



## The Copperbelt University

### CH 110 Tutorial Sheet 3 – September 15, 2015

#### Reactions in Aqueous Solutions

##### Question 1

a) Explain the meaning of the following concepts:

- i) Solute
- ii) Solvent
- iii) Solution

**Solutions:**

A **solute** is a pure substance present in small amounts compared to the solvent in a solution.

A **solvent** is the pure substance of a solution that is present in greatest abundance.

A **solution** is defined as homogeneous mixture of two or more pure substances.

b) Identify a solute and a solvent when sodium chloride and water are mixed.

**Solution:**

**Water** is the solvent and **sodium chloride** is the solute.

c) From the following list of substances, identify substances that can give you a strong electrolyte and those that can give you a weak electrolyte when in solution. Justify your answer.

**Solution:**

- i. Sodium chloride – **strong electrolyte, completely ionized in solution or soluble**
- ii. Ammonium chloride – **strong electrolyte, soluble**
- iii. Sulfuric acid – **strong electrolyte, completely ionized in solution**
- iv. Acetic acid – **weak electrolyte, partially ionized in solution**
- v. Ammonium hydroxide – **weak electrolyte, partially ionized in solution**

d) Both aqueous lead (II) bromide and molten Lead are good conductors of electricity, but they are not both electrolytes.

- i. Explain this observation.

**Solutions:**

Lead (II) bromides are soluble and get solvated – they give ionic solutions. Ions conduct electricity

Metals conduct electricity because of the movement of electrons in them

- ii. Which of the two substances is an electrolyte?

**Solution:**

*Lead bromides is an electrolyte*

- e) When asked what causes electrolytic solutions to conduct electricity, a student responds that it is due to the movement of electrons through the solution. Is the student correct? If not, what should be the correct response?

**Solution:**

*No. electrolytic solutions conduct electricity because of movement of ions in them.*

## Question 2

- a) Calculate the molarity of the following solutions:

- i. A solution of calcium chloride made by dissolving 27g of calcium chloride to make 500ml of solution.

**Solution:**

$$\text{Molarity} = \frac{n}{V} = \left(\frac{m}{M_r}\right) \times \left(\frac{1}{V}\right)$$

$$\text{where } M_r = M_{\text{Ca}} + 2 \times M_{\text{Cl}} = 40.08 + 70.90 = 110.98 \text{ g}$$

$$m = 27 \text{ g and } V = 0.5 \text{ L}$$

$$\text{Molarity} = \frac{n}{V} = \left(\frac{27}{111}\right) \times \left(\frac{1}{0.5}\right) = \frac{54}{111} = \mathbf{0.49 \text{ M}}$$

- ii. A solution with 34.6g of sodium chloride dissolved in 125ml of water.

**Solution:**

$$\text{Molarity} = \frac{n}{V} = \left(\frac{m}{M_r}\right) \times \left(\frac{1}{V}\right)$$

$$\text{where } M_r = M_{\text{Na}} + M_{\text{Cl}} = 22.99 + 35.45 = 58.44 \text{ g}$$

$$m = 34.6 \text{ g and } V = 0.125 \text{ L}$$

$$\text{Molarity} = \frac{n}{V} = \left(\frac{34.6}{58.44}\right) \times \left(\frac{1}{0.125}\right) = \frac{8 \times 34.6}{58.44} = \mathbf{4.74 \text{ M}}$$

- b) Explain how you can prepare the following solutions:

- i. 100.0ml of  $\text{K}_2\text{Cr}_2\text{O}_4$  with a concentration of 1.0M.

**NB: Compound should be corrected to  $\text{KCrO}_4$  or  $\text{K}_2\text{Cr}_2\text{O}_7$ . I take the latter so that the typo is on 4 in the formula**

**Solution:**

$$C_M = \frac{n}{V}$$

where  $C_M$  is the molarity concentration,  $n$  is the number of moles and  $V$  is the volume of the solution. Since the volume is 100.0 we need to dissolve  $n$  moles in 100 ml of water. But the number of moles is

$$n = C_M \times V = 0.1 \text{ L} \times 1.0 \text{ M} = 0.1 \text{ mol}$$

We also know that  $n = \frac{m}{M_r}$  or  $m = n \times M_r$

$$\text{Where } M_r = 2 \times M_K + 2 \times M_{Cr} + 7 \times M_O = 2 \times (40.08 + 52.00) + 7 \times 16.00 \\ = 2 \times (92.08) + 112.00 = 184.16 + 112.00 = \mathbf{296.16 \text{ g/mol}}$$

$$\text{Thus } m = 0.1 \text{ mol} \times 296.16 \frac{\text{g}}{\text{mol}} = \mathbf{29.616 \text{ g}}$$

