1. Electrolytes—Completely break up into ions in water (Arrhenius, 1884 (Nobel Prize, 1903)).
   a. Many ionic compounds and strong acids (HCl, HBr, HI, HNO₃, H₂SO₄, HClO₄)
   b. Different than decomposition because ions are produced.

c. Examples:
- NaCl(s) → Na⁺(aq) + Cl⁻(aq)
- CaCl₂(s) → Ca²⁺(aq) + 2Cl⁻(aq)
- Al₂(SO₄)₃(s) → 2Al³⁺(aq) + 3SO₄²⁻(aq)
Solution Reactions

Types of Solutions

d. Examples

\[ \text{Na}_2\text{CO}_3(s) \rightarrow \]
\[ \text{(NH}_4\text{)}_2\text{Cr}_2\text{O}_7(s) \rightarrow \]
\[ \text{HCl(l)} \rightarrow \]
\[ \text{FeCl}_3(s) \rightarrow \]

e. Hydration Sphere for NaCl

Solution Reactions

Types of Solutions

2. Weak Electrolytes

a. Weak Acids

b. Examples

\( \text{HC}_2\text{H}_3\text{O}_2, \text{HF, HNO}_2 \)

Solution Reactions

Types of Solutions

3. Non-Electrolytes- Do not break up into ions in water

a. Many Molecular Compounds

\( \text{C}_{12}\text{H}_{22}\text{O}_{11}(s) \rightarrow \text{C}_{12}\text{H}_{22}\text{O}_{11}(\text{aq}) \)
Solution Reactions

1. Provide a rough idea of whether something will dissolve in water
2. DO NOT GIVE ACTUAL, NUMERICAL SOLUBILITIES (you must look in a book or do an experiment)

Example:

Na₂CO₃(s) →
Zn(OH)₂(s) →
Na₂S(s) →
CaCl₂(s) →
AgCl(s) →
CuCO₃(s) →

Solubility Rules

<table>
<thead>
<tr>
<th>Very Soluble</th>
<th>Soluble with exceptions</th>
<th>Insoluble with exceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li⁺, Na⁺</td>
<td>Cl⁻, Br⁻, F⁻</td>
<td>OH⁻, S²⁻</td>
</tr>
<tr>
<td>K⁺, NH₄⁺</td>
<td>(Except Ag⁺, Hg²⁺, Pb²⁺)</td>
<td>(Except Ca²⁺, Sr²⁺, Ba²⁺ &amp; “Very”)</td>
</tr>
<tr>
<td>NO₃⁻</td>
<td>SO₄²⁻ (Except Hg²⁺, Pb²⁺, Ca²⁺, Sr²⁺, Ba²⁺)</td>
<td>CO₃²⁻, PO₄³⁻, SO₄³⁻ (Except “Very”)</td>
</tr>
</tbody>
</table>

Examples:

PbSO₄(s) →
Ag₂SO₄ →
KCl(s) →
Fe(OH)₃(s) →
FeSO₄(s) →
Solution Reactions  
**Net Ionic Rxns**

1. Can be Double Replacement Rxns
2. Spectator Ions – Ions present in soln, but do not take part in the rxn
   \[ \text{Pb(NO}_3\text{)}_2(aq) + \text{KI(aq)} \rightarrow \]

Solution Reactions  
**Net Ionic Rxns**

**Practice:**

\[ \text{AgNO}_3(aq) + \text{NaCl(aq)} \rightarrow \]

\[ \text{CaCl}_2(aq) + \text{Na}_2\text{CO}_3(aq) \rightarrow \]

\[ \text{NaNO}_3(aq) + \text{NH}_2\text{OH(aq)} \rightarrow \]

\[ \text{Na}_2\text{SO}_4(aq) + \text{BaBr}_2(aq) \rightarrow \]

\[ \text{Fe}_2(\text{SO}_4)_3(aq) + \text{LiOH(aq)} \rightarrow \]

\[ \text{Na}_2\text{S(aq)} + \text{CuCl}_2(aq) \rightarrow \]

\[ \text{Pb}((\text{C}_2\text{H}_3\text{O}_2)_2)(aq) + \text{NH}_2\text{OH(aq)} \rightarrow \]

