

1. (a) Le Chatelier's principle states that when a system is in equilibrium and it is subjected to an external constraint, the system adjusts itself so as to annul or minimize the effect of the applied constraint.

(C1)

b) Known amounts ~~a~~ moles hydrogen iodide is sealed in a hard glass tube and the tube is heated up to  $450^{\circ}\text{C}$  and the temperature is kept constant until equilibrium ~~equilibrium~~ is attained. The tube is cooled rapidly and broken under ice cold potassium iodide solution. The amount of iodine in the equilibrium mixture is determined by pipetting a known volume of the mixture and titrating it with a standard solution of sodium thiosulphate using starch indicator.

Iodine reacts with thiosulphate ions according to the following equation:



If  $x$  moles of iodine are present at equilibrium, then the equilibrium constant can be determined as follows:



Initial moles

equilibrium moles

$\frac{x}{2}$   $x$   $x$

81  
2

$$K_c = \frac{[T_2][H_2]}{[HI]^2} \quad \checkmark$$



$$(a-2x)$$

$$\begin{array}{c} \text{---} \\ \diagup \quad \diagdown \\ \text{---} \end{array}$$

$$(a-2x)^2$$

c) (ii) A catalyst does not affect the equilibrium position and equilibrium constant ~~but since it affects the forward and backward reactions~~ ~~02~~ equally. However, a catalyst increases the rate of attainment of equilibrium.

(iii) When a small amount of potassium iodide solution is added to the equilibrium mixture, iodide ions from potassium iodide react with iodine to form a soluble complex. The concentration of iodine reduces and thus more hydrogen iodide dissociates to form iodine and thus the equilibrium position shifts to the right but the equilibrium constant is not affected.

(ii) When some hydrogen iodide is withdrawn from the equilibrium mixture the equilibrium position shifts to the left. Iodine and hydrogen combine to form hydrogen iodide. The equilibrium constant is not affected.



Initial  
moles  $\frac{1}{3}$

Reacting  
moles  $-x$   $x$   $2x$

Equilibrium  
Eqns moles  $\frac{1-x}{3}$   $1-x$   $2x$  ✓

$$K_c = \frac{[HI]^2}{[I_2][H_2]} \quad \checkmark$$

$$50 = \frac{(2x)^2}{(1-x)(1-x)} \quad \checkmark$$

$$50 \left(1 - \frac{1}{3}x - x + x^2\right) = 4x^2$$

$$\frac{50}{3} - \frac{50x}{3} - 50x + 50x^2 - 4x^2$$

$$\frac{50}{3} - \frac{200x}{3} + 50x^2 = 4x^2$$

$$50 - 200x + 150x^2 = 12x^2$$

$$138x^2 - 200x + 50 = 0$$

$$x = 0.3212$$

OC

The number of moles of HI at equilibrium =  $0.3212 \times 2$   
 $= 0.6424 \text{ mols}$ ,

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2. (a) An ore is a naturally occurring substance from which a metal or an element is extracted. ✓

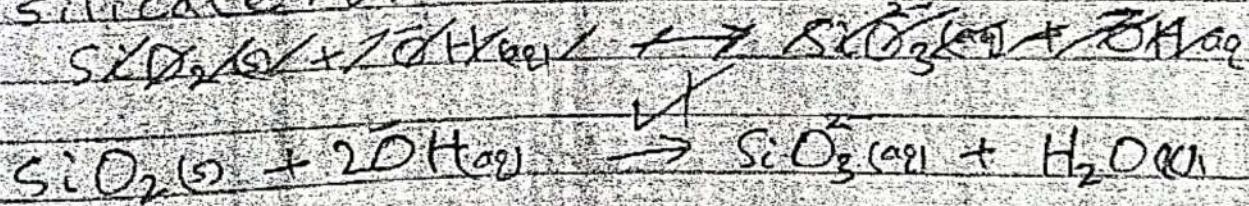
(01)

(b) (i) Bauxite,  $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$  ✓

(01)

(c) (ii) The ore is first roasted at a low temperature and this is to convert all the oxides of iron to +3 oxidation state. The roasted ore crushed into powder and concentrated sodium hydroxide solution is added to the powder and the mixture heated. Aluminium oxide being amphoteric dissolves to form sodium aluminate,  $\text{Al}_2\text{O}_3(s) + 2\text{NaOH}(aq) + 3\text{H}_2\text{O}(l) \rightarrow 2\text{Al}(\text{OH})_4^{(aq)}$

Silicon(iv) oxide present as an impurity and being acidic dissolved to form sodium silicate. ✓

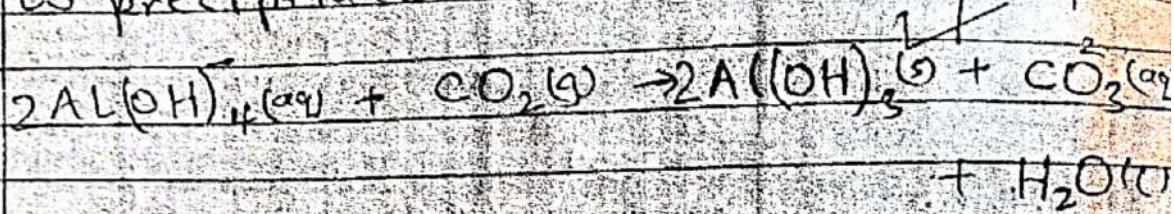


Iron(III) oxide being basic does not dissolve in sodium hydroxide and is filtered off.

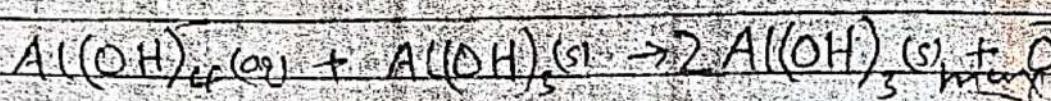
The filtrate is diluted with distilled water and seeded by passing carbon dioxide through it to precipitate aluminium hydroxide. ✓  
Alternatively

The seeding can be carried out by adding freshly precipitated/prepared aluminium hydroxide to the filtrate.

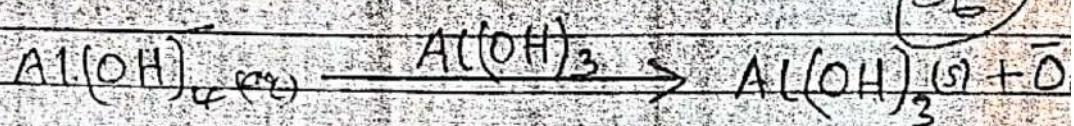
to precipitate more aluminium hydroxide.



Q1

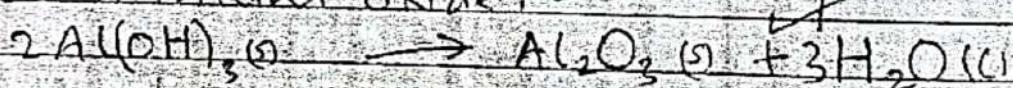


Q2



The precipitated aluminium hydroxide is filtered off, washed and dried.

The dried aluminium hydroxide is heated strongly to form pure / concentrated aluminium oxide.

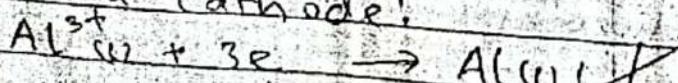


(ii) The concentrated aluminium oxide (bauxite) is dissolved in molten cryolite and the solution formed is electrolysed using graphite (carbon) electrodes.