**The solution would be prepared by weighing 29.6 g of  $K_2Cr_2O_7$  and dissolving it in 100.0 ml of water.**

- ii. 100.0ml of NaCl solution with a concentration of 0.5M

**Solution:**

$$C_M = \frac{n}{V}$$

where  $C_M$  is the molarity concentration,  $n$  is the number of moles and  $V$  is the volume of the solution. Since the volume is 100.0 we need to dissolve  $n$  moles in 100 ml of water. But the number of moles is

$$n = C_M \times V = 0.1 \text{ L} \times 0.5 \text{ M} = 0.05 \text{ mol}$$

We also know that  $n = \frac{m}{M_r}$  or  $m = n \times M_r$

$$\text{Where } M_r = M_{Na} + M_{Cl} = 22.99 + 35.45 = 58.44 \text{ g/mol}$$

$$\text{Thus } m = 0.05 \text{ mol} \times 58.44 \frac{\text{g}}{\text{mol}} = \mathbf{2.922 \text{ g}}$$

**The solution would be prepared by weighing 2.9 g of NaCl and dissolving it in 100.0 ml of water.**

- iii. 250.0ml of copper (II)sulfate dihydrate solution with a concentration of 2.0M

**Solution:**

$$C_M = \frac{n}{V}$$

where  $C_M$  is the molarity concentration,  $n$  is the number of moles and  $V$  is the volume of the solution. Since the volume is 250.0 we need to dissolve  $n$  moles in 250 ml of water. But the number of moles is

$$n = C_M \times V = 0.250 \text{ L} \times 2.0 \text{ M} = 0.50 \text{ mol}$$

We also know that  $n = \frac{m}{M_r}$  or  $m = n \times M_r$

Where

$$M_r = M_{Cu} + M_{SO_4^{2-}} + 2 \times M_{H_2O} = 63.55 + 96.07 + 36.032 = 195.65 \text{ g/mol}$$

$$\text{Thus } m = 0.5 \text{ mol} \times 195.65 \frac{\text{g}}{\text{mol}} = \mathbf{97.8 \text{ g}}$$

**The solution would be prepared by weighing 97.8 g of  $CuSO_4 \cdot H_2O$  and dissolving it in 250.0 ml of water.**

- c) Calculate the number of moles of the following:

- i. 10g of sodium hydroxide

**Solution:**

$$\text{We know that the number of moles } n = \frac{m}{M_r}$$

Where

$$M_r = M_{Na} + M_{OH^-} = 22.99 + 17.008 = 39.998 \text{ g/mol}$$

$$\text{Therefore } n = \frac{m}{M_r} = \frac{10 \text{ g}}{40 \text{ g/mol}} = \mathbf{0.250 \text{ mol}}$$

- ii. 20 ml of 0.1M sulfuric acid

**Solution:**

$$\text{We know that the number of moles } C_M = \frac{n}{V}$$

Where

$$C_M = 0.1 \text{ M and } V = 0.02 \text{ L}$$

$$\text{Therefore } n = 0.1 \text{ M} \times 0.02 \text{ L} = \mathbf{0.002 \text{ mol or 2 millimole}}$$

### Question 3

- a) Calculate the concentration of 250ml HCl made by diluting 18.5ml of 2.3M HCl?

**Solution:**

$$M_1 V_1 = M_2 V_2 \text{ or } M_2 = \frac{M_1 V_1}{V_2} = \frac{18.5 \text{ ml} \times 2.3 \text{ M}}{250 \text{ ml}} = \mathbf{0.17 \text{ M}}$$

- b) A stock solution containing  $\text{Mn}^{2+}$  ions was prepared by dissolving 1.584g pure manganese metal in nitric acid and diluting to a final volume of 1.000L. The following solutions were then prepared by dilution:

For solution A, 50.00mL of stock solution was diluted to 1000.0mL

For solution B, 10.00mL of stock solution A was diluted to 250.0mL

For solution C, 10.00mL of solution B was diluted to 500.0mL.

