Equivalent Mass Concept-I (For elements)

Basic Concepts in Chemistry(BCC)-Lecture-8

Equivalent Mass of Element

- Gram Equivalent Mass of the element is the mass which is produced at any electrode(cathode or anode) during electrolysis by the passage of 1 Faraday of charge(96500 C) i.e 1 mol of electrons.
- Equivalent Mass concept is applicable to a chemical reaction, both spontaneous and non-spontaneous, as it can vary for the same substance taking part in different reactions.

- Atomic Mass and Molecular Masses are unchanged and independent of reactions.
- Elements undergo Oxidation or Reduction reactions always.
- Equivalent masses of elements are used in Faraday's laws of Electrolysis. The central idea behind the laws is for the passage of 1 mole of electrons(1 Faraday charge) during electrolysis, one g. equivalent(1 eq.) of any substance is produced at any electrodes.

- **$Al^{3+} + 3e \rightarrow Al$**
  3 mols of electrons gained to produce 1 mol of Al(27g = g. atomic mass)
  So 1 mol of electrons gained to produce 1/3 mol(27/3=9g) of Al
  Equivalent Mass of Al = 9
  (So for the passage of 1F charge, 9 g of Al is liberated)
- **$O^{2-} \rightarrow O + 2e$**
  2 mols of electrons lost to produce 1 mol of O(16g)
  So 1 mol of electrons lost to produce ½ mole i.e 8g of O.
  Equivalent Mass of O = 8
  (For the passage of 1F charge, 8 g of O is liberated.)

$$Equivalent\ Mass\ of\ Element = \frac{Atomic\ Mass}{Valency\ Factor}$$

$$= \frac{Atomic\ Mass}{No.of\ electrons\ lost\ or\ gained\ per\ atom}$$

$$= \frac{Atomic\ Mass}{Change\ in\ ON\ per\ atom}$$

Valency Factor = 'x' factor/ 'n' factor is dependent on the actual reaction and can be variable for an element showing variable valencies.

- Examples: EM(Na) =23/1 =23
- EM(Ca) = 40/2 = 20
- EM(Al) = 27/3 = 9
- EM(H) = 1/1 = 1
- EM(Cl) = 35.5/1=35.5
- EM(O)= 16/2=8 (most usual, but it can be variable)
- No of g. equivalents = eqs
- No of milli equivalents =1meqs = 10^{-3} eqs

1 eq. = 10^3 meq.

Reaction Dependence of EM

- $Fe + H_2SO_4(dil) \rightarrow FeSO_4 + H_2$
  EM(Fe) = 56/2 = 28
- $2Fe+3Cl_2 \rightarrow 2FeCl_3$
  EM(Fe) = 56/3=18.67
- $4Cu + O_2 \rightarrow 2Cu_2O$
  EM(Cu) = 63.5/1=63.5
- $2Cu+O_2 \rightarrow 2CuO$
  EM(Cu) = 63.5/2 = 31.75

- SAQ: Find the EM of the underlined elements from the reactions or half reactions given
- (a) $Co^{3+} + 3e \rightarrow \underline{Co}$ (Co=59)
- (b) $\underline{Cr} \rightarrow Cr^{2+} + 2e$ (Cr=52)
- (c) $2Na + \underline{O_2} \rightarrow Na_2O_2$ (O=16)
- (d) $K + \underline{O_2} \rightarrow KO_2$
- (e) $\underline{Fe} + H_2O \rightarrow Fe_3O_4 + H_2$ (Fe=56)

- SAQ: Calculate the number of eqs and mmeqs in case of the following.
- (a) 2.0 g of Ca (b) 7.1 Kg of Chlorine
- (c) 27.0 g of Al (d) 1.867 g of Fe used in the reaction with Cl_2
- (e) 0.3175g of Cu used in the reaction with conc. H_2SO_4.

Slogan

- **All Chemical Reactions take place in Equivalents.**
- 1 eq. of a reactant reacts with 1 eq. of the other reactant to produce 1 eq. of any product.
- 'x' eqs of a reactant reacts with 'x' eqs of the other reactant to produce 'x' eqs. of any product.
- In mols, the ratio between reactants and products often may not be in 1:1, but in equivalents it is always 1:1. That is the beauty of EQUIVALENT CONCEPT.
- Hence balancing of an equation is not required if we deal with it in Equivalent concept.

