You have mastered this topic when you can:

1) define or describe these terms: aqueous solution, solvent, solute, solubility, soluble, low solubility, precipitation.
2) use the ***Solubility of Ionic Compounds Chart*** to determine if an ionic compound is soluble or has low solubility.
3) classify, predict products, and write balanced equations for single replacement chemical reactions

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CHEMICAL REACTIONS AND THE KINETIC MOLECULAR THEORY

I) **RECALL** that the ***kinetic molecular theory*** states that for a reaction to occur between two particles, they must collide with each other with the correct orientation and enough force in order to break the bonds that hold them together so new bonds and thus new particles can be formed. When substances exist in a solid state their particles are locked in place and, as a result, do not have the freedom of motion necessary to allow them to collide with the correct orientation and enough force to break their bonds. One of the ways to give particles in the solid state the freedom of motion necessary to react together is to dissolve them in water creating an ***aqueous solution***.

AQUEOUS SOLUTIONS

I) ***An AQUEOUS SOLUTION*** _____

i.e. Iced tea is an example of an ***aqueous solution*** created by mixing iced tea crystals with water When the iced tea crystals are mixed with water they dissolve resulting in the dispersion of their particles in the water creating a tasty ***solution***.

A) An ***aqueous solution*** is composed of two components: **SOLVENT** and **SOLUTE**. ***The SOLVENT is the water. The SOLUTE is the substance added to the solvent***. The ***solute*** is added to and dissolved in the ***solvent***. Consider these examples.

Solution	***Solvent***	***Solute***
Sugar water	water	solid sugar
Salt water	water	solid sodium chloride
Tea	water	flavour & colour molecules
Coffee	water	flavour & colour molecules
Air	nitrogen gas	$O_{2(g)}$, $CO_{2(g)}$, $H_2O_{(g)}$, etc.

II) **SOLUBILITY**

A) ***SOLUBILITY*** _____.

When a compound readily dissolves in water the compound is said to be SOLUBLE. When a compound does not readily dissolve in water the compound is said to have LOW SOLUBILITY. **i.e.** Sugar is ***soluble*** with water while oil has ***low solubility*** with water.

B) SOLUBILITY OF IONIC COMPOUNDS

1) The ***Solubility of Ionic Compounds Chart*** located on page 10 of these notes will help you determine whether an ionic compound is ***soluble*** or has ***low solubility***.

2) ***USE THESE STEPS TO DETERMINE IF AN IONIC COMPOUND IS SOLUBLE OR HAS LOW SOLUBILITY IN WATER***

(1) Identify the anion then find it on the Solubility of Ionic Compounds Chart.

(2) Identify the cation then find it to the right of the anion on the Solubility of Ionic Compounds Chart.

(3) If the combination of anion and cation is SOLUBLE the compound will dissolve in water. If the combination of anion and cation has LOW SOLUBILITY, the compound will not dissolve in water and will remain as a solid.

3) **Sample Problems 1:** State whether these compounds are ***soluble*** or have ***low solubility***.

a) $AgCl_{(s)}$ _____.