Calculate the concentrations of the stock solution, solutions A, B, and C.

**Solution:**

We first get the concentration of the stock solution using the equation

$$C_{\text{Stock or } M_{\text{stock}}} = \frac{n}{V}$$

$$\text{Where } n = \frac{m}{M_r} \text{ when } M_r = 54.94 \frac{\text{g}}{\text{mol}}, m = 1.584 \text{ g and } V = 1.000 \text{ L}$$

$$\text{Thus } n = \frac{m}{M_r} = \frac{1.584 \text{ g}}{54.94 \text{ g/mol}} = 0.0288 \text{ mol and } M_{\text{stock}} = \frac{n}{V} = \frac{0.0288}{1.000} = \mathbf{0.0288 \text{ M}}$$

Using the concentrations of the new solutions are derived from the equation

$$V_{\text{Stock aliquot}} \times M_{\text{Stock}} = V_{\text{new}} \times M_{\text{new}}$$

Making the new concentration the subject of the formula we have

$$M_{\text{new}} = \frac{V_{\text{Stock aliquot}} \times M_{\text{Stock}}}{V_{\text{new}}}$$

We make these calculations using in table below with volumes in mL and concentrations in M

Solution	$V_{\text{Stock aliquot}}$	$M_{\text{Stock}}$	$V_{\text{new}}$	$M_{\text{new}} = \frac{V_{\text{Stock aliquot}} \times M_{\text{Stock}}}{V_{\text{new}}}$
A	50.0	0.0288	1000.0	$\frac{50 \text{ mL} \times 0.0288 \text{ M}}{1000 \text{ mL}} = \mathbf{1.44 \times 10^{-3} \text{ M}}$

B	10.0	0.0288	250.0	$\frac{10 \text{ mL} \times 1.44 \times 10^{-3} M}{250 \text{ mL}} = 5.8 \times 10^{-5} M$
C	10.0	$1.15 \times 10^{-3}$	500.0	$\frac{10 \text{ mL} \times 5.8 \times 10^{-5} M}{500 \text{ mL}} = 1.16 \times 10^{-6} M$

#### Question 4

- a) Predict which of the following substances are likely to be soluble in water:

**Solutions:**

*Use the table in the notes to get answers*

- i) Aluminum nitrate - **Soluble**
- ii) Lead (II) sulfide - **Insoluble**
- iii) Magnesium hydroxide - **Insoluble**
- iv) Iron (III) phosphate - **Insoluble**
- v) Zinc chloride - **Soluble**
- vi) Ammonium carbonate – **Soluble**
- vii) Chromium (III) hydroxide – **Insoluble**

- b) When the following solutions are mixed together, what precipitate (if any) will form?

**Solutions:**

- i) Aqueous Iron (II) sulfate and aqueous potassium chloride – **No precipitate**
- ii) Aqueous aluminum nitrate and aqueous barium hydroxide – **Al(OH)<sub>3</sub>**
- iii) Aqueous calcium chloride and aqueous sodium sulfate – **CaSO<sub>4</sub>**
- iv) Aqueous potassium sulfide and aqueous nickel (II) nitrate – **NiS**
- v) Aqueous carbonate and aqueous magnesium iodide – **MgCO<sub>3</sub>**

- c) For each of the reactions in (b) above, write a:

- i) balanced formula equation

**Solutions:**

1.  $FeSO_4(aq) + 2KCl(aq) \rightarrow FeCl_2(aq) + K_2SO_4(aq)$
2.  $2Al(NO_3)_3(aq) + 3Ba(OH)_2(aq) \rightarrow 3Ba(NO_3)_2(aq) + 2Al(OH)_3(s)$
3.  $CaCl_2(aq) + Na_2SO_4(aq) \rightarrow CaSO_4(s) + 2NaCl(aq)$
4.  $K_2S(aq) + Ni(NO_3)_2(aq) \rightarrow 2KNO_3(aq) + NiS(s)$
5.  $CO_3^{2-}(aq) + MgI_2(aq) \rightarrow MgCO_3(s) + 2I^-(aq)$

