



Department of Examinations - Sri Lanka

G.C.E. (A/L) Examination - 2022 (2023)

02 - Chemistry

Marking Scheme

Predicting the direction of reaction.

The direction of net reaction depends on the relative values of Q_c and K_c .

Reactants \rightarrow Products Reactants and products are at equilibrium. Reactants \leftarrow Products

Movement toward equilibrium changes the value of Q_c until it equals K_c , but the value of K_c remains constant.

This has been prepared for the use of marking examiners. Changes would be made according to the views presented at the Chief/Assistant 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)- 2021 (2022)

විෂය අංකය
Subject No

02

විෂය
Subject

රසායන විද්‍යාව

ලකුණු දීමේ පටිපාටිය/Marking Scheme

I පත්‍රය/Paper I

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

විශේෂ උපදෙස්/Special Instructions:

විෂ් පිළිතුරකට ලකුණු 01 බැගින්/ 01 Mark for each question

මුළු ලකුණු/Total Marks 01 × 50 = 50

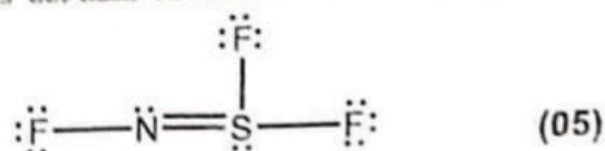
1. (a) State whether the following statements are true or false on the dotted lines. Reasons are not required.

- (i) The Lyman series observed in the emission spectrum of atomic hydrogen lies in the ultra-violet region of the electromagnetic spectrum. True
- (ii) There are only 10 electrons in a calcium atom with the azimuthal quantum number $l=0$. False
- (iii) The number of Lewis dot-dash structures (resonance structures) that can be drawn for the N_2O molecule is 3. True
- (iv) Among the second row elements of the Periodic Table, fluorine has the largest negative value of electron gain energy. True
- (v) The boiling point of argon (Ar) is higher than that of chlorine (Cl_2). False
- (vi) Ne has the highest first ionization energy, among the noble gases He, Ne and Ar. False

(04 marks \times 6 = 24 marks)

1(a): 24 marks

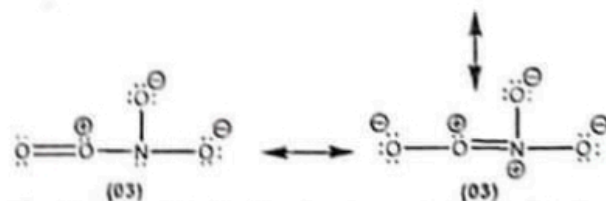
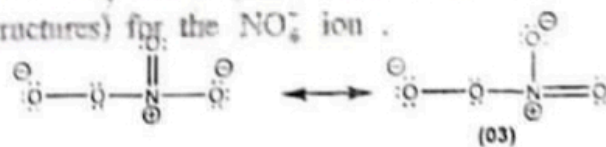
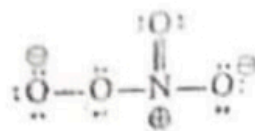
(b) (i) The skeleton of a molecule containing only the elements N, F and S is given below. Draw the most acceptable Lewis dot-dash structure for this molecule.



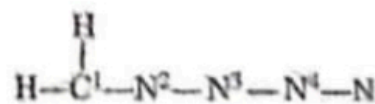
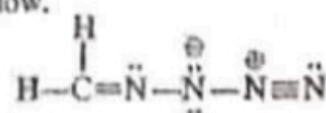
(ii) Give, (I) shapes around the N and S atoms and (II) oxidation numbers of the atoms in the structure drawn in (i) above.

- (I) N ... Angular S trigonal pyramidal or pyramidal (shape) (01)+(01)
- (II) N -1 S +4 (oxidation number) (01)+(01)

(iii) A Lewis dot-dash structure for the NO_3^- ion is given below. Draw three more Lewis dot-dash structures (resonance structures) for the NO_3^- ion.



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



	C^1	N^2	N^3	N^4
I. the number of VSEPR pairs around the atom	3	3	4	2
II. electron pair geometry around the atom	trigonal planar	trigonal planar	tetrahedral	linear
III. shape around the atom	trigonal planar	angular/V	angular/V	linear
IV. hybridization of the atom	sp^2	sp^2	sp^3	sp

(01 mark \times 16 = 16 marks)

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

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

I. H—C ¹	H 1s	C ¹ sp ²
II. C ¹ —N ²	C ¹ sp ²	N ² sp ²
III. N ² —N ³	N ² sp ²	N ³ sp ³
IV. N ³ —N ⁴	N ³ sp ³	N ⁴ sp
V. N ⁴ —N	N ⁴ sp	N 2p, or, sp

(01 mark X 10 = 10 marks)

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

I. C ¹ —N ²	C ¹ 2p	N ² 2p
II. N ⁴ —N	N ⁴ 2p	N 2p
	N ⁴ 2p	N 2p

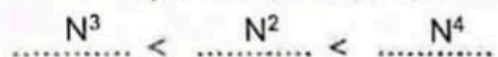
(01 mark X 6 = 06 marks)

(vii) State the approximate bond angles around C¹, N², N³ and N⁴ atoms.

C ¹ (120° ± 1)	N ² (118° ± 1)	N ³ (104° ± 1)	N ⁴ (180° ± 1)
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(01 mark X 4 = 04 marks)

(viii) Arrange the atoms N², N³ and N⁴ in the increasing order of their electronegativity.



(02 marks)

1(b): 56 marks

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

(i) (i) CaF₂, CaCl₂, CaBr₂, CaI₂ (ionic character)



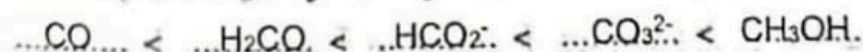
(ii) ClF₅, ClF₂⁺, ClF₂⁻ (bond angle)



(iii) Na⁺, S²⁻, Cl⁻, K⁺ (ionic radius)



(iv) CO, CO₃²⁻, HCO₂⁻, H₂CO, CH₃OH (C—O bond length)



(v) Li, N, F, Mg, P (first ionization energy)



(04 marks x 5 = 20 marks)

1(c): 20 marks

[see page four

2. (a) The questions (i), (ii) and (iii) are based on the following reactions.

A is an ionic compound composed of three elements in the ratio 1:4:1 (Not in order of the chemical formula). One of these is a d-block element that belongs to the fourth period of the Periodic Table. When A is subjected to the flame test, a lilac (purple) flame is observed. On dissolving A in water, a purple coloured solution is obtained.

B is also an ionic compound composed of the same three elements as in A. B dissolves in water to give a green coloured solution.

C is a viscous colourless liquid composed of two elements. It disproportionates to give another colourless liquid D as one of the products. C can act as an oxidizing agent as well as a reducing agent. When C is added to a solution of B, the brown precipitate E is obtained.

F is a compound composed of three elements. One of these elements is a 3d element found in hematite. When $\text{BaCl}_2(\text{aq})$ is added to an aqueous solution of F, the white precipitate G that is insoluble in dil. H_2SO_4 is formed.

H is composed of three elements. When an aqueous solution of H in a test tube is treated with a saturated solution of F, followed by addition of a small volume of conc. H_2SO_4 slowly, along the wall of the test tube, a brown colouration is seen on the surface where the liquids meet. The species responsible for the brown colouration is I. Brown fumes are not evolved when dil. H_2SO_4 is added to H. When H is subjected to the flame test, a yellow flame is observed.

J is the sodium salt of a weak dibasic acid. On treatment of a solution of J with $\text{CaCl}_2(\text{aq})$, the white precipitate K is formed. K reacts with dil. H_2SO_4 to give the weak dibasic acid L as one of the products. A warm solution of J acidified with dil. H_2SO_4 decolourizes an aqueous solution of A.

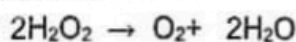
(i) Identify A to L. Note: Write the chemical formulae.

- | | |
|--|--|
| A KMnO_4 | G BaSO_4 |
| B K_2MnO_4 | H NaNO_3 |
| C H_2O_2 | I $[\text{Fe}(\text{NO})]^{2+}$ or $[\text{Fe}(\text{NO})]\text{SO}_4$ |
| D H_2O | J $\text{Na}_2\text{C}_2\text{O}_4$ |
| E MnO_2 | K CaC_2O_4 |
| F FeSO_4 | L $\text{H}_2\text{C}_2\text{O}_4$ (04 marks x 12 = 48 marks) |

(2a(i): 48 marks)

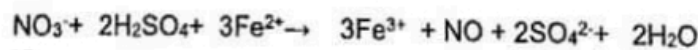
(ii) Give balanced chemical equations for the following (physical states not required).

I. Formation of D from C.



(04)

II. Formation of I.



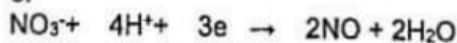
(04)

or

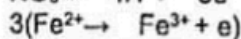


(04)

or



(01)



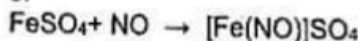
(01)

and



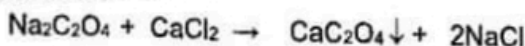
(01)

or



(01)

III. Formation of K.



(05)



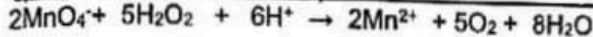
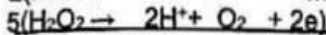
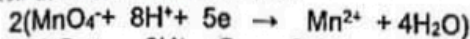
(2a(ii): 14 marks)

I: $[\text{Fe}(\text{H}_2\text{O})_5\text{NO}]_2\text{SO}_4$ or $[\text{Fe}(\text{H}_2\text{O})_5\text{NO}]_2\text{T}$
 can be accepted
 J: Na_2SO_3
 K: CaSO_3
 L: H_2SO_3 can be accepted

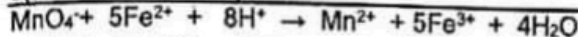
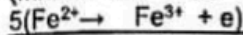
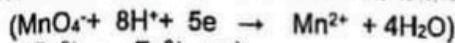
(iii) Give balanced ionic equations for the reactions that take place when A is added to the following solutions (physical states not required).

Do not write in this column.

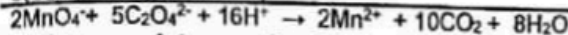
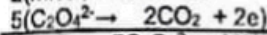
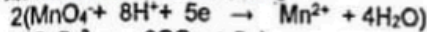
I. an acidified solution of C.



II. an aqueous solution of F acidified with dil. H_2SO_4



III. an acidified solution of J

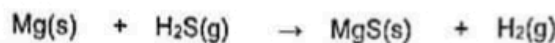


Note: For complete reaction 06 marks For only half reaction 02 marks each

(2a(III): 180 marks)

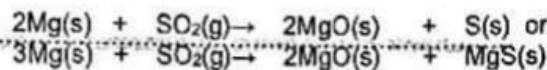
(b) Give balanced chemical equations for the reactions that take place between the following (physical states not required). State the function (oxidizing agent/reducing agent) of H_2S and SO_2 in reactions (i)-(iii).