b) $Ni(NO_3)_{3(s)}$ _____. ***Continued on next page***

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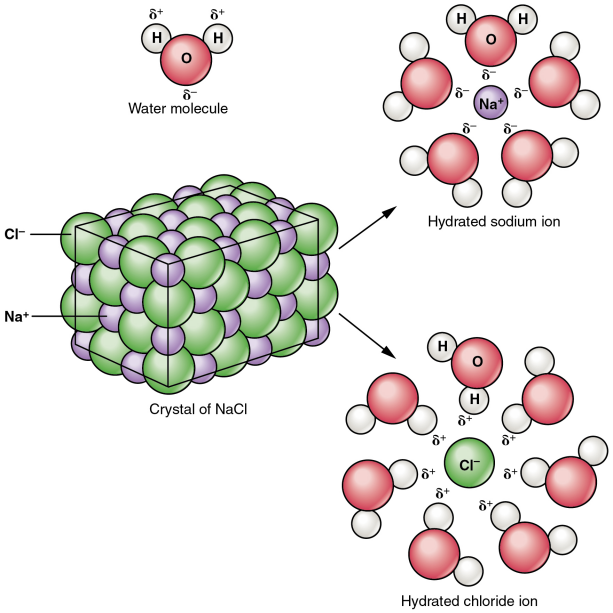
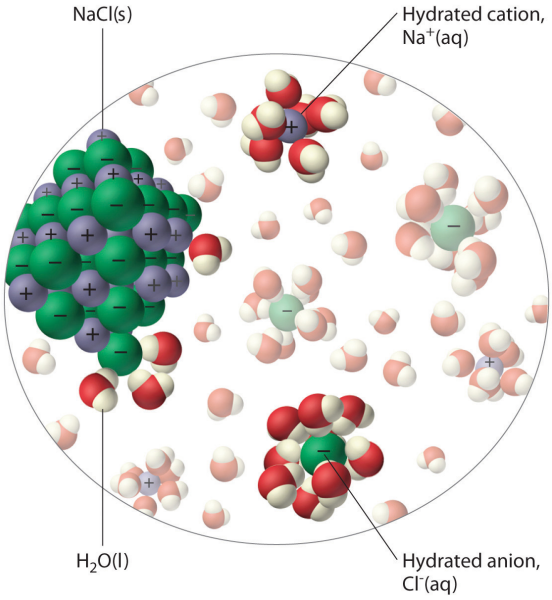
4) **Required Practice 1:** State whether these compounds are ***soluble*** or have ***low solubility***. **{Ans. on pg. 5}**

1. $CuBr_{(s)}$ _____
2. $CuI_{2(s)}$ _____
3. $BeS_{(s)}$ _____
4. $CaS_{(s)}$ _____
5. $ZnSO_{4(s)}$ _____
6. $Ni_2(SO_3)_{3(s)}$ _____
7. $Al_2(CO_3)_{3(s)}$ _____
8. $Pb(C_2H_3O_2)_{2(s)}$ _____
9. $Al(OH)_{3(s)}$ _____
10. $K_3PO_{4(s)}$ _____

III) **THE PROCESS OF DISSOLVING**

A) When a ***soluble*** ionic compound dissolves in water it undergoes the process of **DISSOCIATION**. ***DISSOCIATION of an ionic compound is the process of the compound breaking apart into its component cations and anions as a result of its interaction with water.*** Ionic compounds are either ***soluble*** and they ***dissociate*** or they have ***low solubility*** and do not ***dissociate*** when mixed with water. **RECALL** that ionic compounds are composed of positively charged cations and negatively charged anions and that water is a polar molecule which means it has ends that are positively and negatively charged. When an ionic compound is dissolved in water, its cations are attracted to the negatively charged ends of the water molecule while its anions are attracted to the positively charged ends of the water molecule.





1) ***SOLUBLE* IONIC COMPOUNDS:** If the attraction of the ionic compound's cations and anions to water is stronger than their attraction to each other the bonds holding them together break, they become surrounded by water molecules, and they are spread throughout the water resulting in the ***dissociation*** of the ionic compound.

a) $NaCl_{(s)}$ is a ***soluble*** ionic compound. It is ***soluble*** because its ions are more attracted to water than they are to each other. As a result, **each individual ion** of the compound becomes surrounded by water causing them to ***dissociate***, becomes dispersed amongst the water [REF above diagrams]. The dispersion of an ionic compound as it ***dissociates*** is illustrated by ***dissociation equations***. **NOTICE:** Each ion is separated from each other as each individual ion is surrounded by water molecules.

i.e. $NaCl_{(s)} \rightarrow Na^{1+}{}_{(aq)} + Cl^{1-}{}_{(aq)}$

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b) $K_2CO_{3(s)}$ is a ***soluble*** ionic compound. It is ***soluble*** because its ions are more attracted to water than they are to each other. As a result, **each individual ion** of the compounds ions is surrounded by water causing it to ***dissociate*** as illustrated by this ***dissociation equation***. **NOTICE:** Each ion is separated from each other as each individual ion is surrounded by water molecules.