- ii) complete ionic equation

**Solutions:**

1.  $Fe^{2+}(aq) + SO_4^{2-}(aq) + 2K^+(aq) + 2Cl^-(aq) \rightarrow Fe^{2+}(aq) + 2Cl^-(aq) + 2K^+(aq) + SO_4^{2-}(aq)$
2.  $2Al^{3+}(aq) + 6NO_3^-(aq) + 3Ba^{2+}(aq) + 6OH^-(aq) \rightarrow 3Ba^{2+}(aq) + 6NO_3^-(aq) + 2Al(OH)_3(s)$
3.  $Ca^{2+}(aq) + 2Cl^-(aq) + 2Na^+(aq) + SO_4^{2-}(aq) \rightarrow CaSO_4(s) + 2Na^+(aq) + 2Cl^-(aq)$

4.  $2K^+(aq) + S^{2-}(aq) + Ni^{2+}(aq) + 2NO_3^-(aq) \rightarrow 2K^+(aq) + 2NO_3^-(aq) + NS(s)$
5.  $CO_3^{2-}(aq) + Mg^{2+}(aq) + 2I^-(aq) \rightarrow MgCO_3(s) + 2I^-(aq)$

iii) net ionic equation

**Solutions:**

1.  $Fe^{2+}(aq) + SO_4^{2-}(aq) + 2K^+(aq) + 2Cl^-(aq) \rightarrow Fe^{2+}(aq) + 2Cl^-(aq) + 2K^+(aq) + SO_4^{2-}(aq)$
2.  $2Al^{3+}(aq) + 6OH^-(aq) \rightarrow 2Al(OH)_3(s)$
3.  $Ca^{2+}(aq) + SO_4^{2-}(aq) \rightarrow CaSO_4(s)$
4.  $S^{2-}(aq) + Ni^{2+}(aq) \rightarrow NS(s)$
5.  $CO_3^{2-}(aq) + Mg^{2+}(aq) \rightarrow MgCO_3(s)$

d) Separate samples of a solution of an unknown salt are treated with dilute solutions of HBr, H<sub>2</sub>SO<sub>4</sub>, and NaOH. A precipitate forms in all three cases. Which of the following cations could the solution contain: K<sup>+</sup>, Pb<sup>2+</sup>, Ba<sup>2+</sup>?

**Solution:** Pb<sup>2+</sup>

e) Name the spectator ions in any reactions that may be involved when each of the following pairs of solutions are mixed:

i) Aqueous sodium carbonate and aqueous magnesium sulfate.

**Solution:** Na<sup>+</sup> and SO<sub>4</sub><sup>2-</sup>

ii) Aqueous lead (II) nitrate and aqueous sodium sulfide.

**Solution:** Na<sup>+</sup> and NO<sub>3</sub><sup>-</sup>

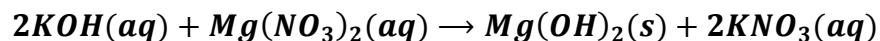
iii) Aqueous ammonium phosphate and aqueous calcium chloride.

**Solution:** NH<sub>4</sub><sup>+</sup> and Cl<sup>-</sup>

f) A 100.0ml aliquot of 0.200M aqueous potassium hydroxide is mixed with 100.0ml of 0.200M aqueous magnesium nitrate.

i) Write a balanced chemical equation for any reaction that occurs.

**Solution:**



ii) What precipitate is formed from this reaction?

**Solution:**



iii) Calculate the mass of the precipitate formed.

**Solution:**

Mole ratios: 2 moles of KOH produce a mole of 1 of Mg(OH)<sub>2</sub>

Moles of KOH used up in this reaction is

$$M_{KOH} \times V_{KOH} = 0.1L \times 0.2M = 0.020 \text{ mol}$$

Therefore  $0.010 \text{ mol Mg(OH)}_2$  is formed. The mass formed is given by the formula

$m = n \times M_r$  since

$$M_r = M_{Mg} + 2 \times M_{OH} = 24.31 + 2 \times 17.008 = 58.33 \text{ g/mol},$$

$$m = n \times M_r = 0.010 \text{ mol} \times 58.33 \frac{\text{g}}{\text{mol}} = \mathbf{0.58 \text{ g}}$$

- iv) Calculate the concentration of each ion remaining in solution after precipitation is complete.

