A/L /2024/ C / 22

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Department of Examinations – Sri Lanka

G.C.E. (A/L) Examination – 2025

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

ශ්‍රී ලංකා විභාග දෙපාර්තමේන්තුව

Department of Examinations – Sri Lanka

අ.පො.ස.(උ.පෙළ)විභාගය/G.C.E. (A/L) - 2025

විෂයය අංකය Subject No: **02**

විෂයය Subject: **Chemistry**

ලකුණු දීමේ පටිපාටිය/ Marking Scheme

I පත්‍රය/ Paper I

ප්‍රශ්න අංකය வினா இல.	පිළිතුරු අංකය விடை இல.	ප්‍රශ්න අංකය வினா இல.	පිළිතුරු අංකය விடை இல.	ප්‍රශ්න අංකය வினா இல.	පිළිතුරු අංකය விடை இல.	ප්‍රශ්න අංකය வினா இல.	පිළිතුරු අංකය விடை இல.	ප්‍රශ්න අංකය வினா இல.	පිළිතුරු අංකය விடை இல.
01.	2	11.	5	21.	4	31.	4	41.	3
02.	4	12.	5	22.	1	32.	2	42.	1
03.	1	13.	4	23.	3	33.	5	43.	4
04.	1	14.	5	24.	5	34.	1	44.	1
05.	2	15.	4	25.	5	35.	2	45.	4
06.	3	16.	1	26.	5	36.	5	46.	3
07.	5	17.	3	27.	2	37.	5	47.	2
08.	2	18.	4	28.	3	38.	All	48.	1
09.	5	19.	4	29.	2	39.	1	49.	3
10.	5	20.	4	30.	2	40.	3	50.	3

✪විශේෂ උපදෙස්/Special Instructions:

එක් පිළිතුරකට ලකුණු 01 බැගින්/ 01 Mark for each question

මුළු ලකුණු/Total Marks   01 × 50 = 50

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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) The pairing of electrons in a particular subshell **does not** take place until all the orbitals of the subshell are singly occupied by electrons with parallel spins. **true**

(ii) The atomic orbitals identified by quantum numbers n and l, (I) $n = 4$ $l = 1$ (II) $n = 4$ $l = 0$ (III) $n = 3$ $l = 2$ can be placed in order of increasing energy as (III) < (II) < (I). **false**

(iii) The electron pair geometry of the SOF_4 molecule is square pyramidal. **false**

(iv) The second ionization energy of Li is less than that of Be. **false**

(v) The electron gain energy of fluorine is a negative value. **true**

(vi) Among the atoms Be, C, Si and S, the atomic radii increase in the order C < Be < S < Si. **false**

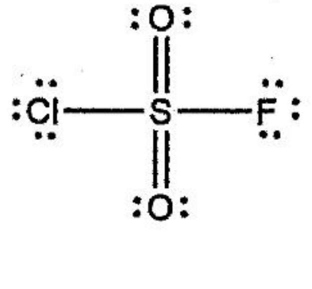
(vii) The boiling point of CH_3NH_2 is higher than that of CH_3F. **true**

(viii) The ionic radii of Al^{3+}, O^{2-}, F^- and S^{2-} decrease in the order $S^{2-} > F^- > O^{2-} > Al^{3+}$. **false**

(04 marks X 8 = 32 marks)

1(a): 32 marks

(*b*) (i) Draw the **most** acceptable Lewis dot-dash structure for the molecule $ClSO_2F$.



(06 marks)

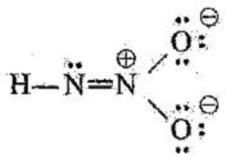
(ii) Give the oxidation state of S in the structure drawn in (i) above.

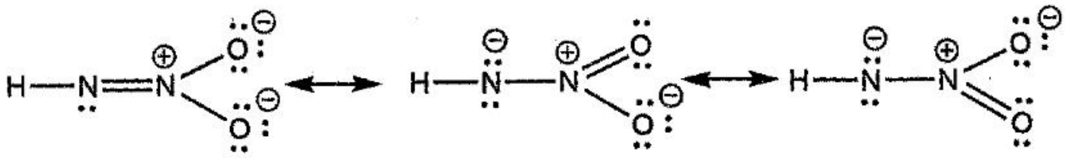
+6 or +VI

(02 marks)

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

(iii) A stable Lewis dot-dash structure for the $HN_2O_2^-$ ion is given below. Draw **two** more Lewis dot-dash structures (resonance structures) for this ion. Indicate the stability of each of the structures drawn by you, relative to the structure given, by writing **stable**, **unstable** or **less stable** under the structure.



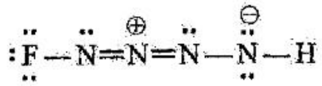


(less stable) (less stable)

(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.



$F—N^1—N^2—N^3—N^4—H$

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

(01 mark × 16 = 16 marks)

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Past Papers Wiki

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

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

I.	$N^1 — F$	N^1 sp^2	F 2p or sp^3
II.	$N^1 — N^2$	N^1 sp^2	N^2 sp
III.	$N^2 — N^3$	N^2 sp	N^3 sp^2
IV.	$N^3 — N^4$	N^3 sp^2	N^4 sp^3
V.	$N^4 — H$	N^4 sp^3	H 1s

(01 mark × 10 = 10 marks)

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

I.	$N^1 — N^2$	N^1 2p	N^2 2p
II.	$N^2 — N^3$	N^2 2p	N^3 2p

(01 mark × 4 = 04 marks)

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

N^1 **(118° ± 1)**, N^2 **(180° ± 1)**, N^3 **(118° ± 2)**, N^4 **(104° ± 1)**

(01 mark × 4 = 04 marks)

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

N^4 < **N^3** < **N^1** < **N^2**

(04 marks)

1(b): 52 marks

(c) (i) Given below are the six successive ionization energies, IE_1–IE_6 (in kJ/mol) of an element in the third period, starting from the first ionization energy (IE_1).

IE_1	IE_2	IE_3	IE_4	IE_5	IE_6
1012	1903	2910	4956	6248	22230

Identify the element and write its electron configuration.

I. element : **P** / Phosphorous **(02 marks)**

II. electron configuration : $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^3$ **(02 marks)**

(ii) A molecule of formula AX_5 has five A—X σ bonds. Here A and X represent symbols of elements and A is the central atom.
Complete the table below by naming the possible molecular shape and giving an example (molecular formula required) for each of the shapes.

	molecular shape	example
I. If AX_5 is polar	square pyramidal	$BrCl_5$/ BrF_5/ClF_5/IF_5 /ICl_5
II. If AX_5 is nonpolar	trigonal bipyramidal	PCl_5/PF_5

IBr_5 cannot
any one.

(mark independently)
(03 marks × 4 = 12 marks)

1(c): 16 marks

2. (*a*) (i) **A** is a water soluble white coloured compound. It is composed of three elements in the ratio 4:2:3 (in the increasing order of atomic mass). The atomic number of each element is less than 20. Two of these elements belong to the *p*-block of the Periodic Table. On heating **A**, a colourless, non-toxic, neutral, tri-atomic gas with a linear structure is evolved as one of the products. **A** is used as a fertilizer.
Identify **A** ....**NH_4NO_3** or ammonium nitrate....

(ii) **B** is also a water soluble white coloured compound. It is composed of the same three elements as **A**. These elements are in the ratio 4:2:2 (in the increasing order of atomic mass). On heating **B**, a colourless, odourless, homo diatomic gas having a high bond dissociation energy is evolved. This gas is obtained industrially by fractional distillation of liquified air.
Identify **B** ....**NH_4NO_2** or ammonium nitrite....

(iii) **C** is a white coloured ionic compound. It is composed of four elements in the ratio 8:2:4:1 (in the increasing order of atomic mass). The atomic number of each element is less than 20. Three of these elements are found in both **A** and **B**. On heating **C**, a colourless basic gas **X** having a strong smell, and a strong acid are formed. On addition of $BaCl_2(aq)$ to an aqueous solution of **C**, a white precipitate that is insoluble in dil. HCl is obtained.
Identify **C** ....**$(NH_4)_2SO_4$** or....

(iv) **D** is a white coloured ionic compound. It is composed of four elements in the ratio 8:1:2:3 (in the increasing order of atomic mass). Three of these elements are found in all three compounds **A**, **B** and **C**. Of the products formed on heating **D**, gas **X** and another gas that turns lime water milky are obtained as two of the products.
Identify **D** ....**$(NH_4)_2CO_3$** or....

(v) **E** is a strong acid. It is composed of the same elements as **A** and **B**. They are in the ratio 3:1:1 (**not** in the increasing order of atomic mass). **E** is a strong oxidizing agent. **E** is manufactured using **X**.
Identify **E** ....**HNO_3** or nitric acid.

2(a): 08 × 5 = 40 marks

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(*b*) Give balanced chemical equations for the reactions that take place on heating **A**, **B**, **C** and **D** identified in (*a*) above.

A $NH_4NO_3(s) \xrightarrow{\Delta} N_2O(g) + 2H_2O(g)$

B $NH_4NO_2(s) \xrightarrow{\Delta} N_2(g) + 2H_2O(g)$

C $(NH_4)_2SO_4(s) \xrightarrow{\Delta} 2NH_3(g) + H_2SO_4(g)$ or $SO_3 + H_2O + 2NH_3$

D $(NH_4)_2CO_3(s) \xrightarrow{\Delta} 2NH_3(g) + CO_2(g) + H_2O(g)$

[Physical states are not required. Δ is not required.]

2(b): 08 × 4 = 32 marks

(*c*) (i) Identify **X** based on the information given in part (*a*) above.

X = NH_3 **(04)**

(ii) Name the process by which **E**, identified in part (*a*)(v) above, is manufactured using **X**.

Ostwald Process **(04)**

(iii) State the other raw material/s used in the above process.

O_2 (Air) + H_2O or O_2 (Air) and H_2O. (02 + 02) **(04)**

(iv) I. On reacting **X** with excess $Cl_2(g)$ a compound **Y** is formed as one of the products. Write the balanced chemical equation for this reaction.

$3Cl_2(g) + NH_3(g) \longrightarrow 3HCl(g) + NCl_3(l)$ **(04)**

II. When **Y** reacts with water, a compound that can be used to disinfect water is formed. Write the balanced chemical equation for the reaction of **Y** with water.

$NCl_3(l) + 3H_2O \longrightarrow NH_3(g) + 3HOCl(aq)$ **(04)**

$NCl_3 + 4H_2O \rightarrow NH_4OH + 3HOCl$

(v) Give **one** chemical test to identify **X**, along with its observation.

Test : **X is reacted with conc. HCl** without 'conc' just (02) marks.

Observation : **white fumes are formed** **(04 + 04)**

or

Test : **X is bubbled through Nessler's reagent** / or using a filter paper soaked with Nessler.

Observation : **brown precipitate/ colouration**

* No marks for Litmus.

2(c) 28 marks

NOTE: PHYSICAL STATES ARE NECESSARY

The symbol of equilibrium ⇌ also needed for all the reactions

3. (a) HX(aq) is a weak acid with $pK_a = 4$ at 25 °C.

(i) Write the equation for the ionization of HX(aq) in an aqueous solution.

$$HX(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + X^-(aq)$$

OR $HX(aq) \rightleftharpoons H^+(aq) + X^-(aq)$ **(05)**

(ii) Write the expression for the equilibrium constant of (i) above.