(i) Mg(s) and $\text{H}_2\text{S(g)}$



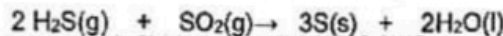
H_2S : Oxidizing agent (01)

(ii) Mg(s) and $\text{SO}_2(\text{g})$



SO_2 : Oxidizing agent (01)

(iii) $\text{H}_2\text{S(g)}$ and $\text{SO}_2(\text{g})$



H_2S : Reducing agent, SO_2 : Oxidizing agent (01+01)

(iv) S(s) and conc. $\text{HNO}_3(\text{aq})$



Note: Physical states are not required

2(b): 20 marks

3. (a) (i) A closed container equipped with a piston contains a given mass of an ideal gas at a constant temperature T . Give the relationship between pressure P and volume V of the gas under a mathematical expression.

$$P \propto \frac{1}{V} \text{ or } PV = K (\text{constant}) \quad (10)$$

(ii) Show that the density d of the ideal gas in (i) above, at a constant temperature T is directly proportional to the pressure P .

$$PV = K$$

$$d = \frac{m}{V} \quad (m = \text{mass of gas}) \quad (02)$$

$$\text{Hence, } P \times \frac{m}{d} = K \quad (02)$$

$$P = \frac{Kd}{m}$$

$$d = \frac{m}{K} P \quad \left(\frac{m}{K} = \text{constant}\right) \quad (02)$$

$$\text{Hence, } d \propto P \quad (02)$$

OR

$$PV = nRT$$

$$P = \frac{n}{V} RT$$

$$P = \frac{m}{M} \times \frac{1}{V} \times RT$$

(m = mass of gas)

(M = relative molecular mass of gas) (02)

$$d = \frac{m}{V} \quad (02)$$

$$\text{Hence, } P = \frac{d}{M} \times RT$$

$$d = \frac{M}{RT} \times P \quad \left(\frac{M}{RT} = \text{constant}\right) \quad (02)$$

$$\text{Hence } d \propto P \quad (02)$$

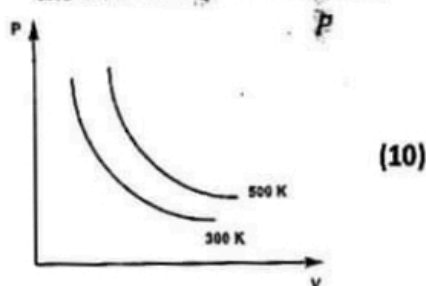
(3a(ii): 10 marks)

If reaction is incorrect, no mark for the function. If correct reaction correct but unbalanced, can be awarded for function.

$\text{SO}_2 + \text{H}_2\text{O}$ not accepted

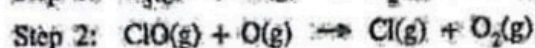
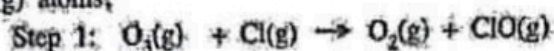
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(iii) Show the variation of P with V of the system in (i) above at the two different temperatures of 300 K and 500 K, by drawing two graphs in the figure given below. Indicate clearly the temperature corresponding to each graph.



3(a): 30 marks

(b) Depletion of $O_3(g)$ occurs according to the mechanism given below in the presence of $Cl(g)$ and $O(g)$ atoms,



(i) Write the overall reaction for the mechanism given above.



(ii) Giving reasons, identify the catalyst and the intermediate product of the above mechanism.

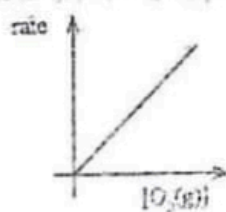
$Cl(g)$ is the catalyst. (05)

Reason: consumed in step (1) and regenerated in step (2) (05)

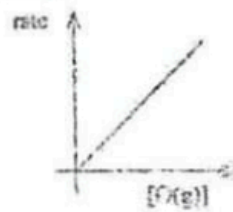
$ClO(g)$ is the intermediate. (05)

Reason: Generated in step (1) and consumed in step (2) (05)

(iii) The following graphs were obtained from an experiment carried out in relation to the overall reaction in (i) above at temperature T . Rates and concentrations are measured in units of $mol\ dm^{-3}\ s^{-1}$ and $mol\ dm^{-3}$ respectively.



Graph 1



Graph 2

Graph 1 was obtained by keeping $[O(g)]$ constant.

Graph 2 was obtained by keeping $[O_3(g)]$ constant.

1. With the help of graphs 1 and 2, deduce orders of the reaction with respect to $O_3(g)$ and $O(g)$. What is the overall order of the reaction?

Graph 1 is a straight line going through the origin. (05)

Hence, order with respect to $O_3(g) = 1$ (05)

Graph 2 is a straight line going through the origin. (05)

Hence, order with respect to $O(g) = 1$ (05)

Hence, overall order of the reaction = 2 (05)

II. If the rate constant of the reaction is k at temperature T , write the rate law of the reaction.



no part marks
(10) mark or zero

physical states
are required

Identify must be
correct for award
marks for reason
ph. states not required

mark independently
graph 1 & 2

physical state
are required for
award marks

III. Derive the units of k .

$$k = \frac{\text{Rate}}{[O_3(g)][O(g)]} = \frac{\text{mol dm}^{-3} \text{s}^{-1}}{(\text{mol dm}^{-3})(\text{mol dm}^{-3})} = \text{mol}^{-1} \text{dm}^3 \text{s}^{-1} \quad (05)$$

IV. In an experiment carried out at temperature T , the concentrations of $O_3(g)$ and $O(g)$ were $1.0 \times 10^{-3} \text{ mol dm}^{-3}$ and $1.0 \times 10^{-4} \text{ mol dm}^{-3}$ respectively. The rate of the reaction was found to be $1.0 \times 10^{-3} \text{ mol dm}^{-3} \text{ s}^{-1}$. Calculate the value of k .

$$\text{Rate} = k[O_3(g)][O(g)]$$

$$1.0 \times 10^{-3} (\text{mol dm}^{-3} \text{s}^{-1}) = k[1.0 \times 10^{-3}](\text{mol dm}^{-3})[1.0 \times 10^{-4}](\text{mol dm}^{-3}) \quad (04 + 01)$$

$$\text{Hence, } k = 1.0 \times 10^4 \text{ mol}^{-1} \text{ dm}^3 \text{ s}^{-1} \quad (04 + 01)$$

3(b): 70 marks

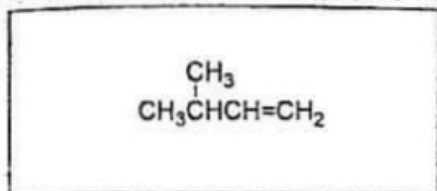
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units should be substituted in the eqn
no mark for write the final unit.

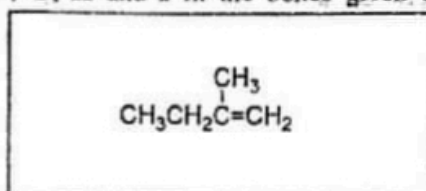
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4. (a) A, B and C are hydrocarbons having the molecular formula C_5H_{10} . None of them show geometric isomerism. Both A and B are chain isomers of C. When A and B are separately treated with cold concentrated H_2SO_4 and the products obtained are diluted with water and heated, D and E are formed respectively. Of the two compounds D and E, only D shows optical isomerism. On catalytic hydrogenation, both compounds A and B give the same compound F, while compound C gives G. When B reacts with HBr in the presence of peroxide, H which is a primary alkyl halide is formed. Compound H when treated with aqueous $NaOH$ gives I.

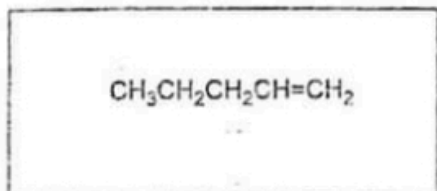
(i) Draw the structures of A, B, C, D, E, F, G, H and I in the boxes given below.



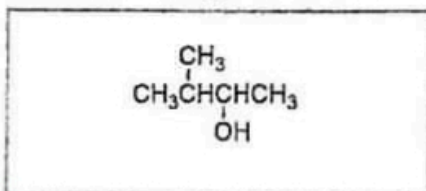
A



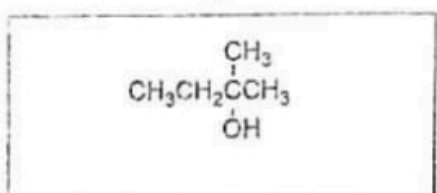
B



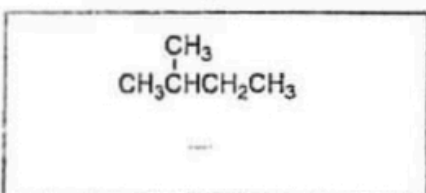
C



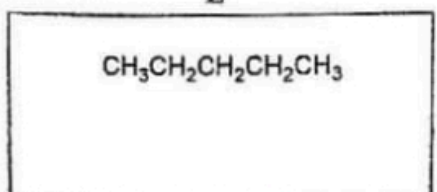
D



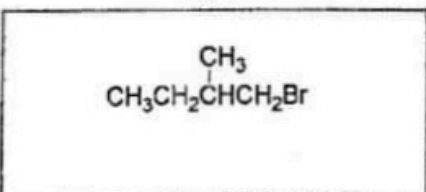
E



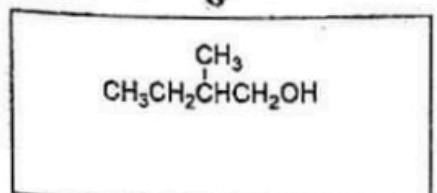
F



G



H



I

(06 marks x 9 = 54 marks)

(4a(i): 54 marks)

For the test, instead of HCl/ZnCl₂,
 ✓ Lucas test or Lucas reagent's
 award only 01 mark given

All three structures
 D, E & F have
 to be correct
 for this part

(ii) Describe a chemical test to distinguish D, E and I from one another.

Add conc. HCl/ZnCl₂ to each compound. (03)

E - Gives a turbidity in a very short time. (01)

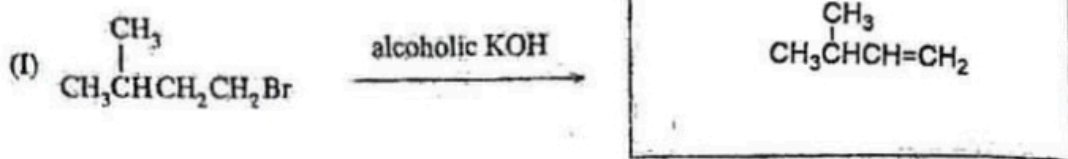
D - Gives a turbidity in a few minutes (01)

I - Does not give a turbidity / Gives a turbidity after a long time. (01)

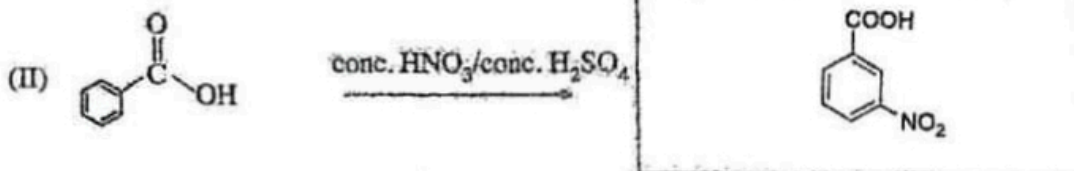
(4a(ii): 060 marks)

4(a): 60 marks

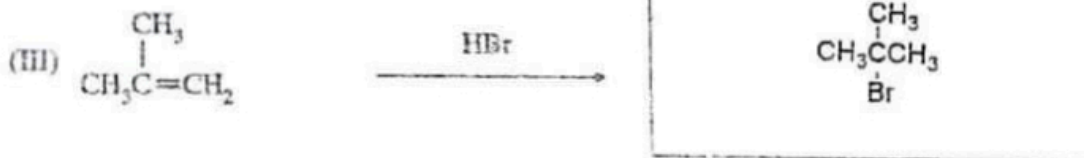
(b) (i) Draw the structures of the products J, K, L, M and N of the following reactions (I-V) in the given boxes.



