Chapter 4
Electrolytes and Precipitation Reactions

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Aqueous Solutions

- **Solution** - a homogeneous mixture of solute + solvent
  - Solute: the component that is dissolved
  - Solvent: the component that does the dissolving (the larger quantity)
- Aqueous solutions are those in which water is the solvent.

- ***Dissociation*** **-** ionic compounds separate into constituent ions when dissolved in solution

$$NaCl(s) \xrightarrow{H_2O} Na^+(aq) + Cl^-(aq)$$

- ***Ionization*** **-** formation of ions by molecular compounds when dissolved

$$HCl(g) \xrightarrow{H_2O} H^+(aq) + Cl^-(aq)$$

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

Writing Dissociation Equations

- **<u>Ionic compounds produce ions</u>**:

E.g. calcium chloride:

$$CaCl_2 \rightarrow Ca^{2+} + 2Cl^-$$

1) There is only one mol of calcium, but two mols of chloride ions hence use 2 in front of chloride as coefficient ($2Cl^-$). Don't leave the 2 as a subscript (~~Cl_2^-~~).
2) Always write the products as ions with the proper valencies – calcium is group two hence 2+.

$$Mg_3(PO_4)_2 \rightarrow 3Mg^{2+} + 2PO_4^{3-}$$

In cases of polyatomic ions – keep them as the polyatomic **ions**, just remove the parenthesis and use the subscript outside as the coefficient in the product/ions.

- **<u>Covalent compounds (except acids) do not ionize:</u>**

CO_2, CH_4 will not ionize.

H_2SO_4 will ionize as follows:

$$H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$$

Electrolytes

Electrolyte: substance that dissolved in water produces a solution that conducts electricity. Will contain ions.

Strong Electrolyte: substances that dissolve completely in water; 100% dissociation

- All water soluble ionic compounds, strong acids and strong bases

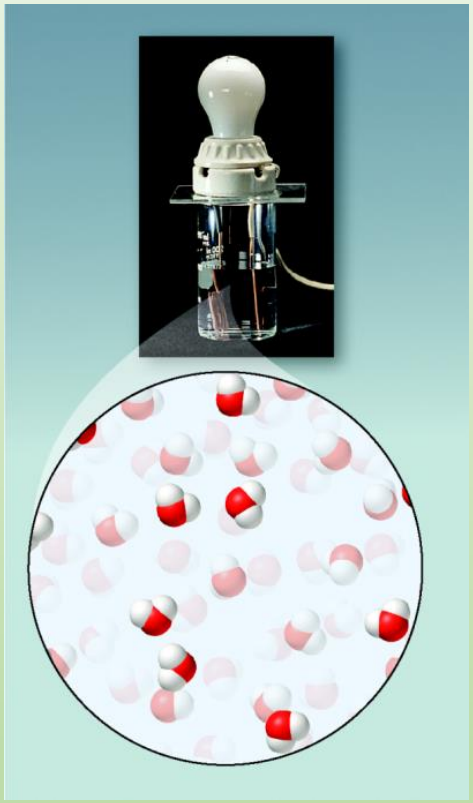
Weak Electrolytes: substances that dissolve partially or dissociate partially in water. This solution does not contain many ions.

- Exist mostly as the molecular form in solution
- Weak acids and weak bases

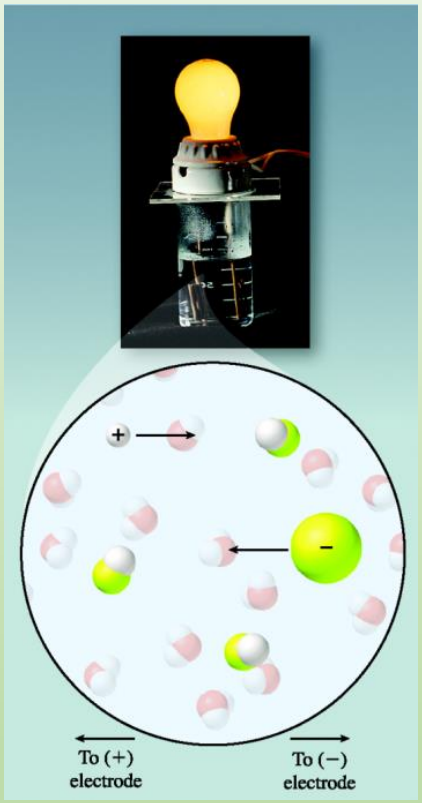
Nonelectrolyte: substance that dissolved in water produces a solution that does not conduct electricity and does not contain ions.