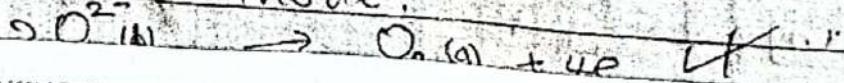
Aluminium ions are discharged at the cathode to form aluminium metal in liquid state and can be siphoned off.

The oxide ions are discharged at the anode to form oxygen gas.

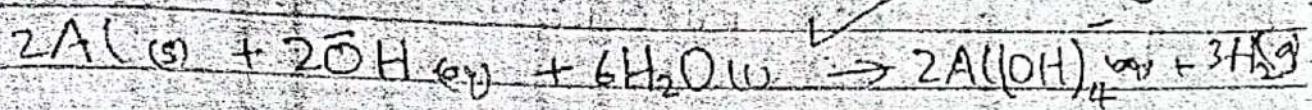
At the cathode:



At the anode:



d) i) Aluminium reacts with hot concentrated sodium hydroxide solution to form  $\text{Al(OH)}_4^-$  and hydrogen gas.



ii) Aluminium reacts with concentrated (or warm dilute) hydrochloric acid to form aluminium chloride and hydrogen gas.



	Al	Cl
%	20	80

molar mass	20	80	1
	27	35.5	
	0.74074	2.25352	

$$\text{mole ratio } \frac{0.74074}{0.74074} : \frac{2.25352}{0.74074}$$

$$1 : 3$$

Simplest empirical formula is  $\text{AlCl}_3$  (03)

$$\text{R.m.m of AlCl}_3 = 0.01192 \times 22400$$

$$= 267.0$$

$$(\text{AlCl}_3)_n = 267$$

$$(27 + 35.5 \times 3) \cdot n = 267$$

$$133.5n = 267$$

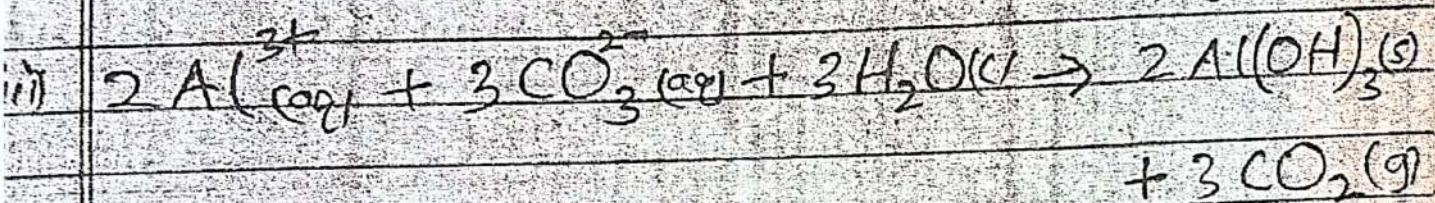
$$n = 2$$

Molecular formula of aluminium  
chloride in  $\text{Al}_2\text{Cl}_6$

(i) white precipitate and effervescence  
of a colourless gas.



Ans ✓



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$$\text{iii) Mass of } \text{CO}_2 = \frac{22.4 \times 44}{22400} \\ = 0.044\text{g}$$

$$\text{Mass of Carbon} = \frac{12 \times 0.044}{44} \\ = 0.0129 \checkmark$$

$$\text{OR Mass of Carbon} = \frac{22.4 \times 12}{22400} \\ = 0.0129$$

$$\text{Mass of hydrogen} = \frac{2 \times 0.0135}{18} \\ = 0.00159 \checkmark$$

$$\text{Mass of oxygen} = 0.6175 - (0.012 + 0.0015) \\ = 0.0049 \checkmark$$

	C	H	O
masses	0.012	0.0015	0.004
moles	0.012 / 12	0.0015 / 1	0.004 / 16
	0.001	0.0015	0.00025

mole ratios	0.001 / 0.00025	0.0015 / 0.00025	0.00025 / 0.00025
	4	6	1

Empirical formula of Q is  $\text{C}_4\text{H}_6\text{O}_1$

$$(iii) PV = \frac{M \times RT}{M_r} \checkmark$$

$$\frac{725 \times 101325 \times 72.67 \times 10^{-5}}{760} = \frac{0.105 \times 8.314 \times 57}{M_r}$$

$$M_r = 70.0 \checkmark$$

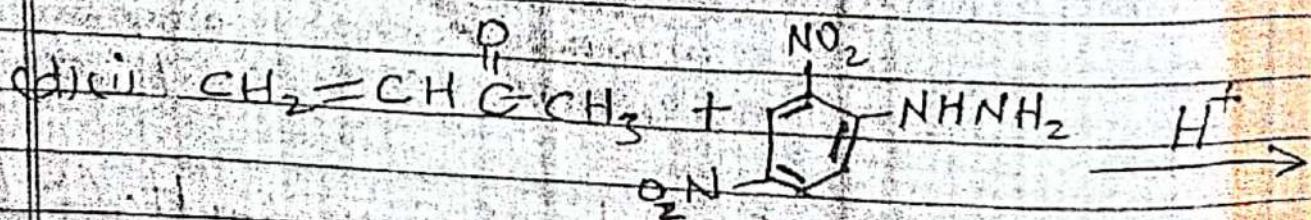
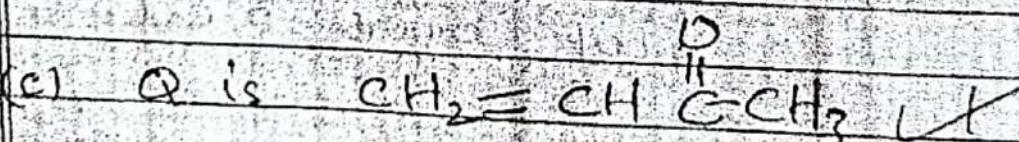
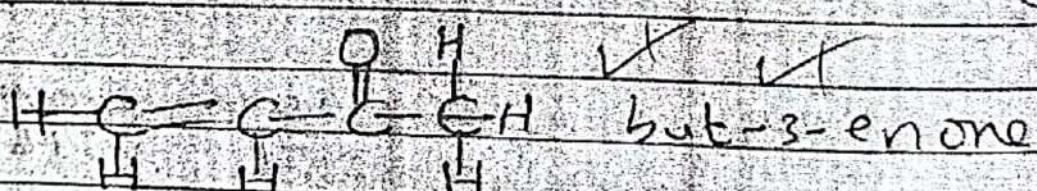
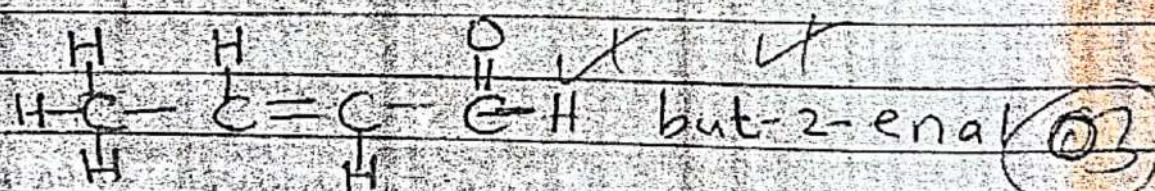
$$(C_4H_6O)_n = 70$$