J



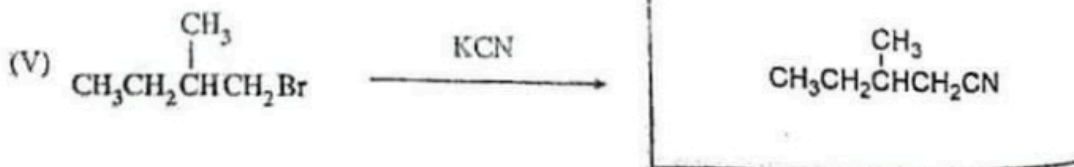
K



L



M



N

(05 marks x 5 = 25 marks)
 (4b(i): 25 marks)

(ii) Selecting from the reactions I-V, give one example each, for each type of reaction given below.

Nucleophilic addition reaction
 Electrophilic addition reaction
 Elimination reaction

Reaction IV
 Reaction III
 Reaction I

(05 marks x 3 = 15 marks)
 (4b(ii): 15 marks)

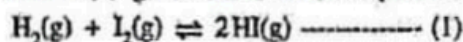
Products must be
 correct for award
 marks

4(b): 40 marks

PART B - ESSAY

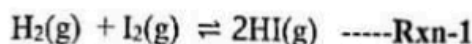
Answer two questions only. (Each question carries 150 marks.)

5. (a) Consider the reaction (1) given below at a temperature of 800 °C.



Initially, 0.45 mol of HI(g) was introduced into a 1.0 dm³ evacuated rigid closed container at 800 °C, and allowed to reach the equilibrium given above. It was found that 0.05 mol of H₂(g) was present at equilibrium.

- (i) Calculate the equilibrium constant
- K_{C_1}
- , for the above equilibrium at a temperature of 800 °C.



Initial con.	0	0	0.45	mol dm ⁻³
Change	0.05	0.05	0.45 - 2 × 0.05	mol dm ⁻³
Eqm con.	0.05	0.05	0.35	mol dm ⁻³

(03+01)

Note: All three concentrations need to be correct for award of 03 marks.

$$K_{C_1} = \frac{[\text{HI}(\text{g})]^2}{[\text{H}_2(\text{g})][\text{I}_2(\text{g})]} \quad (04)$$

Note: Physical states are required for award of marks.

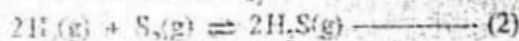
$$K_{C_1} = \frac{[0.35]^2}{[0.05][0.05]} \quad (03 \times 1)$$

Note: If concentrations are not stated but have been substituted into K_{C_1} expression with units award (03+01) marks.

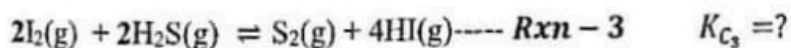
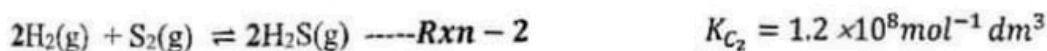
$$K_{C_1} = 49 \quad (03+01)$$

(5a(i): 12 marks)

- (ii) In a separate similar evacuated container at a temperature of 800 °C, reaction (2) takes place with an equilibrium constant
- $K_{C_2} = 1.2 \times 10^8 \text{ mol}^{-1} \text{ dm}^3$
- .



When the two containers are connected together, the following reaction (3) takes place at a temperature of 800 °C.

Calculate the equilibrium constant K_{C_3} for the reaction (3) at a temperature of 800 °C.

$$\text{Rxn-3} = 2 \times \text{Rxn-1} - \text{Rxn-2}$$

$$\therefore K_{C_3} = \frac{K_{C_1}^2}{K_{C_2}} \quad (04)$$

$$K_{C_3} = \frac{(49)^2}{1.2 \times 10^8} \quad (04)$$

$$K_{C_3} = 2.0 \times 10^{-5} \text{ mol dm}^{-3} \quad (03+01)$$

Note: For correct concentration of K_{C_3} using $1/K_{C_3}$ award full marks.

(5a(ii): 12 marks)

(iii) A 1.0 dm³ rigid closed container at a temperature of 800 °C contains an equilibrium mixture of (3) in (ii) above with 5.00 × 10⁻⁵ mol HI(g), 1.25 × 10⁻⁶ mol S₂(g) and 2.50 × 10⁻⁵ mol H₂S(g). Calculate the number of moles of I₂(g) in the above mixture.

For Rxn - 3: $K_{C_3} = \frac{[S_2(g)][HI(g)]^4}{[H_2S(g)]^2[I_2(g)]^2}$

$K_{C_3} = 2.0 \times 10^{-5} \text{ mol dm}^{-3} = \frac{[1.25 \times 10^{-6}][5.0 \times 10^{-5}]^4}{[2.5 \times 10^{-5}]^2[I_2(g)]^2}$ (04)

Note: If only K_{C3} expression is given award (02) marks.

∴ [I₂(g)] = 2.5 × 10⁻⁵ mol dm⁻³

n_{I₂} = 2.5 × 10⁻⁵ mol dm⁻³ × 1.0 dm³ = 2.5 × 10⁻⁵ mol

(04)
(03+01)

(5a(iii)): 08 marks

(iv) An extra 2.50 × 10⁻⁵ mol I₂(g) was added to the equilibrium mixture in (iii) above at a temperature of 800 °C.

- I. Calculate the reaction quotient (Q_c) at the moment the extra I₂(g) is added.
- II. Explain the change in the equilibrium that takes place upon the addition of extra I₂(g).
- III. Sketch the variation in the concentrations of each constituent in the mixture, with time, upon the addition of extra I₂(g).

I. When an extra 2.5 × 10⁻⁵ mol of I₂(g) was added:

New [I₂(g)] = 5.0 × 10⁻⁵ mol dm⁻³ (04)

At this point:

$Q_{C_3} = \frac{[S_2(g)][HI(g)]^4}{[H_2S(g)]^2[I_2(g)]^2}$

$Q_{C_3} = \frac{[1.25 \times 10^{-6}][5.0 \times 10^{-5}]^4}{[5.0 \times 10^{-5}]^2[5.0 \times 10^{-5}]^2}$ (04)

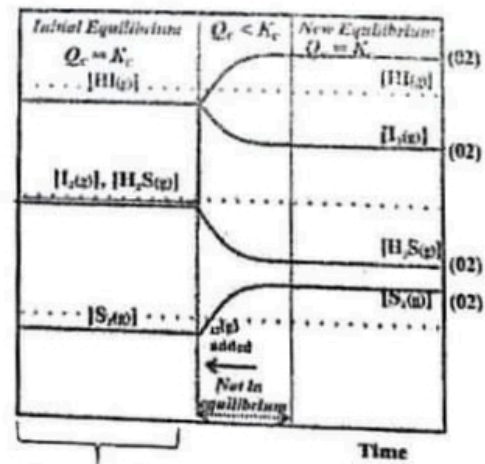
$Q_{C_3} = 5.0 \times 10^{-6} \text{ mol dm}^{-3}$ *1.25 × 10⁻⁶ mol dm⁻³* (04)

Note: If only Q_{C3} expression is given award (02) marks.

II. Since, Q_{C3} < K_{C3} (04)

∴ Reaction will proceed to the right until Q_{C3} = K_{C3} (04)

III.



not required

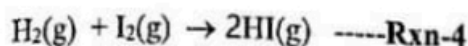
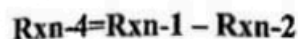
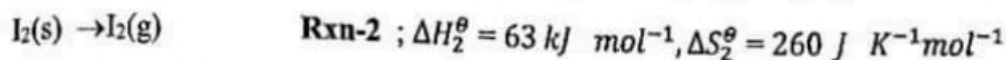
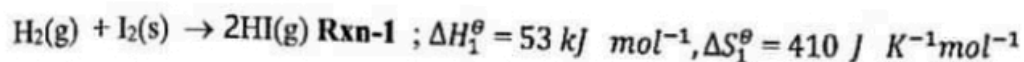
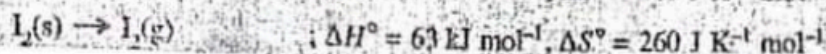
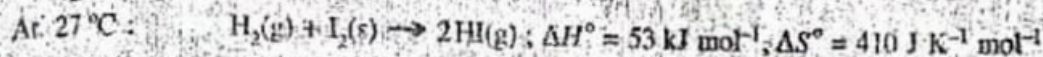
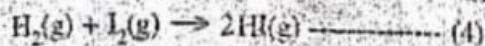
Note: Variations can be given in individual plots.

(08)

(5a(iv)): 28 marks

5(a): 60 marks

(b) (i) Using the data given below, calculate ΔH° , ΔS° and ΔG° for the reaction (4) at 27 °C.



$$\Delta H_4^\circ = \Delta H_1^\circ - \Delta H_2^\circ \quad (02)$$

$$= 53 - 63 = -10 \text{ kJ mol}^{-1} \quad (01 + 01)$$

$$\Delta S_4^\circ = \Delta S_1^\circ - \Delta S_2^\circ \quad (02)$$

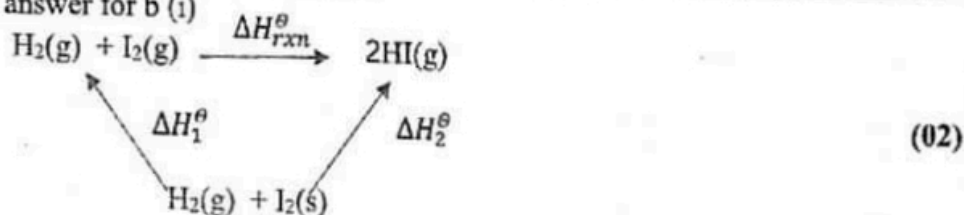
$$= 410 - 260 = 150 \text{ J K}^{-1} \text{ mol}^{-1} \quad (01 + 01)$$

$$\Delta G_4^\circ = \Delta H_4^\circ - T\Delta S_4^\circ \quad (04)$$

$$= -10 - 300 \times 0.150 = -55 \text{ kJ mol}^{-1} \quad (03 + 01)$$

(5b(i): 20 marks)

Alternative answer for b (i)

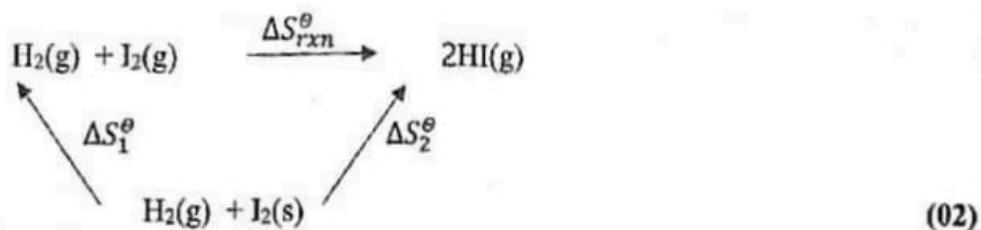


Note : Physical states are required for award of marks.