$K_a = \frac{[H_3O^+(aq)][X^-(aq)]}{[HX(aq)]}$ *OR* $K_a = \frac{[H^+(aq)][X^-(aq)]}{[HX(aq)]}$ **(05)**

(iii) Calculate the pH of a 0.01 mol dm^{-3} solution of HX(aq) at a temperature of 25 °C.

$$HX(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + X^-(aq)$$

	HX(aq)	$H_3O^+(aq)$	$X^-(aq)$		
Initial con.	0.01	0	0	mol dm^{-3}	
Change con.	$-x$	x	x	mol dm^{-3}	
Equi. con.	$0.01 - x$	x	x	mol dm^{-3}	**(02+01)**

$K_a = 1.0 \times 10^{-4} = \frac{x.x}{0.01-x} \approx \frac{x^2}{0.01}$ **(02+02+02)**

02 02 02

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

$x = [H_3O^+(aq)] = 1.0 \times 10^{-3}$ mol dm^{-3} **(02+01)***

$pH = -\log[H_3O^+(aq)] = 3$ **(05)***

no marks

Just for $pH = -\log[H_3O^+_{aq}]$ (02)

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* The above steps can be combined.

Alternate answer:

Ka = antilog [$-pK_a$] = antilog -4

= 1 x 10^{-4} mol dm^{-3} **(02)**

$$HX(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + X^-(aq)$$

eq^m ~~Initial con.~~ C(1-α) Cα Cα mol dm^{-3} **(03)**

$[H^+_{(aq)}]^2 = K_a \times [HX_{aq}]$ $[H^+_{(aq)}] = \sqrt{K_a \times [HX_{aq}]}$ **(02)**

$[H^+_{(aq)}] = \sqrt{1 \times 10^{-4} \times 0.01}$ **(02)**

$[H^+_{(aq)}] = 1 \times 10^{-3}\ mol\ dm^{-3}$ **(02+01)**

$pH = -\log[H_3O^+(aq)] = -\log\ 1 \times 10^{-3} = 3$ **(05)**

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(iv) A volume of 10.00 cm^3 of 0.02 mol dm^{-3} NaOH(aq) solution was added to 25.00 cm^3 of 0.01 mol dm^{-3} HX(aq) solution at a temperature of 25 °C.

I. Write the chemical species present in the solution obtained.

$HX(aq)$, $H_3O^+(aq)$, $X^-(aq)$, $OH^-(aq)$, $Na^+(aq)$ ~~and ($H_2O(l)$)~~ **(01x 05)**

II. What is this type of solution commonly known as?

Buffer solution **(03)**

III. Write the expression for the calculation of pH of this solution.

$pH = pK_a + log\left(\frac{[X^-(aq)]}{[HX(aq)]}\right)$ or $pH = pKa + log\frac{[NaX(aq)]}{[HX(aq)]}$ or $\frac{[Salt]}{[Acid]}$ **(05)**

IV. Calculate the pH of this solution. (log values for 1–10 are given below.)

number	1	2	3	4	5	6	7	8	9	10
log value	0.00	0.30	0.48	0.60	0.70	0.78	0.85	0.90	0.95	1.00

$HX(aq) + NaOH(aq) \rightarrow NaX(aq) + H_2O(l)$ **(03)**

Or

	$HX(aq)$ +	$OH^-(aq)$ →	$X^-(aq) + H_2O(l)$	
Initial moles	$0.01 \times 25 \times 10^{-3}$	$0.02 \times 10 \times 10^{-3}$		
remaining moles	$(0.01 \times 25 \times 10^{-3} - 0.02 \times 10 \times 10^{-3})$ (01)	0	$0.02 \times 10 \times 10^{-3}$ (01)	~~(02)~~
Concentrations (mol dm⁻³)	*0.05/35*		*0.20/35*	**(01+01+01)**

Substituting in $pH = pK_a + log\left(\frac{[X^-(aq)]}{[HX(aq)]}\right)$

$$pH = 4 + log\left(\frac{0.20/35}{0.05/35}\right) = 4 + log(4) = 4 + 0.6 = 4.6$$ **(03+02)**

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Marks can be awarded with the use of Ka expression

V. Calculate the volume of 0.02 mol dm^{-3} NaOH(aq) solution required to be mixed with 100.00 cm^3 of 0.01 mol dm^{-3} HX(aq) to obtain a solution of pH 4.00.

Volume of 0.02 mol dm^{-3} NaOH needed : V cm^3

pH = 4 gives $4 = 4 + log\left(\frac{[X^-(aq)]}{[HX(aq)]}\right)$

$log\left(\frac{[X^-(aq)]}{[HX(aq)]}\right) = \mathbf{0}$; $\frac{[X^-(aq)]}{[HX(aq)]} = \mathbf{1}$; $[X^-(aq)] = [HX(aq)]$ **(04)**

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$$[HX(aq)] = \frac{(0.01\times100\times10^{-3} - 0.02\times V\times10^{-3})}{(100 + V)\times10^{-3}} \text{ mol } dm^{-3}$$ **(02+01)**

$$[X^-(aq)] = \frac{(0.02 \times V \times 10^{-3})}{(100+V) \times 10^{-3}} \text{ mol dm}^{-3}$$ **(02+01)**

$$\frac{(0.01 \times 100 \times 10^{-3} - 0.02 \times V \times 10^{-3})}{(100+V) \times 10^{-3}} = \frac{(0.02 \times V \times 10^{-3})}{(100+V) \times 10^{-3}}$$ **(02)**

$$(0.01 \times 100 \times 10^{-3} - 0.02 \times V \times 10^{-3}) = 0.02 \times V \times 10^{-3}$$

$$(1.0 - 0.02V) = 0.02V$$

$$V = 25\ cm^3$$

(04+01)

Alternative Answer:

pH = 4 = pK_a **(05)**

This is as same as the half equivalence point **(03)**

Concentration of NaOH is twice the concentration of HX **(03)**

Volume of HX at the equivalence point is half the volume of NaOH. **(03)**

Therefore the volume of HX at the half equivelece point is

$\frac{1}{4}$ $volume\ of\ NaOH = 25\ cm^3$ **(03)**

3(a) 70 marks

(*b*) At 25 °C, $MgF_2(s)$ is sparingly soluble in water ($K_{sp} = 6.4 \times 10^{-9}$ mol^3 dm^{-9}). Calculate the maximum mass of $MgF_2(s)$ that is completely soluble in 500.00 cm^3 of 0.20 mol dm^{-3} NaF(aq) solution. Assume that there is no change in volume of the solution upon the addition of $MgF_2(s)$. (F = 19, Mg = 24)

$$MgF_2(s) \rightleftharpoons Mg^{2+}(aq) + 2F^-(aq)$$ **(04)**

$$K_{sp} = [Mg^{2+}(aq)][F^-(aq)]^2$$ **(04)**

First we need to calculate the solubility of $MgF_2(s)$ in the NaF(aq) and take that as s

	$MgF_2(s)$	$\rightleftharpoons$ $Mg^{2+}(aq)$	$+ 2F^-(aq)$	
Initial concentration		0	0.20 mol dm^{-3}	
Concentration change			2s	
Equilibrium concentration			(2s + 0.20) mol dm^{-3}	**(04+01)**

$K_{sp} = 6.4 \times 10^{-9} = s\,(0.20 + 2s)^2 \approx s(0.20)^2$ **(02)**

$s = 1.6 \times 10^{-7}\ mol\ dm^{-3}$ **(04+01)**

Number of moles of $MgF_2(s)$ that can be dissolved in 500 cm^3 of NaF is

$1.6 \times 10^{-7} \times 0.5 = 8.0 \times 10^{-8}\ mol$ **(04+01)**

Mass of $MgF_2(s)$ = $8.0 \times 10^{-8} \times 62 = 4.96 \times 10^{-6}\ g$ **(04+01)**

3(b) 30 marks

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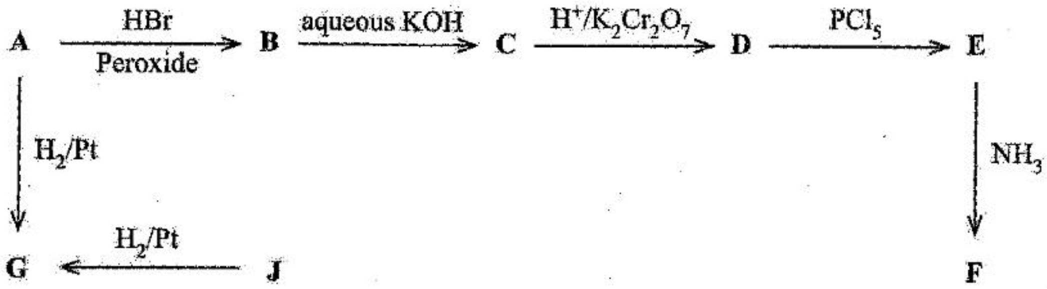
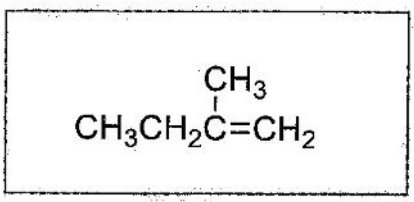
4. (*a*) Consider the reaction scheme given below, in which,

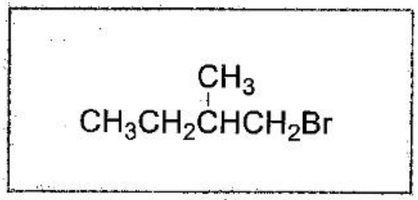
- **A** is a hydrocarbon having the molecular formula C_5H_{10}.
- **D** has the molecular formula $C_5H_{10}O_2$. It exhibits optical isomerism. When **D** is reacted with aqueous Na_2CO_3, CO_2 is liberated.
- **J** has the molecular formula C_5H_8. **J** gives a precipitate with ammonical $AgNO_3$.



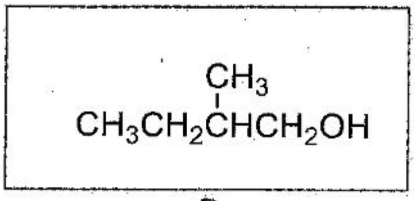
(i) Draw the structures of **A**, **B**, **C**, **D**, **E**, **F**, **G** and **J** in the relevant boxes.



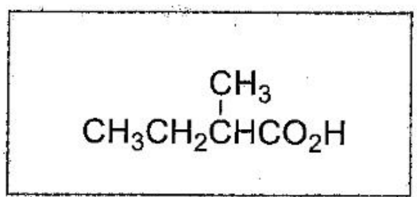
A



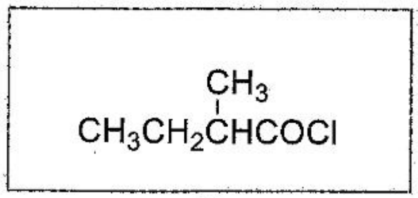
B



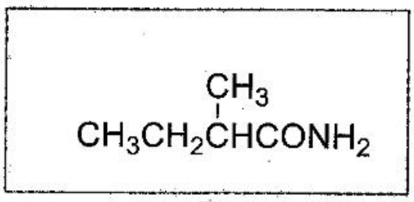
C



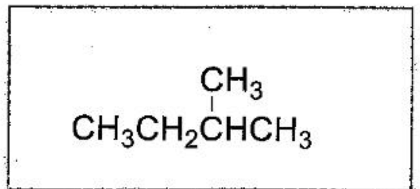
D



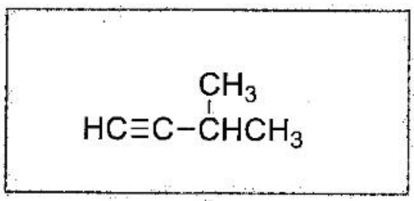
E



F



G

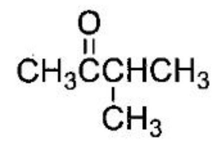


J

06 × 8 = 48 Marks

- When **J** is reacted with $HgSO_4$/dil. H_2SO_4, **K** is formed. **K** can be converted to **G** in one (01) step.

