



**THE COPPERBELT UNIVERSITY
SCHOOL OF MATHEMATICS AND NATURAL SCIENCES**

CHEMISTRY DEPARTMENT

ANSWER KEY

2013 SESSIONAL EXAMINATION – 30 JANUARY 2013

COURSE CODE – CH 110 /CH 120/ FO 130

TIME ALLOWED: TWO (02) HOURS

INSTRUCTIONS TO CANDIDATES:

1. *This paper comprises 6 questions, and is printed on 2 to 5 pages. Candidates are expected to attempt any **four (05)** questions only.*
2. *Each question carries **twenty (20)** marks.*
3. *Candidates are reminded of the need for **clear presentation** in their answers.*
4. *All the parts of a question should be answered **strictly in continuation**.*

SECTION A: ANSWER ALL THREE QUESTIONS IN THIS SECTION

QUESTION ONE (Chemical Equilibrium)

[20 Marks]

(a) Using the equation: $aA_{(g)} + bB_{(g)} \rightleftharpoons cC_{(g)} + dD_{(g)}$

- (i) Derive an expression you would use to calculate K_c given the K_p value of a certain gaseous reaction. [2]

ANSWER:



Using the ideal gas equation;

$$PV = nRT \text{ or } P = \frac{n}{V}RT = [\text{gas}]RT \text{ [0.5]}$$

$$K_p = \frac{P_C^c P_D^d}{P_A^a P_B^b} = \frac{[C]^c (RT)^c [D]^d (RT)^d}{[A]^a (RT)^a [B]^b (RT)^b}$$

$$K_p = \frac{[C]^c [D]^d (RT)^{(c+d) - (a+b)}}{[A]^a [B]^b} \text{ [0.5]}$$

Now

$$K_c = \frac{[C]^c [D]^d}{[A]^a [B]^b} \text{ and } (c + d) - (a + b) = \Delta n$$

$$\text{Hence } K_p = K_c (RT)^{\Delta n} \text{ [1]}$$

where Δn = change in number of moles gaseous).

(Deduct 0.5 marks if Δn is not defined).

- (ii) At 20 °C, the vapour pressure of water is 0.0231 atm. Calculate the K_p and K_c for the process: $H_2O_{(l)} \rightleftharpoons H_2O_{(g)}$ [2]

ANSWER:



$$K_p = P_{H_2O} = \underline{0.0231 \text{ atm}} \text{ [1]}$$

$$K_c = \frac{K_p}{(RT)^{\Delta n}} = \frac{0.0231 \text{ atm}}{(0.0821 \times 293)^1} \text{ where } \Delta n = 1$$

$$\text{Hence } K_c = \underline{9.6 \times 10^{-4} \text{ mol/L}} \text{ [1]}$$

(Deduct 0.5 marks for a value without units).

(b) At 200 °C phosphorus penta-chloride dissociates according to the following reaction: $PCl_{5(g)} \rightleftharpoons PCl_{3(g)} + Cl_{2(g)}$ $\Delta H = +124 \text{ kJ}$

A pure sample of PCl_5 was introduced into an evacuated vessel at 200°C. At equilibrium, the concentration of PCl_5 was found to be $0.5 \times 10^{-1} \text{ mol dm}^{-3}$.

- (i) Calculate the equilibrium concentration of PCl_3 , Cl_2 and the initial concentration of PCl_5 ($K_c = 8.0 \times 10^{-3} \text{ mol dm}^{-3}$) **[4]**

ANSWER:

	$PCl_{5(g)}$	\rightleftharpoons	$PCl_{3(g)} +$	$Cl_{2(g)}$	$\Delta H = +124 \text{ kJ}$
Initial Conc:	y		0	0	
Change in Conc:	-x		+x	+x	
Equilibrium Conc:	y-x		x	x	

$$K_c = \frac{[PCl_3][Cl_2]}{[PCl_5]} \text{ [1]}$$

Using above equilibrium concentrations we have

$$K_c = \frac{x^2}{y-x}$$

with $K_c = 8.0 \times 10^{-3} \text{ mol/dm}^{-3}$ and $y-x = 0.05 \text{ mol/dm}^{-3}$

Thus

$$\begin{aligned} x^2 &= K_c \times (y-x) \text{ or } x = \sqrt{K_c \times (y-x)} \\ x &= \sqrt{8.0 \times 10^{-3} \text{ M} \times 0.05 \text{ M}} = \sqrt{4.0 \times 10^{-4} \text{ M}^2} \\ \underline{x} &= \underline{0.02 \text{ M}} \quad \text{[1]} \end{aligned}$$

And since

$$\begin{aligned} y-x &= 0.05 \text{ M} \text{ or } y = x + 0.05 \\ \underline{y} &= \underline{0.07 \text{ M}} \quad \text{[0.5]} \end{aligned}$$

Hence $[PCl_3] = 0.02 \text{ M}$ **[0.5]**; $[Cl_2] = 0.02 \text{ M}$ **[0.5]**;
Initial conc. of $PCl_5 = 0.07 \text{ M}$ **[0.5]**

(ii) What would be the effect on the position of equilibrium and the value of equilibrium constant K_c if:

1. temperature is increased;
2. pressure is increased and
3. volume is reduced.