- $4Al + 3O_2 \rightarrow 2Al_2O_3$
  4 mols 3 mols
  4X27g 3X32g
  9 g 8 g
  1eq 1eq
- $2Na + O_2 \rightarrow Na_2O_2$ (peroxide)
  2X23g 32g
  23g 16g
  1eq. 1eq

For peroxide formation EM of O = 16)

- $2Al + 6HCl \rightarrow 2AlCl_3 + 3H_2$
  2X27g 3X2 g
  9 g 1.0g
  1eq 1eq.
- So even the product formation remains in equivalents with reactants.

- SAQ: Prove the equivalent concept in the following reactions between reactants only.
  (a) $K + O_2 \rightarrow KO_2$
  (b) $Mg + Cl_2 \rightarrow MgCl_2$
  (c) $2Cu + O_2 \rightarrow 2CuO$
  (d) $4Cu + O_2 \rightarrow 2Cu_2O$
  (e) $2Fe + 3Cl_2 \rightarrow 2FeCl_3$
- SAQ: Prove the equivalent concept between the metal reactant and H_2 product.
  (a) $Fe + H_2SO_4 \rightarrow FeSO_4 + H_2$

Law of Equivalents

- Masses of substances are directly proportional to their Equivalent Masses.

$$\frac{m_1}{m_2} = \frac{E_1}{E_2}$$

Proof:
Let m_1 g of a substance reacts with m_2 g of the other substance
So E_1 g of that substance wil react with $(m_2/m_1)XE_1$ g of the other.
Hence $E_2 = (m_2/m_1)XE_1$; So $m_1/m_2 = E_1/E_2$

Equivalent Mass Concept-II

Basic Concepts in Chemistry(BCC)-Lecture-9

Experimental Determination of EM

- It was done earlier to find the atomic mass of elements.
- Now it has limited significance when isotopic masses are determined correctly in Mass Spectrometers.
- Hydrogen Displacement, metal displacement; Oxide formation or its decomposion, Chloride formation or its decomposition, Double displacement methods etc. were being used to determine EM of metals.

Hydrogen Displacement Method

- *Example: 1.47gm of a metal was treated with excess of dil H_2SO_4 and 541.8cc of hydrogen gas was collected over water at 15^{0}C and 752.5mm of Hg pressure. Calculate the equivalent mass of the metal.(Aqueous tension at 15^{0}C = 12.5mm and density of hydrogen gas at STP =0.000089 gm/cc)*

$$\frac{(752.55 - 12.5)X\ 541.8}{(273 + 15)} = \frac{760\ X\ V_2}{273}$$

V_2 = 500.1 mL(STP); Hence mass of H_2 = 0.000089X500.1 = 0.0445 g

$$\frac{m_M}{m_H} = \frac{E_M}{E_H} \qquad \frac{1.47}{0.0445} = \frac{E_M}{1.008}$$

EM=33.29

- Equivalent Volume method:
- 1 eq of H_2=1 g = 11.2L = 11200 mL at STP
  500.1 mL of H_2(STP) displaced by 1.47g of metal
  11200 mL of H_2(STP) displaced by 32.9 g of metal
- So EM(metal) = 32.9

Metal Displacement Method

- *Example: 0.26gm of Al displaces 0.94gm of a metal from metal Sulphate solution. If the equivalent mass of Aluminium is 9, calculate the equivalent mass of unknown metal. Can you guess the metal? What is its OS in the sulphate, if the atomic mass of metal is 65.5 ?*
- *Solution:* $\frac{m_X}{m_{Al}} = \frac{E_X}{E_{Al}} \Rightarrow \frac{0.94}{0.26} = \frac{E_X}{9}$

$\Rightarrow E_X = 32.53$ The metal could be Zn or Cu (with experimental error)

Valency(OS) of the metal = 65.5/32.53 = 2

Oxide Formation or its Decomposition

- *Example: 50 mg of a metal is heated strongly in air until constant mass of 83.3 mg of its oxide is obtained. Find the equivalent mass of the metal. Can you guess the metal ?*
- *Solution: Mass of oxygen combined = 83.3 – 50=33.3 mg*

$\frac{m_X}{m_O} = \frac{E_X}{E_O} \Rightarrow \frac{0.05}{0.0333} = \frac{E_X}{8} \Rightarrow E_X = 12$