From Hess's Law

$$\therefore \Delta H_1^\circ + \Delta H_{\text{rxn}}^\circ = \Delta H_2^\circ \quad (02)$$

$$\Delta H_{\text{rxn}}^\circ = 53 \text{ kJ mol}^{-1} - 63 \text{ kJ mol}^{-1} = -10 \text{ kJ mol}^{-1} \quad (01 + 01)$$



Note : Physical states are required for award of marks.

$$\Delta S_{\text{rxn}}^\circ = \Delta S_2^\circ - \Delta S_1^\circ \quad (02)$$

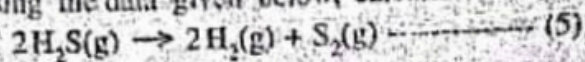
$$= 410 \text{ J K}^{-1} \text{ mol}^{-1} - 260 \text{ J K}^{-1} \text{ mol}^{-1} = 150 \text{ J K}^{-1} \text{ mol}^{-1} \quad (01 + 01)$$

$$\Delta G_4^\circ = \Delta H_4^\circ - T\Delta S_4^\circ \quad (04)$$

$$= -10 - 300 \times 0.150 = -55 \text{ kJ mol}^{-1} \quad (03 + 01)$$

(5b(i): 20 marks)

(ii) Using the data given below, calculate ΔH^\ominus , ΔS^\ominus and ΔG^\ominus for the reaction (5) at 27 °C.



At 27 °C:

	$\Delta H_f^\ominus / \text{kJ mol}^{-1}$	$\Delta S_f^\ominus / \text{J K}^{-1} \text{mol}^{-1}$
$\text{H}_2(\text{g})$:	0	130
$\text{S}_2(\text{g})$:	127	230
$\text{H}_2\text{S}(\text{g})$:	-20	200

$$\Delta H_5^\ominus = 2\Delta H_{f(\text{H}_2(\text{g}))}^\ominus + \Delta H_{f(\text{S}_2(\text{g}))}^\ominus - 2\Delta H_{f(\text{H}_2\text{S}(\text{g}))}^\ominus \quad (04)$$

$$= 0 + 127 - (2 \times -20) = 167 \text{ kJ mol}^{-1} \quad (03 + 01)$$

$$\Delta S_5^\ominus = 2\Delta S_{f(\text{H}_2(\text{g}))}^\ominus + \Delta S_{f(\text{S}_2(\text{g}))}^\ominus - 2\Delta S_{f(\text{H}_2\text{S}(\text{g}))}^\ominus \quad (04)$$

$$= 2 \times 130 + 230 - (2 \times 200)$$

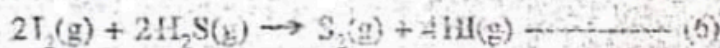
$$= 90 \text{ J K}^{-1} \text{mol}^{-1} \quad (03 + 01)$$

$$\Delta G_5^\ominus = \Delta H_5^\ominus - T\Delta S_5^\ominus = 167 - 300 \times 0.090$$

$$= 140 \text{ kJ mol}^{-1} \quad (03 + 01)$$

(5b(ii): 20 marks)

(iii) Using the answers obtained in (b)(i) and (b)(ii) above, predict giving reasons whether the reaction (6) below is spontaneous or not at 27 °C.



$$\text{Rxn-6} = 2 \times \text{Rxn-4} + \text{Rxn-5}$$

or

$$\therefore \Delta G_6^\ominus = 2\Delta G_4^\ominus + \Delta G_5^\ominus \quad (04)$$

$$\Delta G_6^\ominus = 2(-55) + 140 \quad (04)$$

$$= 30 \text{ kJ mol}^{-1} \quad (03 + 01)$$

$$\Delta G_6^\ominus \text{ is positive} \quad (04)$$

$$\therefore \text{Reaction is non-spontaneous} \quad (04)$$

Note: For correct prediction based on incorrect value for ΔG_6^\ominus , award marks.

(5b(iii): 20 marks)

5(b): 60 marks

- (c) An aqueous solution of volume 1.0 dm^3 in a beaker at a temperature of 25°C contains $2.0 \times 10^{-2} \text{ mol}$ of $\text{Cl}^-(\text{aq})$ ions and $2.0 \times 10^{-2} \text{ mol}$ of $\text{CrO}_4^{2-}(\text{aq})$ ions. Small portions of concentrated aqueous AgNO_3 solution were added slowly to the above solution. At 25°C , $K_{\text{sp}}(\text{AgCl}(\text{s})) = 1.60 \times 10^{-10} \text{ mol}^2 \text{ dm}^{-6}$ and $K_{\text{sp}}(\text{Ag}_2\text{CrO}_4(\text{s})) = 8.0 \times 10^{-12} \text{ mol}^3 \text{ dm}^{-9}$. Assume that there was no significant change in solution volume upon the addition of $\text{AgNO}_3(\text{aq})$ solution.
- (i) Show that AgCl precipitates first by a suitable calculation.

For AgCl



$$K_{\text{sp}} = [\text{Ag}^+(\text{aq})][\text{Cl}^-(\text{aq})] \quad (02)$$

$$[\text{Ag}^+(\text{aq})] = K_{\text{sp}} / [\text{Cl}^-(\text{aq})] \\ = (1.60 \times 10^{-10} / 2.00 \times 10^{-2}) \quad (02)$$

$$= 8.0 \times 10^{-9} \text{ mol dm}^{-3} \quad (01+01)$$

For Ag₂CrO₄



$$K_{\text{sp}} = [\text{Ag}^+(\text{aq})]^2 [\text{CrO}_4^{2-}(\text{aq})] \quad (02)$$

$$[\text{Ag}^+(\text{aq})]^2 = K_{\text{sp}} / [\text{CrO}_4^{2-}(\text{aq})] \\ = (8.0 \times 10^{-12} / 2.00 \times 10^{-2}) \quad (02)$$

$$[\text{Ag}^+(\text{aq})] = 2.0 \times 10^{-5} \text{ mol dm}^{-3} \quad (01+01)$$

$$[\text{Ag}^+(\text{aq})] \text{ needed to precipitate AgCl}(\text{s}) < [\text{Ag}^+(\text{aq})] \text{ needed to precipitate Ag}_2\text{CrO}_4(\text{s}) \quad (02)$$

$$\therefore \text{AgCl}(\text{s}) \text{ precipitates first} \quad (02)$$

(5c(i): 20 marks)

physical states are required for award of marks

- (ii) Calculate the concentration of $\text{Cl}^-(\text{aq})$ ions present in the solution at the time Ag_2CrO_4 starts to precipitate.

$[\text{Cl}^-(\text{aq})]$ present in the solution at the time Ag_2CrO_4 starts to precipitate

$$= (K_{\text{sp}} / 2.0 \times 10^{-5}) \quad (04)$$

$$= (1.60 \times 10^{-10} / 2.0 \times 10^{-5}) \text{ mol dm}^{-3} \quad (02)$$

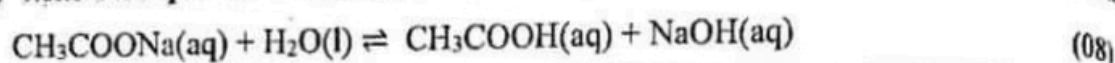
$$= 8.0 \times 10^{-6} \text{ mol dm}^{-3} \quad (04)$$

(5c(ii): 10 marks)

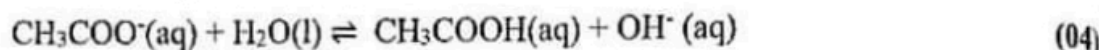
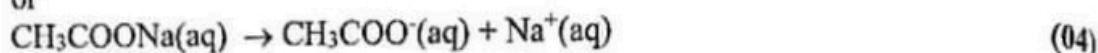
5(c): 30 marks

6. (a) You are provided with an aqueous solution of sodium acetate (CH_3COONa) at 25°C .

(i) Write the equilibrium reaction for the hydrolysis of sodium acetate in aqueous medium.



or



(6a(i): 08 marks)

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

Equilibrium constant for the above hydrolysis

$$K_h = \frac{[\text{CH}_3\text{COOH}(\text{aq})][\text{OH}^-(\text{aq})]}{[\text{CH}_3\text{COO}^-(\text{aq})]}: \text{Eqn-1} \quad (04)$$

Note: Physical states are required for award of marks.

(6a(ii): 04 marks)

(iii) If the dissociation constants for $\text{CH}_3\text{COOH}(\text{aq})$, and $\text{H}_2\text{O}(\text{l})$ are K_a and K_w respectively.

at 25°C , show that $K_h = \frac{K_w}{K_a}$.

$$K_h = \frac{[\text{CH}_3\text{COOH}(\text{aq})][\text{OH}^-(\text{aq})][\text{H}^+(\text{aq})]}{[\text{CH}_3\text{COO}^-(\text{aq})][\text{H}^+(\text{aq})]} \quad (04)$$

$$\therefore \frac{1}{K_a} = \frac{[\text{CH}_3\text{COOH}(\text{aq})]}{[\text{CH}_3\text{COO}^-(\text{aq})][\text{H}^+(\text{aq})]} \quad (04)$$

$$K_w = [\text{H}^+(\text{aq})][\text{OH}^-(\text{aq})] \quad (04)$$

$$\therefore K_h = \frac{K_w}{K_a}$$

(6a(iii): 12 marks)

(iv) Given that $K_a = 1.8 \times 10^{-5} \text{ mol dm}^{-3}$ and $K_w = 1.0 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$ at 25°C , calculate the value of K_h at 25°C .

$$K_h = \frac{K_w}{K_a} = \frac{1.0 \times 10^{-14}}{1.8 \times 10^{-5}} \quad (04)$$

$$= 5.6 \times 10^{-10} \text{ mol dm}^{-3} \text{ or } 5.56 \times 10^{-10} \text{ mol dm}^{-3}$$

(6a(iv): 08 marks)

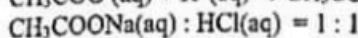
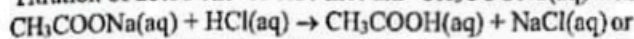
physical states
important

physical states

(3.1) (03+01)
(04)

(v) A portion of 25.00 cm³ of 0.10 mol dm⁻³ CH₃COONa solution is titrated with a solution of 0.10 mol dm⁻³ HCl. What is the volume of 0.10 mol dm⁻³ HCl required to reach the equivalence point? Calculate the pH of the solution at the equivalence point.