  (ii) Draw the structure of **K** and give the reagent/s that can be used to convert **K** to **G** in the relevant boxes.



K

Zn(Hg)/Conc. HCl

Reagent/s

when 'J' is wrong K also wrong.

do not ~~mark independently~~.

06 × 2 = 12 Marks

4(a) 60 Marks

(*b*) For the reactions given below, write the type of reaction [nucleophilic addition (A_N), electrophilic addition (A_E), nucleophilic substitution (S_N), electrophilic substitution (S_E), elimination (E)] and the major product in the relevant cages in the table.

	Reaction	Reaction type	Major product
(i)	$CH_3CH=C(CH_3)-CH_3 \xrightarrow{Br_2}$	A_E	$CH_3CHBr-CBr(CH_3)-CH_3$
(ii)	$CH_3CH_2CH(OH)CH_2CH_3 \xrightarrow[\text{heat}]{\text{anhydrous } Al_2O_3}$	E	$CH_3CH=CHCH_2CH_3$
(iii)	$CH_3CH_2CH_2OH \xrightarrow{HBr}$	S_N	$CH_3CH_2CH_2Br$

03 × 6 = 18 Marks

4(b) 18 Marks

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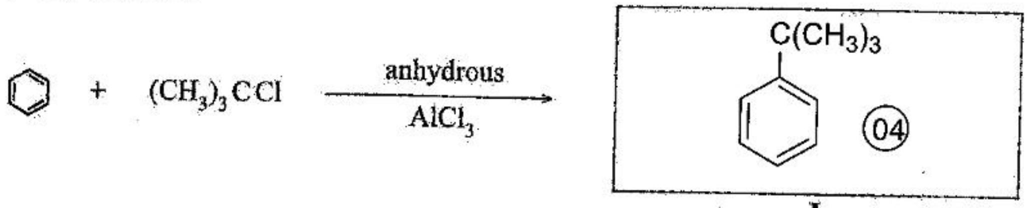
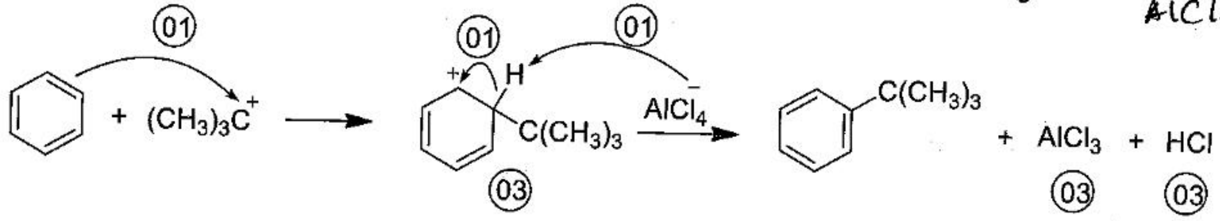
(c) Draw the structure of the major product **L** of the reaction given below. Write the mechanism of this reaction.



L

mechanism:

$(CH_3)_3CCl + AlCl_3 \rightleftharpoons (CH_3)_3\overset{+}{C} + \overset{-}{AlCl_4}$ (03) (03) if the carbocation is wrong no marks for $AlCl_4^-$



18

4(c) 22 Marks

* Only C_2H_5 is accepted. Others should be clearly shown.
(C_3H_7 is not accepted)

PART B — ESSAY

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

NOTE: PHYSICAL STATES ARE NECESSARY

5. (a) At 450 °C, 1.0 mol of $N_2(g)$ and 2.0 mol of $H_2(g)$ were mixed in a 1.0 dm^3 previously evacuated closed-rigid container and allowed to reach the equilibrium given below.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

It was found that 1.0 mol of $NH_3(g)$ was present at the equilibrium.

(i) Calculate the total pressure of the equilibrium system at 450 °C (RT = 6×10^3 J mol^{-1} at 450 °C).

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

Initial con	*1.0*	*2.0*	*0*	*mol dm^-3*	
Changed con	*-x*	*-3x*	*2x*	*mol dm^-3*	
Eqm con.	*1 − x*	*2-3x*	*1.0*	*mol dm^-3*	**(04+01)**

At equilibrium 1.0 mol of $NH_3(g)$ is present

∴ Equilibrium Concentration of $NH_3(g)$: $2x = 1$: $x = 0.5$ *mol dm^-3* **(01+01)**

∴ *Eqm mixture con.* *0.5* *0.5* *1.0* *mol dm^-3* **(02+01)**

Total number of moles in the mixture at equilibrium = 2 mol

Assuming ideal gas behavior: PV = nRT **(03)**

$$P = \frac{nRT}{V} = \frac{2\text{ mol} \times (6\times10^3 \text{ J mol}^{-1})}{1.0 \times 10^{-3}\ m^3} = 1.20 \times 10^7 \text{ Pa}$$ **(04+01)**

18

(ii) Calculate the partial pressures of $N_2(g)$, $H_2(g)$ and $NH_3(g)$ at 450 °C in the equilibrium system.

Using $P_i = X_i P$ **(02)**

$P_{N_{2(g)}} = \frac{0.5}{2} \times 1.20 \times 10^7 \text{ Pa} = 3.0 \times 10^6 \text{ Pa}$ **(03+01)**

$P_{H_{2(g)}} = \frac{0.5}{2} \times 1.20 \times 10^7 \text{ Pa} = 3.0 \times 10^6 \text{ Pa}$ **(03+01)**

$P_{NH_{3(g)}} = \frac{1.0}{2} \times 1.20 \times 10^7 \text{ Pa} = 6.0 \times 10^6 \text{ Pa}$ **(03+01)**

(OR use PV = nRT for three gases)

14

(iii) Calculate the equilibrium constant K_p of the system at 450 °C.

$$K_P = \frac{P^2_{NH_{3(g)}}}{P_{N_{2(g)}}\ P^3_{H_{2(g)}}} = \frac{(6.0 \times 10^6 \text{ Pa})^2}{(3.0 \times 10^6 \text{ Pa})(3.0 \times 10^6 \text{ Pa})^3} = 4.40 \times 10^{-13} \text{ Pa}^{-2}$$

(05) (04 + 01)

05

(~~03+02~~+04+01)

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(iv) Using the value obtained for K_p in (iii) above, calculate the equilibrium constant K_C of the system at 450 °C.

Using $K_P = K_C(RT)^{\Delta n}$: $\Delta n = -2$ **(03+02)**

$K_C = K_P(RT)^2 = 4.40 \times 10^{-13}\ Pa^{-2}\ (6 \times 10^3\ J\ mol^{-1})^2$ **(03)** sub ²

$K_C = 15.84\ mol^{-2}\ dm^6$ / $15.84 \times 10^{-6}\ mol^{-2}m^6$

$K_C = 16\ mol^{-2}\ dm^6$ or $1.6 \times 10^{-5}\ mol^{-2}m^6$ **(04+01)**

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(v) State what changes, if any, take place in the values of partial pressures of $N_2(g)$, $H_2(g)$ and $NH_3(g)$ and the value of K_p, when 1.0 mol of Ar(g) is added to the above system at 450 °C (calculations are **not** required).

There is no change in partial pressures and K_P. "no change". no marks. **(03+02)**

5(a): 60 marks

(*b*) Assume that ΔH° and ΔS° of the reaction $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ do not change with the temperature.

(i) Predict the effect on the equilibrium concentration of $NH_3(g)$ when the temperature of the system is increased.

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ reaction has negative (- ve) ΔS because the number of gaseous species decreases. Therefore (-TΔS) is positive (+ ve) **(05)**

When the equation $\Delta G^{\ominus} = \Delta H^{\ominus} - T\Delta S^{\ominus}$ is considered, **(05)**

TΔS increases with temperature and -TΔS becomes more positive at high temperature.

∴ $\Delta G^{\ominus}$ becomes less negative or positive at high temperature **(05)**

∴ Yield of $NH_3(g)$ decreases at high temperature. **(05)**

20

Alternate answer 1

Reaction is exothermic or ΔH negative **(05)**

According to Le Chatlier Principle **(05)** increase in temperature shifts the equilibrium backwards **(05)**. Therefore, yield of $NH_3(g)$ decreases **(05)**

20

Alternate answer 2

Explanation with Qc also accepted. **(05 x 4)**

(ii) For the above reaction, $\Delta H^\circ = -90 \text{ kJ mol}^{-1}$ and $\Delta S^\circ = -200 \text{ J K}^{-1} \text{ mol}^{-1}$.
Show that the prediction you made in (i) above is correct by calculating the ΔG° values of the reaction at 27 °C and 527 °C.

Applying $\Delta G^\theta = \Delta H^\theta - T\Delta S^\theta$ for two temperatures of

27 °C (300 K) and 527 °C (800 K)

$\Delta G^\theta_{300\,K} = -90\ kJ\ mol^{-1} - 300\ K\ \times (-200\ \times\ 10^{-3}\ kJ\ K^{-1}\ mol^{-1})$

$\Delta G^\theta_{300\,K} = -30\ kJ\ mol^{-1}$ ---------- **(02+02+01)**

$\Delta G^\theta_{800\,K} = -90\ kJ\ mol^{-1} - 800\ K\ \times (-200\ \times\ 10^{-3}\ kJ\ K^{-1}\ mol^{-1})$

$\Delta G^\theta_{300\,K} = +70\ kJ\ mol^{-1}$ ---------- **(02+02+01)**

$\therefore\ \Delta G^\theta$ becomes positive at higher temperatures. ---------- **(05)**

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$\therefore$ The prediction made in (i) is correct.

(if this fact is explained by stating that the reaction is exothermic and hence the reaction proceeds backward as the temperature increased **AWARD ONLY 05 MARKS)**

(iii) Consider the reaction $2NH_3(g) \rightleftharpoons N_2(g) + 3H_2(g)$ occurring in a closed-rigid container at 450 °C.

I. Predict the effect of increasing the temperature on the value of $\left(\frac{[NH_3(g)]^2}{[N_2(g)][H_2(g)]^3}\right)$.

This reaction is endothermic. ---------- **(05)**
The forward reaction is favored at higher temperatures

$\therefore \frac{[NH_{3(g)}]^2}{[N_{2(g)}]\ [H_{2(g)}]^3}$ ratio decreases **(05)**

II. Comment on the time taken for the reaction above to reach the equilibrium in the presence and absence of a catalyst at 450 °C.

Time needed for equilibrium is lower with catalyst **(05)** and no change in the value of equilibrium constant.

III. Explain your answer in II above.

In the presence of a catalyst, both forward and backward reactions occur faster **(03)** and reaction goes through a different mechanism **(03)** having less activation energies. **(04)**

5(b): 60 marks

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(c) (i) Define the 'normal boiling point' of a pure liquid.

Normal boiling point of a pure liquid is the temperature at which the liquid is in equilibrium with its vapor or boils at 1 atm (100 kPa) pressure. **(05)**

OR

The temperature at which the saturated vapour pressure of the liquids equals **1** atm (100 kPa) pressure.

(ii) Write the equilibrium present at the boiling point of pure $CCl_4(l)$.

$CCl_4(l) \rightleftharpoons CCl_4(g)$ OR $CCl_4(g) \rightleftharpoons CCl_4(l)$ **(05)**

(iii) Given that, $\Delta H^{\circ}_{CCl_4(g)} = -95\ kJ\ mol^{-1}$, $\Delta H^{\circ}_{CCl_4(l)} = -128\ kJ\ mol^{-1}$

$\Delta S^{\circ}_{CCl_4(g)} = 309\ J\ K^{-1}\ mol^{-1}$, $\Delta S^{\circ}_{CCl_4(l)} = 214\ J\ K^{-1}\ mol^{-1}$

Calculate the normal boiling point of $CCl_4(l)$.

