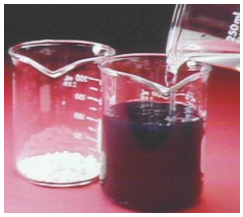
Chapter 4

Reactions in Aqueous Solution



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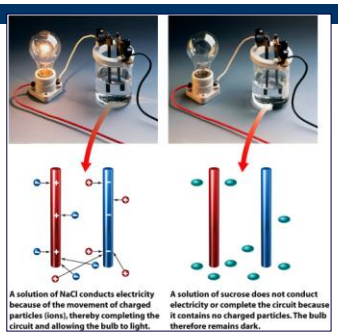
Properties of Aqueous Solutions

- Substances behave differently when they are placed in water, specifically ionic versus co-valent compounds.
- One breaks apart in water, the other does not.
- Which one is more likely to be pulled apart by water molecules?
- Electrolytes are ionic and strong acid solutions (e.g., Gatorade™); Nonelectrolytes are covalent compounds (e.g., sugar); weak electrolytes are in between.

Electrolytes in Aqueous Solutions



A solution of NaCl conducts electricity because of the movement of charged particles (ions), thereby completing the circuit and allowing the bulb to light.

A solution of sucrose does not conduct electricity or complete the circuit because it contains no charged particles. The bulb therefore remains dark.

Strong/Weak Electrolytes

Electrolytic Properties

- ***Strong electrolyte***: substance that, when dissolved in water, results in a solution that can conduct electricity (NaCl) soluble ionic compounds, strong acids
- ***Weak electrolyte***: substance that is a poor conductor of electricity when dissolved in water (CH_3COOH – vinegar) insoluble ionic compounds, weak acids
- ***Nonelectrolyte***: substance that doesn't conduct electricity when dissolved in water (CH_3OH – methanol), covalent compounds

Electrolytes in Aqueous Solutions

TABLE 4.1 Electrolyte Classification of Some Common Substances

Strong Electrolytes	Weak Electrolytes	Nonelectrolytes
HCl, HBr, HI	CH_3CO_2H	H_2O
$HClO_4$	HF	CH_3OH (methyl alcohol)
HNO_3		C_2H_5OH (ethyl alcohol)
H_2SO_4		$C_{12}H_{22}O_{11}$ (sucrose)
KBr		Most compounds of carbon (organic compounds)
NaCl		
NaOH, KOH		
Other soluble ionic compounds		

Table 4-1 Chemistry, 5/e

Strong/Weak Electrolytes

Properties of Aqueous Solutions

- Most reactions in general chemistry take place in an aqueous environment. What does that mean?
- Terms:
  - ***Solution***: homogeneous mixture of two or more substances
  - ***Solute***: substance present in smaller amount
  - ***Solvent***: substance present in greater amount
  - ***Aqueous solution***: solvent is water

Ways Reactions Occur

- Three general categories:
  - ♦ Precipitation: insoluble (solid) product is formed from aqueous solutions
  - ♦ Acid-base neutralization: acid and base react to form water and a salt (ionic compound)
  - ♦ Oxidation-Reduction: electrons are transferred between atoms in reaction
    - Combination
    - Decomposition
    - Single-replacement (metal or hydrogen)

Precipitation (Double-Replacement) Reactions

- Precipitation reactions always begin with two ionic compounds.
- Example: NaCl (aq) + $AgNO_3$ (aq) → ?
- Draw these compounds in two separate aqueous environments. What are the possible products when they are combined?
- **Write formulas of products (based on charges), predict phases (Solubility Rules on back of periodic table), and balance the equation.**

Solubility Rules – on periodic table

TABLE 4.2 Solubility Rules for Common Ionic Compounds in Water at 25°C

Soluble Compounds	Exceptions
Compounds containing alkali metal ions (Li^+, Na^+, K^+, Rb^+, Cs^+) and the ammonium ion (NH_4^+)	
Nitrates (NO_3^-), bicarbonates (HCO_3^-), and chlorates (ClO_3^-)	
Halides (Cl^-, Br^-, I^-)	Halides of Ag^+, Hg_2^{2+}, and Pb^{2+}
Sulfates (SO_4^{2-})	Sulfates of Ag^+, Ca^{2+}, Sr^{2+}, Ba^{2+}, Hg^{2+}, and Pb^{2+}
Insoluble Compounds	**Exceptions**
Carbonates (CO_3^{2-}), phosphates (PO_4^{3-}), chromates (CrO_4^{2-}), sulfides (S^{2-})	Compounds containing alkali metal ions and the ammonium ion
Hydroxides (OH^-)	Compounds containing alkali metal ions and the Ba^{2+} ion