$$(48 + 14n + 16)n = 70$$

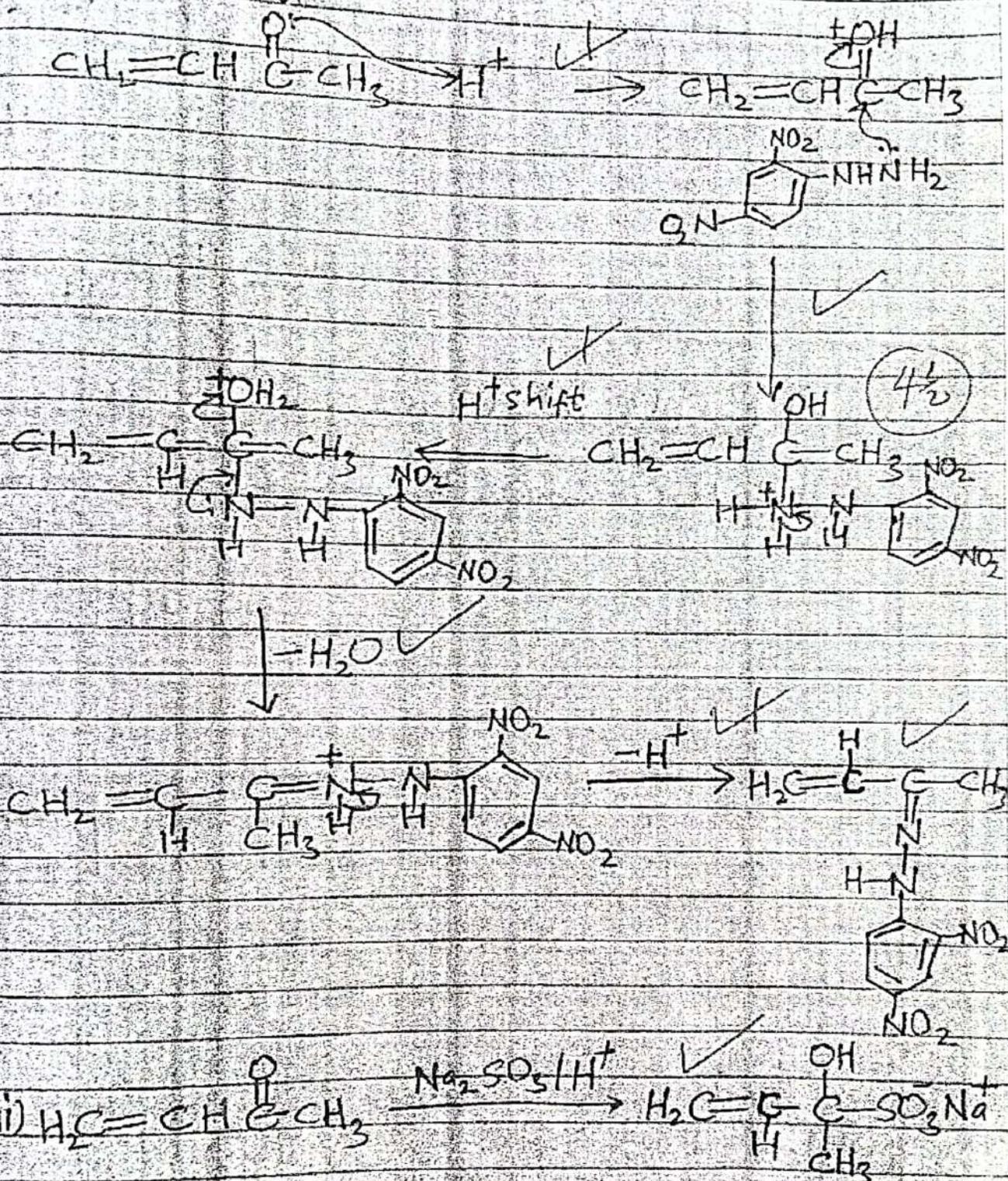
$$70n = 70$$

$$n = 1 \checkmark$$

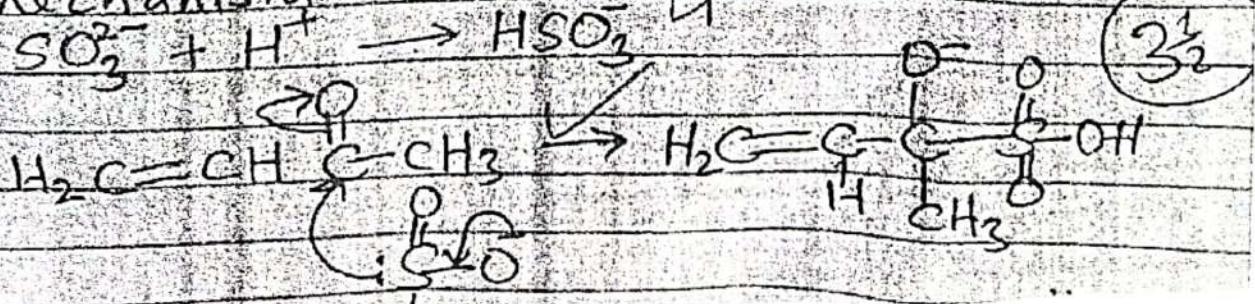
∴ molecular formula of Q is  $C_4H_6O$

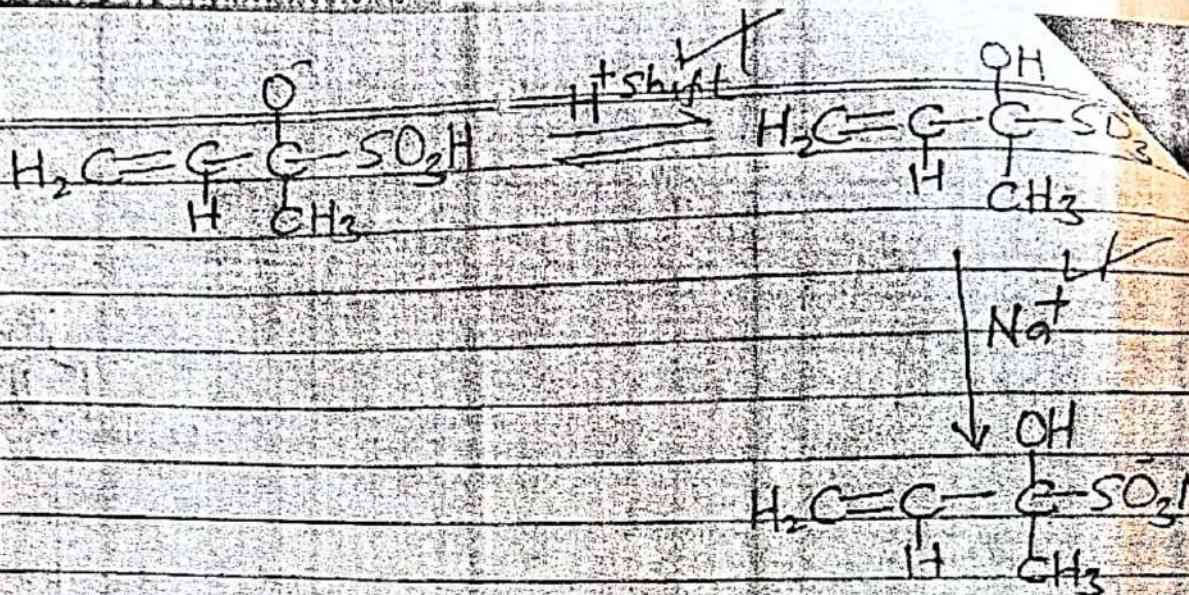


Mechanism

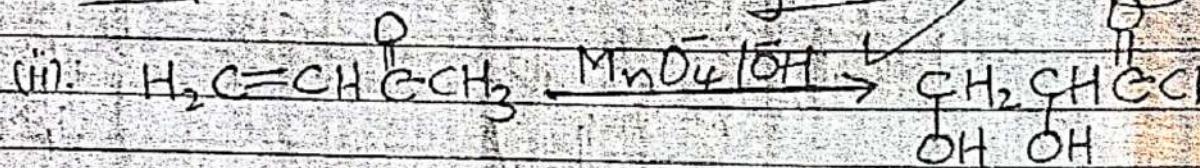


Mechanism





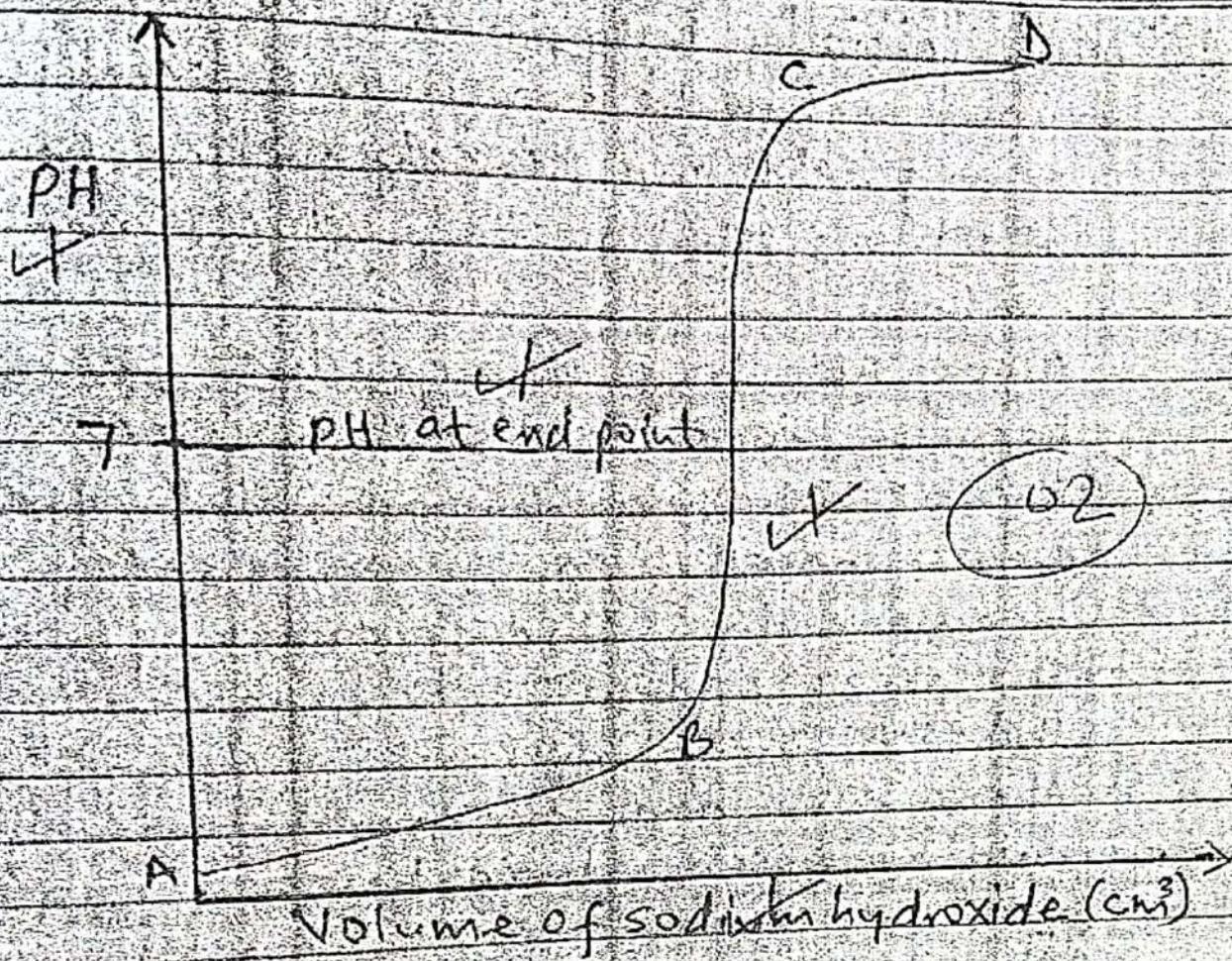