$\Delta H^{\Theta}_{rxn} = -95 - (-128) = 33\ kJ\ mol^{-1}$ **(02+02+01)**

$\Delta S^{\Theta}_{rxn} = 309 - 214 = 95\ J\ K^{-1}\ mol^{-1} = 95 \times 10^{-3}\ kJ\ K^{-1}\ mol^{-1}$ **(02+02+01)**

Applying $\Delta G^{\Theta} = \Delta H^{\Theta} - T\Delta S^{\Theta}$

At equilibrium; $\Delta G^{\Theta} = 0$ *and hence* $\Delta H^{\Theta} = T_b\Delta S^{\Theta}$; T_b is the boiling point **(05)**

$T_b = \frac{\Delta H^{\Theta}}{\Delta S^{\Theta}} = \frac{33\ kJ\ mol^{-1}}{95 \times 10^{-3}\ kJ\ K^{-1}\ mol^{-1}} = 347\ K = 74\ °C$ **(02+02+01)**

5(c): 30 marks

NOTE: PHYSICAL STATES ARE NECESSARY

6. (*a*) Consider the reaction $2NO(g) + Cl_2(g) \rightarrow 2NOCl(g)$ at 25 °C.
The results of an initial-rate experiment carried out at 25 °C for the reaction above are shown below. $[NO(g)]_0$ and $[Cl_2(g)]_0$ are the initial concentrations of NO(g) and $Cl_2(g)$, respectively.

Experiment	$[NO(g)]_0$/mol dm^{-3}	$[Cl_2(g)]_0$/mol dm^{-3}	$\frac{-\Delta[Cl_2(g)]}{\Delta t}$/mol dm^{-3} s^{-1}
1	0.25	0.50	0.75
2	0.25	1.00	3.00
3	0.50	2.00	24.00

(i) Write the expressions for the rate of the reaction with respect to each species appearing in the equation of the reaction.

$2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g)$

$Rate ; \frac{-\Delta[NO(g)]}{2\Delta t} ; \frac{-\Delta[Cl_2(g)]}{\Delta t} ; \frac{\Delta[NOCl(g)]}{2\Delta t}$ **(02x3)**

(ii) Write the rate expression/law for the reaction if the order of the reaction with respect to NO(g) and $Cl_2(g)$ are **a** and **b** respectively, and the rate constant is *k*.

$Rate = k[NO(g)]^a[Cl_2(g)]^b$ **(04)**

(iii) Calculate the values of **a** and **b** and overall order of the reaction.

From experiments 1 and 2;

$k(0.25)^a(0.50)^b = 0.75$ (1) **(04)**

$k(0.25)^a(1.00)^b = 3.00$ (2) **(04)**

$\frac{(1)}{(2)} : \frac{k(0.25)^a(0.50)^b}{k(0.25)^a(1.00)^b} = \frac{0.75}{3.00}$ **(04)**

$\frac{1}{4} = \left(\frac{1}{2}\right)^b ; \; b = 2$ **(04)**

(OR: when [NO(g)] is constant, $[Cl_2(g)]$ is doubled, rate is 4 times

Therefore, order b = 2)

From experiments 2 and 3;

$k(0.50)^a(2.00)^b = 24.00$ (3) **(04)**

$k(0.25)^a(0.50)^b = 3.00$ (2)

$\frac{(3)}{(2)} : \frac{k(0.50)^a(2.0)^b}{k(0.25)^a(1.00)^b} = \frac{24.00}{3.00} = 8$ **(04)**

$(2)^a(2)^2 = 8 = (2)^{(a+2)}$

$(a + 2) = 3 : \; a = 1$ **(04)**

Overall order = (2 + 1) = 3 **(04)**

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(iv) Calculate the rate constant k of the reaction at 25 °C.

$Rate = k[NO(g)][Cl_2(g)]^2$ **(04)**

From experiments 1;

$k(0.25)(0.50)^2 = 0.75$ **(04)**

$k = 12\ dm^6\ mol^{-2}\ s^{-1}$ **(04+01)**

13

(v) Calculate the rate of disappearance of $Cl_2(g)$ at 25 °C when the initial concentrations of NO(g) and $Cl_2(g)$ are 0.50 and 0.10 mol dm^{-3}, respectively.

$Rate\ of\ dissapearence\ of\ Cl_2(g) = \frac{-\Delta[Cl_2(g)]}{\Delta t}$

$= 12 \times (0.50)(0.10)^2 = 0.06\ mol\ dm^{-3}\ s^{-1}$ **(02+01)**

(vi) Calculate the rate of formation of NOCl(g) at 25 °C when the rate of disappearance of $Cl_2(g)$ is 4.5 mol dm^{-3} s^{-1} at 25 °C.

$(Rate\ of\ formation\ of\ NOCl(g) = \frac{\Delta[NOCl(g)]}{\Delta t}$

In the reaction; 2 mol NOCl(g) ≡ $1\ mol\ Cl_2(g)$

$\frac{\Delta[NOCl(g)]}{2\,\Delta t} = \frac{-\Delta[Cl_2(g)]}{\Delta t}$

$\frac{\Delta[NOCl(g)]}{\Delta t} = \frac{2\,\Delta[Cl_2(g)]}{\Delta t}$ **(04)**

$= 2 \times 4.5 = 9.0\ mol\ dm^{-3}\ s^{-1}$ **(04+01)**

09

(vii) Calculate the rate of formation of NOCl(g) at 25 °C when the initial concentrations of NO(g) and $Cl_2(g)$ are 0.20 and 0.30 mol dm^{-3}, respectively.

02 02 01

$Rate\ of\ reaction = 12 \times (0.20)(0.30)^2 = 0.216\ mol\ dm^{-3}\ s^{-1}$ **(02+01+01)**

$Rate\ of\ formation\ of\ NOCl(g) = 2 \times 0.216 = 0.432\ mol\ dm^{-3}\ s^{-1}$ **(02+01+01)**

02 02 01

08

6(a): 75 marks

(*b*) The reaction of Cu powder with nitric acid results in the formation of a red-brown gas containing N and O. In an experiment carried out at 33 °C, the produced gas was collected to a 150 cm^3 vessel. The pressure and mass of the gas were 831.4 mm Hg and 0.300 g, respectively. Calculate the molar mass of the produced gas and give its chemical formula. State the assumption/s made. (1 mm Hg = 133.3 Pa, N = 14, O = 16)

Assuming the ideal gas behavior; **(05)**

$PV = nRT = \frac{m}{M} RT$ **(05+05)**

$P = \frac{m}{V\,M} RT$ **(05)**

$M = \frac{d\,RT}{P}$; $d: density\ of\ the\ gas = \frac{0.30\ g\ dm^{-3}}{150\times10^{-3}} = 2\ g\ dm^{-3}$

04 + 01

$M = \frac{d\,RT}{P} = \frac{2.0\times10^{3} gm^{-3}\times 8.314\ J\ K^{-1}\ mol^{-1}\times 306\ K}{831.4\times 133\ Pa} = 46\ g\ mol^{-1}$ **(05+05)**

(05 for substitution and 05 for answer)

∴ ***The gas is*** NO_2 **(05)**

6(b): 35 marks

(*c*) Two identical containers A and B, contain equal volumes of pure water and 3.0 mol dm^{-3} glycerol aqueous solution, respectively, at a given temperature. Giving reasons, compare,

(i) the vapour pressures of the contents in A and B.

Vapor pressure of glycerol solution is less than that of pure water **(05)** because there is some solvated glycerol is present at the surface layer of the solution.**(05)**

(ii) the boiling points of the contents in A and B.

As the vapor pressure is low for glycerol solution, the boiling point is higher than that of pure water. **(05)**

6(c): 15 marks

(*d*) At a given temperature, an ideal binary liquid mixture was prepared by mixing liquids C and D in a closed container. At this temperature, vapour pressures of C and D are P_C and P_D respectively, and saturated vapour pressures of C and D are P_C° and P_D° respectively. The mole fractions of C and D in the liquid phase are X_C and X_D respectively.

(i) Derive the expression for the relative lowering of the vapour pressure of C at this temperature.

According to the Roultz law, we can write $P_C = P_C^0 X_C$ **(05)**

Lowering of the vapor pressure of the component C = $P_C^0 - P_C = P_C^0 - P_C^0 X_C$ **(05)**

$= P_C^0(1 - X_C) = P_C^0(X_D)$

∴ Relative lowering of the vapor pressure of C $= \frac{P_C^0 - P_C}{P_C^0} = X_D$ **(05)**

15

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(ii) A solution was prepared by dissolving 1.0 mol of glycerol in 900 g of water at 25 °C. Calculate

I. the relative lowering of the vapour pressure (mm Hg)

$$\frac{P_C^0 - P_C}{P_C^0} = X_D = \frac{n_D}{n_D + n_C} = \frac{1}{1 + (900/18)} = \frac{1}{51} \approx 0.02$$ **(02+03)**

II. the vapour pressure (mm Hg) of the solution.

$$\frac{24 - P_C}{24} = 0.02 \quad : P_C = 23.52\ mmHg$$ **(02+02+01)**

At 25 °C, saturated vapour pressure of water is 24 mm Hg. (H = 1, O = 16)
At 25 °C, saturated vapour pressure of glycerol is negligible.

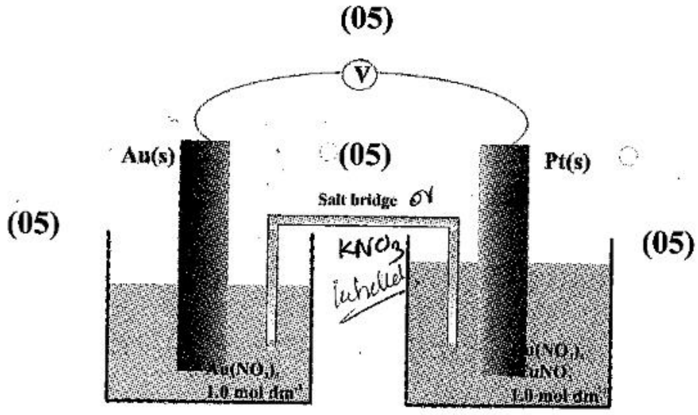
6(d): 25 marks

NOTE: PHYSICAL STATES ARE NECESSARY

7. (*a*) The following electrochemical cell was constructed to study the electrochemical behaviour of the reaction, $3Cu^+(aq) + Au^{3+}(aq) \rightarrow 3Cu^{2+}(aq) + Au(s)$ at 25 °C. The cell consists of an Au(s) electrode in a beaker with 1.0 mol dm^{-3} $Au(NO_3)_3(aq)$ solution and a Pt(s) electrode in another beaker filled with a solution containing 1.0 mol dm^{-3} each of $CuNO_3(aq)$ and $Cu(NO_3)_2(aq)$. The two half-cells were connected *via* a salt-bridge filled with saturated $KNO_3(aq)$ solution and a voltmeter.

$E^\circ_{Au^{3+}(aq)/Au(s)} = 1.50$ V and $E^\circ_{Cu^{2+}(aq)/Cu^+(aq)} = 0.16$ V at 25 °C.

(i) Draw a sketch of the electrochemical cell.



Since this is a sketch, marks can be allowed even two sides are interchanged

(20)

(ii) Identify the anode and the cathode of the cell and write the respective half reactions.

Cathode: $Au^{3+}_{(aq)} | Au_{(s)}$: $half - reaction$: $Au^{3+}_{(aq)} + 3e \rightarrow Au_{(s)}$ **(02+03)**

Anode: $Cu^{2+}_{(aq)} | Cu^{+}_{(aq)}$: $half - reaction$: $Cu^{+}_{(aq)} \rightarrow Cu^{2+}_{(aq)} + e$ **(02+03)**

* no marks for ⇌ sign.

(iii) Identify the positive and negative terminals of this electrochemical cell.

