Unit 4 Name \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Types of Reactions & Date \_\_\_\_\_\_\_\_\_\_\_\_ Block \_\_\_\_

Solution Stoichiometry

Unit 4A – Types of Reactions

### Knowledge/Understanding Goals:

* Know the 5/6 types of inorganic reactions that will be on the AP exam.

### Skills:

1. Be able to identify what type of reaction will occur between reactants.
2. Predict the products of a reaction.
3. Apply stoichiometry to predict amounts of reagents needed and products formed.

### Notes:

There are 5/6 inorganic reactions that you will need to be able to identify and predict the products for:

* Decomposition
* Synthesis
* Single Displacement
* Double Displacement
  + Solution Chemistry: Includes acid/base, precipitation, RedOx reactions
* Combustion

**Synthesis**

In a synthesis reaction, multiple reactants combine to form fewer/larger product molecules.

A + B C

Ex: 4Al(s) + 3O2(g) 2Al2O3(s)

General Types of Synthesis Reactions

1. Metal combines with a Non-metal to form a salt

2Na(s) + Cl2(g) 2NaCl(s)

1. Soluble Metallic Oxides combine with water to form bases (metallic hydroxides)

Na2O (s) + H2O(l) 2NaOH (aq)

*Metallic Oxide*

*Metallic Hydroxide*

1. Non-metallic Oxides and water form acids.

CO2(g) + H2O(l) H2CO3 (aq)

*Non-metallic Oxide*

* Carbonic acids are typically more straight forward

P4O10 (s) + H2O(l) H3PO4(aq)

*Non-metallic Oxide*

* Phosphate, sulfate, and nitrates are a bit more tricky since you must track your oxidation state.
  + **Oxidation State**: the “charge” an atom takes on in a covalent compound. Electrons are still being shared (covalent bonds), so oxidation states are formed/balanced rather than ionic charges.
    - Listed first/middle = electropositive (lower electronegativity)
    - Listed last = electropositive (higher electronegativity)
* Note that the non-metal (P) retains its oxidation state of +5. That is why we formed phosphoric acid (H3PO4) rather than phosphorus acid (H3PO3)

H: 3(+1) = +3

P: 1(+3) = +3

O: 3(-2) = -6

+3

P: 4(+5) = +20

O: 10(-2) = -20

--2

+5

H3PO3

P4O10

H: 3(+1) = +3

P: 1(+5) = +5

O: 4(-2) = -8

+5

H3PO4

1. Metallic Oxides and Non-metallic Oxides form salts

CaO (s) + SO3(g) CaSO4 (s)

*Non-metallic Oxide*

*Metallic Oxide*

1. Boron compounds combine with an electron pair donator (lewis acid/base)

BI3(s) + NH3(g) H3NBI3(s)

Lewis Dot Structure:

1. Common Sense Synthesis (really only one option)

H2(g) + Cl2(g) 2HCl(s)

*E*

2H2(g) + O2(g) 2H2O(l)

**Decomposition**

In a decomposition reaction, a reactant molecule is broken down into multiple products.

A B + C

Ex. 2H2O2 (aq) 2H20 (l) + O2 (g)

General Types of Decomposition Reactions

1. Electrolysis of Ionic Binary Compounds (Salts)
   * Ionic salts can be forced to separate into their metal and non-metal elemental states in the presence of electrical energy.

*E*

2NaCl (s) 2Na (s) + Cl2(g)

\*\*\*Notice this is NOT the dissociation of a salt that we see with dissolving, as dissolving of an ionic compound is not a reaction!\*\*\*

NaCl (aq) Na+(aq) + Cl- (aq)

1. Decomposition of Oxyacids, Metallic Carbonates, and Metallic Chlorates
   * Oxyacids decompose into water and a nonmetallic oxide.

H2SO4(aq) H2O(l) + SO3 (aq)

*Non-Metallic Oxide*

*Oxyacid*

* + Metallic Carbonates decompose into metallic oxides and carbon dioxide.

CaCO3 (aq) CaO(aq) + CO2(g)

*Metallic Oxide*

*Metallic Carbonate*

* + - Typically self-balancing
    - Very common on old AP tests
  + Metallic Chlorates decompose into metallic chlorides and oxygen.

2KClO3(aq) 2KCl (aq) + 3O2(g)

*Metallic Chloride*

*Metallic Chlorate*

* + - Typically require balancing
    - Very common on old AP tests

Specific Types of Decomposition Reactions

1. Ammonium carbonate decomposes into ammonia, water, and carbon dioxide

(NH4)2CO3 (aq) 2NH3(g) + H2O(l) + CO2(g)

1. Ammonium hydroxide decomposes into ammonia and water

NH4OH (aq) NH3(g) + H2O(l)

\*\*\*Note that whenever ammonium is present on the reactant side, there is a good chance ammonia is a product, unless you are working with a single/double displacement reaction\*\*\*

1. Hydrogen peroxide decomposes into water and oxygen

2H2O2 (aq) 2H20 (l) + O2 (g)

\*\*\*Note, oxygen and hydrogen are NOT the products\*\*\*

1. Water decomposes into hydrogen and oxygen

*E*

2H2O(l) 2H2 (g) + O2(g)

**Single Displacement Reactions**

In a single displacement (SD) reaction, a reactant in its elemental state replaces an ion in an ionic compound, forcing the ion to take on its elemental form.