(e) (ii) Purple solution turns green  $\xrightarrow{\text{O}_2}$



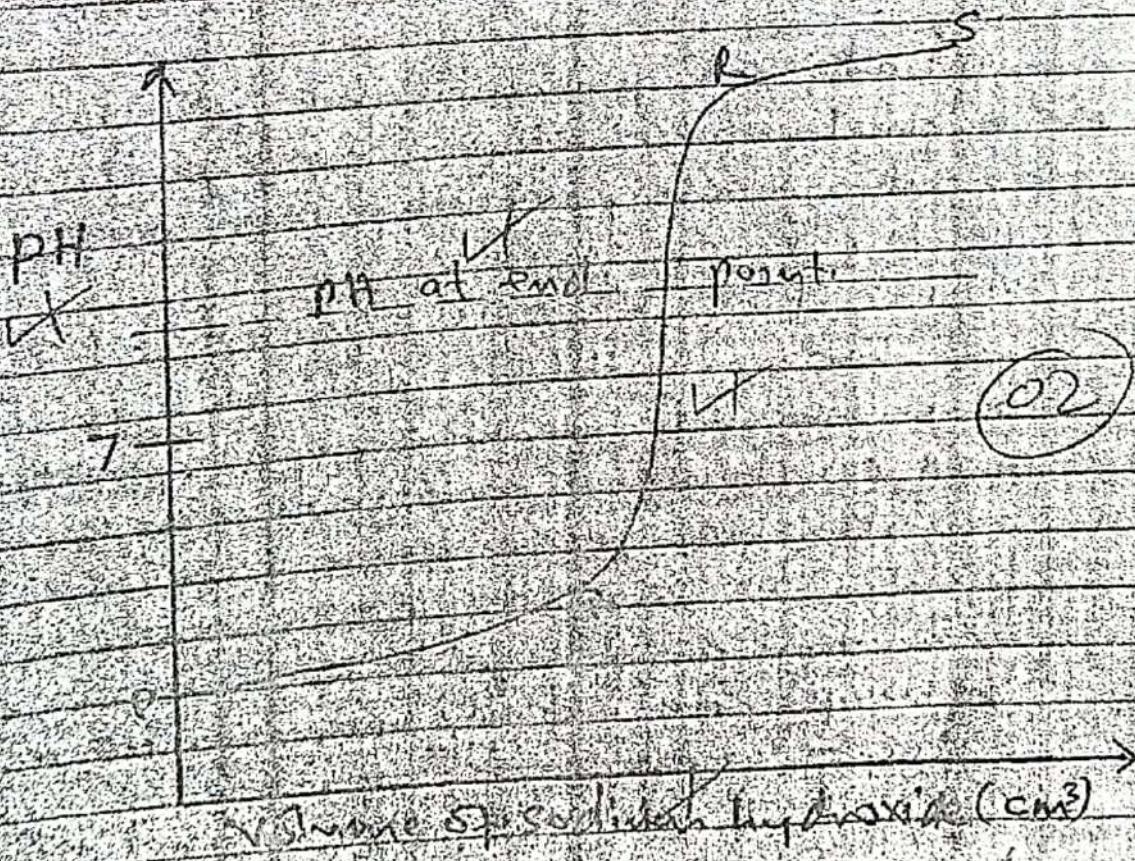
$\checkmark$   
3,4-dihydroxybutan

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(G)



(G)



(b) (ii) Initially the pH of the solution is very low because hydrochloric acid is a very strong acid and partially ionises completely in aqueous solution to produce many hydrogen ions.