Positive terminal : $Au^{3+}_{(aq)} | Au_{(s)}$ (Au electrode) **(03)**

Negative terminal : $Cu^{2+}_{(aq)} | Cu^{+}_{(aq)}$ (Pt electrode) **(03)**

(iv) Calculate E°_{cell} at 25 °C.

$E^0_{cell} = E^0_R - E^0_L$ or $E^0_{cathode} - E^0_{anode}$ or $E^0_{Au^{3+}_{(aq)}| Au_{(s)}} - E^0_{Cu^{2+}_{(aq)}| Cu^{+}_{(aq)}}$ **(04)**

02 02+01

$= (1.5 - 0.16)V = 1.34\,V$ **(02+02+01)** 09

(v) Does the mass of the Pt(s) electrode increase, decrease or remain the same as the cell operates? Explain your answer.

04 03 03

Remain the same :Pt(s) does not react and no Cu(s) formed **(04+03+03)**

(vi) State the ionic species present in the Au(s)-half cell before and after the cell operates.

Before: $Au^{3+}_{(aq)}$ and $NO^{-}_{3(aq)}$ **(01+01)**

After: $Au^{3+}_{(aq)}$, $NO^{-}_{3(aq)}$ and $K^{+}_{(aq)}$ **(01+01+01)**

(vii) After the cell has operated for 30 minutes at 25 °C, 0.197 g of Au(s) was deposited on the Au(s) electrode.

I. Calculate the number of Au moles deposited. (Au = 197 g mol^{-1})

Au(s) moles formed = $\frac{0.197\,g}{197\,g\,mol^{-1}} = 1.0 \times 10^{-3}\,mol$ **(04+01)**

II. Calculate the current (mA) which passed through the cell during the 30 minute period, assuming the current remained constant.

Current, $I = \frac{q}{t}$ **(05)**

can be any

$= \frac{1.0 \times 10^{-3} \times 3 \times 96500}{30 \times 60} = 161\,mA$ or $0.161\,A$ do not chk the answer. **(04+01)**

Substitution of any value or symbol to Faraday constant award the above **05** marks.

* when a potentiometer is connected, only ⇌ can be written for the half cells.

7(a): 75 marks

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(*b*) (i) **A**, **B**, **C**, **D** and **E** are coordination compounds. They have an octahedral geometry.

I. Give the structural formulae or draw the structures of these coordination compounds, selecting the appropriate species from the list given below.

Na^{+}, Cu^{+}, Cu^{2+}, Br^{-}, NH_3

A : An equal number of two types of ligands are coordinated to the metal ion. Its complex ion has a charge of –1.

B : Two types of ligands are coordinated to the metal ion. On addition of $AgNO_3(aq)$ to an aqueous solution of **B**, a pale yellow precipitate soluble in conc. NH_4OH is formed.

C and D : **C** and **D** contain the same elements. However, the complex ion of **C** has a charge of –2, while that of **D** has a charge of –3.

E : Only one type of ligand is coordinated to the metal ion. **E** gives two ions in aqueous solution.

Note : • A complex ion has one metal ion with multiple ligands coordinated to it.

should be drawn

A : $Na[CuBr_3(NH_3)_3]$ **(10)**

B: $[CuBr(NH_3)_5]Br$ ← should be after the [ ] **(10)**

C: $Na_2[CuBr_4(NH_3)_2]$ or $Na_2[CuBr_3(NH_3)_3]$ **(10)**

D: $Na_3[CuBr_4(NH_3)_2]$ or $Na_3[CuBr_5(NH_3)]$ **(10)**

E: $[Cu(NH_3)_6]Br$ **(10)**

Note: Appropriate counter ion for the complexes **A, C,** and **D** is **Na^{+}**. However, if the formula is given correctly and Cu^{+} or Cu^{2+} is given as the counter ion, **award 05 marks** only

II. Give the IUPAC name of **E**.

hexaamminecopper(I) bromide — no marks if 'E' is correct. **(05)**

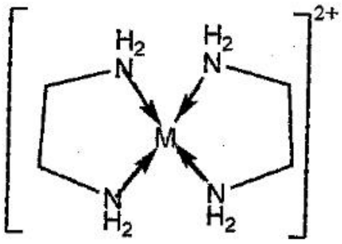
7(b) (i) : 55 marks

AL/2 IE/23

(ii) **X** and **Y** are complex ions of a *d*-block metal ion M(II).
They have a square planar geometry.
X : Only ethylenediamine is coordinated to M(II).
Y : Ethylenediamine and H_2O are coordinated to M(II).
Write the structural formulae of **X** and **Y** and draw their structures.

Note :
- A complex ion has one metal ion with multiple ligands coordinated to it.
- Structure of ethylenediamine $NH_2—CH_2—CH_2—NH_2$.
- Ethylenediamine coordinates to M(II) through both N atoms.
- Use 'en' to denote ethylenediamine in the structural formula.

X: $[M(en)_2]^{2+}$



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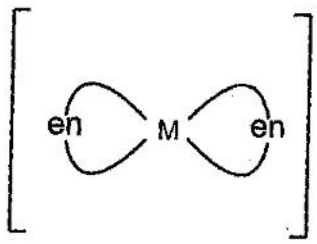

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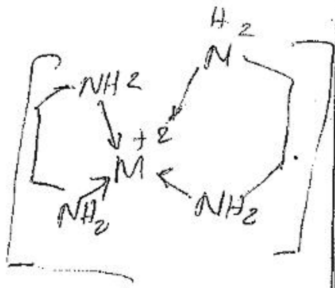
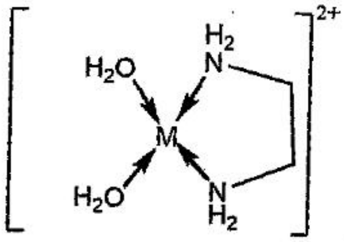


Y: [M(en)~~2~~(OH$_2$)$_2$]$^{2+}$



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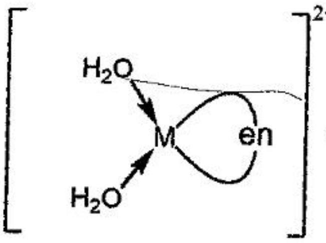

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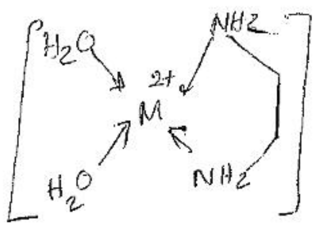

Note: Covalent bonds could be given instead of dative bonds. **(05 x 4 = 20 marks)**

7(b): 45 marks

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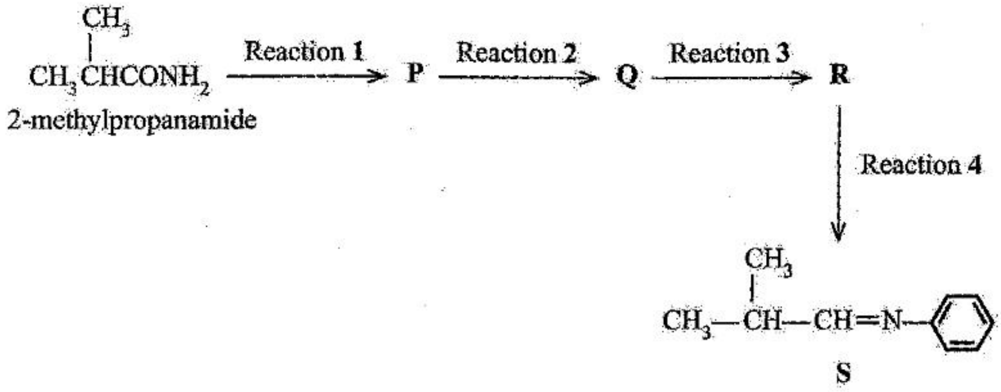
PART C — ESSAY

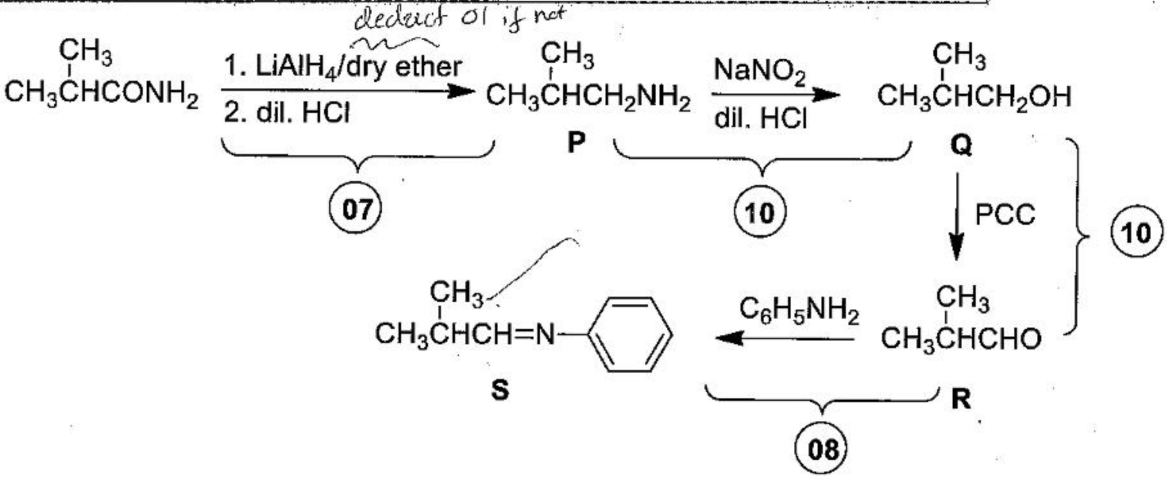
Answer two questions only. (Each question carries **150** ***marks.***)

8. (*a*) Given below is a reaction scheme for the preparation of compound **S** using 2-methylpropanamide as the starting compound.



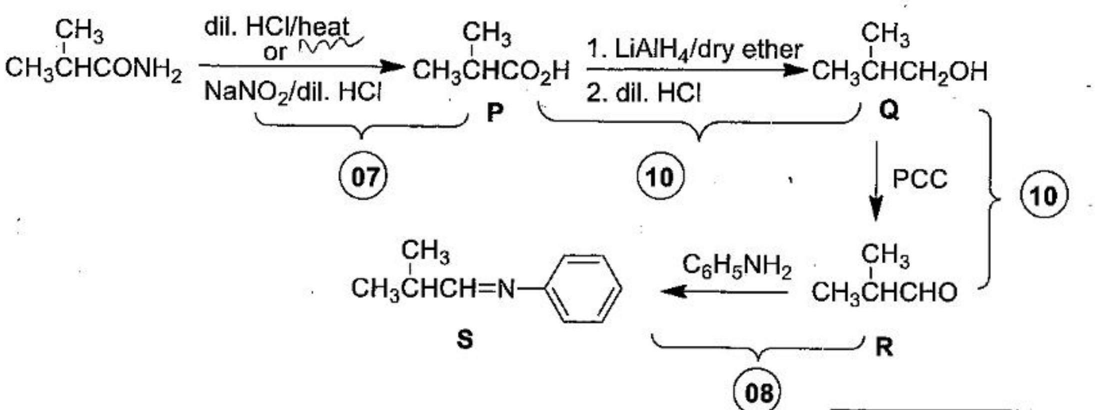
Complete the above reaction scheme by drawing the structures of compounds **P**, **Q** and **R**, and writing the appropriate reagents for reactions **1 – 4**, selecting **only** from the list given below.