AB + C CB + A

Ex: CuSO4(aq) + 2Li(s) Cu(s) + Li2SO4(aq)

General Types of SD Reactions

1. More reactive metal replaces a less reactive metal in a compound.

Zn(s) + Ni(NO3)2 (aq) Ni(s) + Zn(NO3)2 (aq)

* Typically performed by placing a piece of metal in an aqueous ionic solution.
* Metal in the elemental form (neutral) must be more reactive than the metal in the ionic form (+ charge) to replace it.
  + Which is the preferred state to be in, neutral or ion?

1. More reactive non-metal replaces a less reactive non-metal in a compound.

F2(g) + 2NaCl (aq) 2NaF (aq) + Cl2(g)

* Typically involves the displacement of halogens in solution.
* Non-metal in the elemental form (neutral) must be more reactive than the non-metal in the ionic form (+ charge) to replace it.

\*\*\*Note: You are NOT expected to memorize the reactivity series to predict whether an SD reaction will occur or not. Information will be provided to you in the question if necessary\*\*\*

1. Special case of Hydrogen
   * Hydrogen can act as a metal or a non-metal due to its 1 valence electron in the first energy level.
     + - Hydrogen acting as a metal.

Reactive metals can replace hydrogen in cold water.

2Na(s) + 2H2O(l) 2NaOH(aq) + H2(g)

Moderately reactive metals can replace hydrogen in steam.

2Fe(s) + 2H2O(g) 2Fe(OH)2(aq) + H2(g)

Some metals cannot replace hydrogen in water, but can in acids.

Zn(s) + 2HCl(aq) ZnCl2(aq) + H2(g)

* + - * Hydrogen acting as a non-metal.

Hydrogen is less reactive than the halides and will be readily displaced.

2NH3(aq) + 3I2(s) 2NI3(aq) + 3H2(g)

**Double Displacement Reactions**

In a double displacement (DD) reaction, two ionic compounds exchange partners.

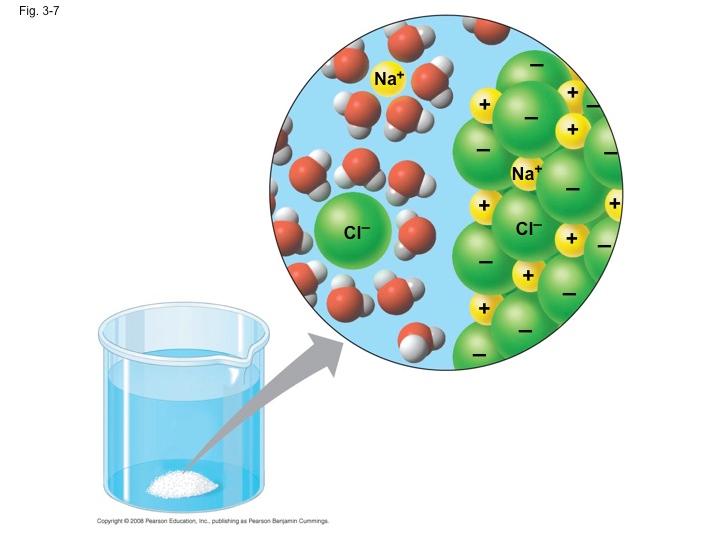
AB + CD CB + AD

Ex: Mg(NO3)2(aq) + 2NaOH(aq) Mg(OH)2(s) + 2NaNO3(aq)

General Types of DD Reactions

1. Precipitation (Metathesis) reactions: Two soluble ionic, salt solutions combine to produce a precipitate

2NaI(aq) + Pb(NO3)2(aq) 2NaNO3(aq) + PbI2(s)

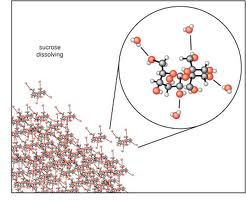
Solubility/Dissolving

In order for a compound to dissolve in water, the combined attraction between each ion and the several water molecules surrounding it must be stronger than the attraction between one the ions. The stronger total attraction wins, which means the NaCl to the right dissociates and the ions dissolve in water.

***dissolve***: when a solute distributes itself throughout a solvent. A solute dissolves if the attraction between the solvent and the solute molecules or ions is stronger than the attraction of the solvent molecules for each other and also stronger than the attraction of the solute molecules or ions for each other.

