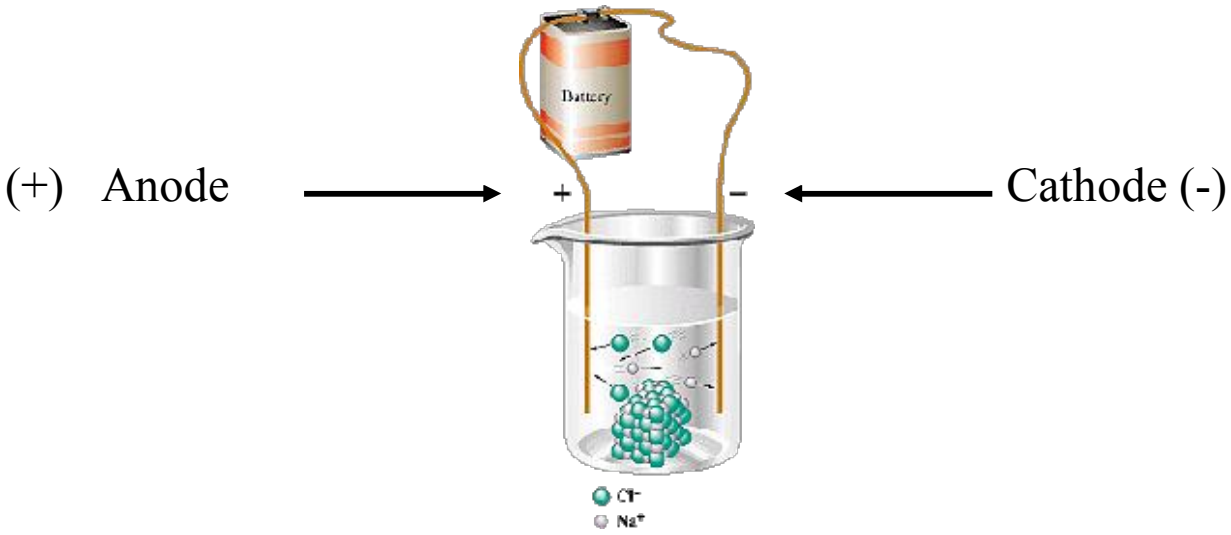
IONS IN AQUEOUS SOLUTION

Ionic Theory of Solutions:

- Proposed by Svante Arrhenius (1884)
- Certain substances produce freely moving ions (mobile ions) when they dissolve in water; the mobile ions conduct an electric current

Substances which are able to conduct electricity by ionic movement are called ELECTROLYTES

- For example: An aqueous solution of NaCl is a good conductor of electricity



According to Arrhenius:

- Substances, which are able to conduct electricity by ionic movement, are called ELECTROLYTES
- Substances, which are not able to conduct electricity by ionic movement, are called NONELECTROL

A particular substance must meet two conditions in order to be an electrolyte:

The substance:
1. must contain ions,
2. the ions must be mobile (free to move)

IONIC SUBSTANCES

PURE FORM		DISSOLVED IN WATER (AQUEOUS SOLUTION)
SOLID	MOLTEN	
$Na^+Cl^-(s)$	$Na^+Cl^-(s) \xrightarrow[\text{dissociation}]{\text{melting}} Na^+(l) + Cl^-(l)$	$Na^+Cl^-(s) \xrightarrow[\text{dissociation}]{H_2O} Na^+(aq) + Cl^-(aq)$
Ions are present, but they are not free to move	**DISSOCIATION** Process by which the **ions** of an ionic substance are separated and made mobile (**free to move**), by melting or dissolving in water	
 Bulb is off	 Bulb glows brightly	
NO CONDUCTANCE	STRONG CONDUCTANCE	
NON ELECTROLYTE	**STRONG ELECTROLYTE**	

NOTE:

1. All **soluble** ionic compounds dissolved in water are STRONG ELECTROLYTES

2. The process by which a substance separates into ions (by melting or by dissolving in water) is referred to, as **DISSOCIATION**.