List of reagents:
$LiAlH_4$/dry ether, $NaNO_2$, dil. HCl, Pyridinium chlorochromate (PCC), $C_6H_5NH_2$



Deduct **01 mark** if dry ether is not written in Reaction 1

Alternate marking scheme for 8(a)



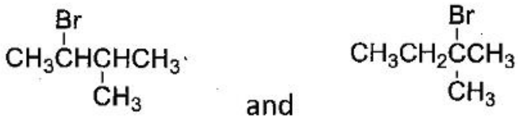
Deduct **01 mark** if dry ether is not written in Reaction 2

8(a): 35 marks

(b) Consider the reaction of 2-methyl-2-butene with HBr.

(i) Give the structures of the two products that could possibly be formed in this reaction.

The two products that could be formed are:



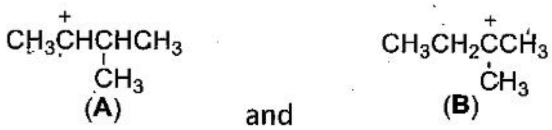
05 + 05

(ii) Stating the type of the reaction and considering the mechanism of the reaction, explain which of these two products is the major product.

(30 marks)

The reaction is an electrophilic addition reaction, and it takes place *via* carbocation. 04

The two carbocations that could be formed are:

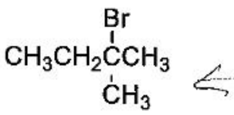


03 + 03

20

Carbocation **B** is more stable than **A**, because it is a tertiary carbocation. Therefore, the reaction proceeds through carbocation **B**. 03 + 03

Therefore, the major product is:

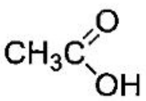


04

8(b): 30 marks

(c) Consider the two compounds, phenol and acetic acid.

(i) State which of these two compounds is more acidic.

(i)  06 or word acetic acid

(ii) Write the chemical equations for the equilibria existing in aqueous medium for each of the compounds.

(ii)  05 or $H^+_{(aq)}$

or 

$$CH_3COOH + H_2O \rightleftharpoons CH_3COO^- + H_3O^+$$ 05 or $H^+_{(aq)}$

$$CH_3COOH_{(aq)} \rightleftharpoons CH_3COO^-_{(aq)} + H^+_{(aq)}$$

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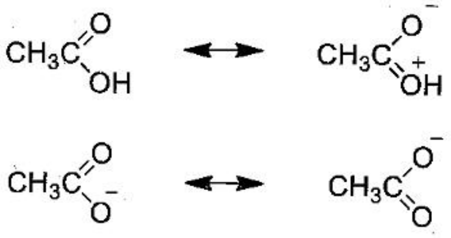
(iii) Draw the resonance structures of the organic chemical species written in the answer to (ii) above.

(iii)

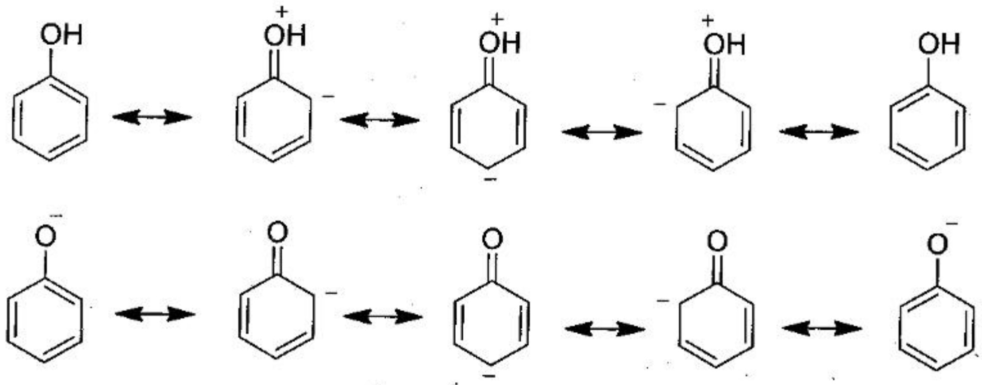
I



(02)

(02)

II



(05)

(05)

Award **01** mark for each correct structure

(iv) Considering the resonance structures, explain your answer to (i) above.

The stabilization of the acetate anion and the phenoxide anion by resonance is respectively greater than the stabilization of acetic acid and phenol. This is because unlike in the resonance structures of acetic acid and phenol, there is no charge separation in the resonance structures of their anions.

(02)

The resonance stabilization of the acetate anion relative to that of acetic acid is greater than the resonance stabilization of the phenoxide anion relative to that of phenol.

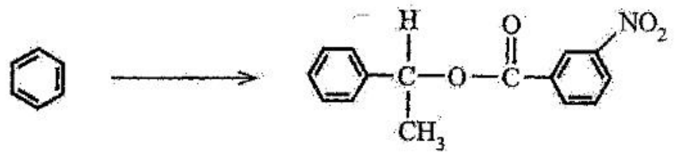
(08).

This is because, while the acetate anion is stabilized by delocalization of its negative charge over two oxygen atoms (**05**), in the phenoxide anion its negative charge is delocalized over one oxygen atom and the carbon atoms (which are less electronegative than oxygen) of the aromatic ring (**05**).
Therefore, acetic acid is more acidic than phenol.

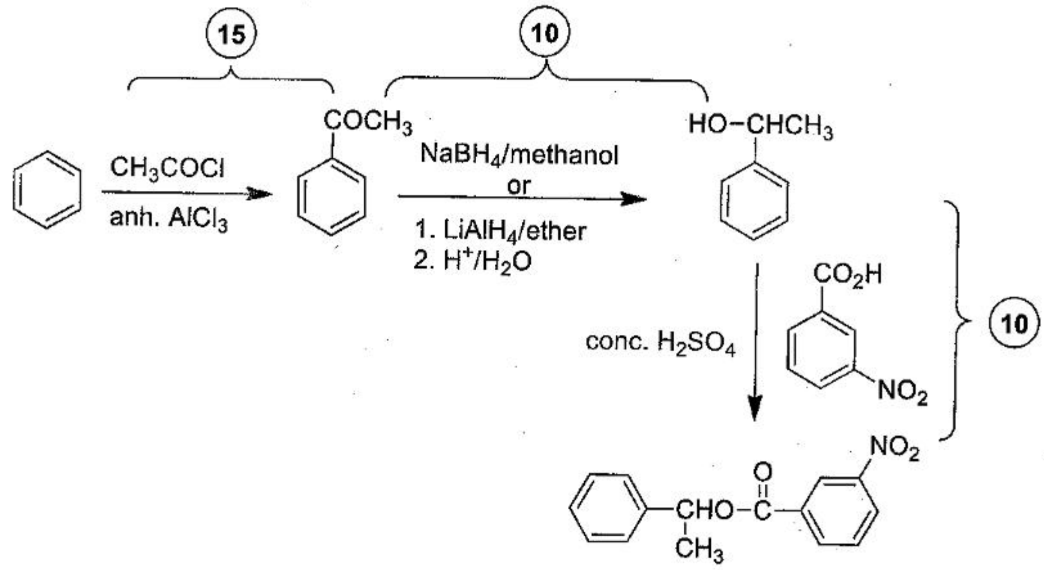
resonance stabilization => not resonance stability.

8(c): 50 marks

(*d*) Show how you would carry out the following conversion in not more than **five (05)** steps.



(35 *marks*)



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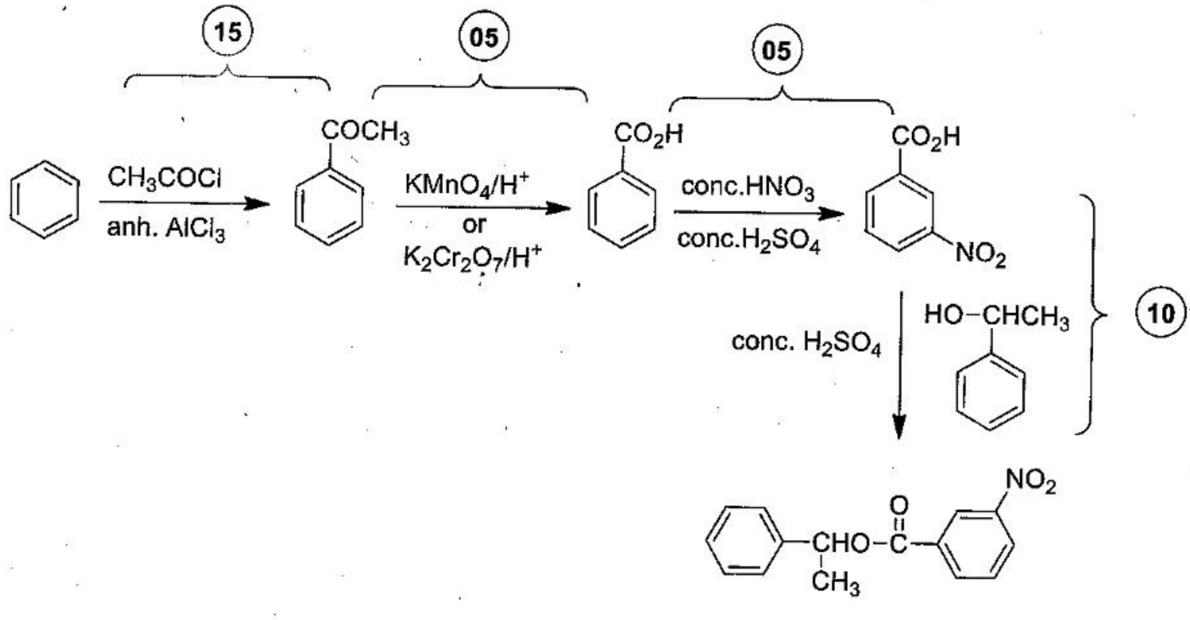

8(d): 35 marks

Note: There may be other reaction schemes given as answers by the students. Marks should be awarded as follows.
However, **IF the answer contains more than 5 steps, NO marks for any step.**

- Introduction of a suitable group through a C – C bond to the benzene ring **- 15 marks**
- Esterification reaction between the correct alcohol and acid **- 10 marks**
- Other reactions in the scheme, if **completely correct** **- 10 marks**

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9. (*a*) An aqueous solution **Y** contains four cations **P, Q, R** and **S**. The following experiments were carried out in sequence to identify these cations.

	Experiment	Observation
1	**Y** was acidified with dil. HCl.	a white precipitate ($\mathbf{P_1}$)
2	$\mathbf{P_1}$ was separated by filtration and H_2S was bubbled through the resulting filtrate.	no precipitate
3	The above filtrate was boiled to completely remove the H_2S. A few drops of conc. HNO_3 were added, the solution was boiled, cooled and NH_4Cl/NH_4OH were added.	a brown precipitate ($\mathbf{Q_1}$)
4	$\mathbf{Q_1}$ was separated by filtration and H_2S was bubbled through the resulting filtrate.	a black precipitate ($\mathbf{R_1}$)
5	$\mathbf{R_1}$ was separated by filtration, the resulting filtrate was boiled to completely remove the H_2S, cooled and NH_4Cl/NH_4OH were added. This solution was warmed and $(NH_4)_2CO_3(aq)$ was added in excess.	a white precipitate ($\mathbf{S_1}$)

The following tests were carried out for the precipitates.