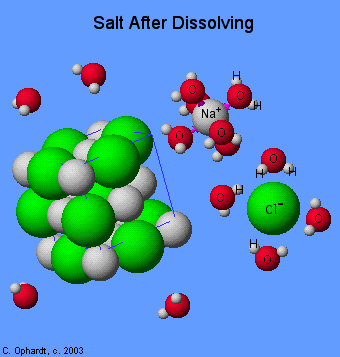
***dissociate***: when an ionic compound splits into cations (positive ions) and anions (negative ions). (start and end with ions)

***ionize***: when a covalent compound forms ions in a solution. (only end with ions)

* Note that dissolution (dissolving), dissociating, and ionizing are different processes.

Ex: Glucose (a covalent molecule) *dissolves* in water,

even though it does not form ions.

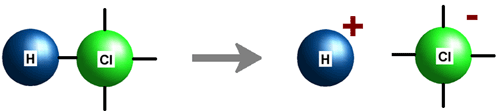
 - Sodium chloride *dissociates* in water into Na+ and Cl−

ions, but it does not ionize because it is already made of

ions.

- HCl *ionizes* in water because the covalent H−Cl bond breaks

and the electrons divide unevenly forming H+ and Cl− ions.



electrolyte: an aqueous solution that contains dissolved ions and conducts electricity.

strong electrolyte: a compound that is almost completely ionized in solution.

For example: NaCl (aq) → Na+ (aq) + Cl− (aq)

HCl (aq) → H+ (aq) + Cl− (aq)

weak electrolyte: a compound that is only partially ionized in solution.

For example: HC2H3O2 (aq)  H+ (aq) + C2H3O2− (aq)

On the other hand, a precipitate (insoluble compound) forms when the attraction between ions is too strong for the water molecule attraction to overcome. So as soon as these ions come into contact with one another in solution, they combine and cannot be dissolved by the water.

The metathesis reaction between sodium carbonate (Na2CO3) and calcium chloride (CaCl2) forms a precipitate:

Na2CO3 (*aq*) + CaCl2 (*aq*) → NaCl (*aq*) + CaCO3 (*ppt*) (1)

Once the calcium carbonate is formed, it doesn’t redissolve.  *I.e.*, reaction (1) happens,

but the reverse reaction (2), doesn’t:

CaCO3 (*s*) + NaCl (*aq*) → CaCl2 (*aq*) + Na2CO3 (*aq*) (2)

You should be able to predict the solubility (whether it will dissolve or not) of most products to see if a precipitate will form.

* + Soluble
    1. All group 1 metals and NH4+ are soluble\*\*\*
    2. All nitrates, chlorates, and acetates are soluble\*\*\*
    3. All halides (not F-) are soluble unless paired with Pb, Ag, or Hg
    4. All sulfates are soluble except when paired with heavy group 2 metals, Pb, Ag, Hg
  + Insoluble

1. All carbonates, phosphates, sulfites, and sulfides are insoluble, unless paired with rule 1 cations
2. All chromates are insoluble, except when paired with Ca, Sr, and rule 1 cations
3. All hydroxides are insoluble, except when paired with Ca, Sr, and rule 1 cations.

Practice: Write out the complete balanced equation for the following reactions, including phases.

* + - 1. Na2CO3( ) + Zn(NO3)2( )
      2. AgC2H3O2( ) + NaCl( )
      3. KOH( ) + Fe(ClO3)2( )
* For precipitate reactions, ionic equations are often written out to isolate the species that are directly involved in a double displacement reaction.

**Full Ionic Equations**: Includes everything from the chemical equation, but anything soluble (aq) is shown dissociated into its ions. Solids, liquids, gases are all left unchanged as they are not dissolved by the solute (water). All molar ratios must remain intact through the use of coefficients!

***Write the full ionic equation for practice problem #1.***

**Net Ionic Equations**: Includes only the species directly involved in the reaction, if there is one. In other words, it includes only the parts of the full ionic equation that change from the reactant side to the product side. (Go from being a soluble ion to an insoluble precipitate)

Any ions that do not change during the reaction are called ***spectator ions*** and are left out of the net ionic equation.

***Write the net ionic equation for practice problem #1.***

The net ionic equation shows that a reaction did occur in problem #1, as a new product was formed; the ZnCO3 precipitate.

***Write out the full and net ionic equations for practice problem #2.***

If every species in your full ionic equation is aqueous, you will have no unchanged species in the equation and therefore no net ionic equation. What does this mean? Draw a diagram of the solutions before and after mixing to support your answer.

1. Acid/Base (neutralization) reactions

According to Svante Arrhenius’s definitions:

1. acids produce H+ ions in aqueous solutions
2. bases produce OH− ions in aqueous solutions

strong acid: an acid that ionizes completely in water.

