

**THE UNITED REPUBLIC OF TANZANIA**  
**NATIONAL EXAMINATIONS COUNCIL**  
**ADVANCED CERTIFICATE OF SECONDARY EDUCATION EXAMINATION**

132/2

**CHEMISTRY 2**

**Time: 3 Hours**

**ANSWERS**

**Mwaka: 2022**

**Instructions**

1. This paper consists of a total of six questions
2. Answer five questions.

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1. (a) (i) A solid Y is added to a mixture of benzene and water. After shaking well and allowing the mixture to equilibrate, 10 cm<sup>3</sup> of the benzene layer was found to contain 0.13 g of Y while 100 cm<sup>3</sup> of the aqueous layer contained 0.22 g of Y. Calculate the value of the distribution coefficient of Y between benzene and water.

The distribution coefficient ( $K_d$ ) is the ratio of the concentration of Y in benzene to its concentration in water at equilibrium.

Concentration of Y in benzene:

$$\text{Volume} = 10 \text{ cm}^3 = 0.01 \text{ dm}^3$$

$$\text{Mass} = 0.13 \text{ g}$$

$$[Y]_{\text{benzene}} = 0.13 / 0.01 = 13 \text{ g dm}^{-3}$$

Concentration of Y in water:

$$\text{Volume} = 100 \text{ cm}^3 = 0.1 \text{ dm}^3$$

$$\text{Mass} = 0.22 \text{ g}$$

$$[Y]_{\text{water}} = 0.22 / 0.1 = 2.2 \text{ g dm}^{-3}$$

$$K_d = [Y]_{\text{benzene}} / [Y]_{\text{water}} = 13 / 2.2 \approx 5.91$$

The distribution coefficient of Y between benzene and water is approximately 5.91.

(ii) Comment on the solubility of Y in benzene and water with respect to the distribution coefficient you have obtained in 1(a)(i).

The distribution coefficient  $K_d = 5.91$  indicates that Y is more soluble in benzene than in water. Since  $K_d > 1$ , the concentration of Y in benzene is 5.91 times higher than in water, meaning Y prefers the organic solvent (benzene) over the aqueous phase. This suggests Y is likely a non-polar or weakly polar compound, as benzene is non-polar and water is polar.

Y is more soluble in benzene than in water, as the  $K_d$  of 5.91 shows a higher concentration in benzene, indicating a preference for the non-polar solvent.

(b) What are the two applications of fractional distillation? Explain briefly.

**Separation of Crude Oil:** Fractional distillation is used in the petroleum industry to separate crude oil into its components (e.g., gasoline, kerosene, diesel) based on their boiling points. The mixture is heated, and fractions are collected at different temperatures in a fractionating column.

**Purification of Liquids:** It is used to purify liquids with close boiling points, such as separating ethanol (boiling point 78°C) from water (100°C) in the production of spirits. The process involves repeated vaporization and condensation to enrich the more volatile component.

Fractional distillation is applied in separating crude oil into fractions like gasoline and kerosene, and in purifying liquids like ethanol from water by exploiting differences in boiling points.

(c) Calculate the percentage by mass of bromobenzene ( $C_6H_5Br$ ) in the distillate when a mixture of bromobenzene and water distills in steam at 95°C. The vapour pressures of bromobenzene and water at 95°C are  $1.59 \times 10^4$  and  $8.50 \times 10^4 \text{ N m}^{-2}$  respectively.

For steam distillation of immiscible liquids, the total vapor pressure is the sum of the vapor pressures of the components:

$$P_{\text{total}} = P_{\text{bromobenzene}} + P_{\text{water}} = 1.59 \times 10^4 + 8.50 \times 10^4 = 1.009 \times 10^5 \text{ N m}^{-2}$$

The mole ratio of the components in the distillate is proportional to their vapor pressures:

$$n_{\text{bromobenzene}} / n_{\text{water}} = P_{\text{bromobenzene}} / P_{\text{water}} = (1.59 \times 10^4) / (8.50 \times 10^4) = 0.187$$