Along AB, there is a gradual increase in pH because the acid is still in excess. At point B is near the end point and any addition of the alkali produces a sharp rise in pH because sodium hydroxide is a strong base. The pH at end-point is equal to 7 because the salt formed does not undergo hydrolysis. Along CD, there is a gradual increase in pH due to excess strong base.

(iii)

Initially at point P, the pH was slightly high because ethanoic acid is a weak acid which partially ionises to produce fewer hydrogen ions.

Along PQ, there is a gradual increase in pH because the acid is still in excess and also the salt formed together with the weak acid constitutes a buffer mixture which resists change in pH.

Point Q is near the end-point and any additional drop(s) of the alkali produces a sharp rise in pH, because the alkali is a strong base.

The pH at the end-point is about seven (7) because the salt formed undergoes hydrolysis to produce hydroxide ions to make the solution basic.

Along RS, the pH increases gradually due to excess strong alkali.

Q)  $1000 \text{ cm}^3$  of  $\text{CH}_3\text{COOH}$  solution contain  $0.2 \text{ mol}$   
 $55 \text{ cm}^3$  of  $\text{CH}_3\text{COOH}$  solution contain  $0.2 \times \frac{55}{1000}$   
 $= 0.011 \text{ mol}$

$1000 \text{ cm}^3$  of  $\text{CH}_3\text{COONa}$  solution contain  $0.2 \text{ mol}$   
 $45 \text{ cm}^3$  of  $\text{CH}_3\text{COONa}$  solution contain  $0.2 \times \frac{45}{1000}$   
 $= 0.009 \text{ mol}$

Total volume of solution  $= 55 + 45$   
 $= 100 \text{ cm}^3$

$$[\text{CH}_3\text{COOH}] = \frac{0.011 \times 1000}{100}$$
$$= 0.11 \text{ M}$$

$$[\text{CH}_3\text{COONa}] = \frac{0.009 \times 1000}{100}$$
$$= 0.09 \text{ M}$$

(32)

$$\text{pH} = \text{p}K_a + \log_{10} \frac{[\text{salt}]}{[\text{acid}]}$$

$$\text{pH} = -\log_{10} 1.75 \times 10^{-5} + \log_{10} \frac{0.09}{0.11}$$

$$= 4.757 + 0.08715$$

$$= 4.844$$

$$\text{(ii) No. of moles of NaOH} = \frac{0.5 \times 0.1}{1000} \\ = 0.0005$$

$$[\text{NaOH}] = \frac{0.0005 \times 1000}{100} \\ = 0.005 \text{ mol dm}^{-3}$$