[3]

ANSWER:

1. Increased temperature:

- Equilibrium will shift to the right [0.5]
- K_c will increase [0.5]

2. Increased pressure:

- Equilibrium will shift to the left [0.5]
- K_c will decrease [0.5]

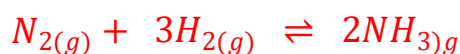
3. Reduced volume:

- Equilibrium will shift to the left [0.5]
- K_c will decrease. [0.5]

(c) At the start of the reaction, there are 0.249 mol N_2 , 3.21×10^{-2} mol H_2 , and 6.42×10^{-4} mol NH_3 in a 3.50 L reaction vessel at 375°C. K_c for the production of ammonia is 1.2 at this temperature. Is the system at equilibrium? If not predict which way the net reaction will proceed.

[5]

ANSWER:



$$[N_2] = \frac{0.249 \text{ mol}}{3.50 \text{ L}} = 0.0711 \text{ M} \quad [0.5]$$

$$[H_2] = \frac{3.21 \times 10^{-2} \text{ mol}}{3.50 \text{ L}} = 9.17 \times 10^{-3} \text{ M} \quad [0.5]$$

$$[NH_3] = \frac{6.42 \times 10^{-4} \text{ mol}}{3.50 \text{ L}} = 1.83 \times 10^{-4} \text{ M} \quad [0.5]$$

$$Q_c = \frac{[NH_3]^2}{[N_2][H_2]^3} = \frac{(1.83 \times 10^{-4} M)^2}{(0.0711M)(9.17 \times 10^{-3}M)^3} = 0.61M^{-2} [1.5]$$

Since $Q_c \neq K_c$ the system is not at equilibrium [1]

$Q_c < K_c$. Hence the net reaction will shift to the right to reach equilibrium. [1]

(d) The solubility product of $Pb_3(PO_4)_2$ is 3.0×10^{-44} . Does a precipitate of $Pb_3(PO_4)_2$ form when 20 mL of 0.01 M Pb^{2+} is added to 80 mL of 1.0×10^{-13} M PO_4^{3-} ? Justify your answer.

[4]

ANSWER:



After mixing:

- Total volume = 20 ml + 80 ml = 100 ml = 0.1 L
- # of mol of Pb^{2+} = CV = $0.01M \times 0.02L = 2.0 \times 10^{-4}mol$

Hence

$$[Pb^{2+}] = \frac{2.0 \times 10^{-4}mol}{0.1L} = 2.0 \times 10^{-3}M \quad [0.5]$$

- # of mol of PO_4^{3-} = CV = $1.0 \times 10^{-13}M \times 0.08L$
 $= 8.0 \times 10^{-15}mol$

Hence

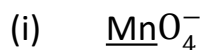
$$[PO_4^{3-}] = \frac{8.0 \times 10^{-15}mol}{0.1L} = 8.0 \times 10^{-14}M \quad [0.5]$$

- $Q = [Pb^{2+}]^3 [PO_4^{3-}]^2 = (2.0 \times 10^{-3}M)^3 \times (8.0 \times 10^{-14}M)^2$
 $= (8.0 \times 10^{-9}M^3) \times (6.4 \times 10^{-27}M^2)$
 $= \underline{\underline{5.12 \times 10^{-35}M^5}} \quad [2]$

Since $Q > K_{sp} (3.0 \times 10^{-44})$ precipitate forms. [1]

QUESTION TWO (Electrochemistry)**[20****Marks]**

(a) What is the oxidation state of the underlined element in each of the following compounds? **[2]**



ANSWER:

MnO_4^- : Let the oxidation state of Mn be f .

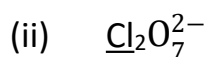
$$1(f) + 4(-2) = -1$$

$$f + (-8) = -1$$

$$f - 8 = -1$$

$$f = -1 + 8$$

$$f = \underline{+7} \text{ [1]}$$



ANSWER:

$\text{Cl}_2\text{O}_7^{2-}$: Let the oxidation state of Cl be n .

$$2(n) + 7(-2) = -2$$

$$2n + (-14) = -2$$

$$2n - 14 = -2$$

$$2n = -2 + 14$$

$$2n = +12$$

$$n = \underline{+6} \text{ [1]}$$

(b) Define each of the following terms:

(i) Anode **[1]**

(ii) Cathode **[1]**

(iii) Standard reduction potential **[1]**

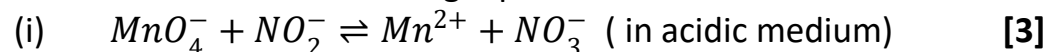
ANSWER:

Anode: This is the electrode at which oxidation takes place (loss of electrons) **[1].**

Cathode: This is the electrode at which reduction takes place (electron gain) **[1].**

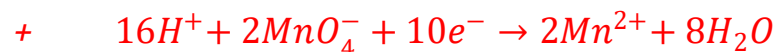
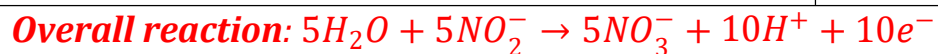
Standard reduction potential: This is the voltage associated with a reduction reaction at the electrode when all solutions are **1 M** and all gases are at **1 atm** and **T = 298 K**. **[1].**

(c) Balance each of the following equations:



ANSWER:

<i>Oxidation half reaction</i>	<i>Reduction half reaction</i>
1. Write unbalanced half reaction $\text{NO}_2^- \rightarrow \text{NO}_3^-$	1. Write unbalanced half reaction $\text{MnO}_4^- \rightarrow \text{Mn}^{2+}$
2. Add H_2O on LHS to balance O $\text{H}_2\text{O} + \text{NO}_2^- \rightarrow \text{NO}_3^-$	2. Add H_2O on RHS to balance O $\text{MnO}_4^- \rightarrow \text{Mn}^{2+} + 4\text{H}_2\text{O}$
3. Add H^+ on RHS to balance H $\text{H}_2\text{O} + \text{NO}_2^- \rightarrow \text{NO}_3^- + 2\text{H}^+$	3. Add H^+ on LHS to balance H $8\text{H}^+ + \text{MnO}_4^- \rightarrow \text{Mn}^{2+} + 4\text{H}_2\text{O}$
4. Balance charge by adding 2 electrons on RHS $\text{H}_2\text{O} + \text{NO}_2^- \rightarrow \text{NO}_3^- + 2\text{H}^+ + 2e^-$	4. Balance charge by adding 5 electrons on LHS $8\text{H}^+ + \text{MnO}_4^- + 5e^- \rightarrow \text{Mn}^{2+} + 4\text{H}_2\text{O}$
5. Multiply above equation by 5 to balance electrons with those used by reduction reaction $5(\text{H}_2\text{O} + \text{NO}_2^- \rightarrow \text{NO}_3^- + 2\text{H}^+ + 2e^-)$	5. Multiply above equation by 2 to balance electrons with those produced by oxidation half reaction $2(8\text{H}^+ + \text{MnO}_4^- + 5e^- \rightarrow \text{Mn}^{2+} + 4\text{H}_2\text{O})$
Required half reaction is $5\text{H}_2\text{O} + 5\text{NO}_2^- \rightarrow 5\text{NO}_3^- + 10\text{H}^+ + 10e^-$ [1]	Required half reaction is $16\text{H}^+ + 2\text{MnO}_4^- + 10e^- \rightarrow 2\text{Mn}^{2+} + 8\text{H}_2\text{O}$ [1]



Cancelling common terms gives: $6H^+ + 5NO_2^- + 2MnO_4^- \rightarrow 5NO_3^- + 2Mn^{2+} + 3H_2O$ [1]

(ii) $Ti^{3+} + Fe(CN)_6^{3-} \rightleftharpoons TiO^{2+} + Fe(CN)_6^{4-}$ (in basic medium) [3]

ANSWER:

Oxidation half reaction	Reduction half reaction
6. Write unbalanced half reaction $Ti^{3+} \rightarrow TiO^{2+}$	5. Write unbalanced half reaction $Fe(CN)_6^{3-} \rightarrow Fe(CN)_6^{4-}$
7. Add H_2O on LHS to balance O $H_2O + Ti^{3+} \rightarrow TiO^{2+}$	6. Balance charge by adding 1 electron on LHS $Fe(CN)_6^{3-} + e^- \rightarrow Fe(CN)_6^{4-}$ [1]
8. Add H^+ on RHS to balance H $H_2O + Ti^{3+} \rightarrow TiO^{2+} + 2H^+$	
9. Add OH^- on both sides $H_2O + 2OH^- + Ti^{3+} \rightarrow TiO^{2+} + 2H^+ + 2OH^-$ Or $H_2O + 2OH^- + Ti^{3+} \rightarrow TiO^{2+} + 2H_2O$ Or $2OH^- + Ti^{3+} \rightarrow TiO^{2+} + H_2O$	
10. Balance charge by adding 1 electrons on RHS $2OH^- + Ti^{3+} \rightarrow TiO^{2+} + H_2O + e^-$ [1]	

Overall reaction: $2OH^- + Ti^{3+} \rightarrow TiO^{2+} + H_2O + e^-$
 $+ Fe(CN)_6^{3-} + e^- \rightarrow Fe(CN)_6^{4-}$



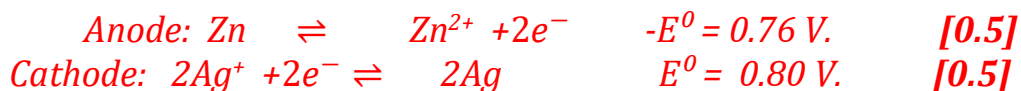
Cancelling electrons on both sides gives: $2\text{OH}^- + \text{Ti}^{3+} + \text{Fe}(\text{CN})_6^{3-} \rightarrow \text{TiO}^{2+} + \text{Fe}(\text{CN})_6^{4-} + \text{H}_2\text{O}$ [1]

(d) A galvanic cell consists of a zinc electrode in a 0.001 M $\text{Zn}(\text{NO}_3)_2$ solution and a silver electrode in a 0.1 M silver nitrate AgNO_3 solution. At 25 °C the standard potentials are $E^\circ_{\text{Ag}^+/\text{Ag}} = +0.80 \text{ V}$ and $E^\circ_{\text{Zn}^{2+}/\text{Zn}} = -0.76 \text{ V}$.

(i) Write the half-reaction of this galvanic cell and its overall reaction.

