Water Chemistry

- A **substance** (matter) is composed of *molecules*, and a molecule is composed of *atoms*.
  - e.g. Water is composed of "H_2O" molecules and each "H_2O" is composed of "H" and "O" atoms.

- **Substances:**
  - **Compounds**: composed of different atoms (e.g. H_2O, NaCl).
  - **Elements**: composed of same atoms (e.g. gases: N_2, H_2, O_2; liquid: mercury; solids: carbon, sulfur).

- **The Atom** consists of:

  (1) A *nucleus* containing *protons* (+ ve charged) and *neutrons* (uncharged), and

  (2) *Electrons* (- ve charged) moving constantly around the nucleus in orderly rings (orbits).

  - An atom normally has the same number of protons as electrons, so that the net electric charge carried is zero.
  - The nucleus constitutes about 99.9% of the weight of the atom.
    - Weight of proton: 1.673×10^{-24} grams
    - Weight of neutron: 1.675×10^{-24} grams
    - Weight of electron: 9.11×10^{-28} grams

- **The atomic number**
  - The number of protons (or electrons)

- **The atomic weight** (g/mol)
  - Atomic weight, AW = number of protons and neutrons.

- A mole is the quantity of a substance which contains Avogador's number (6.02×10^{23}) of elementary entities (atoms, molecules, ..).
- Thus, one mole of any element has 6.02×10^{23} atoms, and one mole of any molecules has 6.02×10^{23} elements.

- *Example:*
  - One mole of carbon (C) has 6.02×10^{23} carbon atoms.
  - The carbon atom has *6 protons* and *6 neutrons* in the nucleus, and 6 electrons.
  - $\therefore$ the atomic number = 6
  - and the AW = 12 g/mol
    - The weight of protons = $6 * 6.02 \times 10^{23} * 1.673 \times 10^{-24} = 6.04$ g/mol

      $\approx$ number of protons
    - The weight of neutrons = $6 * 6.02 \times 10^{23} * 1.675 \times 10^{-24} = 6.05$ g/mol

      $\approx$ number of neutrons
    - $\therefore$ the atomic weight of carbon = 12 g/mol

      $\approx$ number of protons + number of neutrons

- ***Example:***
  - The nitrogen atom (N) has 7 protons and 7 neutrons in its nucleus.
  - $\therefore$ the atomic number = 7, and the AW = 14 g/mol

- **Isotopes**
  - Isotopes are elements that have the same number of protons but different number of neutrons
  - Example: ^{12}C and ^{13}C are isotopes of carbon
    - $^{12}C \rightarrow$ atomic no. = 6 AW = 12 g/mol
    - $^{13}C \rightarrow$ atomic no. = 6 AW = 13 g/mol

- **Radicals**
  - Radicals are groups of atoms act together as one unit (they are not compounds)
  - Examples:
    - OH^- (hydroxide)
    - $SO_4^=$ (sulfate)
    - $CO_3^=$ (carbonate)
    - NO_3^- (nitrate)
    - NH_4^+ (ammonium)

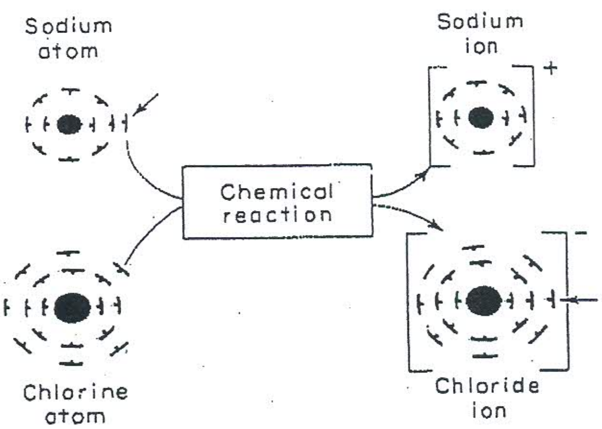
  - Radicals join with other elements forming compounds
    - Examples:
      - H_2SO_4 (sulfuric acid)
      - NaOH (sodium hydroxide)
      - $Fe_2(SO_4)_3$ (ferric sulfate)