Electrolytes

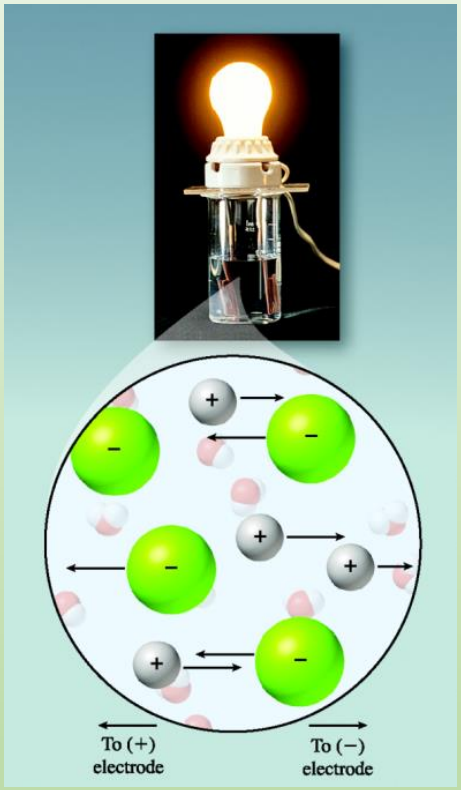
Method to Distinguish Types of Electrolytes



nonelectrolyte



weak electrolyte



strong electrolyte

Strong Acids

These acids dissociate completely

Acid	Ionization Equation
Hydrochloric acid	$HCl(aq) \longrightarrow H^+(aq) + Cl^-(aq)$
Hydrobromic acid	$HBr(aq) \longrightarrow H^+(aq) + Br^-(aq)$
Hydroiodic acid	$HI(aq) \longrightarrow H^+(aq) + I^-(aq)$
Nitric acid	$HNO_3(aq) \longrightarrow H^+(aq) + NO_3^-(aq)$
Chloric acid	$HClO_3(aq) \longrightarrow H^+(aq) + ClO_3^-(aq)$
Perchloric acid	$HClO_4(aq) \longrightarrow H^+(aq) + ClO_4^-(aq)$
Sulfuric acid*	$H_2SO_4(aq) \longrightarrow H^+(aq) + HSO_4^-(aq)$
	$HSO_4^-(aq) \rightleftharpoons H^+(aq) + SO_4^{2-}(aq)$

*Note that although each sulfuric acid molecule has two ionizable hydrogen atoms, it only undergoes the first ionization completely, effectively producing one H^+ ion and one HSO_4^- ion per H_2SO_4 molecule. The second ionization happens only to a very small extent.

Electrolytes – Practical Application

- Our body is about 70% water and we have a number of ionic salts in our body. Some common ions are Na^+, Ca^{2+}, K^+, Cl^-, CO_3^{2-}.
- Electrolytes maintain voltages in our cells; they help with nerve impulses in our nervous system and help with muscle contractions.
- We get electrolytes through our diet and the kidneys are responsible for maintaining an electrolytic balance in the body. If the ions are not in the correct concentration then the above mentioned functions cannot occur.
- One way we lose electrolytes is during sweating. This is two fold – one: we lose water in the body so the concentration of ions change and two: we lose ions also during sweating.
- These ions have to replenished or we can lose muscle control.
- Electrolytes (sports drinks) are commonly used to replace these ions. One has to be careful though – they also have a lot of sugar in them!
- The first electrolyte beverage was invented in University of Florida……

Types of Reactions

Two classifications: one how atoms are rearrangement and the other is chemical reaction

1) Atomic Rearrangement

- **Synthesis** (combination): two substances combine to form one.

  $2\text{Na}(s) + \text{Cl}_2(g) \rightarrow 2\text{NaCl}(s)$

- **Double Displacement**: A reaction in which two elements displaces two elements.