[2]

ANSWER:



Overall reaction:



$$\begin{array}{ll} E^\circ = E^\circ_{\text{Anode}} - E^\circ_{\text{Cathode}} & \\ = (0.76 + 0.80)\text{V} & \\ \text{Zn} + 2\text{Ag} \rightarrow \text{Zn}^{2+} + 2\text{Ag} & E^\circ = 1.56 \text{ V} \quad [1] \end{array}$$

(ii) Write the standard (line) notation of this cell

[1]

ANSWER:



(iii) Calculate the emf of this cell

[2]

ANSWER:

Emf of this cell (E_{cell}) is given by

$$E_{\text{Cell}} = E^\circ_{\text{Cell}} - \frac{0.0257}{n} \ln \frac{[\text{Zn}^{2+}]}{[\text{Ag}^+]^2} \quad [1]$$

Substituting $n = 2$, $[\text{Zn}^{2+}] = 0.001 \text{ M}$, $[\text{Ag}^+] = 0.1 \text{ M}$ gives

$$E_{\text{Cell}} = 1.56 - \frac{0.0257}{2} \ln \frac{(0.001)}{(0.1)^2} = 1.56 - 0.01285 \times \ln(0.1)$$

$$\begin{aligned} E_{\text{Cell}} &= 1.56 - 0.01285 \times -2.302585 = 1.56 + 0.0296 \\ &= 1.589588218 \text{ V} \end{aligned}$$

$$E_{\text{Cell}} = 1.59 \text{ V} [1]$$

(iv) Calculate the ΔG for this cell. Is this reaction spontaneous? [2]

ANSWER:

$$\Delta G^0 = -nFE^0$$

Substituting

$$n = 2 \text{ mol of } e^-, F = 96500 \frac{\text{C}}{\text{mol}} \text{ of } e^- \text{ and } E^0 = 1.56 \text{ J/C}$$

$$\Delta G^0 = -2 \times 96500 \times 1.56 = -301080 \text{ J}$$

$$\underline{\underline{\Delta G^0 = -301.08 \text{ kJ}}} \quad [1]$$

Since $\Delta G^0 < 0$ reaction is spontaneous [1]

(v) Calculate the equilibrium constant K of this redox reaction. [1]

ANSWER:

$$E_{\text{Cell}}^0 = \frac{0.0257}{n} \ln K \quad \text{at } 298 \text{ K} \quad [0.5]$$

$$\ln K = \frac{n}{0.0257} \times E_{\text{Cell}}^0 \quad \text{or} \quad K = e^{(n \times E_{\text{Cell}}^0)/0.0257}$$

Substituting $E^0 = 1.59 \text{ V}$ and $n = 2$ gives

$$K = e^{(2 \times 1.59)/0.0257} = e^{123.73} = 5.465 \times 10^{53}$$

$$K = 5.46 \times 10^{53}$$

Hence the equilibrium constant is 5.46×10^{53} [0.5]

(vi) What would be the effect of increasing the concentration of $\text{Zn}(\text{NO}_3)_2$ solution on this cell? [1]

ANSWER:

The equilibrium will shift to right increasing the number of electrons lost and gained hence the measured potential of the cell will increase. [1]

QUESTION THREE (Acids and Bases)**[20 Marks]**

- (a) Briefly distinguish between an acid and a base by completing the table below **[3]**

ANSWER:*Table summarising models of acids and bases*

Model	Definition of Acid	Definition of Base
1. Arrhenius	<i>H⁺ producer</i>	<i>OH⁻ producer</i>
2. Bronsted-Lowry	<i>H⁺ donor</i>	<i>H⁺ acceptor</i>
3. Lewis	<i>Electron pair acceptor</i>	<i>Electron pair donor</i>

- (b) Give the conjugate acid for each of the following bases **[2]**

(i) Br⁻ (ii) NH₃ (iii) ClO⁻ (iv) CO₃²⁻

ANSWER:*The conjugate acids are*

(i) HBr (ii) NH₄⁺ (iii) ClOH (iv) HCO₃⁻

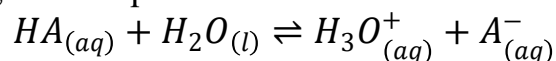
- (c) Classify each of the following as a Lewis Acid or Lewis Base **[2]**

(i) OH₂ (ii) NH₃ (iii) BF₃ (iv) H⁺

ANSWER:

(i) Lewis Base (ii) Lewis Base (iii) Lewis Acid (iv) Lewis Acid

- (d) The general equation for dissociation of an acid in water is



Briefly distinguish between a strong acid and a weak acid by completing the table below. **[4]**

ANSWER:*Table summarising strengths of acids*

Property	Strong Acid	Weak Acid
1. K_a value	K_a is large	K_a is small[1]
2. Position of the dissociation equilibrium	Far to the right	Far to the left[1]
3. Hydrogen ion equilibrium concentration, $[H^+]_e$, compared with original acid concentration, $[HA]_0$	$[H^+]_e \approx [HA]_0$	$[H^+]_e \ll [HA]_0$ [1]
4. Strength of conjugate base compared with basic strength of water	A^- much weaker base than H_2O	A^- much stronger base than H_2O [1]