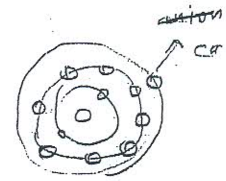
- **Compounds and Elements Formation**
  - Compounds/elements are formed when two or more atoms are joined together through chemical bonds.
  - Bonds are formed by
    - Transfer of electrons from one atom to another (ionic bonds). For example, a sodium atom (Na) gives up an electron to chlorine atom (Cl) to form sodium chloride, NaCl
    - Sharing of electrons equally between identical atoms (covalent bonds). Examples are oxygen (O_2) and hydrogen (H_2) gases.
  - If electrons are lost, the atom becomes +ve charged ion (cation), and the atom is oxidized.

* الذرة إذا اكتسبت الكترون تصبح سالبة الشحنة وتسمى (anion)

- If electrons are gained, the atom becomes –ve charged ion (anion), and the atom is reduced. وتسمى هذه العملية بالاختزال

- *Example (ionic bonding)*
  - Sodium atom (Na) → atomic no. = 11 (i.e. 11 electrons)
  - Chlorine atom (Cl) → atomic no. = 17 (i.e. 11 electrons)
  - One sodium atom combines with one chlorine atom to form sodium chloride (NaCl)



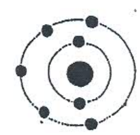


Electron transfer during a chemical reaction, producing a sodium ion (+) and a chloride ion (-)

  - ∴ the valency of Na (oxidation state) = 1+
  - and the valency of Cl = 1-
  - ***The valency*** is the number of electrons that an atom can take, give-up, or share with other atoms. (see Table 2-1)

روابط تكافؤية مشاركة في الالكترونات

- *Example (covalent bonding)*
  - Nitrogen atom (N) → atomic no. = 7 (i.e. 7 electrons)
  - Hydrogen atom (H) → atomic no. = 1 (i.e. 1 electron)



  - One nitrogen atom combines with three hydrogen atoms by sharing electrons to form ammonia gas (NH_3)
  - Valency of N = 3- , and valency of H = 1+

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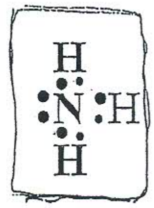


- *Example (covalent bonding)*
  - Hydrogen (H) → atomic no. = 1 (i.e. 1 electrons)
  - Two hydrogen atoms combine by sharing two electrons between them to form hydrogen gas (H_2).

H : H

  - Valency of H = 1+

Note: Some elements can assume several oxidation states from which a variety of ions, and molecules can result.

الوزن الجزيئي

- **Molecular weight, MW (g/mole)** [for compounds and elements]
  - Molecular weight: the sum of atomic weights of the combined elements.
  - Example: the MW of methane gas, $CH_4 = 12 + (4 \times 1) = 16$ g/mol
  - Example: the MW of sodium carbonate, Na_2CO_3

$$= [23x2 + 12 + 16x3] = 46 + 12 + 48 = 106 \text{ g/mol}$$

الوزن المكافئ

- **Equivalent weight, EW** (g/eq → gram per equivalent)

$$EW = \frac{MW \text{ or } AW}{Z}$$

Where Z = absolute value of the ion charge, (e.g. 1 for Na^+ and Cl^-. 2 for Ca^{++})
= absolute value of the electrical charge of the compound.

- Examples:
  - EW of calcium (Ca^{++}) = 40/2 = 20 g/eq
  - EW of sodium (Na^+) = 23/1 = 23 g/eq

- EW of Sodium hydroxide, $NaOH = (23 + 16 + 1) / 1 = 40$ g/eq

NaOH is made of Na^+ and OH^-. The Na^+ has a valency of 1+, thus a compound with one Na ion has a total electrical charge of 1+. Similarly, the OH^- has a charge of 1-, thus a compound with one OH has a total of 1- electrical charge.