HCl (aq) → H+ (aq) + Cl− (aq)

Any acid with a negative *pKa* value (see Appendix 5) is a strong acid. Memorize the following strong acids: HCl, HBr, HI, HNO3, H2SO4, and HClO4.

weak acid: an acid that ionizes only partially in water.

HF (aq)  H+ (aq) + F− (aq)

Assume that any acid you will see on the AP Chemistry exam is a weak acid unless it is one of the strong acids listed above.

strong base: a base that ionizes completely in water.

NaOH (aq) → Na+ (aq) + OH− (aq)

Any base whose conjugate acid has a *pKa* value greater than 14 is a strong base. All soluble oxides and hydroxides of group I and group II metals are strong bases. (Except that aqueous Mg(OH)2 *acts* like a weak base.)

weak base: a base that ionizes only partially in water. Weak bases react with H2O, creating the conjugate acid and OH−.

NH3 (aq) + H2O (ℓ)  NH4+ (aq) + OH− (aq)

Assume that any base you see on the AP Chemistry exam is a weak base unless it is one of the strong bases listed above.

Strong acids and bases are strong electrolytes, meaning that they ionize to produce a large number of ions in water, and the resulting solution is a good conductor of electricity.

Weak acids and bases ionize only partially. This often means that the resulting solution is a weak electrolyte (poor conductor of electricity). However, note that if the weak acid or base is itself an ion, the solution will be a strong electrolyte regardless of the amount of dissociation of the acid or base.

**General Acid/Base Reactions**

* 1. Neutralization of strong bases (hydroxides) and strong acids to form a salt and water.

KOH(aq) + HCl(aq) KCl(aq) + H2O(l)

*Base Acid Salt*

* Remember the criteria for saying a chemical reaction has occurred?
  + We must break chemical bonds, rearrange atoms, form new bonds and produce a new solid, gas, or liquid water.
* So for hydroxide base neutralization reactions, rather than producing a precipitate through double displacement, we form liquid water.

***Write out the full and net ionic equations for the reaction above between potassium hydroxide and hydrochloric acid.***

Practice: Write out the complete balanced equation for the following reactions, including phases.

1) Ca(OH)2( ) + HClO4( )

2) HNO3( ) + KOH( )

Polyprotic acids can behave differently than monoprotic acids. The following reaction has 3 possibilities, depending upon the number of hydrogen neutralized from the acid.

3) H3PO4( ) + LiOH( )

H3PO4( ) + LiOH( )

H3PO4( ) + LiOH( )

* 1. Neutralization of molecular bases (ammonia) to form a salt

NH3(g) + HCl( )

NH3(g) + H2MnO4( )

Careful, polyprotic!

* 1. Neutralization of a carbonate with a strong acid to form a salt, water, and carbon dioxide

Na2CO3( ) + HNO3( )

CaCO3( ) + H2SO4( )

**Combustion Reactions**

In a combustion reaction, a hydrocarbon is burnt in the presence of oxygen. The products of a combustion reaction are water and carbon dioxide.

1. Combustion of hydrocarbons

CxHy(l/g) + O2(g) CO2(g) + H2O(g)

* Typically tricky to balance since you start with an even number of oxygen and end with an odd number.
  + Usually have to apply the “double all of your coefficients” rule
* Note the phase of water since combustion produces a lot of heat energy

1. Combustion of alcohols

CxHyOH (l) + O2(g) CO2(g) + H2O(g)

* Typically easy to balance since you start and end with an odd number of oxygen
* Note the phase of water since combustion produces a lot of heat energy

AP Chem Types of Reactions Worksheet

Balance the following equations, predict the products, and indicate the type of reaction taking place:

1) \_\_\_\_ NaBr + \_\_\_\_ H3PO4

Type of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

2) \_\_\_\_ Ca(OH)2 + \_\_\_\_ Al2(SO4)3

Type of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

3) \_\_\_\_ Mg + \_\_\_\_ Fe2O3

Type of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

4) \_\_\_\_ C2H4 + \_\_\_\_ O2

Type of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

5) \_\_\_\_ PbSO4

Type of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

6) \_\_\_\_ NH3 + \_\_\_\_ I2

Type of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

7) \_\_\_\_ H2O + \_\_\_\_ SO3

Type of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

8) \_\_\_\_P4O6 + \_\_\_\_ H2O

Type of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

9) \_\_\_\_ H2SO4 + \_\_\_\_ NH4OH

Type of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

10) \_\_\_\_ Fe + \_\_\_\_ H2O

Type of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

11) \_\_\_\_ (NH4)2CO3

Type of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

12) \_\_\_\_ Na2O + \_\_\_\_H2O

Type of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

12) \_\_\_\_ C3H8 + \_\_\_\_O2

Type of reaction: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_