i.e. $K_2CO_{3(s)} \rightarrow K^{1+}_{(aq)} + K^{1+}_{(aq)} + CO_3^{2-}{}_{(aq)}$

$\mathbf{K_2CO_{3(s)} \rightarrow 2K^{1+}_{(aq)} + CO_3^{2-}{}_{(aq)}}$

c) **NOTE:** When the formula of a ***soluble*** ionic compound has been dissolved in water its formula is written with the subscript **(aq)** after it (**i.e.** $Ca_3(PO_4)_{2\,(aq)}$). $Ca_3(PO_4)_{2\,(aq)}$ means the ionic compound is ***soluble***, has ***dissociated*** in water, and now exists as **three** calcium ions and **two** phosphate ion floating amongst the water molecules. In other words, $Li_3PO_{4(aq)}$ is an abbreviation for this ***dissociation equation***. **NOTICE:** Each ion is separated from each other as each individual ion is surrounded by water molecules.

i.e. $Ca_3(PO_4)_{2(s)} \rightarrow Ca^{2+}_{(aq)} + Ca^{2+}_{(aq)} + Ca^{2+}_{(aq)} + PO_4^{3-}{}_{(aq)} + PO_4^{3-}{}_{(aq)}$

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

2) **IONIC COMPOUNDS HAVING *LOW SOLUBILITY*:** If the attraction of an ionic compound's cations and anions to each other is stronger than their attraction to water, the bonds holding the cations and anions together remain intact and they remain locked in the ***crystal lattice***. As a result, an ionic compound having ***low solubility*** remains a solid compound, which means it does not ***dissociate***.

a) $BaCO_{3(s)}$ is an ionic compound having ***low solubility***. It has ***low solubility*** because its ions are more attracted to each other than they are to water. As a result, the compound's cations and anions remain locked in place within the ***crystal lattice*** causing the compound to remain as a solid, which means the compound does not dissociate.

A) When a combination of ions within a solution has ***low solubility***, a chemical reaction occurs forming a solid compound, which settles to the bottom of the container. ***The solid compound that forms is called a PRECIPITATE. The formation of a precipitate is described by a PRECIPITATION EQUATION.*** Use the ***Solubility of Ionic Compounds Chart*** located on **page 7** of these notes to determine if the combination of aqueous ions is ***soluble*** and will remain as individual ions floating in solution, or has ***low solubility*** and will form a ***precipitate*** (solid compound).

1) ***USE THESE STEPS TO DETERMINE IF AN IONIC COMPOUND IS SOLUBLE OR HAS LOW SOLUBILITY IN WATER***

(1) Identify the anion then find it on the Solubility of Ionic Compounds Chart.

(2) Identify the cation then find it to the right of the anion on the Solubility of Ionic Compounds Chart.

(3) If the combination of anion and cation is SOLUBLE the compound will dissolve in water. If the combination of anion and cation has LOW SOLUBILITY, the compound will not dissolve in water and will form a PRECIPITATE (solid compound).

2) **Sample Problems 2:** State whether these combinations of ions reacts together and forms a ***precipitate*** by writing its formula, or has ***no reaction*** because the possible compound they form is ***soluble***.

1. $Ni^{3+}_{(aq)} + NO_3^{1-}{}_{(aq)} \rightarrow$ No Reaction

2. $Ca^{2+}_{(aq)} + SO_3^{2-}{}_{(aq)} \rightarrow CaSO_{3(s)}$

3) **Required Practice 2:** State whether these combinations of ions react together and forms a ***precipitate*** by writing its formula, or has ***no reaction*** because the possible compound is ***soluble***. **{Ans. on pg. 5}**