Molar masses:

$$\text{Bromobenzene } (C_6H_5Br) = (6 \times 12) + (5 \times 1) + 79.9 = 156.9 \text{ g mol}^{-1}$$

$$\text{Water } (H_2O) = (2 \times 1) + 16 = 18 \text{ g mol}^{-1}$$

Mass ratio:

$$\text{Mass}_{\text{bromobenzene}} / \text{Mass}_{\text{water}} = (n_{\text{bromobenzene}} \times M_{\text{bromobenzene}}) / (n_{\text{water}} \times M_{\text{water}})$$

$$= (n_{\text{bromobenzene}} / n_{\text{water}}) \times (M_{\text{bromobenzene}} / M_{\text{water}})$$

$$= 0.187 \times (156.9 / 18) \approx 0.187 \times 8.717 \approx 1.63$$

Percentage by mass of bromobenzene:

$$\% \text{ bromobenzene} = (\text{Mass}_{\text{bromobenzene}} / (\text{Mass}_{\text{bromobenzene}} + \text{Mass}_{\text{water}})) \times 100$$

$$= (1.63 / (1.63 + 1)) \times 100 \approx (1.63 / 2.63) \times 100 \approx 62\%$$

The percentage by mass of bromobenzene in the distillate is approximately 62%.

(d) Heptane ( $C_7H_{16}$ ) and octane ( $C_8H_{18}$ ) form an ideal solution. At 373 K, the vapour pressures of pure heptane and octane were 105.2 kPa and 46.8 kPa respectively. Calculate the vapour pressure of the mixture of 26.0 g of heptane and 35.0 g of octane.

Moles of heptane:

$$\text{Molar mass of C}_7\text{H}_{16} = (7 \times 12) + (16 \times 1) = 100 \text{ g mol}^{-1}$$

$$n_{\text{heptane}} = 26.0 / 100 = 0.26 \text{ mol}$$

Moles of octane:

$$\text{Molar mass of C}_8\text{H}_{18} = (8 \times 12) + (18 \times 1) = 114 \text{ g mol}^{-1}$$

$$n_{\text{octane}} = 35.0 / 114 \approx 0.307 \text{ mol}$$

$$\text{Total moles} = 0.26 + 0.307 = 0.567 \text{ mol}$$

Mole fractions:

$$X_{\text{heptane}} = 0.26 / 0.567 \approx 0.459$$

$$X_{\text{octane}} = 0.307 / 0.567 \approx 0.541$$

For an ideal solution:

$$P_{\text{total}} = (P_{\text{heptane}} \times X_{\text{heptane}}) + (P_{\text{octane}} \times X_{\text{octane}})$$

$$= (105.2 \times 0.459) + (46.8 \times 0.541)$$

$$= 48.3 + 25.3 \approx 73.6 \text{ kPa}$$

The vapor pressure of the mixture is approximately 73.6 kPa.

2.(a) Calculate the pH of a sample of pure water at 25°C. Given  $K_w = 10^{-14} \text{ mol}^2 \text{ dm}^{-6}$  at 25°C.

For pure water:



$$K_w = [\text{H}^+] \times [\text{OH}^-] = 10^{-14}$$

Since  $[\text{H}^+] = [\text{OH}^-]$ , let  $[\text{H}^+] = x$ :

$$x \times x = 10^{-14}$$

$$x^2 = 10^{-14}$$

$$x = 10^{-7} \text{ mol dm}^{-3}$$

$$\text{pH} = -\log[\text{H}^+] = -\log(10^{-7}) = 7$$

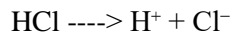
The pH of pure water at 25°C is 7.

(b) A 500 cm<sup>3</sup> of 0.1 M aqueous solution of CH<sub>3</sub>COOH (acetic acid) were mixed with 500 cm<sup>3</sup> of 0.1 M HCl solution. If 3 g of NaOH are added to the mixture, calculate the pH of the mixture before and after addition of NaOH, assuming that no change in volume occurs on mixing.

Before addition of NaOH:

$$\text{Total volume} = 500 \text{ cm}^3 + 500 \text{ cm}^3 = 1000 \text{ cm}^3 = 1 \text{ dm}^3$$

HCl: A strong acid, fully dissociates:



Initial [HCl] = 0.1 M, but after mixing:

$$[\text{HCl}] = (0.1 \times 0.5) / 1 = 0.05 \text{ M}$$

$$[\text{H}^+] \text{ from HCl} = 0.05 \text{ M}$$

CH<sub>3</sub>COOH: A weak acid, partially dissociates:



Initial [CH<sub>3</sub>COOH] = 0.1 M, after mixing:

$$[\text{CH}_3\text{COOH}] = (0.1 \times 0.5) / 1 = 0.05 \text{ M}$$

$$K_a \text{ of CH}_3\text{COOH} \approx 1.8 \times 10^{-5}$$

Since HCl provides a high [H<sup>+</sup>], the dissociation of CH<sub>3</sub>COOH is suppressed (common ion effect). Let's approximate [H<sup>+</sup>] from CH<sub>3</sub>COOH:

$$K_a = ([\text{H}^+] \times [\text{CH}_3\text{COO}^-]) / [\text{CH}_3\text{COOH}]$$

$$[\text{H}^+] \approx 0.05 \text{ M (from HCl)}, [\text{CH}_3\text{COO}^-] = x, [\text{CH}_3\text{COOH}] \approx 0.05:$$

$$1.8 \times 10^{-5} = (0.05 \times x) / 0.05$$

$$x = 1.8 \times 10^{-5} \text{ M}$$

[H<sup>+</sup>] from CH<sub>3</sub>COOH is negligible compared to 0.05 M.

$$\text{Total } [\text{H}^+] \approx 0.05 \text{ M}$$

$$\text{pH} = -\log(0.05) \approx 1.3$$

After addition of NaOH:

Moles of NaOH:

$$\text{Molar mass of NaOH} = 40 \text{ g mol}^{-1}$$

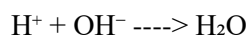
Moles of NaOH =  $3 / 40 = 0.075$  mol

Moles of  $H^+$  from HCl:

Moles of HCl =  $0.05 \times 1 = 0.05$  mol

Moles of  $CH_3COOH = 0.05 \times 1 = 0.05$  mol

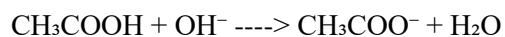
NaOH reacts with  $H^+$  from HCl first (strong acid):



0.05 mol of NaOH reacts with 0.05 mol of  $H^+$  from HCl, neutralizing it completely.

Moles of NaOH remaining =  $0.075 - 0.05 = 0.025$  mol

Remaining NaOH reacts with  $CH_3COOH$ :



0.025 mol of NaOH reacts with 0.025 mol of  $CH_3COOH$ .

Moles of  $CH_3COOH$  remaining =  $0.05 - 0.025 = 0.025$  mol

Moles of  $CH_3COO^-$  formed = 0.025 mol

This forms a buffer solution:

$$[CH_3COOH] = 0.025 / 1 = 0.025 \text{ M}$$

$$[CH_3COO^-] = 0.025 / 1 = 0.025 \text{ M}$$

Use the Henderson-Hasselbalch equation:

$$pH = pK_a + \log([CH_3COO^-] / [CH_3COOH])$$

$$pK_a = -\log(1.8 \times 10^{-5}) \approx 4.74$$

$$pH = 4.74 + \log(0.025 / 0.025) = 4.74 + 0 = 4.74$$

The pH before adding NaOH is approximately 1.3, and after adding NaOH, it is approximately 4.74.

(c) (i) Although lead(II) chloride is sparingly soluble in pure water, it is soluble in concentrated hydrochloric acid. Explain briefly.

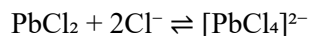
Lead(II) chloride ( $PbCl_2$ ) has a low solubility in water due to its small  $K_{sp}$  ( $1.7 \times 10^{-5}$ ):



In pure water, the equilibrium favors the solid, with low  $[\text{Pb}^{2+}]$  and  $[\text{Cl}^-]$ .

In concentrated HCl, the high  $[\text{Cl}^-]$  shifts the equilibrium:

The common ion effect initially reduces solubility, but excess  $\text{Cl}^-$  forms soluble complexes:



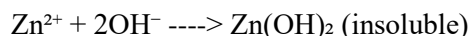
The formation of  $[\text{PbCl}_4]^{2-}$  increases the solubility of  $\text{PbCl}_2$  in concentrated HCl.

$\text{PbCl}_2$  is sparingly soluble in water due to its low  $K_{\text{sp}}$ , but in concentrated HCl, high  $[\text{Cl}^-]$  forms the soluble complex  $[\text{PbCl}_4]^{2-}$ , increasing its solubility.

(ii) A chemist wanted to separate  $\text{Al}^{3+}$  and  $\text{Zn}^{2+}$  using fractional precipitation method. In the first experiment,  $\text{NH}_4\text{OH}$  was added and both  $\text{Al}^{3+}$  and  $\text{Zn}^{2+}$  precipitated. In the second experiment,  $\text{NH}_4\text{OH}$  was added followed by addition of  $\text{NH}_4\text{Cl}$  and only  $\text{Al}^{3+}$  precipitated. Comment briefly on the results obtained in the second experiment.