Titration of 25.00 cm³ of 0.10 mol dm⁻³ CH₃COONa(aq) with 0.10 mol dm⁻³ HCl(aq)



(04)

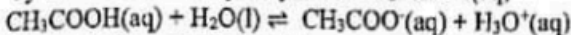
∴ Volume of HCl(aq) needed for the equivalence point = 25.00 cm³

(04)

Calculation of pH at the equivalence point

NaCl(aq) is a neutral salt and therefore pH is determined

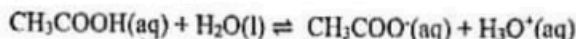
by the dissociation/hydrolysis of CH₃COOH(aq)



(02)

Concentration of CH₃COOH(aq) = 0.05 mol dm⁻³ (volume is doubled)

(02)



Initial con.	0.05	0	0 mol dm ⁻³
Eqm con	0.05-x	x	x mol dm ⁻³

(04)

$$K_a = \frac{[\text{CH}_3\text{COO}^-(\text{aq})][\text{H}_3\text{O}^+(\text{aq})]}{[\text{CH}_3\text{COOH(aq)}]} = \frac{x^2}{0.05-x}$$

$$1.8 \times 10^{-5} \text{ mol dm}^{-3} \sim \frac{x^2}{0.05} \quad (0.05 - x \sim 0.05)$$

(04)

$$x^2 = 90 \times 10^{-8} \text{ or } 9 \times 10^{-7}$$

$$x = 9.49 \times 10^{-4} \text{ mol dm}^{-3}$$

(04)

$$\text{pH} = -\log [\text{H}_3\text{O}^+(\text{aq})] = 3.02 \text{ or } \text{pH} = -\log [\text{H}^+(\text{aq})] = 3.02 \approx 3$$

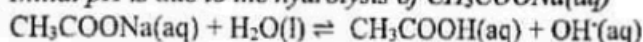
(04)

(6a(v): 28 marks)

(vi) Sketch the titration curve (pH vs. volume of HCl) for the above titration in (v).

pH curve

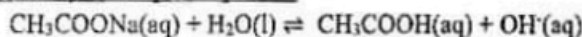
Initial pH is due to the hydrolysis of CH₃COONa(aq)



∴ the solution is basic (weak)

Final pH is just above 1 (0.10 mol dm⁻³ HCl(aq))

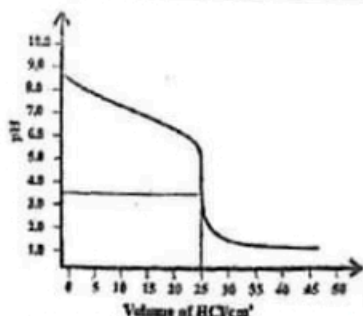
Calculation of initial pH - optional



Initial con.	0.10	0	0 mol dm ⁻³
Eqm con	0.10-x	x	x mol dm ⁻³

$$K_b = K_h = \frac{K_w}{K_a} = \frac{1.0 \times 10^{-14}}{1.8 \times 10^{-5}} = 5.56 \times 10^{-10} = \frac{x^2}{0.05-x}$$

$$\text{pOH} = 5.13 \quad \text{pH} = 8.87$$



y axis with relevant pH (01)

x axis with relevant volumes of HCl (01)

starting pH > 8 (02)

equivalence point pH = 3.02 and volume = 25.00 cm³ (02)

pH at completion (02)

shape (02)

(6a(vi): 10 marks)

(vii) State an indicator which can be used for the titration in (v) above.

Methyl orange

(04)

(6a(vii): 04 marks)

(viii) Explain why it is not possible to titrate a 0.10 mol dm⁻³ CH₃COOH solution with a solution of 0.10 mol dm⁻³ aqueous ammonia.

Difficult to detect end-point (02)

Due to smaller vertical portion/rapid pH change near end point (04)

(6a(viii): 06 marks)

6(a): 80 marks

(b) An ideal binary liquid mixture was prepared by mixing two volatile liquids A and B at a given temperature. When the composition of the liquid phase was $X_A = 0.2$ and $X_B = 0.8$, the pressure of the vapour phase was P (X_A and X_B are mole fractions of A and B respectively in the liquid phase). When the composition of the liquid phase was changed to $X_A = 0.5$, $X_B = 0.5$, the pressure of the vapour phase becomes $\frac{5}{3}P$. At this temperature, saturated vapour pressures of A and B are P_A^0 and P_B^0 respectively.

(i) Show that $P_A^0 = 5P_B^0$.

(i) For an ideal gas mixture: Total pressure P_T is given by

$$P_T = \sum X_i P_i^0 \quad (03)$$

For the initial condition $P_A = 0.2 P_A^0 \quad (03)$

$$P_B = 0.8 P_B^0 \quad (03)$$

Total pressure; $P = P_A + P_B = 0.2 P_A^0 + 0.8 P_B^0 \dots\dots\dots \text{Eqn 1} \quad (03 + 03)$

After the change $P_A = 0.5 P_A^0 \quad (03)$

$$P_B = 0.5 P_B^0 \quad (03)$$

And total pressure = $\frac{5}{3}P \quad (03)$

$$\frac{5}{3}P = 0.5 P_A^0 + 0.5 P_B^0 \dots\dots\dots \text{Eqn 2} \quad (03)$$

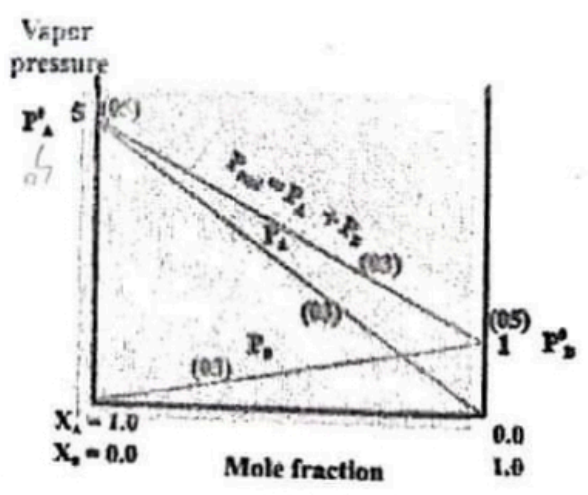
$$\frac{\text{Eqn 1}}{\text{Eqn 2}} = \frac{0.2 P_A^0 + 0.8 P_B^0}{0.5 P_A^0 + 0.5 P_B^0} = \frac{3}{5} \quad (03)$$

$$1.5 P_A^0 + 1.5 P_B^0 = 1.0 P_A^0 + 4.0 P_B^0 \quad (03)$$

$$\therefore P_A^0 = 5 P_B^0 \quad (03)$$

(6b(i): 36 marks)

(ii) Draw the corresponding vapour pressure diagram for the mixture of A and B by showing the variations in P_A , P_B and P_{total} and label the diagram.



(6b(ii): 19 marks)

(iii) Calculate the composition of the liquid phase at the point where $P_A = P_B$.

$$\text{When } P_A = P_B$$

$$P_A = X_A P_A^0$$

$$\text{And } P_B = (1 - X_A) P_B^0 \quad (03)$$

$$\text{As } P_A = P_B \quad (03)$$

$$1 = \frac{P_A}{P_B} = \frac{X_A P_A^0}{(1 - X_A) P_B^0} = \frac{5X_A}{(1 - X_A)} \quad (03)$$

$$(1 - X_A) = 5X_A$$

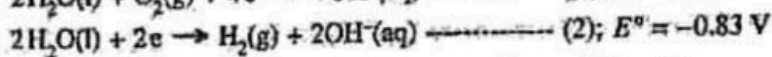
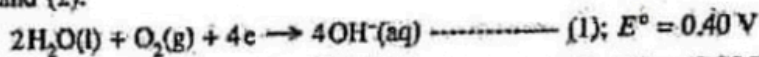
$$X_A = \frac{1}{6} \quad (03)$$

$$X_B = \frac{5}{6} \quad (03)$$

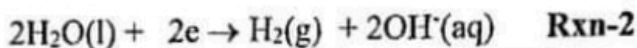
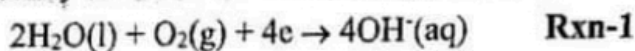
(6b(iii)): 15 marks

6(b): 70 marks

7. (a) A galvanic electrochemical cell was constructed at 25 °C based on the following half-reactions (1) and (2).



(i) Identify the anodic and cathodic half reactions of the cell.

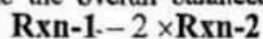


Rxn-1 represents the cathodic half reaction

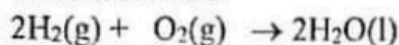
Rxn-2 represents the anodic half reaction

Note: Identifying the anodic half reaction as $2\text{OH}^-(\text{aq}) + \text{H}_2(\text{g}) \xrightarrow{2\text{H}_2\text{O}} \text{H}_2\text{O}(\text{l}) + 2\text{e}^-$ can be accepted. (7a(i): 10 marks)

(ii) Write the overall balanced cell reaction of the cell.



Overall reaction



Note: Physical states are required for award of marks.

(iii) Calculate E_{cell}^\ominus of the cell at 25 °C.

$$E_{\text{cell}}^\ominus = E_{\text{cathode}}^\ominus - E_{\text{anode}}^\ominus \quad \text{or} \quad E_{\text{cell}}^\ominus = E_R^\ominus - E_L^\ominus$$

$$E_{\text{cell}}^\ominus = 0.40 \text{ V} - (-0.83 \text{ V}) = 1.23 \text{ V}$$

Cath - An

(04 + 01)
(7a(iii): 10 marks)

(iv) The cell was operated for a duration of 600 s. During this period, 1.0 mol $\text{H}_2(\text{g})$ was consumed.

I. Calculate the number of moles of electrons which passed through the cell.

II. Calculate the amount of electricity (in coulombs) generated in the cell during its operation ($1 \text{ F} = 96500 \text{ C mol}^{-1}$).

III. Assuming that the current drawn from the cell is constant during the operation, calculate its value.

$$\text{I. } 1.0 \text{ mol} \times \frac{2 \text{ mol e}^-}{1 \text{ mol H}_2} = 2.0 \text{ mol e}^-$$

II. Amount of electricity passed during the operation is

$$2.0 \text{ mol e}^- \times \frac{96500 \text{ C}}{1 \text{ mol e}^-} = 1.93 \times 10^5 \text{ C}$$

III. Current passed through the cell is:

$$I = \frac{q}{t} = \frac{1.93 \times 10^5 \text{ C}}{600 \text{ s}}$$

$$= 321.67 \text{ A or } 322 \text{ A}$$

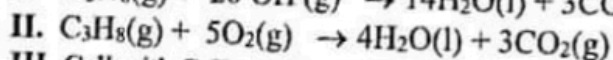
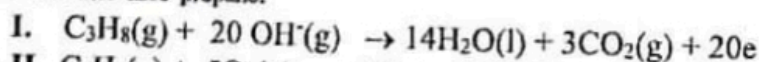
(04 + 01)
(7a(iv): 20 marks)

(v) In the above galvanic electrochemical cell propane ($\text{C}_3\text{H}_8(\text{g})$) is used instead of $\text{H}_2(\text{g})$.

I. Write the half-cell reaction for the propane electrode assuming propane is converted to $\text{CO}_2(\text{g})$ and $\text{H}_2\text{O}(\text{l})$.

II. Derive the balanced equation for the overall cell reaction by using propane instead of $\text{H}_2(\text{g})$ in the answer given in (ii) above.

III. Giving reasons, state one environmental advantage of the cell which uses $\text{H}_2(\text{g})$ over the cell that uses propane.

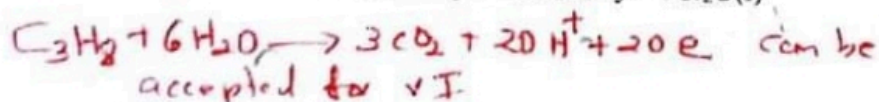


III. Cell with C_3H_8 produces $\text{CO}_2(\text{g})$

$\text{CO}_2(\text{g})$ contributes to global warming

With $\text{H}_2(\text{g})$ product is only the $\text{H}_2\text{O}(\text{l})$

(10)
(05)
(04)
(04)
(02)
(7a(v): 25 marks)



7(a): 75 marks

- (b) (i) X is a d-block element that belongs to the fourth period of the Periodic Table. On reacting X with dil. HCl, the colourless solution X_1 and the gas X_2 are obtained. When X_1 is treated with dil. $\text{NH}_4\text{OH}/\text{NH}_4\text{Cl}$ and H_2S is bubbled through the solution thereafter, the white precipitate X_3 is obtained. X_3 is soluble in dil. HCl. On addition of dil. NaOH to X_1 , the gelatinous white precipitate X_4 is formed. X_4 dissolves in excess dil. NaOH and in excess dil. NH_4OH to give X_5 and X_6 respectively. Both X_5 and X_6 are colourless.
- Identify the species X and X_1 to X_6 . (Give chemical formulae) Note: Reasons are not required.
 - Write the electronic configuration of X.
 - Explain why X_1 is colourless.
 - Write the IUPAC name of X_6 .