- (e) While giving an example of each, briefly explain the terms monoprotic acid, diprotic acid and triprotic acid. [3]

ANSWER:

Monoprotic acid – *is an acid with one acidic proton like HCl* [1]

Diprotic acid – *is an acid with two acidic protons like H_2CO_3* [1]

Triprotic acid – *is an acid with three acidic protons like H_3PO_4* [1]

- (f) The dissociation constant of trichlorophenol ($HC_6H_2Cl_3O$) is $K_a = 1.0 \times 10^{-6}$. Calculate the concentration of all the species and the pH of a 0.05 M solution of trichlorophenol in water. [5]

ANSWER:

STEP 1: Major species in solution are $HC_6H_2Cl_3O$ and H_2O . [1]

STEP 2: Both water and trichlorophenol give hydrogen ions but dissociation of water is weaker than of trichlorophenol.

STEP 3: Dominant equilibrium is dissociation of $\text{HC}_6\text{H}_2\text{Cl}_3\text{O}$, that is,



STEP 4: Equilibrium expression of this weak acid dissociation is

$$K_a = \frac{[\text{H}^+][\text{C}_6\text{H}_2\text{Cl}_3\text{O}^-_{(aq)}]}{[\text{HC}_6\text{H}_2\text{Cl}_3\text{O}]} = 1.0 \times 10^{-6}$$

STEP 5: Table of initial, change in and final concentration of species in equilibrium expression

Species	Initial Concentration	Change in Concentration	Equilibrium Concentration
$\text{HC}_6\text{H}_2\text{Cl}_3\text{O}$	0.05	$-x$	$0.05 - x$
$\text{C}_6\text{H}_2\text{Cl}_3\text{O}^-$	0	$+x$	x
H^+	x	$+x$	x

STEP 6: Substituting equilibrium concentrations into the equilibrium expression gives

$$K_a = \frac{[\text{H}^+][\text{C}_6\text{H}_2\text{Cl}_3\text{O}^-_{(aq)}]}{[\text{HC}_6\text{H}_2\text{Cl}_3\text{O}]} = 1.0 \times 10^{-6} = \frac{(x)(x)}{(0.05 - x)}$$

STEP 7: Solve quadratic expression. In this case, expression can be simplified by assuming that $\text{HC}_6\text{H}_2\text{Cl}_3\text{O}$ dissociates slightly so that $0.05 - x \approx 0.05$ and the equilibrium expression

becomes $1.0 \times 10^{-6} = \frac{x^2}{0.05}$ which yields

$$x^2 \approx (1.0 \times 10^{-6})(5.0 \times 10^{-2}) = 5.0 \times 10^{-8} \text{ and}$$

$$x = \sqrt{5.0 \times 10^{-8}} = \underline{\underline{2.24 \times 10^{-4}}} \quad [1]$$

STEP 8: Check validity of the approximation $[\text{HA}]_0 - x = [\text{HA}]_0$ by confirming that $\frac{x}{[\text{HA}]_0} \times 100 < 5\%$ where 5% is the accuracy of the K_a measurement.

$$\text{Here, validity check gives } \frac{x}{[\text{HA}]_0} \times 100 = \frac{2.24 \times 10^{-4}}{5.0 \times 10^{-2}} \times 100 = 0.45\% \text{ which is acceptable.}$$

STEP 9: According to mass action law in STEP3, hydrogen ion concentration, $[H^+]$, is x value in STEP 7 so that solution $pH = -\log(2.24 \times 10^{-4}) = \underline{\underline{3.65}}$ [1]

Concentration of trichlorophenolate ion, x , equals $[H^+]$. Thus, $[C_6H_2Cl_3O^-] = \underline{\underline{2.24 \times 10^{-4} M}}$ [1] and

Concentration of trichlorophenol is $[HA]_e = [HC_6H_2Cl_3O]_e$ which is given as $[HC_6H_2Cl_3O]_e = 0.05 - x = \underline{\underline{0.0498 M \approx 0.05 M}}$ [1]

(g) Calculate the pH of saliva ($[H^+] = 1.58 \times 10^{-7} M$) and indicate whether the substance is acidic or basic. [1]

ANSWER:

Given that the hydrogen ion concentration of saliva is $[H^+] = 1.58 \times 10^{-7} M$, we calculate pH using the equation $pH = -\log[H^+]$ which gives

$$pH = -\log(1.58 \times 10^{-7}) = \underline{\underline{6.80}}$$

Thus, saliva is acidic since its $pH < 7.00$.

B: ANSWER TWO QUESTIONS IN THIS SECTION

QUESTION FOUR (*Organic Chemistry*)

[20 Marks]

(a) Ascorbic acid or Vitamin C ($C_6H_8O_6$) is an essential Vitamin. It cannot be stored by the body and must be present in the diet.

(i) What is the molar mass of ascorbic acid?

[1]

ANSWER:

If we let M_r be the symbol of molar mass of a substance, then

$$C_6H_8O_6 \text{ Molar mass } (M_r) = 6 \times C_{M_r} + 8 \times H_{M_r} + 6 \times O_{M_r} \quad [0.5]$$

Substituting values periodic table atomic molar masses C_{M_r} , H_{M_r} and O_{M_r} we have

$$\begin{aligned} C_6H_8O_6 M_r &= 6 \times 12.01 + 8 \times 1.01 + 6 \times 16.00 \\ C_6H_8O_6 M_r &= 72.06 + 8.08 + 96.00 = \underline{180.14 \text{ g/mol}} \quad [0.5] \end{aligned}$$

(ii) Vitamin C tablets are taken as a dietary supplement. If a typical tablet contains 500.0 mg of Vitamin C, what amount and number of molecules of Vitamin C does it contain?