First Experiment:

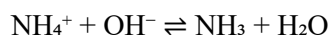
$\text{NH}_4\text{OH}$  provides  $\text{OH}^-$ :



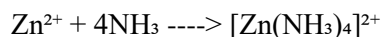
Both  $\text{Al}^{3+}$  and  $\text{Zn}^{2+}$  precipitate as hydroxides due to high  $[\text{OH}^-]$ .

Second Experiment:

$\text{NH}_4\text{OH} + \text{NH}_4\text{Cl}$  forms a buffer, controlling  $[\text{OH}^-]$ :



The lower  $[\text{OH}^-]$  is sufficient for  $\text{Al}(\text{OH})_3$  to precipitate ( $K_{\text{sp}}$  of  $\text{Al}(\text{OH})_3 \approx 1.3 \times 10^{-33}$ ), but not for  $\text{Zn}(\text{OH})_2$  ( $K_{\text{sp}} \approx 3 \times 10^{-17}$ ). Additionally,  $\text{NH}_3$  from  $\text{NH}_4\text{OH}$  forms a soluble complex with  $\text{Zn}^{2+}$ :

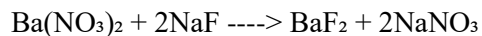


Thus, only  $\text{Al}^{3+}$  precipitates as  $\text{Al}(\text{OH})_3$ , while  $\text{Zn}^{2+}$  remains in solution as  $[\text{Zn}(\text{NH}_3)_4]^{2+}$ .

In the second experiment, the  $\text{NH}_4\text{OH}-\text{NH}_4\text{Cl}$  buffer lowers  $[\text{OH}^-]$ , allowing  $\text{Al}(\text{OH})_3$  to precipitate while  $\text{Zn}^{2+}$  forms the soluble  $[\text{Zn}(\text{NH}_3)_4]^{2+}$  complex, preventing its precipitation.

(d) Equal volumes of  $0.025 \text{ mol dm}^{-3}$  barium nitrate and  $0.010 \text{ mol dm}^{-3}$  sodium fluoride were mixed together. Show whether the solution is saturated, super saturated, or unsaturated.  $\text{BaF}_2$  is  $1.7 \times 10^{-6} \text{ mol}^3 \text{ dm}^{-9}$ .

Reaction:



Initial concentrations (after mixing equal volumes, concentrations halve):

$$[\text{Ba}^{2+}] = 0.025 / 2 = 0.0125 \text{ M}$$

$$[\text{F}^-] = 0.010 / 2 = 0.005 \text{ M}$$

Ionic product (Q) for  $\text{BaF}_2$ :



$$Q = [\text{Ba}^{2+}] \times [\text{F}^-]^2 = 0.0125 \times (0.005)^2 = 0.0125 \times 0.000025 = 3.125 \times 10^{-7}$$

$$K_{\text{sp}} \text{ of } \text{BaF}_2 = 1.7 \times 10^{-6}$$

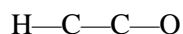
Since  $Q (3.125 \times 10^{-7}) < K_{\text{sp}} (1.7 \times 10^{-6})$ , the solution is unsaturated.

The solution is unsaturated because the ionic product ( $3.125 \times 10^{-7}$ ) is less than the  $K_{\text{sp}}$  ( $1.7 \times 10^{-6}$ ), so no precipitate forms.

3. (a) Compound Q is commonly added to foods to give them the rum flavour. It has the following structural formula:

H

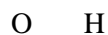
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(i) To which class of organic compounds does the compound Q belong?

The structure is  $\text{H}-\text{C}(\text{H})-\text{C}(\text{O})-\text{O}-\text{C}(\text{H})-\text{C}(\text{H})-\text{H}$ , or  $\text{HCOOCH}_2\text{CH}_3$  (ethyl formate).

It has the form  $\text{RCOOR}'$ , which is an ester.

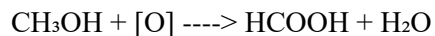
Compound Q belongs to the class of esters.



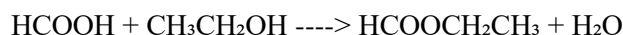
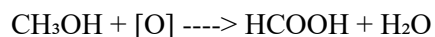
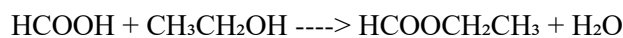
(ii) How can you synthesize compound Q from ethanol and methanol and any other suitable reagent?