  $\text{AgNO}_3(aq) + \text{NaCl}(aq) \rightarrow \text{AgCl}(s) + \text{NaNO}_3(aq)$

- **Single displacement**: A reaction where one element displaces one other element.

  $\text{Zn}(s) + \text{CuSO}_4(aq) \rightarrow \text{ZnSO}_4(aq) + \text{Cu}(s)$

- **Decomposition**: A reaction in which a single compound reacts to give two or more substances.

  $2\text{HgO}(s) \rightarrow 2\text{Hg}(l) + \text{O}_2(g)$

2) Chemical Classification: Types of Chemical Reactions

Precipitation Reactions: where a solid is formed when two solutions are mixed.

Neutralization Reactions: when an acid and base react to from salt and water.

Oxidation–Reduction Reactions: addition or removal of oxygen and/or transfer of electrons.

Precipitation Reactions

- Precipitation (formation of a solid from two aqueous solutions) occurs when product is insoluble in water.
- Reaction type: Double displacement
- What is solubility? Solubility is defined as the maximum amount of a solid that can dissolve in a given amount of solvent at a specified temperature
- Prediction of precipitate is based on solubility rules

Solubility Guidelines

Solubility Guidelines: Soluble Compounds

Water-Soluble Compounds	Insoluble Exceptions
Compounds containing an alkali metal cation (Li^+, Na^+, K^+, Rb^+, Cs^+) or the ammonium ion (NH_4^+)	
Compounds containing the nitrate ion (NO_3^-), acetate ion ($C_2H_3O_2^-$), or chlorate ion (ClO_3^-)	
Compounds containing the chloride ion (Cl^-), bromide ion (Br^-), or iodide ion (I^-)	Compounds containing Ag^+, Hg_2^{2+}, or Pb^{2+}
Compounds containing the sulfate ion (SO_4^{2-})	Compounds containing Ag^+, Hg_2^{2+}, Pb^{2+}, Ca^{2+}, Sr^{2+}, or Ba^{2+}

Solubility Guidelines: Insoluble Compounds

Water-Insoluble Compounds	Soluble Exceptions
Compounds containing the carbonate ion (CO_3^{2-}), phosphate ion (PO_4^{3-}), chromate ion (CrO_4^{2-}), or sulfide ion (S^{2-})	Compounds containing Li^+, Na^+, K^+, Rb^+, Cs^+, or NH_4^+
Compounds containing the hydroxide ion (OH^-)	Compounds containing Li^+, Na^+, K^+, Rb^+, Cs^+, or Ba^{2+}

Solved Problems

1) Identify the Precipitate

$$Pb(NO_3)_2(aq) + 2NaI(aq) \rightarrow 2NaNO_3 \quad + \quad PbI_2$$

PbI_2 – according to solubility rules

2) Classify the following as soluble or insoluble in water

- $Ba(NO_3)_2$ *soluble*
- AgI *insoluble*
- $Mg(OH)_2$ *insoluble*

Writing Equations in Aqueous Solutions

A chemical equation in which the reactants and products are written as if they were molecular substances, even though they may actually exist in solution as ions.

Symbols indicating the states are include: (s), (l), (g), (aq).

For example:

Molecular Equation:

$$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$

Although $AgNO_3$, NaCl, and $NaNO_3$ exist as ions in aqueous solutions, they are written as compounds in the molecular equation.

Ionic Equation:

$$Ag^+(aq) + NO_3^-(aq) + Na^+(aq) + Cl^-(aq) \rightarrow AgCl(s) + Na^+(aq) + NO_3^-(aq)$$

All compounds that dissociate are shown as ions.

Net Ionic Equation:

In this the **spectator ions** (ions on both sides of the equation) are eliminated.

$$Ag^+(aq) + \mathbf{NO_3^-}(aq) + \mathbf{Na^+}(aq) + Cl^-(aq) \rightarrow AgCl(s) + \mathbf{Na^+}(aq) + \mathbf{NO_3^-}(aq)$$

Net ionic equation represents the ions reacting. Those will be (g), (l) and (s) products formed.

$$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$$

Solved Problems

Decide whether the following reaction occurs. If it does, write the molecular, ionic, and net ionic equations.