If not covered by the rules, it is probably **insoluble**. 10

Solubility Rules

- Determine if the following **ionic compounds** will be soluble (aq) or insoluble (s) in water:
- K_2CO_3
- $BaSO_4$
- PbI_2
- $NaClO_4$
- Ag_2S
- $(NH_4)_3PO_4$
- $Cu(OH)_2$

Solubility Rules Answers

- Determine if the following ionic compounds will be soluble (aq) or insoluble (s) in water:
- K_2CO_3 soluble (aq)
- $BaSO_4$ insoluble (s)
- PbI_2 insoluble (s)
- $NaClO_4$ soluble (aq)
- Ag_2S insoluble (s)
- $(NH_4)_3PO_4$ soluble (aq)
- $Cu(OH)_2$ insoluble (s)

Molecular, Ionic, and Net Ionic Equations

- There are 3 ways to represent ppt reactions:
  - ♦ As whole compounds (molecular equation)
  - ♦ As ionic species (ionic equation) – more accurate
  - ♦ As participants in reaction (net ionic equation)
- Any ***aqueous*** ionic substance is written as a compound (e.g., $AgNO_3$), but this isn't accurate. What does this look like in water? It is Ag^+ and NO_3^- ions
- **Solids, liquids, and gases remain as compounds.**

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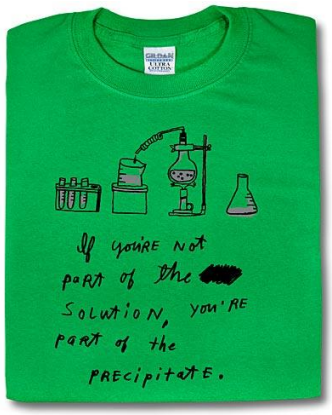
Formation of Silver Chloride

- **Molecular equation**:
  - $NaCl(aq) + AgNO_3(aq) \rightarrow AgCl(s) + NaNO_3(aq)$
- **Ionic equation** (write separate ions for soluble (aq) compounds):
  - $Na^+(aq) + Cl^-(aq) + Ag^+(aq) + NO_3^-(aq) \rightarrow AgCl(s) + Na^+(aq) + NO_3^-(aq)$
- **Net ionic equation** (cancel any identical **ion** on both sides of the equation, called **spectator ions**): $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$
- Note: s, l, and g stay together!!!!!

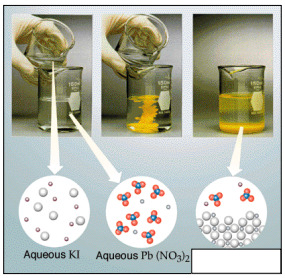
Ag^+/Cl^- ions

Chemistry humor, ha ha!



Precipitation Reactions

- Reaction of lead (II) nitrate and potassium iodide. What is the precipitate?
- Write the molecular, ionic, and net ionic equations.
- Worked Ex. 4.2 – 4.5; Problems 4.4 – 4.8



Acid-Base (Double-Replacement) Reactions

- ***Acid:*** substance that breaks apart in water to form H^+ (e.g., HCl, HNO_3, CH_3COOH, lemon, lime, vitamin C).
  - $HA(aq) \rightarrow H^+(aq) + A^-(aq)$
- ***Base:*** substance that breaks apart in water to form OH^- (e.g., NH_3, Drano™, Milk of Magnesia™)
  - $MOH(aq) \rightarrow M^+(aq) + OH^-(aq)$

acid

base

strong acid

weak acid

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Common Acids and Bases

- You need to KNOW these!!!