$$[\text{CH}_3\text{COOH}] = 0.11 - 0.0005 \\ = 0.1095 \text{ M}$$

$$[\text{CH}_3\text{COONa}] = 0.09 + 0.0005 \\ = 0.0905 \text{ M}$$

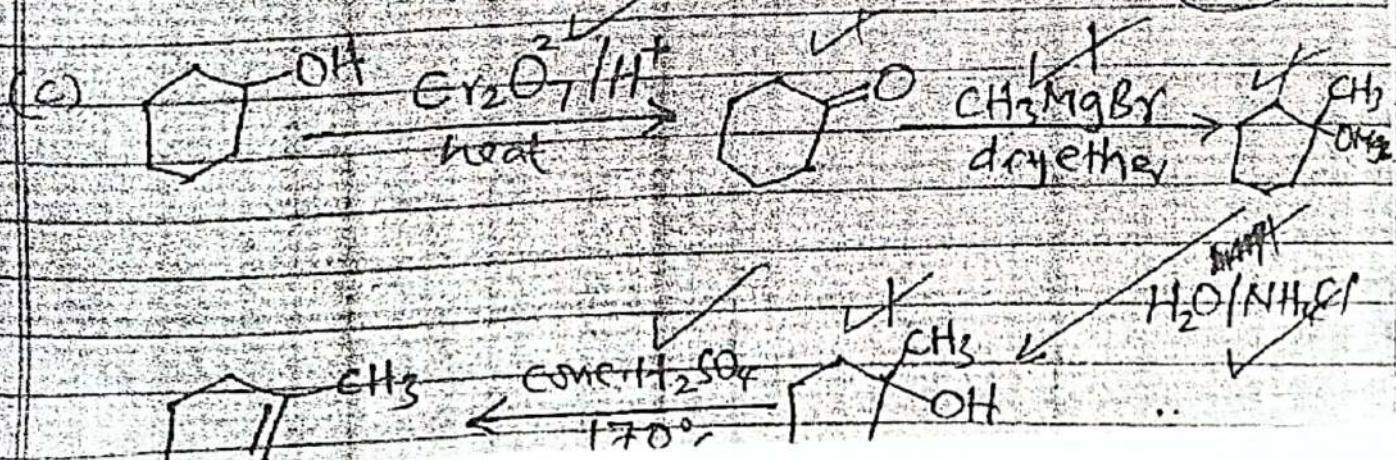
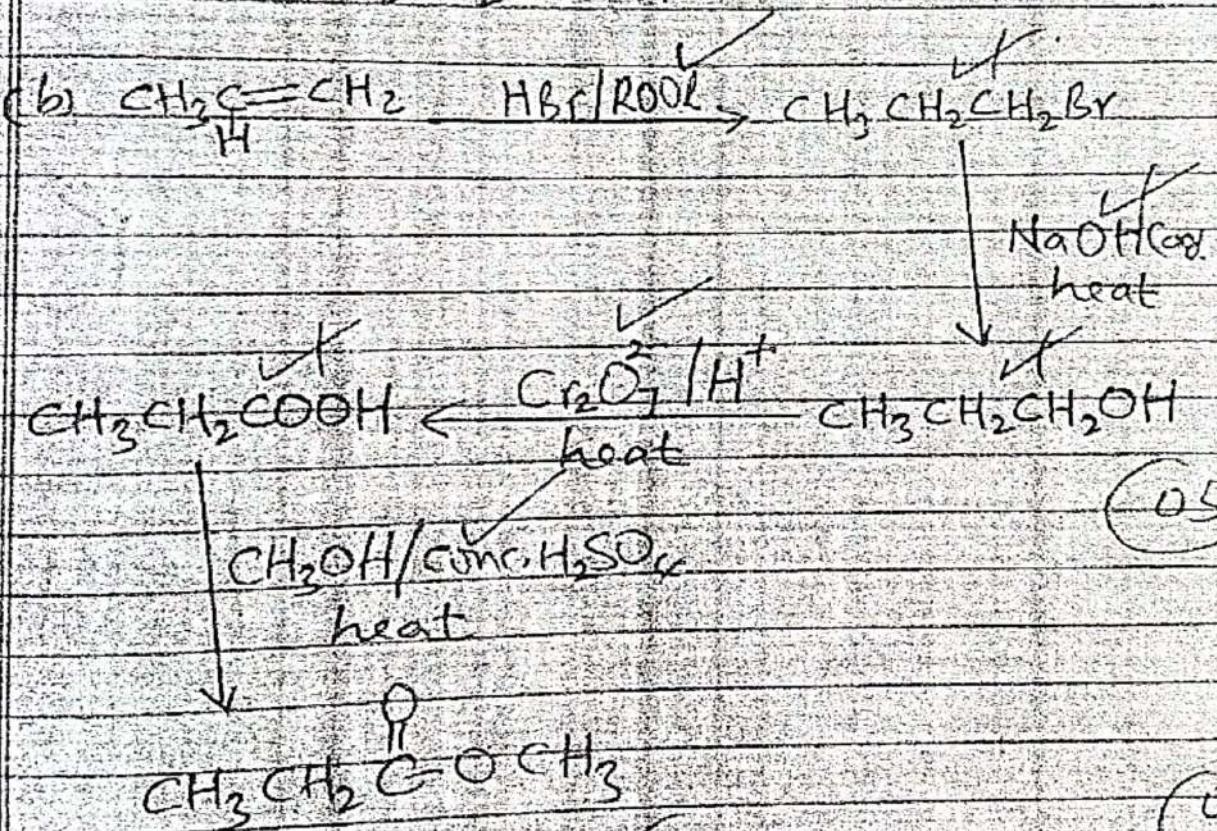
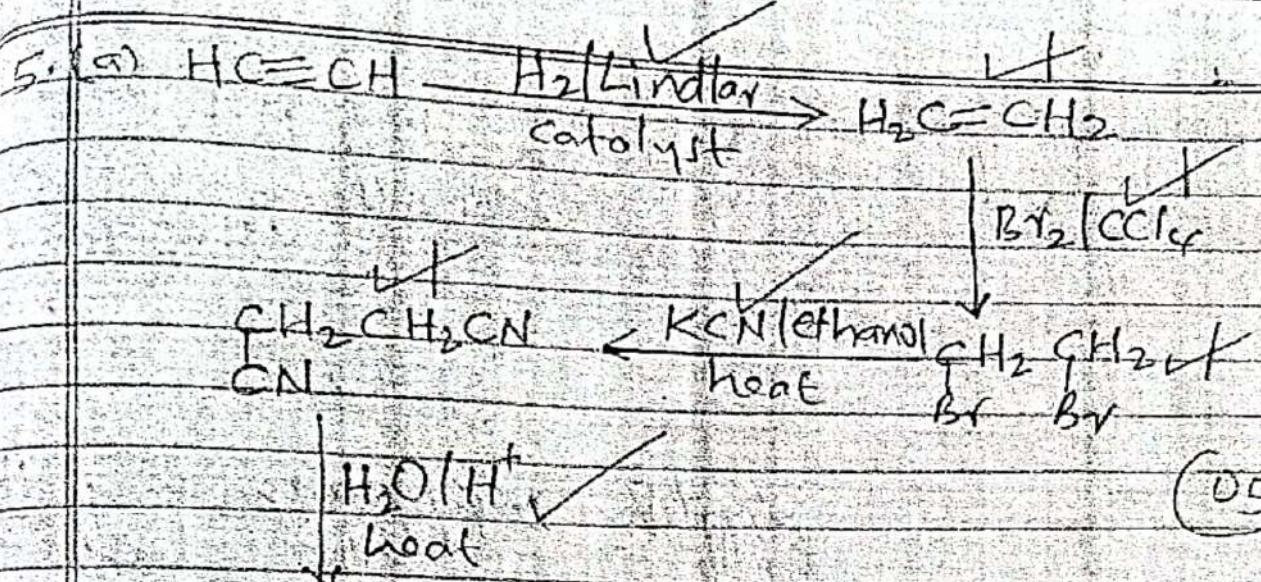
$$\text{pH} = \text{pK}_a + \log_{10} \left( \frac{[\text{salt}]}{[\text{acid}]} \right) \quad (22)$$

$$= -\log_{10} 1.75 \times 10^{-5} + \log_{10} \left( \frac{0.0905}{0.1095} \right)$$