[4]

ANSWER:

If we let n be the number of moles of substance of mass m and molar mass M_r , then

$$n = \frac{m}{M_r} \quad [1]$$

Substituting $m=500 \text{ mg}$ and $M_r=180.14 \text{ g/mol}$ gives

$$n = \frac{0.5 \text{ g}}{180.14 \text{ g/mol}} = 2.78 \times 10^{-3} \text{ mol} \quad [1]$$

If we let N be the number of molecules in n moles of a Vitamin C

$$N = n \times N_A \quad [1]$$

where N_A is Avogadro's number (6.022×10^{23})

Therefore

$$N = 2.78 \times 10^{-3} \text{ mol} \times 6.022 \times 10^{23} \frac{\text{molecules}}{\text{mol}} = \underline{1.67 \times 10^{21}} \quad [1]$$

- (b) A compound that contains only carbon, hydrogen and oxygen is 48.64% C and 8.16% H by mass. What is the empirical formula of this substance? [3]

ANSWER:

The % fraction of oxygen is

$$100 - (48.64 \%C + 8.16\% H) = 100 - 56.8 = 43.2 \quad [0.5]$$

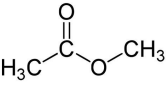
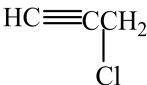
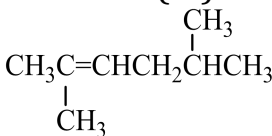
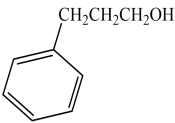
The masses each component element of the compound is known if we take it that we have a 100 g of the compound, we can proceed to calculating the number of moles of each component to determine the empirical formula as shown in the table below. [0.5]

Parameter	Element		
	C	H	O
mass in g (m) &	48.64	8.16	43.20
molar mass in g/mol (M_r)	12.01	1.01	16.00
No. of moles $n = \frac{m}{M_r}$	$\frac{48.64}{12.01} = 4.05$	$\frac{8.16}{1.01} = 8.08$	$\frac{43.20}{16.00} = 2.70$
Mole ratio got by dividing by smallest no. of moles gives	$\frac{4.05}{2.70} = 1.5$	$\frac{8.08}{2.70} = 2.99$	$\frac{2.70}{2.70} = 1.00$
Integral mole ratio used in empirical formula is	3	6	2

The empirical formula is obtained using the integral mole ratio as a subscript of each element in the table, that is, $C_3H_8O_2$ [2]

- (c) Give the IUPAC names of each of the following compounds [4]

ANSWER:

(i)	(ii)	(iii)	(iv)
			
Methyl ethanoate	3-Chloropropyne	2,5-dimethyl-2-hexene	3-phenylpropanol

(d) Write chemical equations showing exactly what happens when $\text{CH}_3\text{CH}=\text{CH}_2$ undergo,

(i) Complete oxidation in oxygen. [1]

ANSWER:



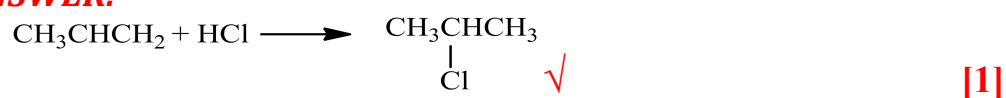
(ii) Incomplete oxidation in oxygen, but no soot formed. [1]

ANSWER:



(iii) Addition reaction with hydrogen chloride. [1]

ANSWER:



(e) Give the correct structural formula of the following functional groups.

(i) An aldehyde.

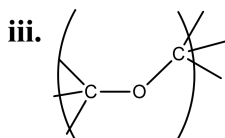
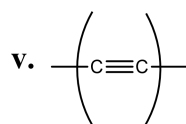
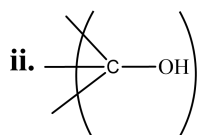
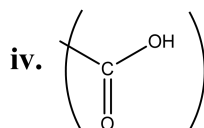
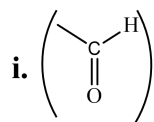
(ii) An alcohol

(iii) An ether

(iv) A carboxylic acid

(v) An alkyne.

[5]



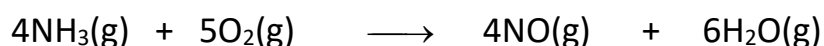
QUESTION FIVE (Chemical Kinetics and Nuclear Chemistry) [20 Marks]

(a) What is chemical kinetics and why is it important to study it? [2]

ANSWER:

Chemical kinetics is the study of speeds or rates of chemical reactions. It is important because it provides insight into why some reactions are fast and others slow. It also provides information about reaction mechanisms.

(b) Ammonia can be made to burn according to the reaction



Suppose at a particular moment during the reaction the ammonia is reacting at the rate of $0.24 \text{ mol} \cdot \text{dm}^{-3} \cdot \text{s}^{-1}$.