- X: Zn (04)

X_1 : ZnCl_2 or Zn^{2+} or $[\text{Zn}(\text{H}_2\text{O})_6]^{2+}$ (04)

X_2 : H_2 (04)

X_3 : ZnS (04)

X_4 : $\text{Zn}(\text{OH})_2$ (04)

X_5 : Na_2ZnO_2 or $\text{Na}_2[\text{Zn}(\text{OH})_4]$ or $[\text{Zn}(\text{OH})_4]^{2-}$ or ZnO_2^{2-} (04)

X_6 : $[\text{Zn}(\text{NH}_3)_4]^{2+}$ (04)
 - $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2$ (02)
 - $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10}$ ($X_1 = \text{Zn}^{2+}$) (02)
- All d-orbitals are filled (i.e. no partially filled d-orbitals are available) (03)
- tetraamminezinc(II) ion (02)

(7b(i): 37 marks)

- (ii) Y is also a d-block element that belongs to the same row as X in the Periodic Table. Y has two common oxidation numbers n and m. m is greater than n. Y^{n+} forms the pink coloured species Y_1 in aqueous solution. On treatment of the solution containing Y_1 with dil. NaOH the pink precipitate Y_2 is formed. When H_2S is bubbled through a slightly basic solution containing Y_1 , the black precipitate Y_3 is obtained. The yellowish-brown species Y_4 is formed on addition of excess conc. ammonia to a solution containing Y_1 . On treatment of a solution containing Y_1 with conc. HCl, the blue coloured species Y_5 is obtained. On exposure of Y_4 to air, the brownish-red species Y_6 is formed.

- Give the values of n and m.
- Identify the species Y and Y_1 to Y_6 . (Give chemical formulae) Note: Reasons are not required.
- Write the electronic configurations of Y^{n+} and Y^{m+} .
- Write the IUPAC name of Y_5 . (75 marks)

- n = 2 m = 3 Note: n = +2 and m = +3 can be accepted. (02 + 02)
- Y: Co (04)

Y_1 : $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$ (04)

Y_2 : $\text{Co}(\text{OH})_2$ (04)

Y_3 : CoS (04)

Y_4 : $[\text{Co}(\text{NH}_3)_6]^{2+}$ (04)

Y_5 : $[\text{CoCl}_4]^{2-}$ (04)

Y_6 : $[\text{Co}(\text{NH}_3)_6]^{3+}$ (04)
- Y^{2+} : $1s^2 2s^2 2p^6 3s^2 3p^6 3d^7$ (02)

Y^{3+} : $1s^2 2s^2 2p^6 3s^2 3p^6 3d^6$ (02)
- tetrachloridocobaltate(II) ion (02)

(7b(ii): 38 marks)

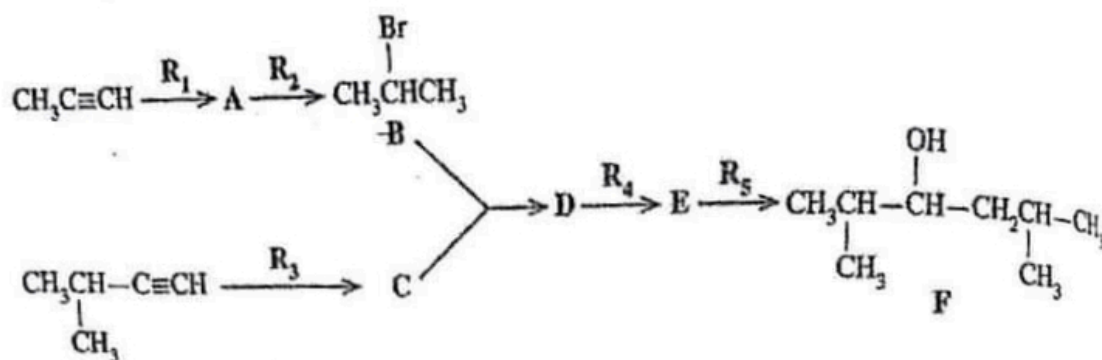
no marks for capital letter
no marks for (ii) simple reason

7(b): 75 marks

PART C - ESSAY

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

8. (a) Preparation of the compound F has been carried out using $\text{CH}_3\text{C}\equiv\text{CH}$ and $(\text{CH}_3)_2\text{CHC}\equiv\text{CH}$ according to the reaction scheme given below.

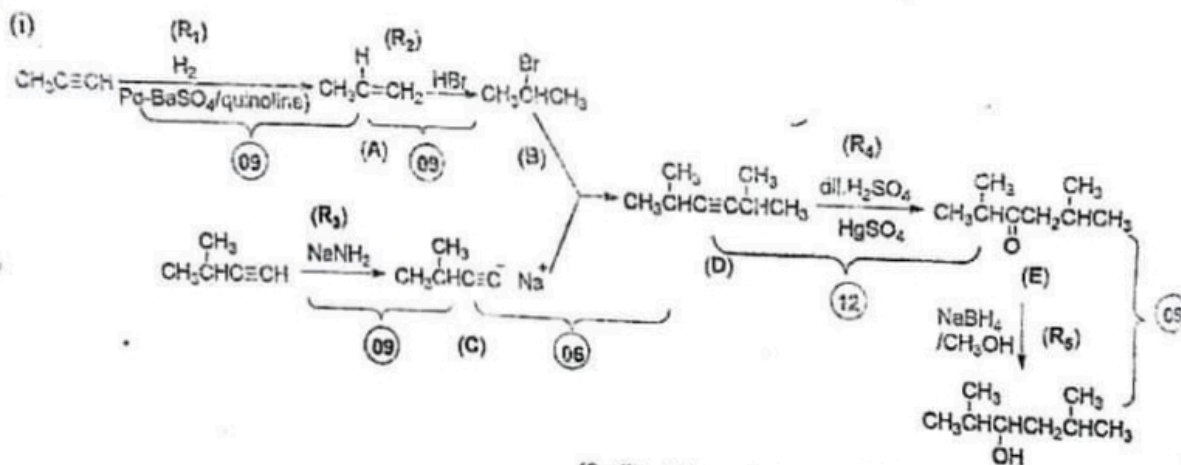
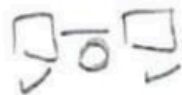


- (i) Give the structures of the compounds A, C, D and E and the reagents R_1 , R_2 , R_3 , R_4 and R_5 .
Only the chemical substances given below should be used either singly or as combinations as reagents.

Chemical substances:

H_2 , NaNH_2 , NaBH_4 , HgSO_4 , HBr , $\text{dil. H}_2\text{SO}_4$, $\text{Pd-BaSO}_4/\text{Quinoline catalyst}$, CH_3OH

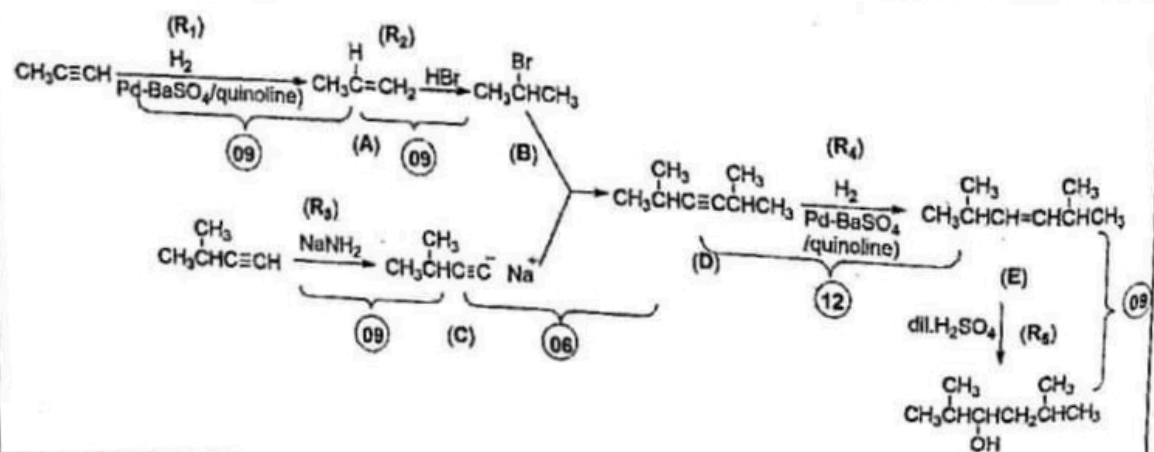
If the starting material and the product are correct award marks for reagent



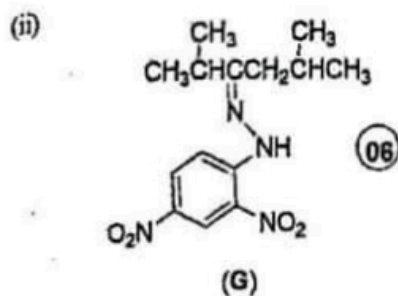
(8a(i): 54 marks)

If CH_3OH is not given for R_5
Deduct 03 marks

Alternative answer for (i)



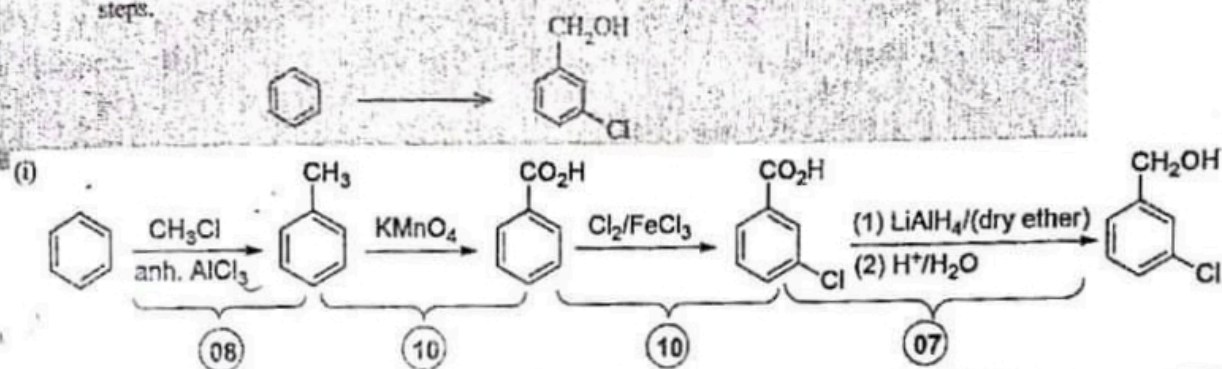
(ii) Compound F was reacted with $H^+/K_2Cr_2O_7$. When the product obtained from this reaction is reacted with 2,4-dinitrophenylhydrazine (2,4-DNP), compound G is formed. Give the structure of G.