Precipitate	Test	Observation
$\mathbf{P_1}$	dil. NH_4OH was added to $\mathbf{P_1}$.	a colourless solution ($\mathbf{P_2}$)
	The following solutions were added separately to aliquots of $\mathbf{P_2}$.	
	I. KI(aq)	a dark yellow precipitate ($\mathbf{P_3}$)
	II. $Na_2S_2O_3(aq)$ / Δ	a black precipitate ($\mathbf{P_4}$)
$\mathbf{Q_1}$	$\mathbf{Q_1}$ was dissolved in dil. HNO_3. The following solutions were added separately to aliquots of the resulting solution.	
	I. $NH_4SCN(aq)$	a deep red solution ($\mathbf{Q_2}$)
	II. $K_4[Fe(CN)_6](aq)$	a dark blue precipitate ($\mathbf{Q_3}$)
$\mathbf{R_1}$	$\mathbf{R_1}$ was dissolved in warm dil. HCl, the solution was cooled and the following solutions were added separately to aliquots of the resulting solution.	
	I. a few drops of dil. NH_4OH	a green precipitate ($\mathbf{R_2}$)
	II. excess dil. NH_4OH	a deep blue solution ($\mathbf{R_3}$)
	III. a few drops of dil. NH_4OH/ dimethylglyoxime (DMG)	a deep red precipitate ($\mathbf{R_4}$)
$\mathbf{S_1}$	$\mathbf{S_1}$ was dissolved in dil. HCl. The following solutions were added separately to aliquots of the resulting solution.	
	I. dil. H_2SO_4	a white precipitate that was insoluble in dil. HNO_3 ($\mathbf{S_2}$)
	II. $K_2CrO_4(aq)$	a yellow precipitate ($\mathbf{S_3}$)
	$\mathbf{S_1}$ was subject to the flame test.	a pale green flame

Identify the four cations **P, Q, R** and **S**. Write chemical formulae of the compounds/species $\mathbf{P_1}$–$\mathbf{P_4}$, $\mathbf{Q_1}$–$\mathbf{Q_3}$, $\mathbf{R_1}$–$\mathbf{R_4}$, and $\mathbf{S_1}$–$\mathbf{S_3}$ associated with each cation.

Note : Chemical equations and reasons are **not** required.

(a)

P:	Ag^{+}	**(05)**
Q:	Fe^{2+} or Fe^{3+}	**(05)**
R:	Ni^{2+}	**(05)**
S:	Ba^{2+}	**(04)**

P_1:	$AgCl$	**(04)**
P_2:	$[Ag(NH_3)_2]^{+}$	**(04)** may have OH^- or Cl^- as counter ion
P_3:	AgI	**(04)**
P_4:	Ag_2S	**(04)**

Q_1:	$Fe(OH)_3$	**(04)**
Q_2:	$Fe(SCN)_3$ or $[Fe(SCN)(H_2O)_5]^{2+}$	**(04)***
Q_3:	$Fe_4[Fe(CN)_6]_3$ (or) $KFe[Fe(CN)_6]$	**(04)**

*number of SCN^- may vary from 1-6 but correct charge allocation has to be done accordingly

R_1:	NiS	**(04)**
R_2:	$[Ni(OH)_2]$	**(04)**
R_3:	$[Ni(NH_3)_6]^{2+}$	**(04)**
R4:	$[Ni(DMG)_2]$	**(04)****

**Ni-DMG complex can be accepted

S_1:	$BaCO_3$	**(04)**
S_2:	$BaSO_4$	**(04)**
S_3:	$BaCrO_4$	**(04)**

9(a): 75 marks

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(*b*) The mineral named siderite, contains mainly $FeCO_3$. Siderite is formed when calcium ions (Ca^{2+}) of $CaCO_3$ in limestone are replaced by ferrous ions (Fe^{2+}) over a long period of time. Therefore, $FeCO_3$ in siderite is mixed with $CaCO_3$. In addition, siderite also contains impurities such as silica in small quantities.

8.5 g of such a siderite sample was thermally decomposed at 900 °C under oxygen free conditions until a constant mass was obtained. The mass of the remaining sample was 5.2 g. During thermal decomposition, $CaCO_3$ is converted to CaO and $FeCO_3$ is converted to FeO.

Another 1.7 g of the above siderite sample was dissolved in excess dilute H_2SO_4 acid, filtered, and the resulting solution was diluted to 100.00 cm^3 with distilled water. When 25.00 cm^3 of the resulting solution was titrated with 0.04 mol dm^{-3} $KMnO_4$, the end-point reading of $KMnO_4$ was 12.50 cm^3.

Assume that the quantities of metals other than Fe and Ca in the siderite sample are negligible. (C = 12, O = 16, Ca = 40, Fe = 56)

(i) Calculate the mass percentage of $CaCO_3$ in the siderite sample.

$FeCO_3 \longrightarrow FeO + CO_2$ **(02)**

$CaCO_3 \longrightarrow CaO + CO_2$ **(02)**

Amount of CO_2 produced $= \frac{8.5\text{ g}-5.2\text{ g}}{44} = 0.075$ mol **(02) + (02)**

Total moles of $FeCO_3 + CaCO_3 = 0.075$ mol **(02)**

$KMnO_4$ required to react with 25.00 cm^3 of Fe^{+2} solution

$= 0.04 \times 12.5 \times 10^{-3}$ or 5×10^{-4} mol **(03)**

Amount of $KMnO_4$ required to react with 100 cm^3 of Fe^{2+} solution
(or Amount of $KMnO_4$ required to react with 1.7 g of Siderite sample)

$= 5 \times 10^{-4} \times \frac{100}{25}$ or 2×10^{-3} mol **(03)**

Amount of $KMnO_4$ required to react with 8.5 g of Siderite sample

$= 2 \times 10^{-3} \times \frac{8.5}{1.7}$ or 0.01 mol **(03)**

steps can be combined

$5\,Fe^{2+} + MnO_4^- + 8H^+ \longrightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$ **(04)**
(*balanced ionic or chemical equation*)

Amount of $FeCO_3$ in 8.5 g of Siderite sample = 0.01×5 or 0.05 mol **(03)**

Amount of $CaCO_3$ in 8.5 g of Siderite sample = 0.075 - 0.05 or 0.025 mol **(03)**

Mass of $CaCO_3$ = 0.025×100 or 2.5 g **(03)**

For molar mass of 100 for $CaCO_3$ .... **(01)**

Mass % of $CaCO_3 = \frac{2.5\text{ g}}{8.5\text{ g}} \times 100 = 29.4\%$ **(03) + (02)**

Note: The mass conversion (8.5 to 1.7 or 1.7 to 8.5) can be done at any step and relevant 03 marks can be awarded.

9(b)(i) 38 marks

Alternate answer

$FeCO_3 \longrightarrow FeO + CO_2$ **(02)**

$CaCO_3 \longrightarrow CaO + CO_2$ **(02)**

Amount of $KMnO_4$ required = $0.04 \times 12.5 \times 10^{-3}$ or 5×10^{-4} mol **(03)**

$5\,Fe^{2+} + MnO_4^{-} + 8H^{+} \longrightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$ **(04)**

Amount of Fe^{2+} in 25 cm^3 $= 5 \times 10^{-4} \times 5 = 2.5 \times 10^{-3}$ mol **(03)**

Amount of Fe^{2+} in 100 cm^3 $= 2.5 \times 10^{-3} \times 4 = 1 \times 10^{-2}$ mol **(03)**

Amount of Fe^{2+} in 8.5 g of Siderite sample $= \frac{1 \times 10{-}2\ \text{mol}}{1.7\ g} \times 8.5$ g

$= 0.05$ mol **(03)**

Moles of CO_2 from $FeCO_3$ $= 0.05 \times 44$ g mol^{-1}

For molar mass of 44 for CO_2 **(01)**

$= 2.2$ g **(03)**

Total mass of CO_2 $= 8.5\ g - 5.2\ g = 3.3$ g **(02)**

Mass of CO_2 from $CaCO_3$ $= 3.3\ g - 2.2\ g = 1.1$ g **(02)**

Moles of $CaCO_3$ $= \frac{13.3\ g - 2.2\ g}{44} = 0.025$ mol * **(01)**

Mass of $CaCO_3$ = 0.025 mol x 100 g mol^{-1}

$= 2.5$ g **(03)**

For molar mass of $CaCO_3$ **(01)**

Mass % of $CaCO_3$ $= \frac{2.5\ g}{8.5\ g} \times 100 = 29.4\%$ Sub. **(03)** + **(02)**

(ii) Calculate the percentage of impurities, other than $CaCO_3$, in the siderite sample.

Mass of $FeCO_3$ in 8.5 g of Siderite sample $= 0.05 \times 116$

$= 5.8$ g **(03)**

For molar mass of 116 for $FeCO_3$ **(01)**

Mass of $FeCO_3$ and $CaCO_3$ $= 2.5 + 5.8 = 8.3$ g **(03)**

% of impurities $= \frac{8.5 - 8.3}{8.5} \times 100$ Silica mass = 0.2 **(03)**

$= 2.35\%$ $\frac{0.2}{8.5} \times 100\%$ **(02)**

9(b)(ii) 12 marks

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Alternate answer for 9(b) (ii)

Mass % of $CaCO_3$ = 29.4%

Mass of $FeCO_3$ = 0.05 ×116 or 5.8 g **(02)**

For molar mass of 116 for $FeCO_3$ **(01)**

Mass % of $FeCO_3$ = $\frac{5.8}{8.5} \times 100\%$ **(02)**

= 68.24% **(02)**

Total % = 29.4 + 68.24 = 97.64% **(03)**

% of impurities = 100 - 97.64 = 2.36% **(02)**

Ignore the difference in the second decimal place

9(b)(ii) 12 marks

(iii) When 8.5 g of the siderite sample was thermally decomposed in the presence of oxygen, $FeCO_3$ decomposes giving Fe_2O_3 and Fe_3O_4 in 1:1 molar ratio whereas $CaCO_3$ decomposes to CaO.
Calculate the mass of the remaining residue after this thermal decomposition.

8.5 g of Siderite sample has 0.05 moles of $FeCO_3$

$5FeCO_3 + O_2 \longrightarrow Fe_2O_3 + Fe_3O_4 + 5CO_2$ **(06)**

moles 0.05 0.01 0.01 **(01) + (01) + (01)***

Mass of Fe_2O_3 = 0.01 × 160 = 1.6 g **(02)**

For molar mass of Fe_2O_3 as 160 **(01)**

*These **03** marks can be awarded here or using these mole values in the calculations

$CaCO_3 \longrightarrow CaO + CO_2$

moles 0.025 0.025 **(01) + (01)***

*These **02** marks can be awarded here or using these mole values in the calculations

Mass of Fe_3O_4 = 0.01 × 232 = 2.32 g **(02)**

For molar mass of Fe_3O_4 as 232 **(01)**

Mass of CaO = 0.025 × 56 = 1.4 g **(02)**

For molar mass of 56 for CaO **(01)**

Mass of the residue = 1.6 + 2.32 +1.4 + 0.2 = 5.52 g **(03) + (02)**

Alternate answer for 9(b) (iii)

$5FeCO_3 + O_2 \longrightarrow Fe_2O_3 + Fe_3O_4 + 5CO_2$ **(06)**

moles 0.05 0.01 0.05 **(01) + (01) + (01)***

$CaCO_3 \longrightarrow CaO + CO_2$

moles 0.025 0.025 **(01) + (01)***

*These **05** marks can be awarded here or using these mole values in the calculations

Initial mass of the Siderite sample:

8.5 g Siderite sample + 0.01 mol (0.32 g) = 8.83 g **(03)**

Loss of weight = 0.05×44 (from $FeCO_3$) + 0.025×44 (from $CaCO_3$) **(03)**

= 2.2 g + 1.1 g = 3.3 g **(03)**

Mass of the residue = 8.82 - 3.3 = 5.52 g **(03) + (02)**

9(b) (iii) 25 marks

9(b): 75 marks

10. (*a*) Consider the industrial manufacture of TiO_2.

(i) Name the process by which TiO_2 is produced from rutile.

Chloride process **(05)**

(ii) Name the required raw materials (other than rutile) for the above process.

coke **(04)**
Cl_2 **(04)**
O_2(air) **(04)**

(iii) Name the **two** main steps associated with the above process.

Chlorination **(04)**
Oxidation **(04)**

(iv) Give balanced chemical equations for the reactions which take place under each of the above mentioned steps.