The metal could most likely be Mg

- *Example: A sample of a metal weighing 0.8g was first dissolved in conc. HNO_3 to form its nitrate. The metal nitrate formed is then strongly heated until constant dry mass is obtained. Reddish brown gas is evolved during ignition. The mass of metal oxide formed was 1.0 g. Calculate the equivalent mass of the metal.*
- *This is indirect method:*
- M + HNO_3 → $M(NO_3)_x$ + NO_2 + H_2O (unbalanced)
- $M(NO_3)_x$ → M_2O_x + NO_2 + O_2 (unbalanced)
- *Mass of Oxygen = 1 – 0.8 = 0.2 g*

$\Rightarrow \frac{0.8}{0.2} = \frac{E_X}{8} \Rightarrow E_X = 32$

- *Example: On heating 1.127 gm of a metallic oxide in a current of hydrogen, 0.9g of metal was formed. Calculate the equivalent mass of the metal.*
- *Solution: M_2O_x → M + O_2 (unbalanced)*
- *Mass of oxygen = 1.127 – 0.9 = 0.227g*

$\Rightarrow \frac{0.9}{0.227} = \frac{E_X}{8} \Rightarrow E_X = 31.71$

The metal is most likely to be Copper and it was Copper(II) oxide.

Equivalent Volume Method

- 1 g eq. mass of Oxygen = 8g = 5.6 L at STP
- So Equivalent volume of Oxygen = 5.6 L
- So we can find the mass of metal that combine with 5.6L of oxygen at STP, which will give its EM.

Chloride Method

- *Example: Chloride of a metal M contains 47.23% of the metal by mass. Find the equivalent mass of the metal.*
- *Solution: % of Chlorine = 100-47.23=52.73*

$\frac{m_X}{m_{Cl}} = \frac{E_X}{E_{Cl}} \Rightarrow \frac{47.23}{52.73} = \frac{E_X}{35.5} \Rightarrow E_X = 31.77$

- SAQ : 0.475 gm of a metal chloride was formed by the reaction of certain mass of the metal with excess of chlorine. If the equivalent mass of the metal is 12, what is the mass of the metal reacted?

Double Displacement Reaction

- Equivalent Mass of an Ionic Compound used in Metathesis Reaction =

EM(cation) + EM(anion)

EM of an Ion = $\frac{Ionic\ Mass}{Valency}$

$EM(SO_4^{2-}) = 96/2=48$; $EM(O^{2-}) = 16/2=8$
$EM(NO_3^{-}) = 62/1=62$; $EM(Cl^{-}) = 35.5/1 = 35.5$
$EM(Ba^{2+}) = AM/2$

$EM(BaSO_4) = E(Ba^{2+}) + E(SO_4^{2-}) = AM/2 + 48$

$$\frac{m_{Metal\,sulfate}}{m_{metal\,chloride}} = \frac{E_{M^{x+}} + E_{SO_4^{2-}}}{E_{M^{x+}} + E_{Cl^-}}$$

$$\frac{m_{metal}}{m_{metal\,sulfate}} = \frac{E_M}{E_{M^{x+}} + E_{SO_4^{2-}}}$$

- The masses of the reactant and product in a precipitation reactions are measured. Then the law of equivalents is used.
- Example 1: 0.925 g of anhydrous barium chloride was dissolved in water and treated with excess sulphuric acid. The weight of the dry barium sulphate obtained was 1.036. Find the equivalent mass of the barium. Also find the percentage of error with respect to the theoretical value.
- Solution: Barium chloride + H_2SO_4 → Barium sulphate+HCl
- $m(BaCl_2) = 0.925$ g; $m(BaSO_4) = 1.036$ g

$$\frac{m_{BaCl_2}}{m_{BaSO_4}} = \frac{E_{BaCl_2}}{E_{BaSO_4}} = \frac{E_{Ba^{2+}} + E_{Cl^-}}{E_{Ba^{2+}} + E_{SO_4^{2-}}} = \frac{x + 35.5/1}{x + 96/2}$$

$$\frac{0.925}{1.036} = \frac{x + 35.5/1}{x + 96/2}$$

x = 68.12 (EM of Ba)
AM(Ba) = 68.12 × valency(2) = 136.24

- Examle 2: 1.53 g of metal hydroxide on strong heating produced 0.995 g of its oxide. Calculate the equivalent mass of the metal.
- *Solution:*