- EW of Ferric sulfate, $Fe_2(SO_4)_3 = [2x55.8 + (32+4x16)x3] / 6$

  $= 400 / 6 = 66.7$ g/eq

Note: The ferric ion has a valency of 3+, thus a compound with 2 ferric ions has a total electrical charge of 6+. Similarly, the sulfate radical has a charge of 2-, thus a compound with 3 sulfate radicals has a total charge of 6-

- **Chemical Analysis of Water**
  - When inorganic compounds are placed in water, they *ionize* or *dissociate* into ions:
    - $MgSO_4 \rightarrow Mg^{++} + SO^{=}$
    - $Na_2SO_4 \rightarrow Na^+ + SO_4^{=}$
    - $NaCl \rightarrow Na^+ + Cl^-$

- Concentrations of ions, elements and molecules in water are expressed in:
  - mg/L
  - ppm (part per million) ≡ mg/L

    (because one liter of water weighs 1,000,000 mg)
  - milliequivalent per liter (meq/L)

$$meq/L = \frac{mg/L}{\text{equivalent weight}} = \frac{mg/L}{EW\ (g/eq)}$$

Note: 1 equivalent (eq) = 1000 milliequivalent (meq)

- Advantages of reporting concentrations in meq/L:
  - Can check the accuracy of the analyses for major ions,

    $\sum$ meq/L of cations = $\sum$ meq/L of anions
  - Can present the results graphically.
  - One "eq" or "meq" of an ion or molecule is chemically equivalent to one "eq" or "meq" of a different ion or molecule. Thus, Concentrations in meq/L can be added, subtracted or converted easily.

- **Example:**

  Water has the following chemical characteristics:

  Calcium, Ca^{++} = 35.8 mg/L — Magnesium, Mg^{++} = 9.9 mg/L

  Sodium, Na^{+} = 4.6 mg/L — Potassium, K^{+} = 3.9 mg/L

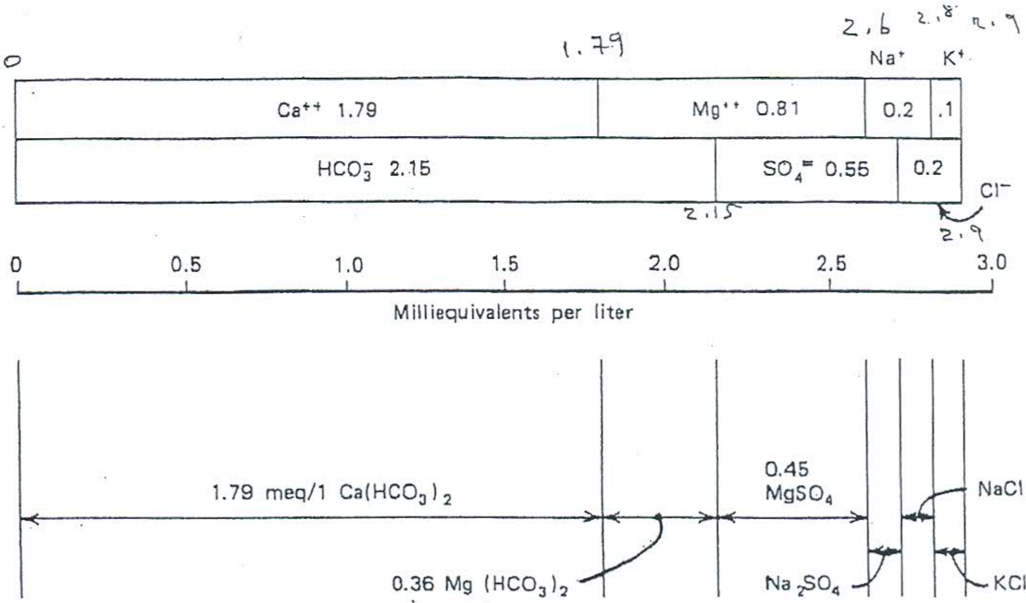
  Bicarbonate, HCO_3^{-} = 131 mg/L — Sulfate, $SO_4^{=}$ = 26.4 mg/L

  Chloride, Cl^{-} = 7.1 mg/L

Draw the milliequivalent per liter bar graph and list the hypothetical combinations of chemicals for this water.