Ethyl formate ( $\text{HCOOCH}_2\text{CH}_3$ ) can be synthesized from ethanol ( $\text{CH}_3\text{CH}_2\text{OH}$ ) and methanol ( $\text{CH}_3\text{OH}$ ):

Oxidize methanol to formic acid ( $\text{HCOOH}$ ) using a strong oxidizing agent like  $\text{KMnO}_4$ :



Esterify formic acid with ethanol using a catalyst like  $\text{H}_2\text{SO}_4$ :



(iii) What is the IUPAC name of compound Q?

The structure  $\text{HCOOCH}_2\text{CH}_3$  has:

Formate (from  $\text{HCOO}^-$ ) as the acid part.

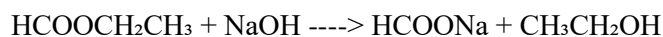
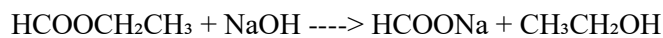
Ethyl (from  $\text{CH}_3\text{CH}_2^-$ ) as the alcohol part.

IUPAC name: ethyl methanoate.

The IUPAC name of compound Q is ethyl methanoate.

(iv) Compound Q can react with  $\text{NaOH}$  in presence of heat. How can you represent this reaction using a chemical equation?

Ethyl methanoate reacts with  $\text{NaOH}$  (saponification) to form the sodium salt of the acid and the alcohol:



(b)(i) The boiling point of ethanoic acid is higher than that of ethanol.

Ethanoic acid ( $\text{CH}_3\text{COOH}$ ,  $118^\circ\text{C}$ ) has a higher boiling point than ethanol ( $\text{CH}_3\text{CH}_2\text{OH}$ ,  $78^\circ\text{C}$ ) because:

Ethanoic acid forms hydrogen bonds via its  $-\text{COOH}$  group, and it can form dimers (two molecules linked by two H-bonds), leading to stronger intermolecular forces.

Ethanol forms hydrogen bonds via its -OH group but cannot form dimers, so its intermolecular forces are weaker.

Ethanoic acid has a higher boiling point than ethanol due to stronger hydrogen bonding and dimer formation in ethanoic acid.

(ii) Methylamine is a stronger base than ammonia. Trimethylamine and n-propylamine have the same molecular mass but the former boils at a lower temperature (276 K) than the latter (322 K).

Methylamine vs. ammonia: Methylamine ( $\text{CH}_3\text{NH}_2$ ) is a stronger base than ammonia ( $\text{NH}_3$ ) because the  $\text{CH}_3$  group is electron-donating (+I effect), increasing electron density on N, making the lone pair more available to donate ( $\text{pK}_b$  of  $\text{CH}_3\text{NH}_2 \approx 3.4$ ,  $\text{NH}_3 \approx 4.75$ ).

Boiling points: Trimethylamine ( $(\text{CH}_3)_3\text{N}$ , 276 K) has a lower boiling point than n-propylamine ( $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2$ , 322 K) because:

n-Propylamine has two N-H bonds, allowing stronger hydrogen bonding ( $\text{N-H}\cdots\text{N}$ ).

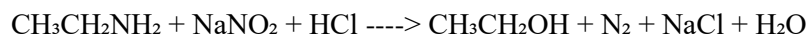
Trimethylamine has no N-H bonds (all are N- $\text{CH}_3$ ), so it only has weaker dipole-dipole and London forces.

Methylamine is a stronger base than ammonia due to the +I effect of the  $\text{CH}_3$  group, and trimethylamine boils at a lower temperature than n-propylamine because it lacks hydrogen bonding.

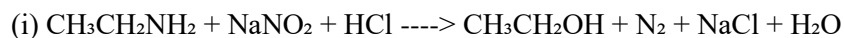
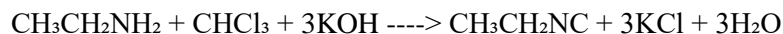
(c) (i) Complete the following organic reactions:



(i) Primary amines with  $\text{NaNO}_2/\text{HCl}$  at  $0-5^\circ\text{C}$  undergo diazotization:



(ii) The carbylamine reaction with  $\text{CHCl}_3$  and  $\text{KOH}$  forms an isocyanide:



(d) Arrange the following organic compounds in order of increasing basic strength:

$\text{C}_6\text{H}_5\text{NH}_2$ ,  $(\text{C}_6\text{H}_5)_2\text{NH}$ ,  $\text{C}_2\text{H}_5\text{NH}_2$ ,  $\text{NH}_3$

Basic strength depends on the availability of the lone pair on N:

$\text{C}_6\text{H}_5\text{NH}_2$  (aniline): The lone pair on N is delocalized into the benzene ring via resonance, reducing basicity ( $\text{pK}_b \approx 9.4$ ).