$$\frac{mass(metal\ hydroxide)}{mass(metal\ oxide)} = \frac{E(metal\ hydroxide)}{E(metal\ oxide)} = \frac{E_{M^{x+}} + E_{OH^-}}{E_{M^{x+}} + E_{O^{2-}}}$$

$$\Rightarrow \frac{1.53}{0.995} = \frac{E_{M^{x+}} + 17}{E_{M^{x+}} + 8} \qquad \Rightarrow E_{M^{x+}} = 8.739$$

Assignments

- 1. 24 g of a metal produced 22.4 L of H_2 gas at STP from an acid. What is the equivalent mass of the metal? Guess which is the metal?
- 2. Enough steam was passed over 5 g of red hot iron till all the iron reacted completely to produce 2.67 L of H_2 gas at STP. Calculate the equivalent mass of iron. Justify this by writing the equation.
- 3. 0.12 g of a metal combines with 56 ml of O_2 gas at STP. Calculate the equivalent mass of the metal.

- 4. 0.640 g of an unknown metal gave 0.851 g of its chloride. Calculate the equivalent mass of the metal. Can you guess which is the metal?
- 5. 1.314 g of an unknown metal displaced 2.158g of sliver from $AgNO_3$ solution. Find the equivalent mass of the unknown metal. Could you guess the metal?
- 6. 3.31 g of pure and dry nitrate of a metal was dissolved in water and treated with excess of potassium chromate solution. A coloured precipitate of metal chromate was obtained which was separated and dried and weighed to 3.23 g. Calculate the equivalent mass of metal.(Cr=52)

- 7. 0.45 g of metal gave 176.6 mL of hydrogen at 23^0C and 743 mm pressure when treated with dilute sulphuric acid. Calculate the equivalent mass of the metal. (Aq. tension at 23^0C = 21 mm) If the specific heat of the metal is 0.091, what would be the exact atomic mass of the metal ?
- 8. The oxide of an element contains 31.78 % of oxygen and the vapour density of its chloride is 79. Calculate the atomic mass of the element.

- 9. A metal forms a volatile chloride whose VD is 74.6. The specific heat of the metal is 0.55. Find the exact atomic mass of the metal and the formula of its chloride.
- 10. 0.139 g of a metal when dissolved in dilute HCl evolved 29.5 mL of hydrogen when collected over water at 13^0C and 741 mm pressure. What would be the weight of oxygen present in 100 g of the oxide of the metal ? (Aq. tension at 13^0C = 11.2 mm)

- 11. The bromide of a metal contains 90% bromine. The oxide of the same metal contains 47% oxygen. What is the equivalent mass of bromine ?
- 12. 1.05 g of the metallic carbonate of a metal left on ignition 0.5 g of its oxide. Calculate the equivalent mass of the metal.
- 13. 1.0 g of an acid when completely acted upon by Mg gave 1.301 g of anhydrous magnesium salt. Find the equivalent mass of the acid. (Mg = 24, H=1)
- 14. Chloride of a metal 'M' contains 47.23% of the metal. 1.0 g of this metal displaced from a compound 0.88 g of another metal 'N'. Find the equivalent mass of M and N.

- 15. 5 g of an oxide of iron when heated in hydrogen leaves 3.5 g metal. Calculate the equivalent mass of iron and deduce the formula of its oxide.
- 16. A sulphate of a solid element contains 42.2% of element by mass. What is the equivalent mass of the element ? Also, calculate the percentage by mass of the element in its oxide, assuming it has same valency in both the compounds.
- 17. In the previous numerical, the specific heat of a solid element is 0.0442 cal/g K. Calculate the exact atomic mass of the element. Also give the formula of its sulphate.

Answers to Assignments

- 1. 12 2.21 3.12 4.107.6
- 5. 65.76 6.103.5 7. 32.57, 64.14
- 8. 51.5 9. 7.2, MCl_4
- 10. 57.57, 12.2g
- 11. 81.18 12. 12 13. 36.54
- 14. M=31.77, N= 27.96 15. 18.67, Fe_2O_3
- 16.35; 81.4%
- 17. 140, $M(SO_4)_2$