TABLE 4.2 Some Common Acids and Bases

Strong acid	$HClO_4$	Perchloric acid	NaOH	Sodium hydroxide	Strong base
	H_2SO_4	Sulfuric acid	KOH	Potassium hydroxide	
	HBr	Hydrobromic acid	$Ba(OH)_2$	Barium hydroxide	
	HCl	Hydrochloric acid	$Ca(OH)_2$	Calcium hydroxide	
	HNO_3	Nitric acid			
Weak acid	H_3PO_4	Phosphoric acid	NH_3	Ammonia	Weak base
	HF	Hydrofluoric acid			
	CH_3CO_2H	Acetic acid			

- Strong acids: HCl, HBr, HI, $HClO_4$, H_2SO_4, HNO_3
- Strong bases: LiOH, KOH, NaOH, RbOH, CsOH, $Ca(OH)_2$, $Sr(OH)_2$, $Ba(OH)_2$

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Acid-Base Neutralization

- Neutralization reaction: reaction between acid and base; products are usually a salt (ionic compound) and water
- $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$
- Acid + base → salt + water
- What are the ionic and net ionic equations for these reactions?
- KOH (aq) + H_2SO_4 (aq) →
- NH_3 (aq) + HCl (aq) →
- Worked Ex. 4.6, 7; Problems 4.9, 4.10, 11

Acid-Base Reaction

HCl

$Mg(OH)_2$

Acid + Base → H_2O + Salt

Water is created from H^+ and OH^-

$2HCl_{(aq)} + Mg(OH)_{2(s)} \rightarrow 2H_2O_{(l)} + MgCl_{2(aq)}$

The salt is created from spectator ions

Group Work

- Determine the products of the reaction. Identify the phase of **each compound**, and balance the equation. Also write the ionic and net ionic equations.
- Molecular: $Na_2S + Cr(NO_3)_3$ →
- Complete Ionic:
- Net Ionic:

Group Answers

- Molecular: $3Na_2S(aq) + 2Cr(NO_3)_3(aq)$ → $Cr_2S_3(s) + 6NaNO_3(aq)$
- Complete Ionic: $6Na^+(aq) + 3S^{2-}(aq) + 2Cr^{3+}(aq) + 6NO_3^-(aq)$ → $Cr_2S_3(s) + 6Na^+(aq) + 6NO_3^-(aq)$
- Net Ionic: $2Cr^{3+}(aq) + 3S^{2-}(aq)$ → $Cr_2S_3(s)$

Complete/Balance These Equations

- Complete and balance these equations. Write ionic and net ionic equations, if applicable.
- **$Na_2S(aq) + CuCl_2(aq)$ →**
- **$KNO_3(aq) + CaCl_2(aq)$ →**
- **$KOH(aq) + H_2SO_4(aq)$ →**

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Complete/Balance These Equations

- $Na_2S(aq) + CuCl_2(aq)$ → **$2\ NaCl(aq) + CuS(s)$**
  - **$Cu^{2+}(aq) + S^{2-}(aq)$ → $CuS(s)$**
- $2\ KNO_3(aq) + CaCl_2(aq)$ → **$2\ KCl(aq) + Ca(NO_3)_2(aq)$**
  - **No reaction**
- $2KOH(aq) + H_2SO_4(aq)$ → **$2H_2O\ (l) + K_2SO_4\ (aq)$**
  - **$H^+\ (aq) + OH^-\ (aq)$ → $H_2O\ (l)$**

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Oxidation-Reduction Reactions

- ***Oxidation-Reduction (redox) reactions***: electron-transfer reactions
- When iron rusts, it loses electrons to form a cation, oxygen gain electrons to form an anion: $4\ Fe(s) + 3\ O_2(g) \rightarrow 2\ Fe_2O_3(s)$
- Use oxidation number rules to determine gain and loss of electrons.
- Oxidation numbers are assigned as if elements in compounds completely transferred electrons (like in ionic compounds).

Assigning Oxidation Numbers

- 1) An atom (or molecule) in its elemental state has an oxidation number of 0.
- 2) An atom in a monatomic ion (Na^+, Cl^-) has an oxidation number identical to its charge.
- 3a) Hydrogen has an oxidation number of +1, unless it is combined with a metal, in which case it has an oxidation number of –1.
- 3b) Oxygen usually has an oxidation number of -2. Oxygen in peroxides (O_2^{2-}) has an oxidation number of -1.