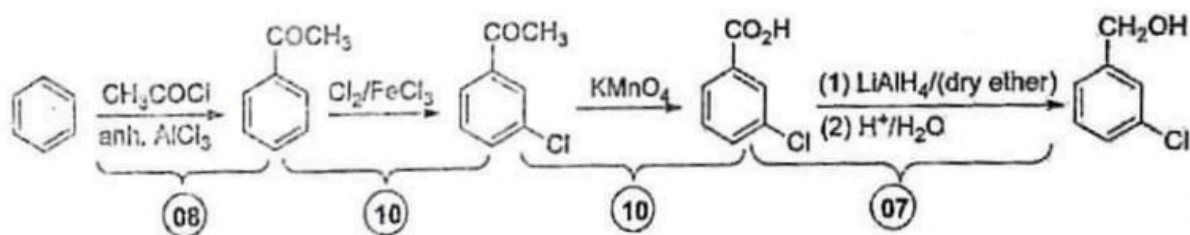
(8a(ii): 06 marks)

8(a): 60 marks

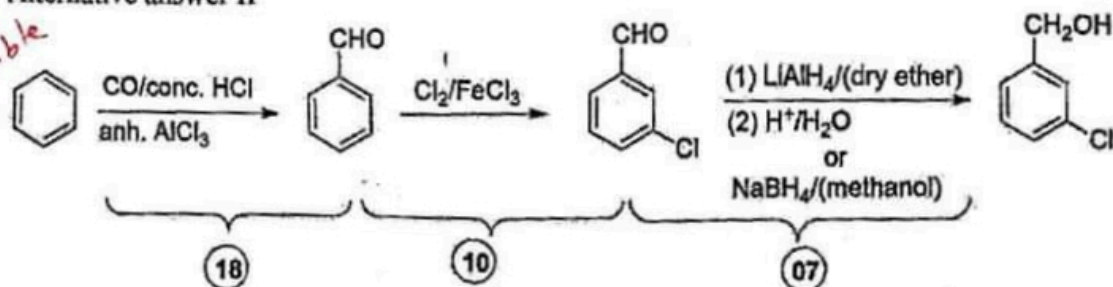
(b) (i) Show how the transformation given below can be carried out using not more than four (04) steps.



Alternative answer I



Alternative answer II

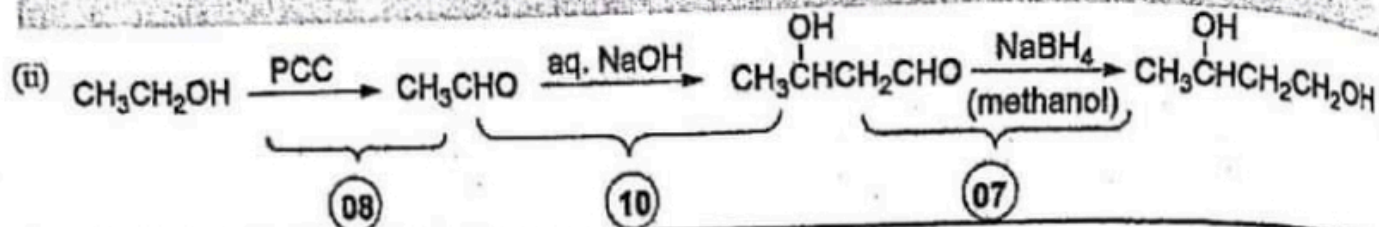


Alternative answer II.

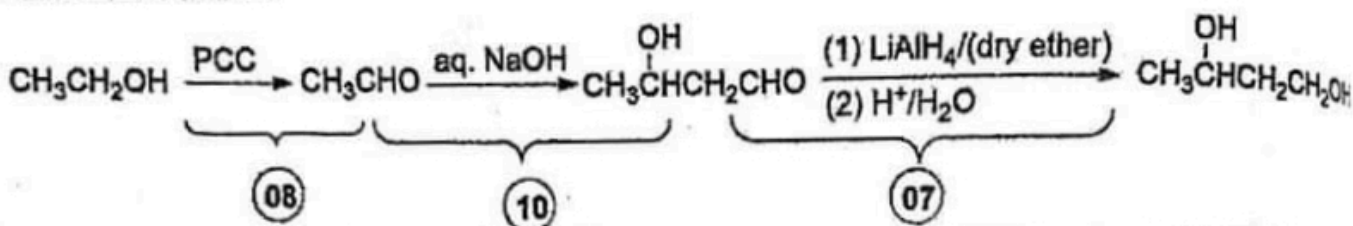
The first reaction in this answer is not in the syllabus. However, marks are allocated for correct chemistry.

(8b(i): 35 marks)

(ii) Show how the transformation given below can be carried out using not more than three steps.



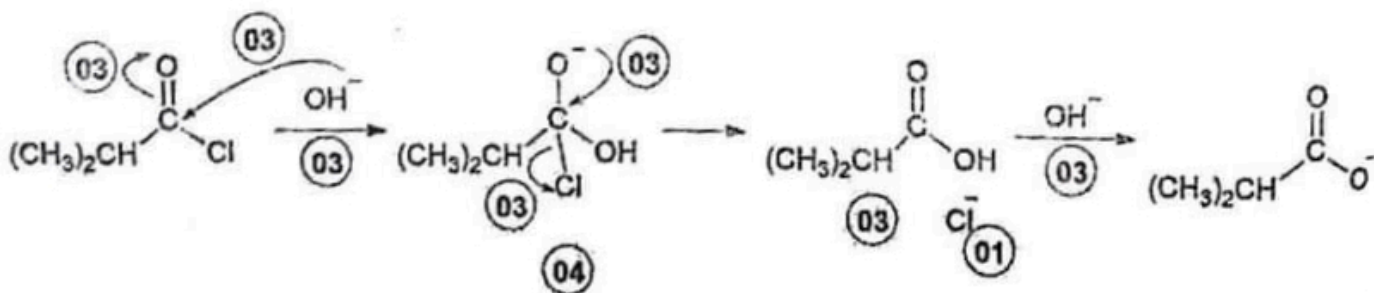
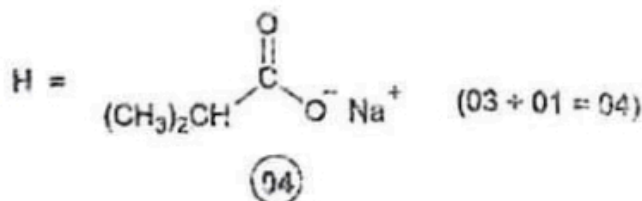
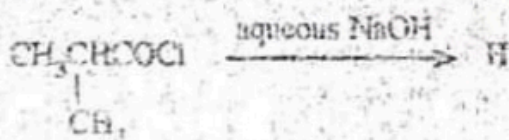
Alternative answer



(8b(ii): 25 marks)

8(b): 60 marks

(c) Give the structure of the product H of the following reaction. Write the mechanism of this reaction.



8(c): 30 marks

9. (a) A and B are water soluble inorganic compounds. A is coloured while B is colourless. When aqueous solutions of A and B are mixed together, the white precipitate C and the water soluble compound D are formed. C dissolves in dil. HCl to give the gas E with a pungent smell as one of the products. When E is passed through a solution of acidified $K_2Cr_2O_7$, the solution turns green. Addition of dil. NH_4OH to an aqueous solution of A gives a green precipitate F. F dissolves in excess dil. NH_4OH to give a dark blue solution G. A black precipitate is formed when H_2S is bubbled through an aqueous solution of A to which NH_4OH/NH_4Cl has been added. On addition of $AgNO_3(aq)$ to an aqueous solution of B, a white precipitate H that is soluble in dil. NH_4OH is formed. Addition of $Pb(NO_3)_2(aq)$ to an aqueous solution of B gives a white precipitate I that is soluble in hot water. When dil. H_2SO_4 is added to an aqueous solution of B, a white precipitate J that is insoluble in dil. HCl is formed. B gives a green coloured flame in the flame test.

(i) Identify the species A to J. (Give chemical formulae) Note: Reasons are not required.

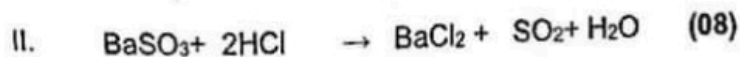
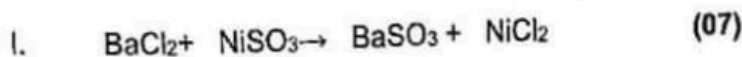
A:	$NiSO_3$	(06)
B:	$BaCl_2$	(06)
C:	$BaSO_3$	(06)
D:	$NiCl_2$ or $[Ni(H_2O)_6]Cl_2$	(06)
E:	SO_2	(06)
F:	$Ni(OH)_2$	(06)
G:	$[Ni(NH_3)_6]^{2+}$	(06)
H:	$AgCl$	(06)
I:	$PbCl_2$	(06)
J:	$BaSO_4$	(06)

(9a(i): 60 marks)

(ii) Write balanced chemical equations for the following:

I. Formation of C and D

II. Dissolution of C in dil. HCl

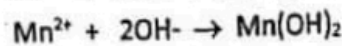
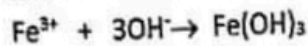
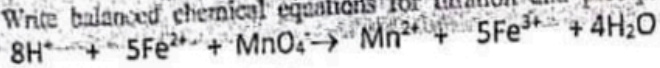


(9a(ii): 15 marks)

9(a): 75 marks

(b) An iron ore, X, contains FeO, Fe₂O₃ and inert substances. The following experimental procedure was used to determine the mass percentages of FeO and Fe₂O₃ in X.
A mass of 0.4800 g of X was dissolved in 10 cm³ of concentrated acid. This solution was filtered to remove insoluble matter, and thereafter diluted to 50.00 cm³ using distilled water. This entire diluted solution was titrated with 0.020 mol dm⁻³ KMnO₄ solution. The titration reading at the end point was 20.00 cm³. The pH of the entire solution, obtained after the titration, was raised to 12. At this stage, the metal ions in solution were precipitated as their hydroxides. The precipitate was filtered and dried until a constant mass was obtained. The mass of the precipitate obtained was 0.5706 g.

(i) Write balanced chemical equations for titration and precipitation reactions.



(06)

(03)

(03)

(9b(i): 12 marks)

(ii) Calculate the mass percentages of FeO and Fe₂O₃ in X.

Note: Assume that the composition does not change during drying of metal hydroxides and there is no effect from dissolved oxygen in solution.