**Solution:**

The moles of the magnesium nitrate is remaining in solution is  $0.01 \text{ mol}$ , that is  $0.01 \text{ mol}$  of  $\text{Mg}^{2+}$  ion and  $0.02 \text{ mol}$  of  $\text{NO}_3^-$ . A similar amount was used to make Potassium nitrate. The total volume of the solution is  $0.2 \text{ L}$ . Thus the concentrations are

$$\text{NO}_3^- = \frac{0.04 \text{ mol}}{0.2 \text{ L}} = \mathbf{0.20 \text{ M}} \text{ and } \text{Mg}^{2+} = \frac{0.01 \text{ mol}}{0.2 \text{ L}} = \mathbf{0.05 \text{ M}};$$

$$\text{K}^+ = \frac{0.02 \text{ mol}}{0.2 \text{ L}} = \mathbf{0.10 \text{ M}}$$

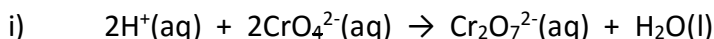
### Question 5

- a) Calculate the oxidation state for the underlined atom in each of the following:

**Solution:**

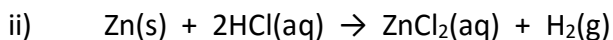
- |  |   |
|--|---|
| i) $\text{KMMnO}_4 \Rightarrow 1 + x - 8 = 0; x = 7$ | vi) $(\text{NH}_4)_2\text{Ce(SO}_4)_3 \Rightarrow 2 + x - 6 = 0; x = 4$ |
| ii) $\text{SrCCr$                                    | vii) $\text{CCr$  |
| iii) $\text{CCr$                                     | viii) $\text{Na}_4\text{Fe(OH)}_6 \Rightarrow 4 + x - 6 = 0; x = 2$     |
| iv) $\text{PbSO}_3 \Rightarrow 2x - 14 = -2; x = 6$  | ix) $\text{NH$  |
| v) $\text{NaBiO}_3 \Rightarrow 1 + x - 6 = 0; x = 5$ | x) $\text{PO$   |

- b) Specify which of the following are Redox reactions. For the Redox reactions, identify the reducing agent, the oxidizing agent, the substance oxidized, and the substance reduced.



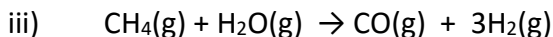
**Solution:**

Not a redox reaction!



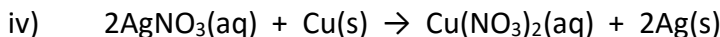
**Solution:**

Redox reaction;  $\text{H}^+$  is the oxidizing agent, Zn is oxidized, Zn is the reducing agent and hydrogen is reduced.



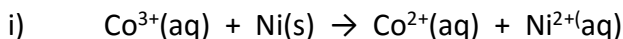
**Solution:**

Redox reaction; Hydrogen in water is the oxidising agent, it oxidises carbon in methane. Carbon is the reducing agent it reduces hydrogen.



Redox reaction; Cu oxidized, oxidizing agent is  $\text{Ag}^+$ , Cu is the reducing agent, it reduces  $\text{Ag}^+$

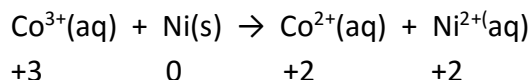
c) Balance the following Redox reaction equations using oxidation numbers:



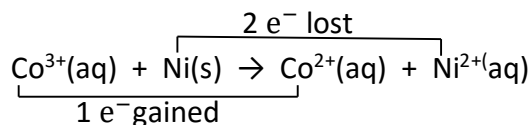
**Solution:**

Step 1. Unbalanced equation is:  $\text{Co}^{3+}(\text{aq}) + \text{Ni}(\text{s}) \rightarrow \text{Co}^{2+}(\text{aq}) + \text{Ni}^{2+}(\text{aq})$

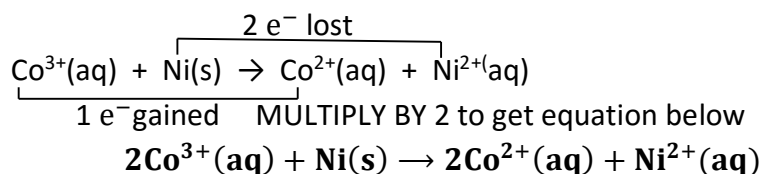
Step 2. We start by writing the oxidation numbers of each specie in the equation



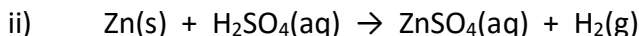
Step 3. We show how electrons are gained and lost