1. $K^{1+}_{(aq)} + Br^{1-}{}_{(aq)} \rightarrow$ _____
2. $Al^{3+}_{(aq)} + OH^{1-}{}_{(aq)} \rightarrow$ _____
3. $Pb^{2+}_{(aq)} + Cl^{1-}{}_{(aq)} \rightarrow$ _____
4. $Pb^{4+}_{(aq)} + I^{1-}{}_{(aq)} \rightarrow$ _____
5. $Ca^{2+}_{(aq)} + S^{2-}{}_{(aq)} \rightarrow$ _____
6. $Ni^{2+}_{(aq)} + SO_3^{2-}{}_{(aq)} \rightarrow$ _____
7. $Al^{3+}_{(aq)} + CO_3^{2-}{}_{(aq)} \rightarrow$ _____
8. $Pb^{2+}_{(aq)} + C_2H_3O_2^{1-}{}_{(aq)} \rightarrow$ _____
9. $Ba^{2+}_{(aq)} + OH^{1-}{}_{(aq)} \rightarrow$ _____
10. $Cu^{1+}_{(aq)} + PO_4^{3-}{}_{(aq)} \rightarrow$ _____

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B) **RECALL** that the formation of a ***solid***, known as a ***precipitate***, is evidence that a chemical reaction has occurred. Keep this in mind when a question asks you to determine whether or not a compound has formed or a reaction has occurred.

CHEMICAL REACTIONS THAT ALWAYS INVLOLVE AQUEOUS IONIC REACTANTS

I) **SINGLE REPLACEMENT REACTIONS:** _____

_____

MEMORIZE the general pattern for a single replacement reaction.

Element$_{(s, l \text{ or } aq)}$ + compound$_{(aq)}$ → new element$_{(s, l \text{ or } g)}$ + new compound$_{(s, l, g \text{ or } aq)}$

$A_{(s, l \text{ or } g)} + BC_{(aq)} \rightarrow B_{(s, l \text{ or } aq)} + AC_{(s, l \text{ or } g)}$

A) ***Single replacement reactions*** are spontaneous which means they are not endothermic, do not require any energy for them to occur.

B) **MEMORIZE THE PATTERNS LISTED IN BOLD BELOW IN ORDER TO USE THEM TO PREDICT THE FORMULAE OF PRODUCTS FORMED**

Element$_{(s, l \text{ or } aq)}$ + compound$_{(aq)}$ → new element$_{(s, l \text{ or } g)}$ + new compound$_{(s, l, g \text{ or } aq)}$

1) **metal element$_{(s)}$ + compound$_{(aq)}$ → new metal element$_{(s)}$ + new compound$_{(s \text{ or } aq)}$**
   a) ***<u>Metals replace metals</u>*** according to the ***activity series*** described on page 7 of these notes.
      e.g. $Cu_{(s)} + 2AgNO_{3(aq)} \rightarrow Cu(NO_3)_{2(aq)} + 2Ag_{(s)}$; $Zn_{(s)} + 2HCl_{(aq)} \rightarrow ZnCl_{2(aq)} + H_{2(g)}$

2) **non-metal element$_{(s, l, g)}$ + compound$_{(aq)}$ → new non-metal element$_{(s, l, g)}$ + new compound$_{(s, l, g \text{ or } aq)}$**
   a) ***<u>Non-metals replace non-metals</u>*** according to the ***activity series*** described on **page 8** of these notes, or according to the ***periodic trend for non-metal reactivity within the periodic table***.
      e.g. $Cl_{2(g)} + 2KI_{(aq)} \rightarrow I_{2(l)} + 2KCl_{(aq)}$; $F_{2(g)} + 2HCl_{(aq)} \rightarrow Cl_{2(g)} + 2HF_{(aq)}$

C) The **ACTIVITY SERIES**. Some elements are more reactive than others. The difference in the reactivity of elements is reflected in the **ACTIVITY SERIES OF METALS AND HALOGENS**, which is an arrangement elements from most to least reactive, and in the periodic table in the form of the ***periodic trends for non-metal reactivity within groups and periods***. A copy of the ***Activity Series of Metals and Halogens*** is **page 8** of these notes.
1) The **ACTIVITY SERIES OF METALS** is used to predict the products of a ***single replacement reaction*** involving an aqueous compound and a metal element.
   a) **Sample Problems 3a:** State whether or not a reaction will occur between these combinations of substances. Write a balanced equation if a reaction occurs.
      i) $Cu_{(s)} + AgNO_{3(aq)} \rightarrow ? + ?$

      In this equation the solid copper metal atom is trying to replace the silver ions in the compound. The ***Activity Series of Metals*** indicates that copper is more reactive than silver, which means a spontaneous reaction occurs in which the ***copper <u>replaces</u> the silver*** creating a new compound and a new solid metal element as illustrated by this equation. The formation of a new solid product is evidence that a chemical reaction has occurred.