$(\text{C}_6\text{H}_5)_2\text{NH}$  (diphenylamine): Two phenyl groups further delocalize the lone pair, making it even less basic ( $\text{pK}_b \approx 13$ ).

$\text{NH}_3$  (ammonia): No substituents to withdraw electrons ( $\text{pK}_b \approx 4.75$ ).

$\text{C}_2\text{H}_5\text{NH}_2$  (ethylamine): The  $\text{C}_2\text{H}_5$  group is electron-donating (+I effect), increasing electron density on N, making it the most basic ( $\text{pK}_b \approx 3.4$ ).

Order:  $(\text{C}_6\text{H}_5)_2\text{NH} < \text{C}_6\text{H}_5\text{NH}_2 < \text{NH}_3 < \text{C}_2\text{H}_5\text{NH}_2$

$(\text{C}_6\text{H}_5)_2\text{NH} < \text{C}_6\text{H}_5\text{NH}_2 < \text{NH}_3 < \text{C}_2\text{H}_5\text{NH}_2$

4. (a) During a tour to one of the emerging local industries in Tanzania, it was noticed that some of the machine parts made up of iron were corroding. What do you think would be the factors affecting the extent of corrosion?

Factors affecting iron corrosion:

Presence of Moisture: Water is needed for the electrochemical reaction of rusting ( $\text{Fe} + \text{O}_2 + \text{H}_2\text{O} \rightarrow \text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$ ).

Oxygen Availability:  $\text{O}_2$  acts as an oxidizing agent in rusting.

Electrolytes: Salts (e.g.,  $\text{NaCl}$ ) in water increase conductivity, accelerating corrosion.

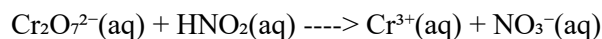
Temperature: Higher temperatures increase the rate of corrosion by speeding up the reaction.

pH: Acidic conditions (low pH) enhance corrosion by providing  $\text{H}^+$  ions.

Surface Area: More exposed surface area increases the rate of corrosion.

The factors affecting iron corrosion include moisture, oxygen, electrolytes, temperature, pH, and surface area, all of which influence the electrochemical rusting process.

4. (b) By using half-reaction method, balance the following redox reaction if it takes place in an acidic medium:



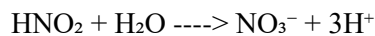
Oxidation half-reaction:  $\text{HNO}_2 \rightarrow \text{NO}_3^-$

Balance N: Already balanced.

Balance O by adding  $\text{H}_2\text{O}$ :



Balance H by adding  $\text{H}^+$ :



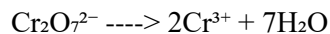
Balance charge: Left  $(-1 + 0 = -1)$ , Right  $(-1 + 3 = +2)$ , add  $3\text{e}^-$  to right:



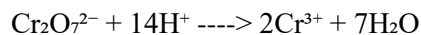
Reduction half-reaction:  $\text{Cr}_2\text{O}_7^{2-} \rightarrow \text{Cr}^{3+}$

Balance Cr:  $\text{Cr}_2\text{O}_7^{2-} \rightarrow 2\text{Cr}^{3+}$

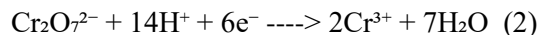
Balance O by adding  $\text{H}_2\text{O}$ :



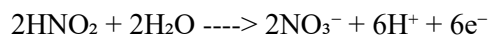
Balance H by adding  $\text{H}^+$ :



Balance charge: Left  $(-2 + 14 = +12)$ , Right  $(2 \times 3 = +6)$ , add  $6\text{e}^-$  to left:



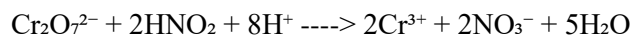
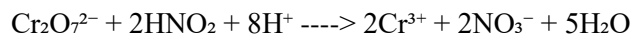
Combine: Multiply (1) by 2 to balance electrons:



Add to (2):

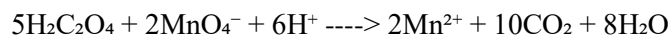


Simplify:



(c) Ethanedioic acid crystal,  $\text{H}_2\text{C}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ , weighing 0.9 g was dissolved in a  $0.25 \text{ dm}^3$  distilled water. A  $25.0 \text{ cm}^3$  of the resulting solution required  $33.0 \text{ cm}^3$  of potassium permanganate(VII) solution for complete reaction during a titration experiment. Calculate the concentration of potassium permanganate(VII) solution.