Solution Reactions  
**Net Ionic Rxns**

\[ \text{BaCl}_2(aq) + \text{K}_2\text{SO}_4(aq) \rightarrow \]

1. The driving force for many reactions is the formation of a:
   a) Solid (precipitate)
   b) Liquid
   c) Gas
### Solution Reactions

**Water forming Rxns**

1. A special type of double replacement - neutralization
2. Acids
   a. produce $H^+$
   b. Often start with $H$ (HCl)
3. Bases
   a. produce $OH^-$
   b. Hydroxides (Drano, NaOH)

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaOH (aq) + HCl (aq)</td>
<td></td>
</tr>
<tr>
<td>HClO₄ (aq) + LiOH (aq)</td>
<td></td>
</tr>
<tr>
<td>Ca(OH)₂(aq) + HNO₃ (aq)</td>
<td></td>
</tr>
<tr>
<td>Mg(OH)₂(s) + HCl (aq)</td>
<td></td>
</tr>
</tbody>
</table>

### Solution Reactions

**Gas forming Rxns**

1. Carbonates plus acids
2. Carbonic acid – unstable (in soda)
   $H₂CO₃(aq) \rightarrow H₂O(l) + CO₂(g)$
3. Examples:
   - $CaCO₃(s) + HCl(aq) \rightarrow MgCO₃(s) + HNO₃(aq)$

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaHCO₃(aq) + HNO₃(aq)</td>
<td></td>
</tr>
<tr>
<td>Na₂S(aq) + HCl(aq)</td>
<td></td>
</tr>
</tbody>
</table>

### Solution Reactions

**Net Ionic Rxns**

**Mixed Types**

- $Fe(NO₃)₃(aq) + Na₂CO₃(aq)$
- $SrCO₃(s) + HCl(aq)$
- $HBr(aq) + LiOH(aq)$

### Solution Reactions

**Two Types of Chemical Rxns**

1. Exchange of Ions – no change in charge/oxidation numbers
   - Acid/Base Rxns
     - $NaOH + HCl$
### Solution Reactions

- **Precipitation Rxns**
  
  $$\text{Pb(NO}_3\text{)}_2(aq) + \text{KI(aq)} \rightarrow $$

- **Dissolving Rxns**
  
  $$\text{CaCl}_2(s) \rightarrow $$

### Solution Reactions

- **Exchange of Electrons**
  
  - Changes in oxidation numbers/charges
  
  $$\text{Cu(s) + 2AgNO}_3(aq) \rightarrow \text{Cu(NO}_3\text{)}_2(aq) + 2\text{Ag(s)}$$

  *Remove spectator ions*

  $$\text{Cu(s) + 2Ag}^+(aq) \rightarrow \text{Cu}^{2+}(aq) + 2\text{Ag(s)}$$

### Solution Reactions

- **Oxidation Numbers**
  
  1. Involves taking compounds apart
  
  2. Oxidation numbers – Pretend charges for all compounds (as if they exist as a monoatomic ion)
  
  3. Rules

### Solution Reactions

- **Elements = 0**
  
  - Fe, H₂, P₄, Cl₂
  
  - Na⁺, O²⁻, Al³⁺

- **Monoatomic Ions**
  
  - Charge

- **Use “bankables” to calculate the rest**

- **Gr I**
  
  - O⁻²

- **Gr II**
  
  - H⁺, F⁻

  *“the higher the oxidation #, the more oxidized the element”*

### Solution Reactions

- **Review of Oxidation**
  
  Calculate the oxidation numbers for:

  - HClO
  
  - Cr³⁺

  - S₈
  
  - Fe₂(SO₄)₃

  - Mn₂O₇
  
  - SO₃²⁻

  - KMnO₄
  
  - NO₃⁻

  - HSO₄⁻
**Solution Reactions**

**Oxidation**

1. Classical Definition – addition of oxygen
   \[ \text{Fe} + \text{O}_2 \rightarrow \text{Fe}_2\text{O}_3 \]

2. Modern Definition – an increase in oxidation number
   \[ \text{Na} + \text{O}_2 \rightarrow \text{Na}_2\text{O} \]
   \[0 \quad +1\]
   Na was oxidized

**Solution Reactions**

**Reduction**

1. Classical Definition – addition of hydrogen
   \[ \text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3 \]
   (Haber process)

2. Modern Definition – decrease (reduction) in oxidation number
   \[ \text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3 \]
   \[0 \quad -3\]
   N was reduced

**Solution Reactions**

**Example**

In the following reactions, which element is oxidized, which is reduced?

- \[ \text{Al} + \text{HBr} \rightarrow \text{AlBr}_3 + \text{H}_2 \]
- \[ \text{Fe} + \text{Cu(NO}_3)_2 \rightarrow \text{Fe(NO}_3)_2 + \text{Cu} \]
- \[ \text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{O} \]

**Solution Reactions**

**Activity Series**

- Used to predict if a particular redox reaction will occur
- Redox reactions - also called single replacement reactions
- Not every element can replace every other
  - Higher elements get oxidized
  - Lower elements get reduced

<table>
<thead>
<tr>
<th>Metal</th>
<th>Oxidation Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithium</td>
<td>Li(s) → Li^(aq) + e^-</td>
</tr>
<tr>
<td>Potassium</td>
<td>K(s) → K^(aq) + e^-</td>
</tr>
<tr>
<td>Barium</td>
<td>Ba(s) → Ba^(aq) + 2e^-</td>
</tr>
<tr>
<td>Calcium</td>
<td>Ca(s) → Ca^(aq) + 2e^-</td>
</tr>
<tr>
<td>Sodium</td>
<td>Na(s) → Na^(aq) + e^-</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg(s) → Mg^(aq) + 2e^-</td>
</tr>
<tr>
<td>Aluminum</td>
<td>Al(s) → Al^(aq) + 3e^-</td>
</tr>
<tr>
<td>Manganese</td>
<td>Mn(s) → Mn^(aq) + 2e^-</td>
</tr>
<tr>
<td>Zinc</td>
<td>Zn(s) → Zn^(aq) + 2e^-</td>
</tr>
<tr>
<td>Chromium</td>
<td>Cr(s) → Cr^(aq) + 2e^-</td>
</tr>
<tr>
<td>Iron</td>
<td>Fe(s) → Fe^(aq) + 2e^-</td>
</tr>
<tr>
<td>Cobalt</td>
<td>Co(s) → Co^(aq) + 2e^-</td>
</tr>
<tr>
<td>Nickel</td>
<td>Ni(s) → Ni^(aq) + 2e^-</td>
</tr>
<tr>
<td>Tin</td>
<td>Sn(s) → Sn^(aq) + 2e^-</td>
</tr>
<tr>
<td>Lead</td>
<td>Pb(s) → Pb^(aq) + 2e^-</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>H_(2)(g) → 2H^(aq) + 2e^-</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu(s) → Cu^(aq) + 2e^-</td>
</tr>
<tr>
<td>Silver</td>
<td>Ag(s) → Ag^(aq) + e^-</td>
</tr>
<tr>
<td>Mercury</td>
<td>Hg(s) → Hg^(aq) + 2e^-</td>
</tr>
<tr>
<td>Platinum</td>
<td>Pt(s) → Pt^(aq) + 2e^-</td>
</tr>
<tr>
<td>Gold</td>
<td>Au(s) → Au^(aq) + 3e^-</td>
</tr>
</tbody>
</table>
Solution Reactions
Will Copper metal replace silver in an aqueous solution of silver nitrate?