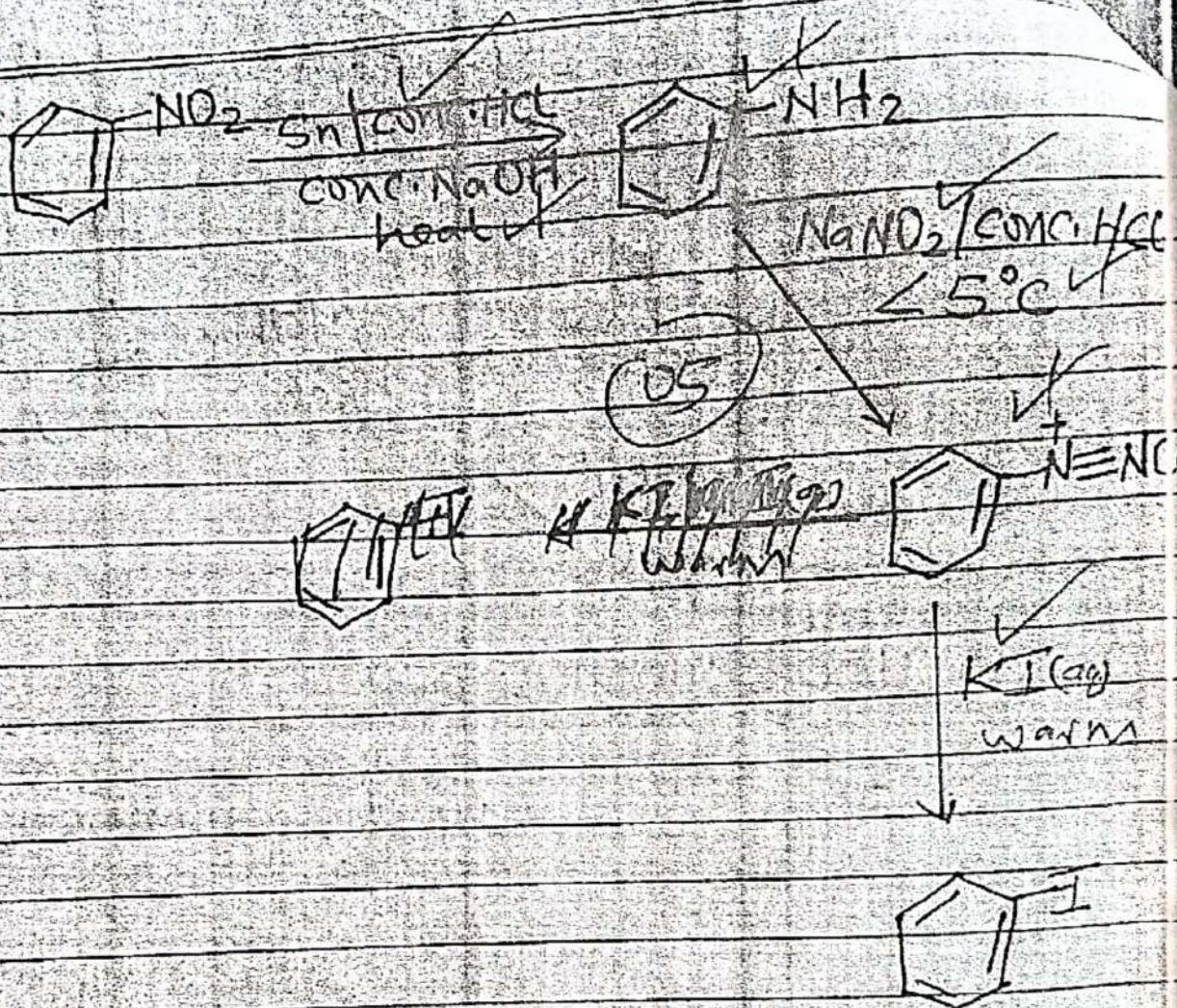
$$= 4.757 + -0.08277$$

$$= 4.674$$

$$\therefore \text{Change in pH} = 4.674 - 4.670 \\ = 0.004$$



(d)



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(a)(i) Partition law states that the solute distributes itself between two immiscible solvents in contact in such a way that the ratio of the concentration of the solute in the two solvents is a constant at constant temperature.

(01)

(ii) Temperature is kept constant

- Solute should not associate or dissociate in the two solvents
- Solvents should be immiscible (02)
- Solute should not satyrate any of the two solvents.

(b)(i) Let  $x$  g be the mass of iodine extracted by  $50\text{cm}^3$  of carbon disulphide.

Mass of iodine that remained in aqueous layer =  $(50-x)$  g

$$K_D = \frac{[\text{I}_2]_{\text{CS}_2}}{[\text{I}_2]_{\text{H}_2\text{O}}} \quad \text{unit}$$

$$84.0 = \frac{x}{500} : \frac{50-x}{1000} \quad \checkmark$$

(02)

$$84.0 = \frac{x}{500} \times \frac{1000}{(50+x)}$$

$$84.0(50-x) = 2x$$

$$4200 - 312x = 2x$$

$$4200 = 314x$$

$$x = 48.8272 \text{g}$$

(ii) Let  $x_1$  g be the mass of iodine extracted by the 1st  $250\text{cm}^3$  portion of carbon disphide  
 $\therefore$  mass of  $I_2$  that remained in aqueous layer  
 $= (50 - x_1)$  g

$$84.0 = \frac{x_1}{250} \div \frac{50 - x_1}{1000}$$

$$84.0 = \frac{4x_1}{(50 - x_1)}$$

$$21.0 = \frac{x_1}{(50 - x_1)}$$

$$21.0(50 - x_1) = x_1$$

$$1.050 - 21.0x_1 = x_1$$

$$22x_1 = 1.050$$

$$x_1 = 47.7273\text{g}$$

04

$\therefore$  mass of  $I_2$  left in aqueous layer

$$= 50 - 47.7273$$

$$= 2.2727$$

Let  $x_2$  g be the mass of iodine extracted by the 2nd  $250\text{cm}^3$  portion of carbon disphide  
 $\therefore$  mass of iodine that remained in the aqueous layer  $= (2.2727 - x_2)$  g

$$84.0 = \frac{x_2}{250} \div \frac{2.2727 - x_2}{1000}$$

$$84.0 = \frac{4x_2}{(2.2727 - x_2)}$$

$$21.0(2.2727 - x_2) = x_2$$

$$47.7267 - 2(x_2) = x_2$$

$$\frac{22x_2}{22} = \frac{47.7267}{22.0}$$

$$x_2 = 2.16949$$

∴ Total mass of iodine extracted by  
two successive  $250\text{cm}^3$  portions of carbon  
disulphide =  $47.7273 + 2.16949$   
=  $49.8967\text{ g.}$

(c) (iii)  $n = \frac{0.6}{0.1}$  ✓  
 $n = 6.0$  ✓

(01)

iii)  $1000\text{cm}^3$  of HCl contain 0.04 moles  
 $25\text{cm}^3$  of HCl contain  $\frac{0.04 \times 20}{1000}$  ✓  
 $= 0.0008$



mole ratio HCl :  $\text{NH}_3 = 1:1$

no of moles of  $\text{NH}_3 = 0.0008$  moles

~~$25\text{cm}^3$  of free ammonia contains 0.0008 mole  
 $1000\text{cm}^3$  of free ammonia contains  $0.0008 \times 40$~~   
~~25~~  
~~- 0.032M~~

$$1000 \text{ cm}^3 \text{ of HCl contains 1 mole}$$

$$35 \text{ cm}^3 \text{ of HCl contains } \frac{1}{1000} \times 35 = 0.035$$

$$= 0.035$$

mole ratio HCl : NH<sub>3</sub> = 1 : 1

No. of moles of NH<sub>3</sub> = 0.035 moles

$$25 \text{ cm}^3 \text{ of solution contains } 0.035 \text{ moles of NH}_3$$

$$\therefore 1000 \text{ cm}^3 \text{ solution contains } \frac{0.035}{25} \times 1000 = 1.4 \text{ M}$$

Total concentration of ammonia = 1.4M

mole ratio [Ni<sup>2+</sup>] : [NH<sub>3</sub>]<sub>fixed</sub> = 1 : 6

$$\frac{0.1}{[\text{NH}_3]_{\text{fixed}}} = \frac{1}{6}$$

$$[\text{NH}_3]_{\text{fixed}} = 0.1 \times 6$$

$$= 0.6 \text{ M}$$

$$[\text{NH}_3]_{\text{free in H}_2\text{O}} = 1.4 - 0.6$$

$$= 0.8 \text{ M}$$

$$K_B \rightarrow \frac{[\text{NH}_3]_{\text{free in H}_2\text{O}}}{[\text{NH}_3]_{\text{free in HCl}_2}}$$

$$\rightarrow \frac{0.8}{0.032}$$

$$= 25.0$$

A graph of  $[C(NH_3)_0.1M\text{NiSO}_4]$  against  $[NH_3]_c$

( $\mu$  mol/l)

1.0

0.90

0.80

0.70

0.60

0.50

0.40

0.30

0.20

0.10

0.05

0.00

0

0.02 0.04

0.06 0.08 0.10 0.12

$NH_3 \text{ C}_3$  (mol/l)

(O2)

0.5

0.70

0.90

1.10

1.30

1.5

1.70

1.90

2.10

2.30

2.5

2.7

2.9

3.1

3.3

3.5

3.7

3.9

4.1

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10.9

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11.7

11.9

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45.1

45.3

45.5

45.7

45.9

46.1

46.3

46.5

46.7

46.9

47.1

47.3

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60.7

60.9

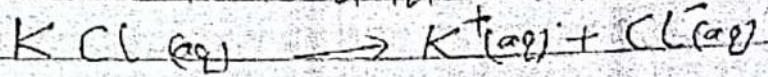
61.1

61.3

61.5

6

7. (a) Potassium chloride is a strong electrolyte and dissociates completely to form potassium ions and chloride ions.