$KBr + MgSO_4 \rightarrow$

Determine the product formulas by double displacement method

- K^+ and SO_4^{2-} make K_2SO_4
- Mg^{2+} and Br^- make $MgBr_2$

Determine whether the products are soluble:

K_2SO_4 is soluble and $MgBr_2$ is soluble

$KBr + MgSO_4 \rightarrow$ no reaction

Solved Problems

Decide whether the following reaction occurs. If it does, write the molecular, ionic, and net ionic equations.

$NaOH + MgCl_2 \rightarrow$

Determine the product formulas by double displacement method

- Na^+ and Cl^- make NaCl
- Mg^{2+} and OH^- make $Mg(OH)_2$

Determine whether the products are soluble

- NaCl is soluble and $Mg(OH)_2$ is insoluble

Molecular Equation

Balance the reaction and include state symbols

$$2NaOH(aq) + MgCl_2(aq) \rightarrow 2NaCl(aq) + Mg(OH)_2(s)$$

Ionic Equation

$$2Na^+(aq) + 2OH^-(aq) + Mg^{2+}(aq) + 2Cl^-(aq) \rightarrow 2Na^+(aq) + 2Cl^-(aq) + Mg(OH)_2(s)$$

Net Ionic Equation

$$2OH^-(aq) + Mg^{2+}(aq) \rightarrow Mg(OH)_2(s)$$

One more….

Decide whether the following reaction occurs. If it does, write the molecular, ionic, and net ionic equations.

$$K_3PO_4 + CaCl_2 \rightarrow$$

Determine the product formulas:

- K^+ and Cl^- make KCl; Ca^{2+} and PO_4^{3-} make $Ca_3(PO_4)_2$

Determine whether the products are soluble:

- KCl is soluble and $Ca_3(PO_4)_2$ is insoluble

Molecular Equation

(Balance the reaction and include state symbols)

$$2K_3PO_4(aq) + 3CaCl_2(aq) \rightarrow 6KCl(aq) + Ca_3(PO_4)_2(s)$$

Ionic Equation

$$6K^+(aq) + 2PO_4^{3-}(aq) + 3Ca^{2+}(aq) + 6Cl^-(aq) \rightarrow 6K^+(aq) + 6Cl^-(aq) + Ca_3(PO_4)_2(s)$$

Net Ionic Equation

$$2PO_4^{3-}(aq) + 3Ca^{2+}(aq) \rightarrow Ca_3(PO_4)_2(s)$$

Another one….

Aqueous solutions of silver nitrate and sodium sulfate are mixed. Write the net ionic reaction.

$$2AgNO_3(aq)+Na_2SO_4(aq) \rightarrow 2NaNO_3(?)+Ag_2SO_4(?)$$

Determine solubility of salts. All nitrates are soluble but silver sulfate is insoluble

Molecular Equation

$$2AgNO_3(aq)+Na_2SO_4(aq) \rightarrow 2NaNO_3(aq)+Ag_2SO_4(s)$$

Ionic equation

$$2Ag^+(aq) + 2NO_3^-(aq) + 2Na^+(aq) + SO_4^{2-}(aq) \rightarrow 2Na^+(aq) + 2NO_3^-(aq) + Ag_2SO_4(s)$$

Cancel spectators

$$2Ag^+(aq) + 2\cancel{NO_3^-}(aq) + 2\cancel{Na^+}(aq) + SO_4^{2-}(aq) \rightarrow 2\cancel{Na^+}(aq) + 2\cancel{NO_3^-}(aq) + Ag_2SO_4(s)$$

Net ionic equation

$$2Ag^+(aq) + SO_4^{2-}(aq) \rightarrow Ag_2SO_4(s)$$

Key Words and Concepts

- **Ions in Aqueous Solution**
  - Electrolytes
  - Acids
- **Types of Chemical Reactions**
  - Synthesis
  - Double displacement
  - Single displacement
  - Decomposition
- **Precipitation Reactions**
  - Solubility Rules
  - Molecular, Ionic and Net Ionic Equations