Reaction (in acidic medium):



Moles of  $\text{H}_2\text{C}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ :

$$\text{Molar mass} = (2 \times 1) + (2 \times 12) + (4 \times 16) + (2 \times 18) = 126 \text{ g mol}^{-1}$$

$$\text{Moles} = 0.9 / 126 \approx 0.00714 \text{ mol}$$

$$\text{Concentration in } 0.25 \text{ dm}^3 = 0.00714 / 0.25 \approx 0.0286 \text{ M}$$

Moles in  $25.0 \text{ cm}^3$  ( $0.025 \text{ dm}^3$ ):

$$\text{Moles of } \text{H}_2\text{C}_2\text{O}_4 = 0.0286 \times 0.025 = 0.000715 \text{ mol}$$

From the equation, 5 moles of  $\text{H}_2\text{C}_2\text{O}_4$  react with 2 moles of  $\text{MnO}_4^-$ :

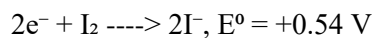
$$\text{Moles of } \text{MnO}_4^- = (2 / 5) \times 0.000715 = 0.000286 \text{ mol}$$

$$\text{Volume of } \text{MnO}_4^- = 33.0 \text{ cm}^3 = 0.033 \text{ dm}^3$$

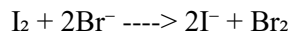
$$\text{Concentration of } \text{MnO}_4^- = 0.000286 / 0.033 \approx 0.00867 \text{ M}$$

The concentration of the potassium permanganate solution is approximately 0.00867 M.

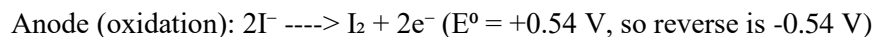
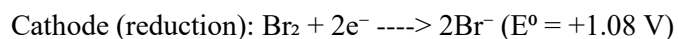
(d) With a reason, predict if the reaction will occur when iodine and bromine are added to a solution containing ions of iodide and bromide both maintained at 1 M. The electrode potential for the reactions are given as follows:



Calculate the cell potential:



$$E_{\text{cell}} = E_{\text{cathode}} - E_{\text{anode}}$$



$$E_{\text{cell}} = 1.08 - 0.54 = 0.54 \text{ V}$$

Since  $E_{\text{cell}} > 0$ , the reaction is spontaneous.  $\text{Br}_2$  will oxidize  $\text{I}^-$  to  $\text{I}_2$ , while  $\text{Br}^-$  remains unreacted.

The reaction will occur because  $E_{\text{cell}} = 0.54 \text{ V}$  is positive, indicating spontaneity;  $\text{Br}_2$  oxidizes  $\text{I}^-$  to  $\text{I}_2$ .

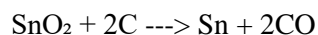
5 (a) (i) What is the difference between periodicity and diagonal relationship?

Periodicity refers to the repeating trends in properties of elements across periods and down groups in the periodic table, such as atomic size, ionization energy, and electronegativity.

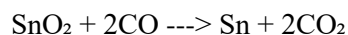
Diagonal relationship refers to the similarities in properties between certain pairs of diagonally adjacent elements in the periodic table, especially in the second and third periods (e.g., lithium and magnesium, beryllium and aluminum). These similarities are due to similar charge density and electronegativity.

(ii) How is tin reduced by thermal method in the reverberatory furnace? Explain briefly while supporting your answer with appropriate chemical equations.

In a reverberatory furnace, tin oxide ( $\text{SnO}_2$ ) is reduced by carbon or carbon monoxide at high temperature.



or



The carbon or carbon monoxide acts as a reducing agent to convert tin oxide into metallic tin.

5 (b) "Lithium and magnesium relate diagonally in a periodic table of elements." By giving three reasons, briefly justify this statement.

- Both lithium and magnesium form nitrides ( $\text{Li}_3\text{N}$  and  $\text{Mg}_3\text{N}_2$ ), unlike other elements in their respective groups.

- Both form sparingly soluble hydroxides and carbonates, unlike their group members which form more soluble compounds.
- Both exhibit similar polarizing power due to high charge density, leading to compounds with covalent character.

5 (c) The metallic characters of the elements change across the period. Illustrate this concept with reference to chlorides and hydrides of the elements of period 3.

Across period 3 from sodium to chlorine, metallic character decreases and non-metallic character increases.