- (i) What is the rate at which oxygen is reacting?
- (ii) What is the rate at which water is being formed? [5]

ANSWER:

Data given;

$$\text{Rate}(\text{NH}_3) = - \frac{0.24 \text{ mol NH}_3}{\text{dm}^3 \text{ s}}$$

From the chemical equation we can form the following ratios for ammonia, oxygen and water.

$$\frac{5 \text{ mol O}_2}{4 \text{ mol NH}_3} \text{ and } \frac{6 \text{ mol H}_2\text{O}}{4 \text{ mol NH}_3}$$

Using these ratios we can now calculate the rates

$$\text{Rate for O}_2 = - \frac{0.24 \text{ mol NH}_3}{\text{dm}^3 \text{ s}} \times \frac{5 \text{ mol O}_2}{4 \text{ mol NH}_3} = - 0.30 \text{ mol} \cdot \text{dm}^{-3} \cdot \text{s}^{-1}$$

$$\text{Rate for H}_2\text{O} = \frac{0.24 \text{ mol NH}_3}{\text{dm}^3 \text{ s}} \times \frac{6 \text{ mol H}_2\text{O}}{4 \text{ mol NH}_3} = 0.36 \text{ mol} \cdot \text{dm}^{-3} \cdot \text{s}^{-1}$$

(c) The rate law equation of a first order reaction can be written as;

$$\ln[A]_o - \ln[A]_t = kt$$

Show that at half time, $t_{1/2} = \frac{0.693}{k}$ [3]

ANSWER:

Half-life ($t_{1/2}$) is the time taken for half the reactants to be consumed.

Therefore at $t_{1/2}$, $[A]_t = \frac{1}{2}[A]_o$

Substituting the values in the equation, we obtain

$$\ln\left(\frac{[A]_o}{\frac{1}{2}[A]_o}\right) = kt_{1/2} \text{ or } \ln 2 = kt_{1/2} \text{ or } 0.693 = kt_{1/2}$$

$$\text{Therefore, } t_{1/2} = \frac{0.693}{k}$$

(d) At 300 K, the reaction;



is observed to exhibit the following dependence of rate on concentration

Initial NOCl concentration (M)	Initial rate of formation of NO (mol.dm ⁻³ .s ⁻¹)
0.30	3.60 x 10 ⁻⁹
0.60	1.44 x 10 ⁻⁸
0.90	3.24 x 10 ⁻⁸

Use the information in the table to answer the questions

- (i) What is the rate law for the reaction?
- (ii) What is the rate constant?
- (iii) By what factor would the rate increase if the initial concentration of NOCl were increased from 0.30 to 0.45 M [5]

ANSWER:

(i) The table shows that when the concentration doubles, the rate increases four fold.

0.3 to 0.6 = Double (two fold), while 3.60 x 10⁻⁹ to 1.44 x 10⁻⁸ is four fold

This only happens if it's a second order reaction

$$(Rate) = k[a]^2$$

$$(Rate) = k[2a]^2$$

$$(Rate) = 4(k[a]^2)$$

*Therefore the rate law for the reaction = **$k [NOCl]^2$***

(ii) Using the relation

(Rate) = $k[a]^2$ and making k the subject of the formula

$$k = \frac{Rate}{[a]^2} = \frac{3.60 \times 10^{-9}}{[0.3]^2}$$

$$= 4.00 \times 10^{-8} . M.s^{-1}$$

*(iii) Since we know the **rate constant** for the reaction, we substitute the concentrations in 2 equations to calculate respective rates*

$$At\ 0.30M\ rate = 4.00 \times 10^{-8} (0.30)^2 = 3.6 \times 10^{-9} mol.dm^{-3}.s^{-1}$$

$$At\ 0.45M, rate = 4.00 \times 10^{-8} (0.45)^2 = 8.1 \times 10^{-9} mol.dm^{-3}.s^{-1}$$

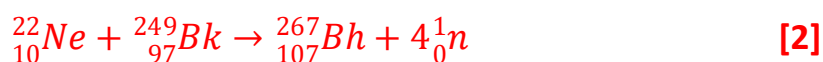
This is an increase of 2.25

(e) A reported synthesis of the transuranium element bohrium ($_{107}\text{Bh}$) involved the bombardment of berkelium-249 ($_{97}\text{Bk}$) with neon-22 ($_{10}\text{Ne}$) to produce bohrium-267.

(i) Write a nuclear reaction for this synthesis. [2]

ANSWER:

The nuclear reaction is



(ii) The half-life of bohrium is 15.0 seconds. If 199 atoms of bohrium-267 could be synthesized, how much time would elapse before only 11 atoms of bohrium-267 remain? [3]

ANSWER:

We use the equation $N_t = N_0 e^{-kt}$ or $\ln\left(\frac{N_t}{N_0}\right) = -kt$ [1]

And solve for t after substituting for $k = \frac{0.693}{t_{1/2}}$ so that

$$-t = \left(\frac{t_{1/2}}{0.693}\right) \times \ln\left(\frac{N_t}{N_0}\right) \quad [1]$$

Putting $t_{1/2} = 15.0$ seconds, $N_t = 11$ atoms and $N_0 = 199$ atoms gives,

$$-t = -62.67 \text{ or } \underline{t = 62.7 \text{ seconds}} \quad [1]$$

QUESTION SIX (Thermochemistry and Chemical Bonding) [20 Marks]