3. SOLUBLE IONIC SUBSTANCES ARE COMPLETELY DISSOCIATED IN AQUEOUS SOLUTION (all ions are separated and free to move).

EXAMPLES:

$$NaOH(aq) \longrightarrow Na^{+}(aq) + OH^{-}(aq)$$

NOTE: **1** mole of **NaOH** produces by dissociation: 2 moles of ions: - **1** mole of **Na^{+}** ions, and
- **1** moles of **OH^{-}** ions

$$MgCl_2(aq) \longrightarrow Mg^{2+}(aq) + 2\ Cl^{-}(aq)$$

magnesium chloride — magnesium ions — chloride ions

NOTE: **1** mole of **$MgCl_2$** produces by dissociation: 3 moles of ions:- **1** mole of **Mg^{2+}** ions, and
- **2** moles of **Cl^{-}** ions

$$Na_2SO_4(aq) \longrightarrow 2\ Na^{+}(aq) + SO_4^{2-}(aq)$$

sodium sulfate — sodium ions — sulfate ions

NOTE: **1** mole of **Na_2SO_4** produces by dissociation: 3 moles of ions: - **2** moles of **Na^{+}** ions, and
- **1** mole of **SO_4^{2-}** ions

---

4. PARTLY SOLUBLE IONIC SUBSTANCES ARE PARTIALLY DISSOCIATED IN AQUEOUS SOLUTION (some, but not all, ions are separated and free to move)

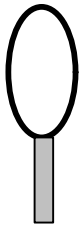
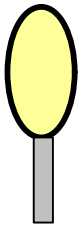
PURE MOLECULAR SUBSTANCES

SOLID STATE	LIQUID STATE	GASEOUS STATE
Solid Sucrose	Liquid Water	Gaseous Hydrogen Chloride
$C_{12}H_{22}O_{11}(s)$	$H_2O(l)$	$HCl(g)$
molecules only present	molecules only present	molecules only present
		
Bulb is off	Bulb is off	Bulb is off
NO CONDUCTANCE	NO CONDUCTANCE	NO CONDUCTANCE
NONELECTROLYTE	NONELECTROLYTE	NONELECTROLYTE

CONCLUSION:

- **Molecular Substances in pure form are NONELECTROLYTES, since they contain molecules only (no ions)**

MOLECULAR SUBSTANCES IN AQUEOUS SOLUTION

Sucrose dissolved in water	Acetic acid dissolved in water	Hydrogen chloride dissolved in water
 Bulb is off	 Bulb glows dimly	 Bulb glows brightly
No mobile ions present (molecules only present)	A few mobile ions present (mostly molecules)	Only mobile ions present (no molecules)
Molecules separate $\mathbf{C_{12}H_{22}O_{11}(s) \longrightarrow C_{12}H_{22}O_{11}(aq)}$	Molecules separate into ions: $\mathbf{HC_2H_3O_2(aq) \longrightarrow H^+(aq) + C_2H_3O_2^-(aq)}$ at the same time: Ions combine and form molecules: $\mathbf{H^+(aq) + C_2H_3O_2^-(aq) \longrightarrow HC_2H_3O_2(aq)}$	Molecules separate into ions $HCl(aq) \longrightarrow H^+(aq) + Cl^-(aq)$
No Ionization	**Partial Ionization**	**Complete Ionization**
No Conductance	Weak Conductance	Strong Conductance
NONELECTROLYTE	WEAK ELECTROLYTE	STRONG ELECTROLYTE

CONCLUSIONS:

1. Some molecular substances do not interact with water when they dissolve in it, and as such, they do not form ions.

   They exist in aqueous solution as **MOLECULES ONLY**, and are **NONELECTROLYTES (NE).**
   Example: Sucrose

2. Some molecular substances interact with water and their molecules form ions.

   This is referred to as **IONIZATION**. Ionization can be of two types:

(A) PARTIAL IONIZATION

- Some molecular substances interact only partially with water and a very few of their molecules change into ions.
- In partial ionization, two processes take place at the same time, and a dynamic equilibrium is established.