A 0.1M potassium chloride produces 0.1M potassium ions and 0.1M chloride ions making a total of 0.2M.

(04)

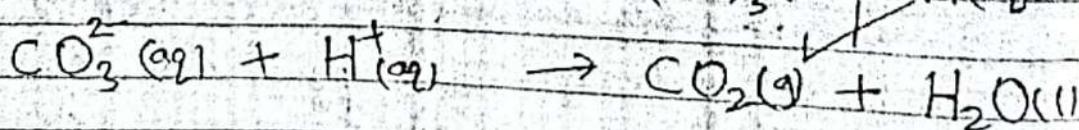
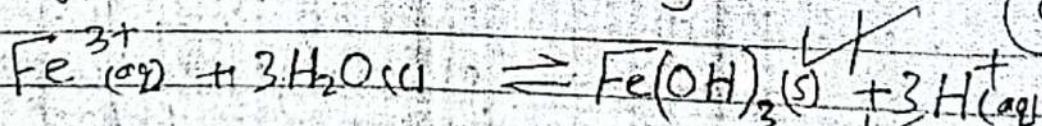
Urea is a non-electrolyte which does not associate or dissociate and its concentration remains 0.2M.

Since the two solutions have the same concentration, the number of non-volatile particles of two ~~other~~ solutions is the same and thus they will have the same boiling points.

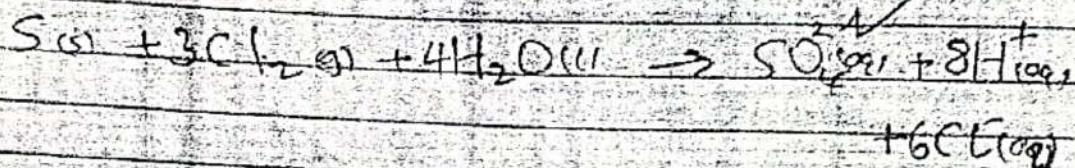
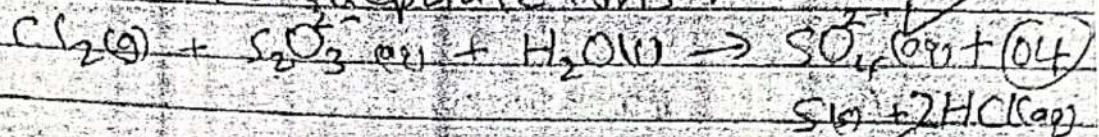
(b) Iron(II) ions in iron(III) sulphate have small ionic radii and high charge, and therefore they have very high charge density and very high polarising power.

In aqueous solution, iron(III) ions undergo hydrolysis to form iron(III) hydroxide which is insoluble and hydrogen (hydronium) ions which react with carbonate ions to form carbon dioxide gas.

(04)



(c) Chlorine is a strong oxidising agent which oxidises sulphite ions to sulphate ions and sulphur which is again oxidised to sulphate ions.



(d) Lithium has electronic configuration  $1s^2 2s^1$  while beryllium has electronic configuration  $1s^2 2s^2$ . The  $2s$  orbital of lithium has one electron and thus thermodynamically ~~un~~ unstable and the incoming electron is strongly attracted and can easily enter the  $2s$  orbital and thus heat is lost. While the  $2s$  orbital of beryllium is full and thus thermodynamically ~~un~~ stable. The incoming electron is strongly repelled and thus energy must be supplied. (64)

(f) Aluminium ion has small ionic radius and high charge and thus high charge density. Chloride ion has a bigger ionic radius than fluoride ions. Therefore aluminium ion strongly polarises the chloride ion leading to covalent character and thus in aluminium chloride there is sharing of electrons due to covalent bonds and therefore aluminium can acquire octet through dimer formation. (64)

The fluoride with small ionic radius can not easily be polarised and aluminium fluoride is predominantly ionic.

8. (a)  $ns^2$  ✓

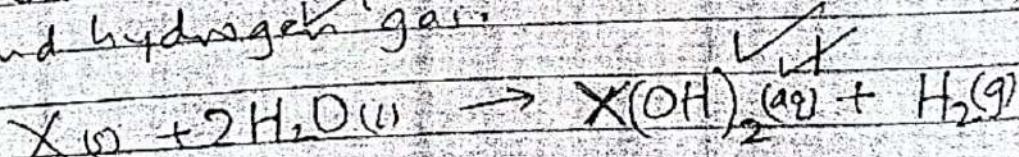
(01)

(b) (i) Beryllium does not react with water under any condition.

Magnesium reacts with cold water very slowly to form magnesium hydroxide and hydrogen gas. However, magnesium reacts vigorously with steam on heating to form magnesium oxide and hydrogen gas.

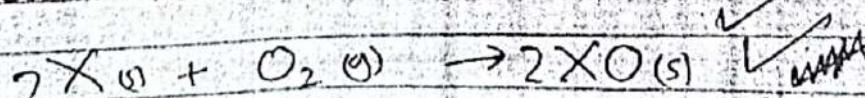


The rest of elements react with cold water vigorously to form hydroxides and hydrogen gas.



( $X = Ca, Sr, Ba$ )

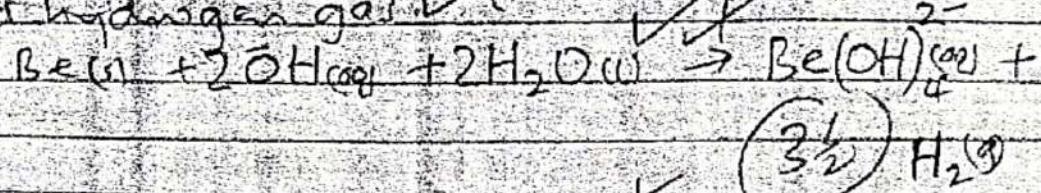
(ii) All group(II) elements react with dry air when heated to form normal oxides.



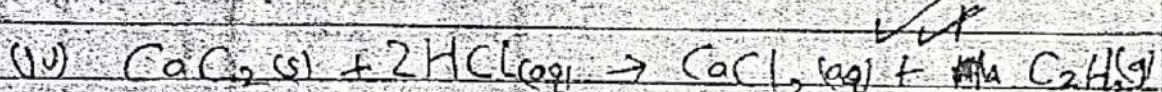
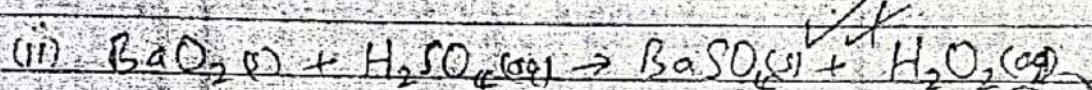
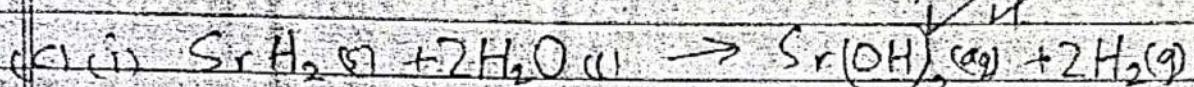
( $X = Be, Mg, Ca, Sr, Ba$ )

(32)

(iii) beryllium reacts with hot concentrated sodium hydroxide to form sodium beryllate and hydrogen gas.



The rest of the elements do not react with sodium hydroxide.



[20]