(H = 1, O = 16, Mn = 55, Fe = 56)

$$\text{Moles of MnO}_4^- = 0.02 \text{ mol dm}^{-3} \times 20 \times 10^{-3} \text{ dm}^3 = 4.0 \times 10^{-4} \text{ mol} \quad (03)$$

$$\text{As } \frac{n \text{ Fe}^{2+}}{n \text{ MnO}_4^-} = \frac{5}{1} \quad (03)$$

$$\text{Moles of Fe}^{2+} = 5 \times 0.02 \times 20 \times 10^{-3} \text{ mol} = 2.0 \times 10^{-3} \text{ mol} \quad (03)$$

$$\text{Molar mass of FeO} = 56.0 + 16.0 = 72 \text{ g mol}^{-1} \quad (02)$$

$$\text{Mass of FeO} = 2 \times 10^{-3} \text{ mol} \times 72 \text{ g mol}^{-1} \quad (03)$$

$$= 0.144 \text{ g} \quad (03)$$

$$\% \text{ FeO} = \frac{0.144}{0.480} \times 100\% \quad (03)$$

$$= 30\% \quad (03)$$

Precipitate contains Fe(OH)₃ and Mn(OH)₂ (04)

$$\text{Molar mass of Fe(OH)}_3 = 56.0 + (16.0 \times 3) + (1 \times 3) = 107.0 \text{ g mol}^{-1} \quad (02)$$

$$\text{Mass of Fe(OH)}_3 \text{ precipitated from FeO} = 2 \times 10^{-3} \text{ mol} \times 107.0 \text{ g mol}^{-1} = 0.214 \text{ g} \quad (03)$$

$$\text{Molar mass of Mn(OH)}_2 = 55.0 + (16 \times 2) + (1 \times 2) = 89.0 \text{ g mol}^{-1} \quad (02)$$

$$\text{Mass of Mn(OH)}_2 \text{ precipitated from KMnO}_4 \text{ titration} = \frac{0.02}{1000} \times 20 \text{ mol} \times 89 \text{ g mol}^{-1} = 0.0356 \text{ g} \quad (03)$$

$$\text{Mass of Fe(OH)}_3 \text{ that resulted due to Fe}_2\text{O}_3 = 0.5706 \text{ g} - 0.214 \text{ g} - 0.0356 \text{ g} \quad (02+02+02 = 06)$$

$$= 0.321 \text{ g} \quad (03)$$

No marks after this if the mass of Fe(OH)₃ is wrong

$$\text{Moles of Fe(OH)}_3 \text{ that resulted due to Fe}_2\text{O}_3 = \frac{0.321 \text{ g}}{107 \text{ g mol}^{-1}} = 3.0 \times 10^{-3} \text{ mol} \quad (03)$$

$$\text{Moles of Fe}_2\text{O}_3 = \frac{1}{2} \times 3.0 \times 10^{-3} \text{ mol} = 1.5 \times 10^{-3} \text{ mol} \quad (03)$$

$$\text{Molar mass of Fe}_2\text{O}_3 = (56 \times 2) + (16 \times 3) = 160 \text{ g mol}^{-1} \quad (02)$$

$$\text{The mass of Fe}_2\text{O}_3 = 1.5 \times 10^{-3} \text{ mol} \times 160 \text{ g mol}^{-1} = 0.240 \text{ g} \quad (03)$$

$$\% \text{ Fe}_2\text{O}_3 = \frac{0.240 \text{ g}}{0.480 \text{ g}} \times 100\% \quad (03)$$

$$= 50\% \quad (03)$$

(9b(ii): 63 marks)

half reaction
not accepted

23

10.(a) The following questions [(i) - (v)] are based on the manufacture of sulphuric acid by the Contact Process.

(i) State the **three** raw materials used.

Sulfur (S) / ores containing S / S obtained as a byproduct during petroleum refining / S extracted from earth / metal sulfides (03)

Air (03)

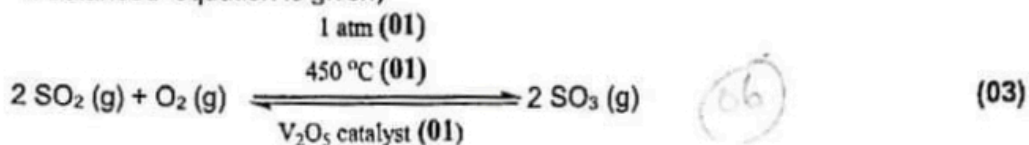
H₂O (03)

(10a(i): 09 marks)

(ii) Write balanced chemical equations for the reactions taking place. State proper conditions where necessary.



(marks may also be allocated for metal sulfide + O₂ → SO₂ + metal oxide if balanced equation is given)



Note : Physical states not required.

(10a(ii): 15 marks)

(iii) State two strategies used to increase the efficiency of the Contact Process.

Using several steps to convert entire amount of SO₂ to SO₃ via catalytic surfaces/chambers (03)

Using atmospheric air to increase O₂ concentration to maintain O₂:SO₂ ratio as 1:1 (03)

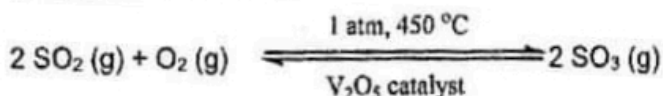
(10a(iii): 06 marks)

(iv) State two principles used in the determination of the optimum conditions for the Contact Process and briefly explain each principle using a reaction you specified in part (ii) above.

Le Chatelier Principle (03)

Counter Current Principle (03)

Le Chatelier Principle



Because this reaction is highly exothermic, decreasing the temperature is expected to favour the forward reaction. But low temperatures will decrease rate of reaction.

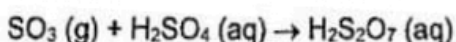
Therefore an optimum temperature of 450 °C will be used. (01+01+01+01)

Or

Increasing O₂ concentration favours the forward reaction. Therefore although a ratio of 2:1 is suggested by stoichiometry, actually a 1:1 ratio of SO₂ : O₂ is used.

(01+01+01+01)

Counter Current Principle



SO₃ gas moves in an upward direction while H₂SO₄ trickles downward enabling the more efficient absorption of SO₃ into H₂SO₄. (01+01+01+01)

Note : Reaction must be indicated or specified to award marks

(10a(iv): 14 marks)

(v) Name two industries which utilize sulphuric acid as a raw material.

phosphate fertilizer or ammonium sulphate fertilizer manufacturing industries

artificial fiber (rayon and plastics) industries

manufacture of detergents containing alkyl and aryl sulfonates

dyes / explosive / medicine manufacturing industry

battery acid manufacture

industries which dry gases

Any two

(03 marks x 2 = 06 marks)

(10a(v): 06 marks)

10(a): 50 marks

(b) Gaseous compounds of carbon, nitrogen and sulphur with various oxidation numbers directly contribute to global environment issues.

(i) Name two non-halogenated carbon compounds and one nitrogen compound that directly contribute to global warming and state the oxidation numbers of C and N in these compounds.

CO₂ +4

CH₄ -4

N₂O +1

(02 marks for compound and 01 mark for oxidation state)

(03 marks x 3 = 09 marks)

(10b(i): 09 marks)

(ii) State how the three compounds you named in (i) above are released to the atmosphere due to human activities.

CO₂ : Carbon compounds of fossil fuel and biomass are converted to CO₂ by combustion

or

Biomass grounded during deforestation is converted /oxidized to CO₂ by aerobic microorganisms /bacterial action.

CH₄ : Improper disposal of waste materials produce CH₄ due to the action of anaerobic microorganisms on organic matter.

or

Extensive rearing of ruminant animals in animal farming releases CH₄ due to conversion of organic matter by gut bacteria.

or

CH₄ is released to the atmosphere by fossil fuel retrieval and refinery process.

N₂O : Soil bacterial action on nitrogen fertilizer produces N₂O

(03 marks x 3 = 09 marks)

(10b(ii): 09 marks)

(iii) Explain how the compounds you mentioned in (i) above contribute to global warming.

The above three compounds are greenhouse gases (02)

These greenhouse gases absorb infrared radiation that are reradiated from planet surface. (02)

The infrared absorption retains thermal energy for a longer time and heats up the planet and maintains the temperature. (02)

Elevation of the composition these gases due to human activities (02)

Retention of more IR radiation energy and elevates the global temperature. (02)

(02 marks x 5 = 10 marks)

(10b(iii): 10 marks)

(iv) Name two nitrogen compounds with the oxidation numbers of N that directly contribute to photochemical smog.

02 NO +2 01

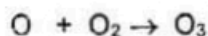
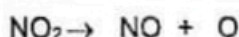
NO₂ +4 01

(02 marks for compound and 01 mark for oxidation state)

(06 marks)

(10b(iv): 06 marks)

(v) Write balanced chemical equations for the formation of tropospheric ozone by a nitrogen compound you stated in (iv) above.



(03 marks x 2 = 06 marks)

(10b(v): 06 marks)

(vi) Explain why the tropospheric ozone level reaches its maximum level in the afternoon.

Solar radiation is the essential factor for photochemical smog (02)

Intensity of solar radiation reaches the maximum at noon (02)

and therefore photochemical smog reaches its maximum level in the afternoon.

(10b(vi): 04 marks)

(vii) State three water quality parameters that are affected as a result of the dissolution of oxides of nitrogen and sulphur in water bodies.

pH/ acidity

electrical conductivity

algal nutrient (NO₃⁻/ PO₄³⁻ - any one)

heavy metal (As₂O₃²⁻ / Cd²⁺ / Pb²⁺ / Hg²⁺ - any one) levels

water hardness/ Ca²⁺, Mg²⁺ levels.

Any three

(02 marks x 3 = 06 marks)

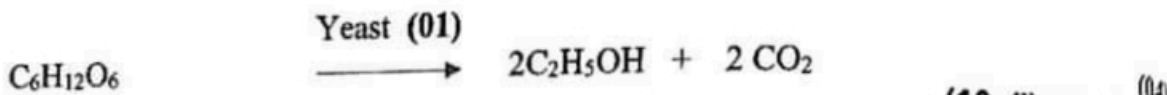
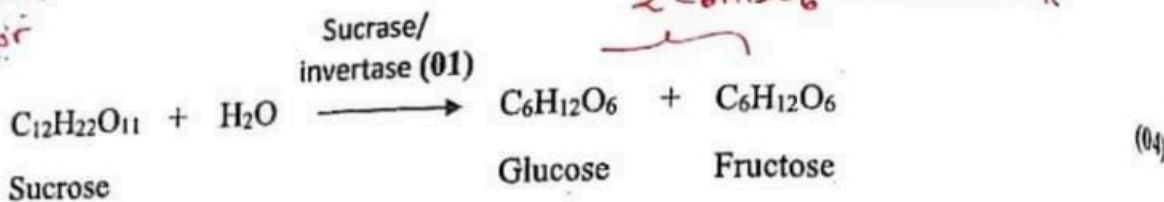
(10b(vii): 06 marks)

10(b): 50 marks

(c) The following questions are based on chemical products related to plant sources.

(i) Give relevant balanced equations to indicate the chemical changes that take place when ethanol in coconut toddy is produced by fermentation of sweet toddy.

If the balanced equation is correct award marks for the enzymes



(10c(i): 10 marks)

(ii) Explain why it is necessary to remove free fatty acids from plant oils taken as raw materials in the production of bio-diesel.

To obtain biodiesel of high purity. (04)

To have high yield of biodiesel (04)

If plant oils contain free fatty acids (RCOOH), they may react with NaOH to give soap (RCOONa). (04)

If soap is formed, foam is also formed, which inhibits (the catalytic action of NaOH used for) the transesterification reaction. (03)

(10c(ii): 15 marks)

(iii) Explain briefly why essential oils can be extracted from plant materials by steam distillation at a temperature which is below the boiling points of both pure water and essential oil.

Essential oil and water are immiscible (04)

Gaseous phase can be considered as a mixture of saturated vapours of water and essential oil. (04)

$$P_T = P^0_{\text{H}_2\text{O}} + P^0_{\text{essential oil}} \quad (04)$$

The mixture boils when $P_T = P_{\text{external}}$ (04)

In the case of pure liquids $P_{\text{external}} = P^0_{\text{liquid}}$ at the boiling point. (04)

In the mixture since both the liquids contribute, P_T becomes equal to P_{external} at a temperature lower than the boiling points of either liquid. (05)

(10c(iii): 25 marks)

10(c): 50 marks

06. (a)

(vi) Sketch the titration curve (pH vs. volume of HCl) for the above titration in (v).

