_2$ gives 8 x 233 g of $BaSO_4$ **(03)**

∴ 16 g $FeS_2$ gives $\frac{8 \times 233}{4 \times 120} \times 16$ g of $BaSO_4$ **(03)**

Theoretical mass of $BaSO_4$ = 62.13 g **(03)**

Experimental mass of $BaSO_4$ = 31.13 g

% conversion $= \frac{31.13}{62.13} \times 100$ **(03)**

= 50.1% **(04)**

50.0 ± 0.1

150.2

(50.0

50.10

**(9b(ii): 25 marks)**

## ALTERNATE ANS 1

4 moles $FeS_2$ → 8 moles $H_2SO_4$ → 8 moles $BaSO_4$

Mass of $FeS_2$ in 20.0 g of iron pyrite $= 20.0 \times \frac{80}{100}$ **(03)**

= 16.0 g **(03)**

Moles of $BaSO_4$ $= \frac{31.13}{233}$ mol

Moles of $H_2SO_4$ $= \frac{31.13}{233}$ mol **(03)**

Moles of $FeS_2$ reacted $= \frac{1}{2} \times \frac{31.13}{233}$ mol **(03)**

Experimental mass of $FeS_2$ reacted $= \frac{1}{2} \times \frac{31.13}{233}$ mol x 120 g $mol^{-1}$ **(03)**

= 8.016 g **(03)**

% conversion $= \frac{8.016g}{16g} \times 100\%$ **(03)**

= 50.1% **(04)**

**(9b(ii): 25 marks)**

## ALTERNATE ANS 2

4 moles $FeS_2 \rightarrow$ 8 moles $H_2SO_4 \rightarrow$ 8 moles $BaSO_4$

Mass of $FeS_2$ in 20.0 g of iron pyrite $= 20.0\ g \times \frac{80}{100}$ **(03)**

$= 16.0$ g **(03)**

Moles of $FeS_2$ $= \frac{16.0}{120}$ mol **(03)**

Theoretical mass of $BaSO_4$ $= \frac{16}{120} \times 2$ mol $\times$ 233 g $mol^{-1}$ **(03)**

$= 62.13$ g **(03)**

Experimental mass of $BaSO_4$ reacted $= 31.13$ g **(03)**

% conversion $= \frac{31.13g}{62.13g} \times 100\%$ **(03)**

$= 50.1\%$ **(04)**

**(9b(ii): 25 marks)**

## ALTERNATE ANS 3

4 moles $FeS_2 \rightarrow$ 8 moles $H_2SO_4 \rightarrow$ 8 moles $BaSO_4$

Mass of $FeS_2$ in 20.0 g of iron pyrite $= 20.0\ g \times \frac{80}{100}$ **(03)**

$= 16.0$ g **(03)**

Moles of $FeS_2$ $= \frac{16.0}{120}$ mol **(03)**

Theoretical moles of $H_2SO_4$ $= \frac{16}{120} \times 2$ mol

Theoretical mass of $H_2SO_4$ $= \frac{16}{120} \times 2$ mol $\times$ 98 g $mol^{-1}$

$= 26.13$ g **(03)**

Moles of BaSO4 $= \frac{31.13}{233}$ mol

Moles of $H_2SO_4$ $= \frac{31.13}{233}$ mol

Experimental mass of $H_2SO_4$ $= \frac{31.13}{233}$ mol $\times$ 98 g $mol^{-1}$ **(03)**

= 13.09 g (03)

% conversion $= \frac{13.09g}{26.13g} \times 100\%$ (03)

= 50.1% (04)

**(9b(ii): 25 marks)**

(iii) Calculate the amount of iron pyrite required to produce 8 kg of $H_2SO_4$ by soil microbes when the conversion percentage of $FeS_2$ in iron pyrite to $SO_4^{2-}$ is 100%.
(Relative atomic mass : O = 16, S = 32, Fe = 56, Ba = 137)

$H_2SO_4$ = 8 kg = 8000 g (03)

Molar mass $H_2SO_4$ = 98 (03)

Moles $H_2SO_4 = \frac{8000}{98}$ (03)

If the conversion is 100%

∴ moles of $FeS_2$ required $= \frac{8000}{98} \times \frac{1}{2}$ (03)

= 40.8 moles (03)

= 40.8 x 120 g

= 4896 g (03)

∴ amount of iron pyrite required to produce 8 kg of $H_2SO_4$ $= \frac{4896}{80} \times 100$ g (03)

= 6120 g

= 6.12 kg (04)

**9b(iii): 25 marks**

**9(b): 75 marks**

10. (*a*) The following questions are based on the Solvay process.

(i) What is the main product of the Solvay process?

$Na_2CO_3$ / sodium carbonate (04)

(ii) What is the main by-product of the Solvay process?

$CaCl_2$ / calcium chloride (04)

(iii) What are the raw materials (starting materials) used in the Solvay process?

NH$_3$ gas, **(04)**

CO$_2$ gas, | CaCO$_3$ | limestone **(04)**

Brine (purified concentrated NaCl solution free from Ca$^{2+}$, Mg$^{2+}$ and SO$_4^{2-}$ made from sea water **(04)**

**(10a(iii): 12 marks)**

(iv) Which one of these raw materials in (iii) above is not consumed in the process but is recycled repeatedly?