Solution Reactions
Will aqueous iron(II)chloride oxidize magnesium metal?

Solution Reactions
Can aluminum foil reduce Fe(NO₃)₂ to iron metal?

Solution Reactions
Can aluminum foil react with HCl?

Solution Reactions
Which of the following metals will be oxidized by Pb(NO₃)₂: Zn, Cu, and/or Fe?

Solution Reactions
Will barium metal react with nickel(II)nitrate?

Solution Reactions
Will iron(II)chloride react with calcium metal?

Solution Reactions
Will aluminum chloride react with gold?

Solution Reactions
Will calcium metal dissolve in HNO₃?
MgCO$_3$(s) + HNO$_3$(aq) →
Zn(NO$_3$)$_2$(aq) + Ag(s) →
CuCl$_2$(s) → (placed in water)
K(s) + NiCl$_2$(aq) →
Sn(s) + CuCl$_2$(aq) →
PbSO$_4$(s) → (placed in water)
Fe(s) + HCl (aq) →
Mg(OH)$_2$(s) + HCl(aq) →

Identifying Oxidizing/Reducing agents
Oxidizing agent – gets reduced
Reducing agent – get oxidized

K + ZnCl$_2$ →
AgNO$_3$ + Ni →
Li + CaCl$_2$ →
Cr(NO$_3$)$_3$ + Na →

Solution Reactions

1. Molarity = measure of the concentration of a solution
2. Molarity = moles/liter
   Similar to Density = g/L

3. Which is more concentrated?
   1 M HCl        3 M HCl

   Crowded classroom example

Solution Reactions

1. What is the molarity of a soln that contains 49.05 g of H$_2$SO$_4$ in enough water to make 250.0 mL of soln? (Ans: 2.00 M)
2. What is the molarity of a soln made by dissolving 23.4 g of Na$_2$SO$_4$ in enough water to make 125 mL of soln? (Ans: 1.32 M)
Solution Reactions  

3. How many grams of NaOH are in 5.00 mL of 0.0900 M NaOH? (Ans: 0.018 g)

4. What volume of 0.0764 M HCl is needed to provide 0.0694 g of HCl? (Ans: 25 mL)

Solution Reactions  

1. What is the concentration of all the ions in the following solutions?
   - 2 M NaOH
   - 2 M Ca(OH)$_2$
   - 0.08 M K$_3$PO$_4$

Solution Reactions  

1. Mixing from a solid
2. How would you prepare 350.0 mL of 0.500 M Na$_2$SO$_4$? (Ans: dilute 24.9 g to 350 mL)

Solution Reactions  

3. How would you prepare 500.0 mL of 0.133 M KMnO$_4$? (Ans: dilute 10.5 g to 500 mL)
4. How would you prepare 250.0 mL of 0.00200 M NaOH? (Ans: dilute 0.02 g to 250 mL)

Solution Reactions  

1. Dilution Formula: 
   \[ M_1V_1 = M_2V_2 \]
2. Used when you are starting with a more concentrated soln. (Grape juice concentrate, Coke syrup)
Solution Reactions

3. What is the molarity of a solution of KCl that is prepared by diluting 855 mL of 0.475 M solution to a volume of 1.25 L? (Ans: 0.325 M)

4. You have a 2.5 L bottle of 12.0 M HCl. What volume of it must be diluted to make 500.0 mL of 0.100 M HCl? (Ans: 4.17 mL)

Solution Reactions

1. How many grams of water form when 25.0 mL of 0.100 M HNO₃ is completely neutralized by NaOH? (Ans: 0.045 g)

2. What volume of 0.500 M HCl is needed to react completely with 33.1 g of Pb(NO₃)₂? (Ans: 400.0 mL)

Solution Reactions

3. What is the molarity of NaOH solution if 22.0 mL is needed to neutralize 15.0 mL of 0.100 M HCl? (Ans: 0.0682 M)

4. What is the molarity of an NaOH solution if 48.0 mL is needed to neutralize 35.0 mL of 0.144 M H₂SO₄? (Ans: 0.210 M)

Write net ionic equations:
NaHCO₃(aq) + HNO₃(aq) →
MgCO₃(s) + HNO₃(aq) →
BaCl₂(aq) + H₂SO₄(aq) →
Fe₂S(s) + HCl(aq) →