Step 4. Show coefficients needed to equalize the electrons gained and lost



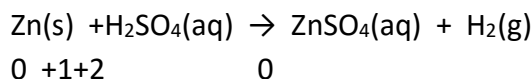
Step 5. All elements are balanced therefore the above equation is the required balanced equation



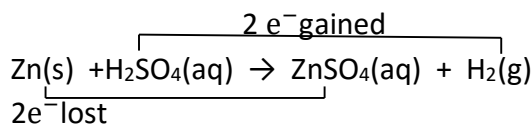
**Solution:**

Step 1. Unbalanced equation is:  $\text{Zn}(\text{s}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{ZnSO}_4(\text{aq}) + \text{H}_2(\text{g})$

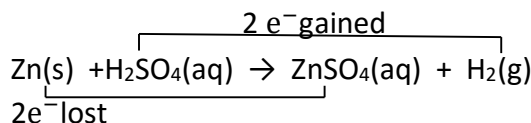
Step 2. We start by writing the oxidation numbers of each specie in the equation



Step 3. We show how electrons are gained and lost

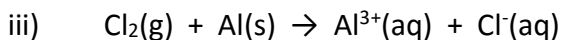
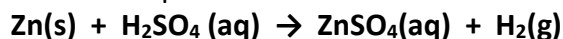


Step 4. There are no coefficients needed to equalize the electrons gained & lost





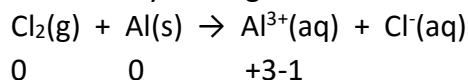
Step 5. All elements are balanced therefore the equation below is the required balanced equation



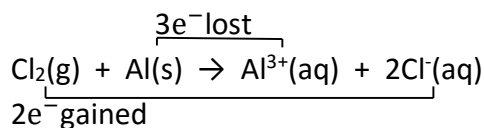
**Solution:**

Step 1. Unbalanced equation is:  $\text{Cl}_2(\text{g}) + \text{Al(s)} \rightarrow \text{Al}^{3+}(\text{aq}) + \text{Cl}^-(\text{aq})$

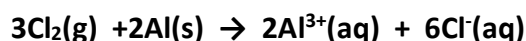
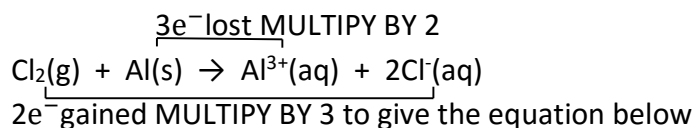
Step 2. We start by writing the oxidation numbers of each specie in the equation



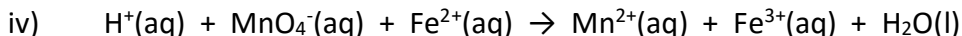
Step 3. We show how electrons are gained and lost



Step 4. Show arecoefficients needed to equalize the electrons gained and lost

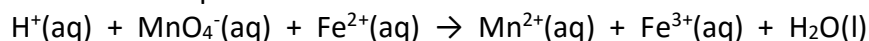


Step 5. All elements are balanced therefore the equation above is the required balanced equation.

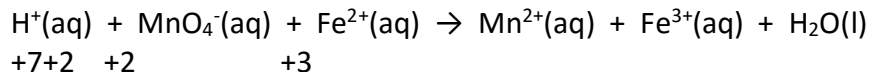


**Solution:**

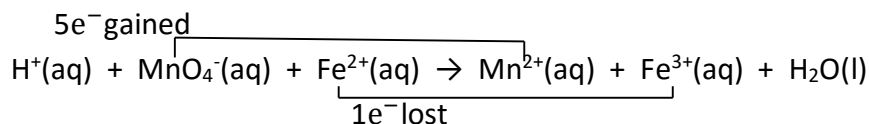
Step 1. Unbalanced equation is:



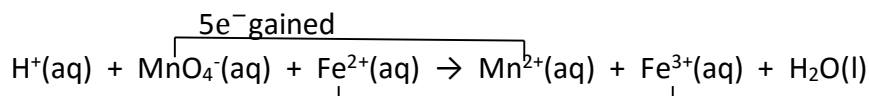
Step 2. We start by writing the oxidation numbers of each specie in the equation