      $Cu_{(s)} + 2AgNO_{3(aq)} \rightarrow \quad +$

      ii) $Zn(NO_3)_{2(aq)} + Ni_{(s)} \rightarrow ? + ?$

      In this equation the solid nickel metal is trying to replace the zinc ions in the compound. The ***Activity Series of Metals*** indicates that nickel is less reactive than zinc. This means the reaction is not spontaneous and the nickel will not replace the zinc, thus no reaction occurs. The lack of formation of a solid product is evidence that a chemical reaction has not occurred.

      $Zn(NO_3)_{2(aq)} + Ni_{(s)} \rightarrow$

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2) The **ACTIVITY SERIES FOR HALOGENS** follows the reactivity trends for non-metals on the periodic table. **RECALL** ***that the non-metal reactivity increases from left to right and bottom to top on the periodic table***.
   a) **Sample Problems 3b:** State whether or not a reaction will occur between these combinations of substances. Write a balanced equation if a reaction occurs.

      i) $AlBr_{3(aq)} + Cl_{2(g)} \rightarrow ? + ?$

      In this equation the chlorine gas is trying to replace the bromide ions in the compound. The ***Activity Series of Halogens*** indicates that chlorine is more reactive than bromine. This means the ***chlorine will replace the bromide*** creating a new compound and a new non-metal element as illustrated by this equation. The formation of a gas product is evidence that a chemical reaction has occurred.

      $$2AlBr_{3(aq)} + 3Cl_{2(g)} \rightarrow \qquad +$$

      ii) $MgCl_{2(aq)} + S_{(s)} \rightarrow ? + ?$

      In this equation the solid sulphur is trying to replace the chloride ions in the compound. According to the ***chemical reactivity trend for non-metals on the periodic table***, sulphur is less reactive than chlorine. This means the sulphur will not replace the chlorine, which means no reaction occurs. The lack of formation of a solid, liquid or gas product is evidence that a chemical reaction has not occurred.

      $$MgCl_{2(aq)} + S_{(s)} \rightarrow$$

3) **Required Practice 3:** Use the Activity Series to predict the products of these reactions. Indicate reactions that don't occur with NR. **{Ans. on pg. 5}**

1. $Zn_{(s)} + CuCl_{2(aq)} \rightarrow$ _____
2. $Br_{2(aq)} + CaCl_{2(aq)} \rightarrow$ _____
3. $Pb_{(s)} + HCl_{(aq)} \rightarrow$ _____
4. $Cl_{2(g)} + NaI_{(aq)} \rightarrow$ _____
5. $Ca_{(s)} + H_2O_{(l)} \rightarrow$ _____
6. $Au_{(s)} + ZnSO_{4(aq)} \rightarrow$ _____
7. $Sn_{(s)} + AgNO_{3(aq)} \rightarrow$ _____
8. $Al_{(s)} + H_2O_{(l)} \rightarrow$ _____
9. $Br_{2(aq)} + MgI_{2(aq)} \rightarrow$ _____
10. $Al_{(s)} + ZnSO_{4aq)} \rightarrow$ _____

ANSWERS TO THE REQUIRED PRACTICE

Required Practice 1 from page 2

1. Low solubility **2.** Soluble **3.** Soluble **4.** Soluble **5.** Soluble **6.** Low solubility **7.** Low solubility **8.** Soluble **9.** Low solubility **10.** Soluble