- Sodium and magnesium form ionic chlorides ( $\text{NaCl}$ ,  $\text{MgCl}_2$ ), which are solids with high melting points and soluble in water.
- Aluminium forms covalent  $\text{AlCl}_3$ , which sublimes easily and is hydrolyzed in water.
- Silicon forms  $\text{SiCl}_4$ , a covalent liquid that fumes in moist air due to hydrolysis.
- Phosphorus, sulfur, and chlorine form covalent molecular chlorides ( $\text{PCl}_3$ ,  $\text{PCl}_5$ ,  $\text{S}_2\text{Cl}_2$ ,  $\text{Cl}_2$ ), which are volatile and hydrolyze easily.

Hydrides also show this trend:

- Sodium and magnesium form ionic hydrides ( $\text{NaH}$ ,  $\text{MgH}_2$ )
- Aluminium to chlorine form covalent hydrides like  $\text{AlH}_3$  (unstable),  $\text{SiH}_4$ ,  $\text{PH}_3$ ,  $\text{H}_2\text{S}$ ,  $\text{HCl}$  — low boiling, reactive gases or liquids.

6 (a) By giving a reason, arrange the following complex compounds in order of increasing their magnetic properties:  $[\text{MnCl}_4]^{2-}$ ;  $[\text{FeF}_6]^{3-}$ ;  $[\text{Fe}(\text{CN})_6]^{4-}$

Magnetic property depends on the number of unpaired electrons.

- $[\text{Fe}(\text{CN})_6]^{4-}$  is low spin due to strong field ligand  $\text{CN}^-$ ,  $\text{Fe}^{2+}$  has 0 unpaired electrons.
- $[\text{FeF}_6]^{3-}$  is high spin,  $\text{F}^-$  is weak field ligand,  $\text{Fe}^{3+}$  has 5 unpaired electrons.
- $[\text{MnCl}_4]^{2-}$  is also high spin,  $\text{Mn}^{2+}$  has 5 unpaired electrons. However, tetrahedral field splitting is less than octahedral, so it still shows strong magnetic property.

Order of increasing magnetic properties:



6 (b) Briefly explain the following:

(i) A concentrated aqueous copper(II) chloride solution is bright green in color but changes to light blue when diluted with water.

In concentrated solution,  $\text{Cu}^{2+}$  exists as  $[\text{CuCl}_4]^{2-}$  complex which is green due to presence of  $\text{Cl}^-$  ligands. Upon dilution,  $\text{Cl}^-$  ions are replaced by water molecules forming  $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$  which is light blue.

(ii) The d orbitals for both zinc and copper contain paired electrons, but copper is considered a transition element while zinc is not.

Copper has an incompletely filled d subshell in its +2 oxidation state ( $3d^9$ ), so it meets the definition of a transition element. Zinc in +2 state has a completely filled d subshell ( $3d^{10}$ ), so it does not show typical transition element properties like variable oxidation states or colored compounds.

6 (c) You have been employed as a chemist in a chemical industry which plan to use transition elements as catalysts in their production. Briefly, explain four applications/uses of transition elements as catalysts. Support your answer with one chemical equation in each case.

- Iron (Fe) in Haber process:  $\text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3$

- Vanadium(V) oxide ( $\text{V}_2\text{O}_5$ ) in Contact process:  $2\text{SO}_2 + \text{O}_2 \rightarrow 2\text{SO}_3$

- Nickel (Ni) in hydrogenation of oils:  $\text{C}=\text{C} + \text{H}_2 \rightarrow \text{C}-\text{C}$

- Platinum (Pt) or rhodium (Rh) in catalytic converters:  $2\text{CO} + 2\text{NO} \rightarrow 2\text{CO}_2 + \text{N}_2$

Transition elements work as catalysts due to their variable oxidation states and ability to form complexes with reactants.

6 (d) (i) With an example in each case, explain two types of polymers based on physical properties.



- Thermoplastics: Soften on heating, can be reshaped. Example: Polyethylene
- Thermosetting plastics: Harden permanently after heating, cannot be reshaped. Example: Bakelite

(ii) Why Tanzania government banned the use of polymers obtained from ethylene monomers? Briefly, explain.

Polyethylene is non-biodegradable and causes environmental pollution due to accumulation in soil and water bodies. It is resistant to decomposition and harms wildlife, leading to its regulation or ban.

(iii) How does the structural differences of High Density Polythene (HDP) and Low Density Polythene (LDP) account for their differences in behaviour and nature?

HDP has linear chains with minimal branching, resulting in higher crystallinity, density, strength, and melting point. LDP has highly branched chains, leading to lower density, weaker intermolecular forces, softer texture, and lower melting point.