$$HC_2H_3O_2\,(aq) \rightleftharpoons H^+\,(aq) + C_2H_3O_2^-\,(aq)$$

99 molecules 1 ion 1 ion

- The predominant species in solution are molecules.
- The weak conductance is due to the very few ions present (one out of every hundred molecules ionizes)
- These substances exist in aqueous solution **MOSTLY AS MOLECULES** (a very few ions) and are called **WEAK ELECTROLYTES (WE)**

Example:

An aqueous solution of ammonia:

$$NH_3\,(aq) + H_2O\,(l) \rightleftharpoons NH_4^+\,(aq) + OH^-\,(aq)$$

Mostly molecules **A very few ions**

(B) COMPLETE IONIZATION

- For some molecular substances the interaction with the water molecules is essentially complete, and all their molecules change into ions.
- This is referred to as **complete ionization**.
- These substances exist in aqueous solution as **IONS ONLY**, and as such are **STRONG ELECTROLYTES (SE)**

Examples:

$HCl(aq)$, $HNO_3(aq)$, $H_2SO_4(aq)$ (for the loss of one H^+)

$$HCl(aq) \longrightarrow H^+(aq) + Cl^-(aq)$$

$$HNO_3(aq) \longrightarrow H^+(aq) + NO_3^-(aq)$$

$$H_2SO_4(aq) \longrightarrow H^+(aq) + HSO_4^-(aq)$$

SUMMARY: ELECTROLYTES AND NONELECTROLYTES

IONIC SUBSTANCES				**MOLECULAR SUBSTANCES**			
Solid	Liquid	Aqueous Solution		Solid Form	Liquid Form	Aqueous Solution	
		Soluble	Partly Soluble				
NaCl(s) NaOH(s)	NaCl(l) NaOH(l)	NaCl(aq) NaOH(aq)	$PbCl_2$(aq)	$C_{12}H_{22}O_{11}$(s) $HC_2H_3O_2$(s)	$C_{12}H_{22}O_{11}$(l) $HC_2H_3O_2$(l)	NH_3(aq) $HC_2H_3O_2$(aq)	HCl(aq) HNO_3(aq)
NE	**SE**	**SE**	**WE**	NE	NE	WE	**SE**
Ions present but not to move	Ions present and free to move	Ions present and free to move	Few ions and and free to move	No ions (molecules only)	No Ions (molecules only)	Few ions (mostly molecules free to move	Ions only (no molecules) free to move
No **Dissoc'n**	Complete **Dissoc'n**	Complete **Dissoc'n**	Partial **Dissoc'n**	No **Ionization**	No **Ionization**	Partial **Ionization**	Complete **Ionization**