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Rules continued

- 3c) Halogens usually have an oxidation number of -1 (except when bonded to oxygen or in polyatomic ions).
- 4) The sum of oxidation numbers is 0 for a neutral compound and is equal to the net charge for a polyatomic ion. (Example: NaCl = 0, SO_4^{2-} = -2)
  - ♦ 4a) For ***binary ionic compounds***, the position of the element in the periodic table may be useful:
  - ♦ Group IA: +1; Group IIA: +2; Group VIIA: –1; Group VIA: –2; Group VA: –3

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Example

- H_2SO_4
  - H = +1; O = –2
  - S is unknown, so leave this for last.
  - ♦ The overall charge on this compound is 0.
  - ♦ Use algebra to solve for S:
  - ♦ 2(+1) + 1(x) + 4(-2) = 0
- Solve for each element: $MgCr_2O_7$
- Worked Ex. 4.8; Problem 4.13

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Assigning Oxidation Numbers

- Determine values of the oxidation number of **each element** in these compounds or ions:

H_2O	SO_2
CCl_4	H_2O_2
$Fe_3(PO_4)_2$	MnO_4^-
$NaNO_3$	$KClO_4$

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Assigning Oxidation Numbers

- Determine values of the oxidation number of each element in these compounds or ions:

H_2O	H: +1, O: -2
SO_2	S: +4, O: -2
CCl_4	C: +4, Cl: -1
H_2O_2	H: +1, O: -1
$Fe_3(PO_4)_2$	Fe: +2, P: +5, O: -2
MnO_4^-	Mn: +7, O: -2
$NaNO_3$	Na:+1, N:+5, O: -2
$KClO_4$	K: +1, Cl: +7, O: -2

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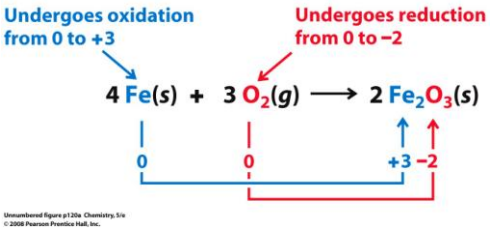
Oxidation-Reduction Reactions

- ***Oxidized***: atom, molecule, or ion becomes more positively charged
  - ♦ Loss of electrons is oxidation (LEO)
- ***Reduced***: atom, molecule, or ion becomes less positively charged (reduced charge)
  - ♦ Gain of electrons is reduction (GER)
- Or: OIL RIG (oxidation is loss; reduction is gain)


Redox 1


Redox 2

Assigning Oxidation Numbers

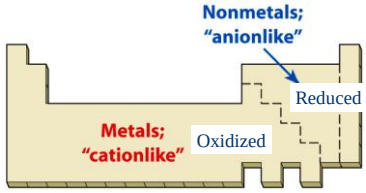


Oxidation-Reduction Reactions

- The substance oxidized causes the other substance to be reduced and is called the **reducing agent**.
- The substance reduced causes the other substance to be oxidized and is called the **oxidizing agent**.
- 4 Fe*(s)* + $3O_2$*(g)* → $2Fe_2O_3$*(s)*
- Worked Ex. 4.9; Problems 4.14, 4.15

Oxidation-Reduction Reactions

- Identify the element or ion oxidized/reduced. Also identify the oxidizing agent and the reducing agent.
- Zn*(s)* + 2HCl*(aq)* → $ZnCl_2$*(aq)* + H_2*(g)*



Group Work

- Identify the oxidation number of **each element** in the compounds or ions below:
- $Ba(ClO_3)_2$
- SO_3^{2-}
- For the reaction below, identify what has been oxidized and reduced; identify the oxidizing agent and the reducing agent.
- Cu(s) + $2AgNO_3$(aq) → 2Ag(s) + $Cu(NO_3)_2$(aq)

Group Answers

- Ba: +2 S: +4
- Cl: +5 O: -2
- O: -2

- Cu(s) + $2AgNO_3$(aq) → 2Ag(s) + $Cu(NO_3)_2$(aq)
- Cu: oxidized Ag^+: reduced
- Cu: reducing agent $AgNO_3$: oxidizing agent

Redox Reactions

- Combination (1 product)
  - ♦ Na*(s)* + Cl_2*(g)* →
- Decomposition (1 reactant) – usually give off gases
  - ♦ $CuCO_3$*(s)* →
- Single Replacement (or Displacement) (start and end with an element and a compound)
  - ♦ Zn*(s)* + HCl*(aq)* →

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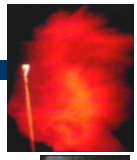
Combination Reactions



- element + element ⟶ compound
  - ♦ $H_2(g)$ + $O_2(g)$ →
- metal + nonmetal ⟶ ionic compound
  - ♦ $Na(s)$ + $Cl_2(g)$ ⟶
- nonmetal + nonmetal ⟶ covalent compound
  - ♦ $C(s)$ + $O_2(g)$ ⟶
- Why are these redox reactions?