NH$_3$ gas **(04)**

(v) Identify the first step of the Solvay process in which raw materials are mixed inside a tower which consists of perforated clay trays. Explain why this is carried out at a low temperature.

Ammonification (mixing NH$_3$ gas and Brine using the counter current principle) **(02)**

Ammonification is an exothermic process **(03)**

If the temperature increases, efficiency of dissolving NH$_3$ gas in Brine decreases and hence low temperature is maintained. **(03)**

**OR**

Dissolution of ammonia is exothermic ($\Delta H < 0$) **(01)**

and the entropy change ($\Delta S$) is negative) ($\Delta S < 0$) **(01)**

According to $\Delta G = \Delta H - T\Delta S$ **(01)**

When $\Delta S$ is negative, $-T\Delta S$ term is +ve. **(01)**

When temp increases $\Delta G$ becomes less negative, **(01)**

This reduces efficiency of dissolving in water; therefore low Temp more suitable **(03)**

(vi) Give **three** uses of the main product of the Solvay process.

To remove hardness of water

Used in glass industry

Used in paper industry

Used in soap and detergent industry to improve the cleaning action

Used as a powerful cleaning agent (washing soda)

**Any three (03 marks x 3 = 09 marks)**

(vii) Give **three** reasons contributing to the economic profitability of the Solvay process.

NaCl and $CaCO_3$ can be obtained easily with low cost

$NH_3$ is not used and can be used repeatedly by recycling

Portion of $CO_2$ can be reused

**(03 marks x 03 = 09 marks)**

**10(a): 50 marks**

(*b*) Briefly explain each of the following statements.

(i) Agriculture contributes to global warming.

Related to agriculture:

- $N_2O$ **(02)** and $CH_4$ **(02)** contribute to global warming
- Both are greenhouse gases **(02)**
- Increase in their concentration contributes to global warming. **(02)**

Formation of $N_2O$:

- Action of denitrifying bacteria **(02)** on
- nitrogen containing fertilizers **(02)** produce $N_2O$

Formation of $CH_4$:

- Paddy cultivation in marsh and water logged area **(02)** favour anaerobic decomposition of organic matter to produce $CH_4$. **(01)**
- Decomposition of organic matter disposed indiscriminately **(02)** undergo anaerobic decomposition to produce $CH_4$. **(01)**
- Digestion of organic/cellulose matter in guts of ruminant animals (cows, goat, sheep) undergoing bacterial decomposition under anaerobic conditions **(02)** produce $CH_4$

**(10b(i): 20 marks)**

(ii) Iron extraction contributes to global warming.

Related to iron extraction:

- $CO_2$ contributes to global warming
- $CO_2$ is a greenhouse gas and
- increase in concentration contributes to global warming

**(02x3)**

Formation of $CO_2$:

Fossil fuels and coke used in iron extraction are converted to $CO_2$ during combustion **(04)**

**(10b(ii): 10 marks)**

(iii) Transportation contributes to photochemical smog.

In your answer indicate how the chemical species responsible for the given environmental effect in each of the statements above is/are formed.

Related to transportation:

Species that contribute to photochemical smog

NO and volatile hydrocarbons ($CH_3(CH_2)_nCH_3$, n = 1-4) **(02x2)**

- NO and volatile hydrocarbons undergo reactions in the presence of sunlight to produce volatile short chain aldehydes and other toxic chemicals (PAN, PBN)
- Aldehydes are further polymerized to produce suspended particles in the atmosphere
- These particles can form large particles by deposition of dust, water vapour, etc
- These large particles can scatter sunlight reducing the visibility/transparency of the atmosphere and appear like a mist in the lower atmosphere

**(02 x 8 = 16)**

**(10b(iii): 20 marks)**

**10(b): 50 marks**

(c) (i) The following questions are based on vinegar production.

I. State what is the process used in the production of natural vinegar.

microbial activity / microbial fermentation or fermentation **(04)**

II. Write the name of the active chemical ingredient present in natural vinegar.

**(04)**

acetic acid

III. Name the titrant and the indicator used in the quantitative determination of the active chemical ingredient in natural vinegar.

Titrant – NaOH **(04)**

Indicator – Phenolphthalein **(04)**

IV. State the difference in composition between natural vinegar and artificial vinegar.

Natural vinegar contains salts, simple sugars, esters and alcohols in minute quantities. any 2 **~~(01x4)~~** 02x2 = 4

However, synthetic vinegar contains only acetic acid. **~~(02)~~** 02

(ii) The following questions are based on the extraction of essential oils from plants.

I. Name three methods that can be used to extract essential oils.

steam distillation

solvent extraction

pressing

**(04 marks x 3 = 12 marks)**

II. State which of the above methods is based on the application of Daltons Law of partial pressures.

steam distillation

**(04 marks)**

III. Name the major compound present in each of the essential oils given below.

- Citronella oil
- Cinnamon root oil
- Cinnamon leaf oil

citronella – geraniol

cinnamon root – camphor

cinnamon leaf - eugenol

**(04 marks x 3 = 12 marks)**

**10(c): 50 marks**