Required Practice 2 from page 5

1. No reaction **2.** $Al(OH)_{3(s)}$ **3.** $PbCl_{2(s)}$ **4.** No reaction **5.** No reaction **6.** $NiSO_{3(s)}$ **7.** $Al_2(CO_3)_{3(s)}$ **8.** No reaction **9.** No reaction **10.** $Cu_3PO_{4(s)}$

Required Practice 3 from page 4

a. $Zn_{(s)} + CuCl_{2(aq)} \rightarrow Cu_{(s)} + ZnCl_{2(aq)}$
b. $Br_{2(aq)} + CaCl_{2(aq)} \rightarrow NR$
c. $Pb_{(s)} + 2HCl_{(aq)} \rightarrow H_{2(g)} + PbCl_{2(s)}$
d. $Cl_{2(aq)} + 2NaI_{(aq)} \rightarrow I_{2(s)} + 2NaCl_{(aq)}$
e. $Ca_{(s)} + H_2O_{(l)} \rightarrow H_{2(g)} + CaO_{(aq)}$
f. $Au_{(s)} + ZnSO_{4(aq)} \rightarrow NR$
g. $Sn_{(s)} + 4AgNO_{3(aq)} \rightarrow 4Ag_{(s)} + Sn(NO_3)_{4(aq)}$
h. $2Al_{(s)} + 3H_2O_{(l)} \rightarrow 3H_{2(g)} + Al_2O_{3(s)}$
i. $Br_{2(aq)} + MgI_{2(aq)} \rightarrow I_{2(s)} + MgBr_{2(aq)}$
j. $2Al_{(s)} + 3ZnSO_{4(aq)} \rightarrow 3Zn_{(s)} + Al_2(SO_4)_{3(aq)}$

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SOLUBILITY OF IONIC COMPOUNDS

An ionic compound is soluble if it can form a concentration of greater than 0.1 M @ 25°C

Anion	**Cation**	
All	**NH_4^{1+}, Ions from Group 1: H^{1+}, Li^{1+}, Na^{1+}, K^{1+}, Rb^{1+}, Cs^{1+}**	SOLUBLE
NO_3^{1-}	All cations	SOLUBLE
$C_2H_3O_2^{1-}$	Ag^{1+}	LOW SOLUBILITY
	All other cations	SOLUBLE
Cl^{1-} Br^{1-} I^{1-}	Ag^{1+}, Cu^{1+}, Tl^{1+}, Pb^{2+}, Hg_2^{2+}, Hg^{1+}	LOW SOLUBILITY
	All other cations	SOLUBLE
S^{2-}	NH_4^{1+}, H^{1+}, **Li^{1+}, Na^{1+}, K^{1+}, Rb^{1+}, Cs^{1+}**, Be^{2+}, Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}, Ra^{2+}	SOLUBLE
	All other cations	LOW SOLUBILITY
OH^{1-}	NH_4^{1+}, H^{1+}, **Li^{1+}, Na^{1+}, K^{1+}, Rb^{1+}, Cs^{1+}**, Tl^{1+}, Sr^{2+}, Ba^{2+}	SOLUBLE
	All other cations	LOW SOLUBILITY
SO_4^{2-}	Ag^{1+}, Pb^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}, Ra^{2+}	LOW SOLUBILITY
	All other cations	SOLUBLE
CO_3^{2-} PO_4^{3-} SO_3^{2-}	NH_4^{1+}, H^{1+}, **Li^{1+}, Na^{1+}, K^{1+}, Rb^{1+}, Cs^{1+}**	SOLUBLE
	All other cations	LOW SOLUBILITY

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ACTIVITY SERIES OF METALS

MOST REACTIVE lithium
potassium
barium
calcium
sodium
magnesium
aluminum
zinc
iron
nickel
tin
lead
(hydrogen)
Copper
Silver
LEAST REACTIVE Gold

ACTIVITY SERIES FOR HALOGENS

MOST REACTIVE fluorine
chlorine
bromine
iodine
LEAST REACTIVE astatine

ACTIVITY SERIES FOR NON-METALS

Chemical reactivity of non-metals increases as follows.

1) moving left to right within a period
2) bottom to top within a group

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