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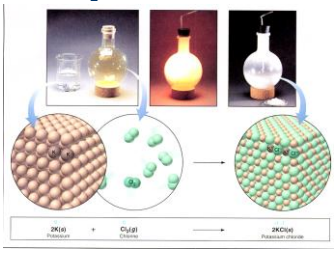
Combination Reactions

- $Mg + O_2$
- $K + Cl_2$



Decomposition Rxns Produce Gases

- Compound ⟶ 2 elements; element + compound; or 2 compounds
- Oxides, peroxides
  - ♦ Give off O_2
- Nitrates
  - ♦ Give off NO_2 , NO_2^-
- Carbonates
  - ♦ Give off CO_2
- Ammonium salts
  - ♦ Give off NH_3

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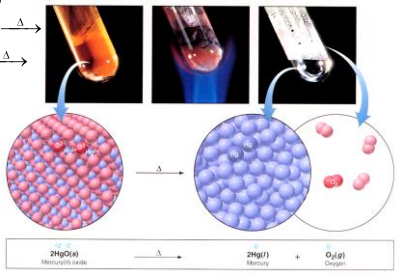
Decomposition Reactions

- NH_4Cl (s) ⟶
- $NiCO_3$(s) ⟶
- CuO(s) ⟶



Single-Displacement Reactions

- element + compound → compound + element (The more metallic/active element in the compound is displaced.)
- Metal Displacement
  - ♦ $Zn(s) + Cu(NO_3)_2(aq) \rightarrow Cu(s) + Zn(NO_3)_2(aq)$
- Hydrogen Displacement
  - ♦ $Mg(s) + HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$


Alkali Metals


Zn+$SnCl_2$

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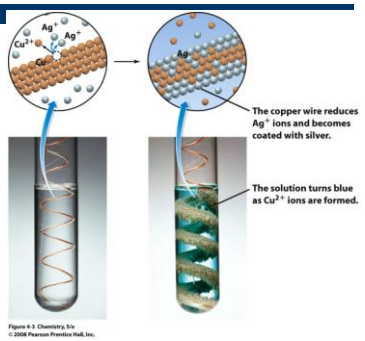
Single Displacement: Cu + $AgNO_3$



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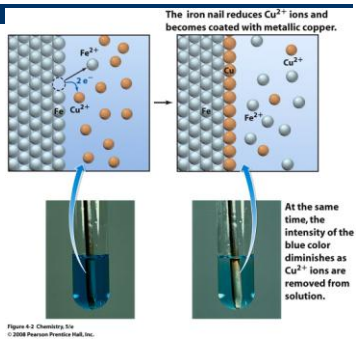
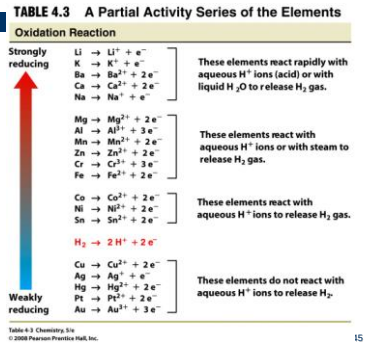
Single Displacement: Fe + $Cu(NO_3)_2$



Activity Series

- The higher the metal on the activity series, the more active that metal.
- Translation: higher metals on the chart will form ions as products.



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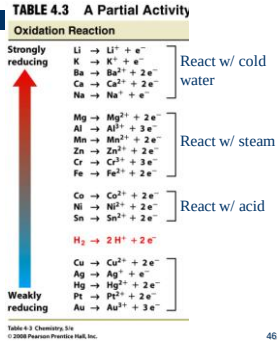
Predict whether a reaction occurs

- Na + H_2O
- Fe + H_2O
- Fe + $Cr(NO_3)_2$
- Ni + Pb^{2+}
- Ag + Mg^{2+}
- Zn + Co^{2+}
- Worked Ex. 4.10; Problems 4.16, 4.17



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Combustion Reactions

- Burning hydrocarbons
- $C_xH_yO_z + O_2\ (g) \rightarrow CO_2\ (g) + H_2O\ (g)$
- Methanol, CH_3OH
- $\_CH_3OH\ (l) + \_O_2\ (g) \rightarrow \_CO_2\ (g) + \_H_2O\ (g)$