IONIC AND MOLECULAR EQUATIONS

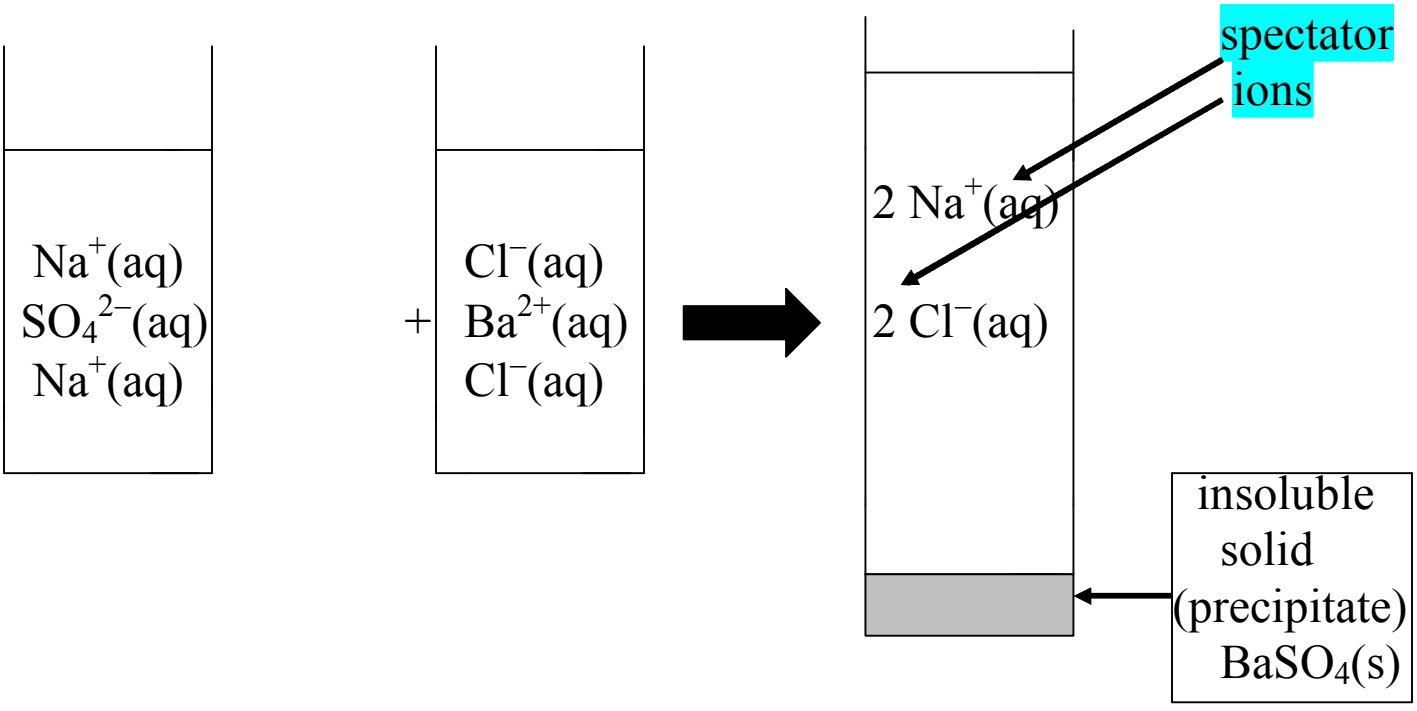
- Chemical reactions which take place in aqueous solution are caused by the interactions between ions and are referred to as IONIC REACTIONS.

- Most IONIC REACTIONS are DOUBLE DISPLACEMENT REACTIONS (also called METATHESIS REACTIONS)

$$A^+X^- + B^+Y^- \longrightarrow A^+Y^- + B^+X^-$$

- Consider: the reaction between an aqueous solution of sodium sulfate and an aqueous solution of barium chloride forms a solid which is insoluble in water (in time, it settles as the bottom of the test tube and is referred to as A PRECIPITATE)

$$Na_2SO_4(aq) + BaCl_2(aq) \longrightarrow \text{A PRECIPITATE}$$
(soluble salt) (soluble salt) (opaque suspension)



Molecular Equation:

$Na_2SO_4(aq)$ + $BaCl_2(aq)$ ⟶ $BaSO_4(s)$ + $2NaCl(aq)$

clear solution + clear solution ⟶ insoluble solid (precipitate) + clear solution

- This equation does not show which substances exist in ionic form.

Complete (Total) Ionic Equation:

- Strong electrolytes are written as separate ions in solution (completely dissociated)

$2Na^+(aq)$ + $SO_4^{2-}(aq)$ + $Ba^{2+}(aq)$ + $2\ Cl^-(aq)$ ⟶ $BaSO_4(s)$ + $2\ Na^+(aq)+2\ Cl^-(aq)$

Spectator Spectator Spectator Ions

- Spectator Ions: Ions in an ionic equation which do not take part in the reaction

$SO_4^{2-}(aq) + Ba^{2+}(aq) \longrightarrow BaSO_4(s)$

- This equation: - is called the **NET IONIC EQUATION** (focuses on the main event)
  - is obtained by canceling out the spectator ions:
  -

~~$2Na^+(aq)$~~ + $SO_4^{2-}(aq)$ + $Ba^{2+}(aq)$ + ~~$2\ Cl^-(aq)$~~ ⟶ $BaSO_4(s)$ + ~~$2\ Na^+(aq)$~~ + ~~$2\ Cl^-(aq)$~~

Spectator Spectator precipitate Spectator Ions

Net Ionic Equation: $SO_4^{2-}(aq) + Ba^{2+}(\sout{aq}) \longrightarrow BaSO_4(s)$