<u>Chlorination</u>

$TiO_2(s) + C(s) \rightarrow Ti(s) + CO_2(g)$ --------(A) **(05)**

Stream of chlorine is passed over mixture of rutile and coke

$Ti(s) + 2Cl_2(g) \rightarrow TiCl_4(g)$ --------(B) **(05)**

OR

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

$TiO_2(s) + C(s) + 2Cl_2 \rightarrow TiCl_4(g) + CO_2(g)$ **(10)**

Note: Physical states not required to award marks for the balanced equation

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Oxidation

$TiCl_4$ is reacted with oxygen and TiO_2 is formed.
$TiCl_4(g) + O_2(g) \rightarrow TiO_2(s) + 2Cl_2(g)$ **(05)**

Note: Physical states not required

(v) Explain how the above process contributes to Global Warming.

combustion.
Burning of fuel / coke no marks for oxidation. **(05)**
Production of CO_2 during the process **(05)**

10(a): 50 marks

(*b*) NO, NO_2, SO_2, CH_4, CF_2Cl_2 and CF_2HCl are among the pollutants that contribute to various environmental problems. Except for the two halogenated compounds, the others are released into the environment through both natural processes and human activities.

(i) State **two** natural processes and **two** human activities that release NO to the environment.

Natural processes: lightning, nitrifying bacteria, volcanic eruptions

Any two

Human activities: motor vehicle emissions, industrial emissions, any combustion in air above 900 °C *Any two*

need the temp. steel, cement, glass
no marks for 'high temp'

(02 x 4 = 08 marks)

(ii) Acid rain, global warming, ozone layer depletion and photochemical smog are four major atmospheric problems. Briefly describe each of these phenomena and identify **two** gases each from the above list that make a **significant contribution** to each of the phenomena.

Acid rain: precipitation of acidic compounds from the atmosphere

Global warming: increased atmospheric temperature due to the increasing levels of greenhouse gases

Ozone layer depletion: reduction of stratospheric ozone levels due to the radicals that catalyse the destruction of ozone

Photochemical smog: formation of smoke and fog due to a series of chemical reactions in the lower atmosphere under the influence of sunlight.

(02 x 4 = 08 marks)

Contributors to acid rain: NO, NO_2, SO_2
Contributors to global warming: CH_4, CF_2Cl_2, CF_2HCl
Contributors to ozone layer depletion: NO, NO_2, CF_2Cl_2, CF_2HCl
Contributors to photochemical smog: NO, NO_2

Any two

Mark the first two answers only in each case

(02 x 8 =16 marks)

(iii) Explain why CF_2HCl was introduced as an alternative to CF_2Cl_2 as an attempt to protect the ozone layer.

CF_2Cl_2 is nonreactive in the troposphere *(2)*. The presence of an H in the CF_2HCl makes it more reactive than CF_2Cl_2 *(2)*. Thus, the chance of reaching CF_2HCl to the stratosphere is lower than that of CF_2Cl_2 *(2)*. Hence, the contribution of forming Cl radicals due to CF_2HCl is less than that of CF_2Cl_2 *(2)*.

(02 x 4 = 08 marks)

(iv) In an industrial zone where sulfur containing coal is used as a fuel, it is reported that fish are dying in nearby lakes. Giving reasons suggest a suitable method to control this environmental problem.

Burning of S-containing coal releases SO_2 into the atmosphere *(2)*. In the atmosphere, SO_2 is oxidised and dissolves in H_2O to form H_2SO_4 acid, contributing to acid precipitation and killing fish *(2)*. To prevent acid precipitation, SO_2 should be removed before it is released to the atmosphere *(2)*. Bases such as $CaCO_3$ or dolomite (or any other appropriate example) *(2)* can neutralise the acid, reducing the problem *(2)*.

(02 x 5 = 10 marks)

10(b): 50 marks

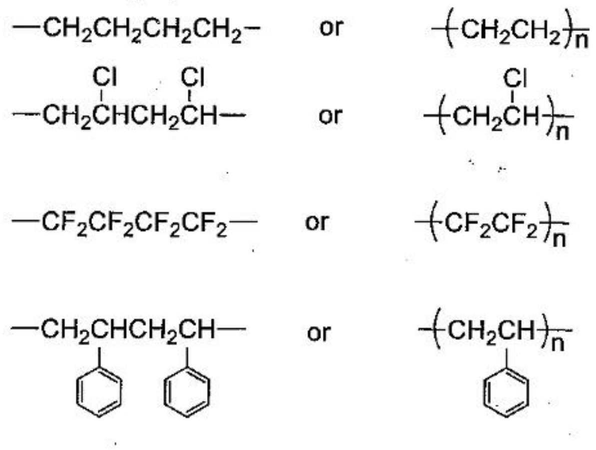
(c) (i) I. Give the classification of polymers according to the type of reaction taking place during the polymerization process.

Addition polymers
Condensation polymers

(04 × 2 = 08 marks)

II. Draw **two** structures each, for each of the classes of polymers you stated in (I) above.

Addition polymers:



Any two

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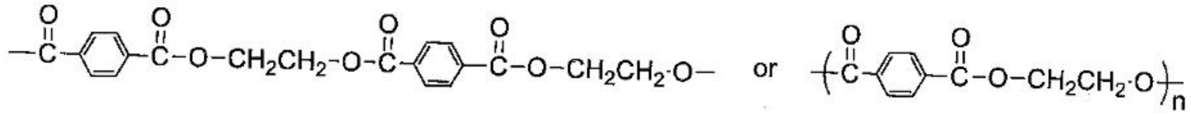
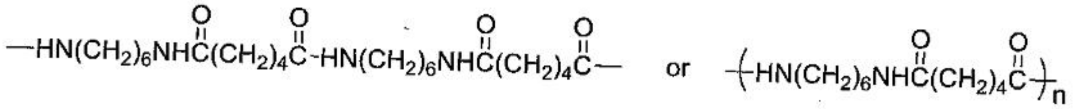
Condensation polymers

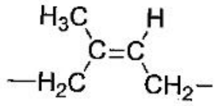




(03 × 4 = 12 marks)

10c (i) 20 marks

(ii) I. Draw the structure of the repeating unit of natural rubber.



(04)

II. Write the name of the process that is used to change the elastic property of natural rubber and name the substance used in the process.

Vulcanization

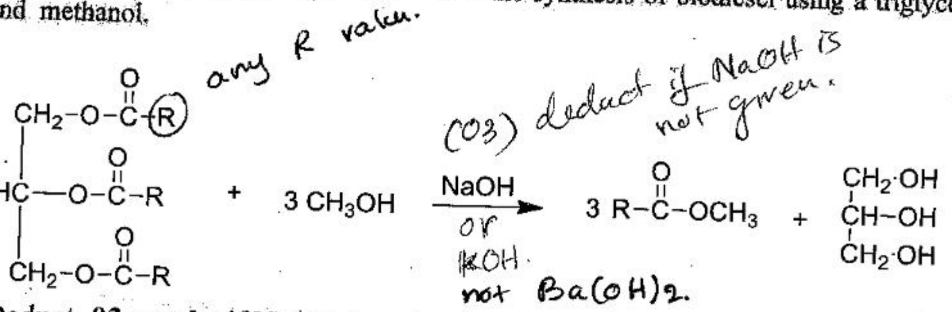
Sulphur

(03)

(03)

10c (ii) 10 marks

(iii) I. Give a balanced chemical equation to show the synthesis of biodiesel using a triglyceride and methanol.



[Deduct **03 marks** if NaOH is not written.]

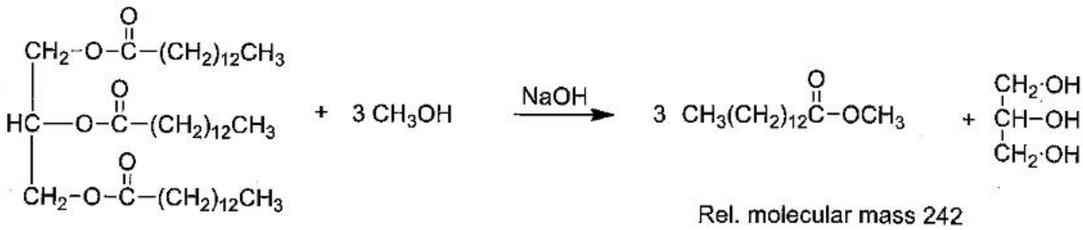
(08)

II. Write the name given to the type of reaction used in the production of biodiesel.

Transesterification

(04)

III. Calculate the mass of biodiesel produced from 7.22 g of the triglyceride of $CH_3(CH_2)_{12}COOH$. ($H = 1$, $C = 12$, $O = 16$)



Rel. molecular mass 722

Rel. molecular mass 242

722 g ⟶ $242 \times 3 = 726$ g

7.22 g ⟶ 7.26 g

Calculation of relative molecular mass of triglyceride	**(01)**
Calculation of the relative molecular mass of the methyl ester	**(01)**
Molar ratio	**(02)**
Answer	**(04)**

10c (iii) 20 marks

10(c): 50 marks

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Amendment 01

G.C.E. (A/L) Examination – 2025
02 - Chemistry

AMENDMENTS TO THE MARKING SCHEME – 2025 (CHEMISTRY)

(Date 21.12.2025)

Paper II – PART A - Structured Essay

2. (c) (iii) O_2(Air) and H_2O **(02 + 02)**

(v) If given as reacted with HCl **(02)**

Award **(04)** marks only if given as **conc.** HCl

Paper II – PART B - Essay

6. (b) The allocation of marks was changed and value of 133.3 to be used instead of 133

Assuming the ideal gas behavior; **(05)**

$PV = nRT = \frac{m}{M} RT$ **(05)**

$P = \frac{m}{V\,M} RT$ **(05)**

$M = \frac{d\,RT}{P}$; $d: density\ of\ the\ gas = \frac{0.30\ g\ dm^{-3}}{150\times10^{-3}} = 2\ g\ dm^{-3}$ **(04+01)**

$M = \frac{d\,RT}{P} = \frac{2.0\ g\ dm^{-3} \times 8.314\ J\ K^{-1}\ mol^{-1} \times 306\ K}{831.4\ mm\ Hg \times 133.3\ Pa} = 45.9 = 46\ g\ mol^{-1}$ **(05+05)**

(05 for substitution and 05 for answer)

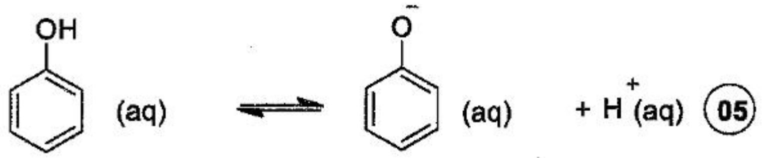
7. (b) (ii) M(II) or M^{2+} can be accepted instead of the charge on the complex.

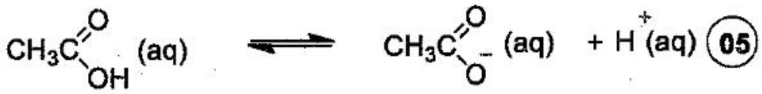
Lone pairs on metal M cannot be accepted.

Y : $[M(en)_2(OH_2)_2]^{2+}$ to be corrected as Y : $[M(en)(OH_2)_2]^{2+}$

Paper II – PART C - Essay

8(c)(ii) The following can be accepted.

(ii) 



9. (a) Q3 $KFe[Fe(CN)_6]$ can be accepted (given in translation of Browning & Joseph)

(04)

10 (b) iii Alternate answer

CF_2Cl_2 is nonreactive in the troposphere (*2*). The C–H bond in CF_2HCl is dissociated by solar rays in the lower atmosphere (*2*). Therefore, (considerable part of) this compound is decomposed before it reaches the ozone layer (*2*). Hence, the contribution of forming Cl radicals due to CF_2HCl is less than that of CF_2Cl_2 (*2*).

(08)

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