Reaction Types

Reaction Types Animated

Types of Reactions Summary

- Precipitation: use Solubility Rules (AB + CD → AD + CB)
- Acid-Base Neutralization: acid + base → salt + water (AB + CD → AD + H_2O)
- Combination: start with elements (A + B → AB)
- Decomposition: often produces gas (AB → A + B)
- Single Displacement: use Activity Series to predict if a reaction occurs (A + BC → B + AC)
- Combustion:
  - Hydrocarbon + $O_2(g) \rightarrow CO_2(g) + H_2O(g)$

Classify (and balance) these rxns

1. $Co(s) + AgNO_3(aq) \rightarrow$
2. $Fe(s) + HCl(aq) \rightarrow$
3. $Na_2CO_3(s) \xrightarrow{\Delta}$
4. $Ca(s) + H_2O(l) \rightarrow$
5. $CaCO_3(s) \xrightarrow{\Delta}$
6. $HClO_4(aq) + KOH\ (aq) \rightarrow$
7. $BaCl_2(aq) + Na_2SO_4(aq) \rightarrow$

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Classify (and balance) these rxns

8. $HgO(s) \xrightarrow{\Delta}$
9. $LiOH(aq) + H_2SO_4(aq) \rightarrow$
10. $Na_2CrO_4(aq) + Ni(NO_3)_2(aq) \rightarrow$
11. $Li(s) + O_2(g) \rightarrow$
12. $Mg(OH)_2(aq) + 2HCl(aq) \rightarrow$
13. $NH_3(g) + HCl(g) \rightarrow$
14. $NiCO_3(s) \xrightarrow{\Delta}$
15. $Ca(s) + F_2(g) \rightarrow$

Classify these reactions by type

Single disp. 1. $Co(s) + 2AgNO_3(aq) \rightarrow Co(NO_3)_2(aq) + 2Ag(s)$
Single disp. 2. $Fe(s) + 2HCl(aq) \rightarrow FeCl_2(aq) + H_2(g)$
Decomp. 3. $Na_2CO_3(s) \rightarrow Na_2O(s) + CO_2(g)$
Single disp. 4. $Ca(s) + 2H_2O(l) \rightarrow Ca(OH)_2(aq) + H_2(g)$
Decomp. 5. $CaCO_3(s) + heat \rightarrow CaO(s) + CO_2(g)$
Acid-base neut. 6. $HClO_4(aq) + KOH(aq) \rightarrow KClO_4(aq) + H_2O(l)$
Precip. 7. $BaCl_2(aq) + Na_2SO_4(aq) \rightarrow BaSO_4(s) + 2NaCl(aq)$
Decomp. 8. $2HgO(s) \rightarrow 2Hg(l) + O_2(g)$
Acid-base neut. 9. $2LiOH(aq) + H_2SO_4(aq) \rightarrow Li_2SO_4(aq) + 2H_2O(l)$
Precip. 10. $Na_2CrO_4(aq) + Ni(NO_3)_2(aq) \rightarrow 2NaNO_3(aq) + NiCrO_4(s)$
Combo. 11. $4Li(s) + O_2(g) \rightarrow 2Li_2O(s)$
Acid-base neut. 12. $Mg(OH)_2(aq) + 2HCl(aq) \rightarrow 2MgCl_2(aq) + H_2O(l)$
Combo. 13. $NH_3(g) + HCl(g) \rightarrow NH_4Cl(s)$
Decomp. 14. $NiCO_3(s) \rightarrow NiO(s) + CO_2(g)$
Combo. 15. $Ca(s) + F_2(g) \rightarrow CaF_2(g)$

Group Work

- Determine what type of reaction will happen for each set of reagents below.
- Predict products of the following reactions.
- Write correct phases for the products and balance each equation:
- ___ Al (s) + ___ $NaNO_3$ (aq) →
- ___ Na (s) + ___ O_2 (g) →
- ___ Na_2SO_4 (aq) + ___ $Pb(NO_3)_2$ (aq) →

Group Answers

- SR: Al (s) + $NaNO_3$ (aq) → **No reaction**
- Combo: 4 Na (s) + O_2 (g) → **2 Na_2O (s)**
- DR/PPT: Na_2SO_4 (aq) + $Pb(NO_3)_2$ (aq) → $2NaNO_3$ (aq) + $PbSO_4$ (s)

The End

- Given reactants, be able to identify the reaction type, predict the products of reaction (with correct phases), and balance the equation – similar to the worksheet questions!