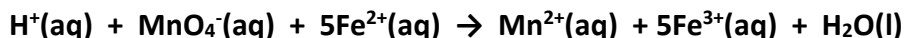
Step 3. We show how electrons are gained and lost



Step 4. Show arecoefficients needed to equalize the electrons gained and lost

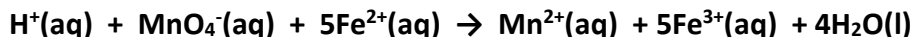


1e<sup>-</sup>lost MULTIPLY BY 5

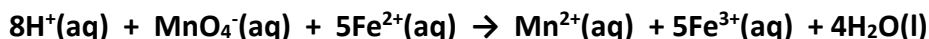


Step 5. Show coefficients needed to balance the remaining elements.

**Balance O:**



**Balance H:**



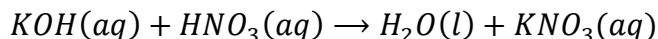
All elements are now balanced.

### Question 6

a) Write the balanced formula equation for the following acid-base reactions:

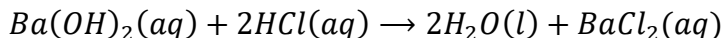
i) Potassium hydroxide (aqueous) and nitric acid

**Solution:**



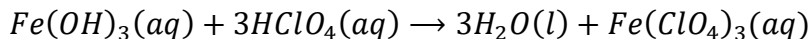
ii) Barium hydroxide (aqueous) and hydrochloric acid.

**Solution:**



iii) Perchloric acid (aqueous) and solid iron (III) hydroxide

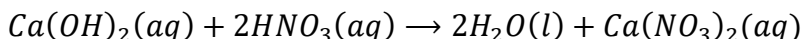
**Solution:**



b) What volume of 0.0200 M calcium hydroxide is needed to neutralize 35.00 ml of 0.0500 M nitric acid?

**Solution:**

**The reaction is**



A mole of calcium hydroxide neutralizes 2 moles nitric acid.

The moles of Nitric Acid is  $n = M_1 \times V_1 = 35 \times 0.05 \text{ mmol} = 3.5 \times 0.5 = 1.75 \text{ mmol}$

The moles of Calcium Hydroxide required is  $1.75/2 = 0.875 \text{ mmol} = M_2 V_2$

Since  $M_2 = 0.0200 \text{ M}$ ,  $V_2 = \frac{n}{M_2} = \frac{8.75 \times 10^{-4}}{2.00 \times 10^{-2}} \text{ L} = 4.375 \times 10^{-2} \text{ L} = 43.75 \text{ ml}$

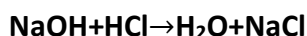
c) What volume of each of the following bases would react completely with 25.00 mL of 0.200 M HCl?

- i) 0.100 M NaOH
- ii) 0.050 M Ba(OH)<sub>2</sub>
- iii) 0.250 M KOH

**Solution:**

**Moles of HCl = 25.00 mL x 0.2 M = 2.5 x 2 mmol = 5 mmol.**

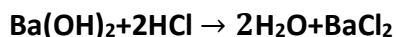
**(i) The reaction of NaOH with HCl is**



**We require 5 mmol of solution NaOH, that is 5mmol =  $V_2 \times 0.100 \text{ M}$**

$$V_2 = \frac{n}{M_2} = \frac{5 \times 10^{-3}}{1.00 \times 10^{-1}} L = 5 \times 10^{-2} L = 50 \text{ ml}$$

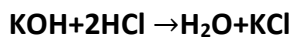
**(ii) The reaction of Ba(OH)<sub>2</sub> with HCl is**



**We require 2.5 mmol of solution Ba(OH)<sub>2</sub>, i.e., 2.5 mmol =  $V_2 \times 0.050 \text{ M}$**

$$V_2 = \frac{n}{M_2} = \frac{2.5 \times 10^{-3}}{5.00 \times 10^{-2}} L = 5 \times 10^{-2} L = 50 \text{ ml}$$

**(iii) The reaction of KOH with HCl is**



**We require 5 mmol of solution KOH, i.e., 5 mmol =  $V_2 \times 0.250 \text{ M}$**

$$V_2 = \frac{n}{M_2} = \frac{5 \times 10^{-3}}{2.50 \times 10^{-1}} L = 2 \times 10^{-2} L = 20 \text{ ml}$$