(a) The first law of thermodynamics can be summarized in the following relation

$$\Delta E_{\text{universe}} = \Delta E_{\text{system}} + \Delta E_{\text{surrounding}} = \text{constant}$$

Define the terms;

(i) System

(ii) Surroundings

(iii) Universe

[3]

ANSWER:

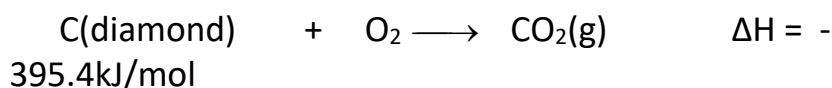
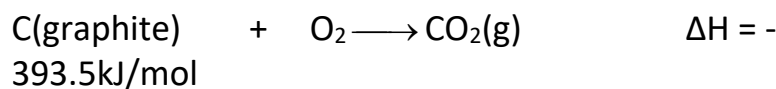
(i) Universe is everything around us

(ii) System is a part of universe (everything) that is under investigation

(iii) Surrounding is everything outside the part under investigation

Universe = system + surroundings

- (b) Carbon occurs in two forms; graphite and diamond. The enthalpy of combustion of graphite is -393.5kJ/mol and that of diamond is -395.4kJ/mol



Calculate ΔH for the conversion of graphite to diamond [2]

ANSWER:

Write the equations in such a manner that it gives;



This means reversing the second equation

The $\Delta H = \underline{+1.9 \text{ kJ}}$

- (c) Find molar combustion enthalpy of $\text{C}_2\text{H}_5\text{OH}$ using following molar enthalpies of matters;

$$\Delta H \text{ C}_2\text{H}_5\text{OH}(\text{l}) = -280.33 \text{ kJ/mol}$$

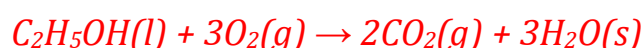
$$\Delta H \text{ CO}_2(\text{g}) = -393.3 \text{ kJ/mol}$$

$$\Delta H \text{ H}_2\text{O}(\text{l}) = -284.5 \text{ kJ/mol}$$

[5]

ANSWER:

We should first write combustion reaction of $\text{C}_2\text{H}_5\text{OH}$;



We use following formula to find unknown enthalpy;

$$\Delta H_{\text{Reaction}} = \Sigma a \Delta H_{(\text{Products})} - \Sigma b \Delta H_{(\text{Reactants})}$$

$$\Delta H_{\text{Combustion}} = (2\Delta H_{\text{CO}_2(\text{g})} + 3\Delta H_{\text{H}_2\text{O}(\text{l})}) - (\Delta H_{\text{C}_2\text{H}_5\text{OH}(\text{l})} + 3\Delta H_{\text{O}_2})$$

$$\Delta H_{\text{Combustion}} = [2.(-393.3) + 3.(-284.5)] - [-280.3]$$

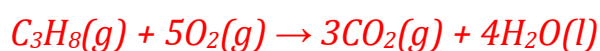
$$\Delta H_{\text{Combustion}} = -1,359.8 \text{ kJ/mol}$$

(d) Given table shows standard molar enthalpy of formation of some matters.

Matter	Molar formation enthalpy kJ/mol
CO ₂ (g)	-393.3
C ₃ H ₈ (g)	-104.6
H ₂ O(l)	-251.0

Find enthalpy change of C₃H₈(g) + 5O₂(g) → 3CO₂(g) + 4H₂O(l) using data given in the table. **[5]**

ANSWER:



$$\Delta H = \{3\Delta H_{CO_2} + 4\Delta H_{H_2O}\} - \{1\Delta H_{C_3H_8} + 5\Delta H_{O_2}\}$$

Since O₂ is element, molar formation enthalpy of it is zero.

$$\Delta H = \{3 \times (-393.3) + 4 \times (-251.0)\} - \{1 \times (-104.6) + 5(0)\}$$

$$\Delta H = -2184.05 + 104.6$$

$$\Delta H = -2079.5 \text{ kJ/mol (it is negative, thus reaction is exothermic)}$$

(e) Carbon forms single, double and triple bonds to achieve a filled octet as shown in the first row of the table below. Copy this table in your answer book and complete its last four rows. **[5]**

ANSWER:

Carbon bonding combination	$\begin{array}{c} \\ -C- \\ \end{array}$	$\begin{array}{c} \\ C= \\ \end{array}$	$=C=$	$\equiv C-$
Number of (i) Sigma bonds [1]	<i>4</i>	<i>3</i>	<i>2</i>	<i>2</i>
(ai) Pi bonds [1]	<i>0</i>	<i>1</i>	<i>2</i>	<i>2</i>
Molecular geometry around carbon atom [1]	<i>Tetrahedral</i>	<i>Trigonal Planar</i>	<i>Linear</i>	<i>Linear</i>
Hybridisation of carbon atom [1]	<i>sp³</i>	<i>sp²</i>	<i>sp</i>	<i>sp</i>
Carbon atom bond angles [1]	<i>109.5°</i>	<i>120°</i>	<i>180°</i>	<i>180°</i>

THE END