Solution:

Component	mg/L	Equivalent weight	meg/L
Ca^{++}	35.8	40/2 = 20	35.8/20 = 1.79
Mg^{++}	9.9	24.4/2 = 12.2	9.9/12.2 = 0.81
Na^{+}	4.6	23/1 = 23	4.6/23 = 0.20
K^{+}	3.9	39.1/1 = 39.1	3.9/39.1 = 0.10
		$\sum$ cations	2.9
HCO_3^{-}	131	61/1 = 61	131/61 = 2.15
$SO_4^{=}$	26.4	96/2 = 48	26.4/48 = 0.55
Cl^{-}	7.1	35.5/1 = 35.5	7.1/35.5 = 0.20
		$\sum$ anions	2.9



Hypothetical combinations

Note:

- The concentration of $Ca(HCO_3)_2$ is 1.79 meq/L
- The concentration of $Ca(HCO_3)_2$ in mg/L = 1.79 meg/L x EW of $Ca(HCO_3)_2$

  = 1.79 x 81 = 145 mg/L
- The concentration of $Ca(HCO_3)_2$ in mg/L as $CaCO_3$ = 1.79 meg/L x EW of $CaCO_3$ = 1.79 x 50 = 89.5 mg/L

- **Standard Solutions**
  - A standard solution is a solution whose strength or reacting value per unit volume is known.
  - Standards solutions are used in volumetric analysis for many determinations such as chlorides, acidity, alkalinity, etc.

  - *Molar solutions*
  - A *molar solution* is a solution that contains one molecular weight of a substance per liter of water.
  - The symbol "M" is used as the abbreviation for "molar" or "molarity".

- A half-molar solution is expressed either as 0.5 M or M/2.

- To prepare one liter of a 1.0 M (or M/1) sulfuric acid solution [H_2SO_4] (MW = 98 g/mol), add 98 g of concentrated H_2SO_4 to distilled water in a 1-L volumetric flask, mix and then add enough distilled water to the 1-L mark.

- To make a 1-L of 0.02 M (or M/50) acid from the 1.0 M solution, we can calculated how many mL of the 1.0 M solution to add to 1-L of water:

$$mL_1 \times M_1 = mL_2 \times M_2$$

$$mL_1 \times 1.0 = 1000 \times 0.02 \quad \rightarrow mL_1 = 20 \text{ mL}$$

That is, dilute 20 mL of 1 M acid solution to 1000 mL with distilled water and mix thoroughly to make a 1-L 0.02 M acid solution.

Molarity (mole/L) = Weight of substance per unit volume of water (g/L) / MW (g/mole)

$= \frac{g/l}{Mw\,(g/mole)}$

❑ *Normal solutions*

- A normal solution is a solution that contains one equivalent weight of a substance per liter of water.
- The symbol "N" is used as the abbreviation for "normal" or "normality".
- To make a 1.0 N H_2SO_4 solution, add 49 g of concentrated H_2SO_4 to distilled water and dilute to the 1-L mark. [EW of H_2SO_4 = 98/2 = 49 g/eq].

Normality (eq/L) = Weight of a substance per unit volume of water (g/L) / EW (g/eq)

eq/L

$= \frac{g/l}{EW\,(g/eq)}$

H = 1
S = 32
O = 16

- *Example*

  If a solution contains 5 g of NaOH per Liter, calculate the concentration of NaOH in terms of weight/volume units expressed as (a) mg/L, (b) molarity, and (c) normality.

  MW of NaOH = 23 + 16 + 1 = 40 g/mol

  EW of NaOH = 40 / 1 = 40 g/eq

Solution:

(a) concentration in mg/L = 5000 mg/L

(b) concentration in molarity = 5 (g/L) / 40 (g/mol) = 0.125 mol/L = 0.125 M

(c) concentration normality = 5 (g/L) / 40 (g/eq) = 0.125 eq/L = 0.125 N