Write eqns if they occur
Fe(NO₃)₂(s) → (placed in water)
PbSO₄(s) → (placed in water)
Sn(s) + HCl(aq) →
Pt(s) + NiCl₂(aq) →

Solution Reactions

Fe(NO₃)₂(s) → (placed in water)
C₂H₆(g) + O₂(g) →
K₂CO₃(aq) + Fe(NO₃)₂(aq) →
K(s) + CoCl₂(aq) →
Mg(OH)₂(s) + HCl(aq) →
CaCl₂(aq) + Ag(s) →
4. CH₃COOH is a weak electrolyte, HBr is a strong electrolyte, so CH₃COOH needs to be more concentrated.

16. Mg²⁺ + 2F⁻
   Al³⁺ + 3NO₃⁻
   H⁺ + ClO₄⁻
   Na⁺ + CH₃COO⁻

20. Soluble (c), (e)

22. a) Ni(OH)₂  b) NR  c) CuS

24. 2Cr³⁺(aq) + 3CO₂⁻(aq) → Cr₂(CO₃)₃(s)
   Ba²⁺(aq) + SO₄²⁻(aq) → BaSO₄(s)
   Fe³⁺(aq) + 2OH⁻(aq) → Fe(OH)₂(s)

26. CO₃²⁻ (only one that forms with all three)

50. +4  +2  +3 -2  +3  +6

52. a) Acid/base  b) Redox, Fe reduced  c) precipitation  d) Redox, Zn oxidized

54. Ni  +  2H⁺ → Ni²⁺ + H₂
   Fe  +  2H⁺ → Fe²⁺ + H₂
   Mg  +  2H⁺ → Mg²⁺ + H₂
   Zn  +  2H⁺ → Zn²⁺ + H₂

56. Mn + Ni²⁺ → Mn³⁺ + Ni
   NR
   2Cr³⁺ + 3Ni²⁺ → 2Cr³⁺ + Ni
   NR
   H₂ + Cu²⁺ → Cu + 2H⁺

Warm-Up:

Zn(NO₃)₂(aq) + K₃PO₄(aq) →

KNO₃(aq) + HCl(aq) →

Al₂(CO₃)₃(s) + HCl(aq) →

KHCO₃(aq) + HCl(aq) →
Bi^{3+} + 3OH^{-} \rightarrow Bi(OH)_3
H^+ + OH^{-} \rightarrow H_2O
CaCO_3 + 2H^+ \rightarrow Ca^{2+} + CO_2 + H_2O
Pb^{2+} + SO_4^{2-} \rightarrow PbSO_4
NR
H^+ + OH^{-} \rightarrow H_2O
MgCO_3 + 2H^+ \rightarrow Mg^{2+} + CO_2 + H_2O
Sr^{2+} + CO_3^{2-} \rightarrow SrCO_3
NR
Ag^+ + I^{-} \rightarrow AgI

H^+ + OH^{-} \rightarrow H_2O
HCO_3^{-} + H^+ \rightarrow H_2O + CO_2
SrCO_3 + 2H^+ \rightarrow Sr^{2+} + CO_2 + H_2O
Pb^{2+} + 2Cl^{-} \rightarrow PbCl_2
Cu^{2+} + 2OH^{-} \rightarrow Cu(OH)_2

Solution Reactions

What you will turn in:
1. Neatly recopied data table
2. Summary chart of your solubility rules
3. Questions
   a. Where did your results disagree with the book's solubility rules?
   b. Why might this have occurred?
   c. List three questions you or another student still may have after completing this experiment.