CHEMISTRY 103 – Help Sheet #3  
Chemical Reactions  
Summer topics may not include all fall/spring semester topics: Do the topics appropriate for your course  
Prepared by Dr. Tony Jacob  
http://www.chem.wisc.edu/areas/elec (Resource page)

NUGGETS: Balancing Rxns; Electrolytes; Acids/Bases; Solubility Rules; Writing Molecular, Complete Ionic, and Net Ionic Reactions; Types of Reactions; Redox Reactions: assigning oxidation numbers; 1D redox rxn, what is oxidized, what is reduced, what is the oxidizing agent, what is the reducing agent; metal activity series

CHEMICAL EQUATIONS: reactants (the starting reagents) yield products (the ending materials)  
Be able to balance chemical equations; balanced reaction means the number of atoms and total charges on each side of the reaction are the same

IDENTIFYING ACIDS/BASES – STRONG and WEAK

**Acids (HA):** Produce H⁺ in solution (e.g., HCl → H⁺ + Cl⁻); for Chem 103: 1) acids begin with H in the formula (except: H₂O), or 2) contain a –COOH group.

**Strong acids (memorize):** acids that completely break up (dissociate) into H⁺ and A⁻; strong electrolytes;  
HCl (hydrochloric acid), HBr (hydrobromic acid), HI (hydroiodic acid), HNO₃ (nitric acid),  
H₂SO₄ (sulfuric acid; H₂SO₄ → H⁺ + HSO₄⁻), HClO₄ (perchloric acid)

**Weak acids:** an acid that is not a strong acid; dissociate (break up) a little; weak electrolytes  
*Common weak acids (there are many weak acids):* CH₃COOH (acetic acid; memorize);  
H₃PO₃ (phosphoric acid; memorize); H₂CO₃ (carbonic acid; memorize); HCN (hydrocyanic); HCOO⁻ (formic acid)

**Bases:** Produce OH⁻ in solution (e.g., NaOH → Na⁺ + OH⁻)

**Strong bases (memorize):** bases that completely dissolve generating OH⁻; strong electrolytes;  
Group IIA hydroxides: LiOH, NaOH, KOH; Group IIA hydroxides: Ca(OH)₂, Sr(OH)₂ and Ba(OH)₂

**Weak bases:** a base that is not a strong base; produce a little OH⁻; weak electrolytes;  
*Common weak base (there are many weak bases):* NH₃ (ammonia; memorize)

### Solubility Rules

<table>
<thead>
<tr>
<th>Usually Soluble</th>
<th>Exceptions</th>
<th>Usually Insoluble</th>
<th>Exceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li⁺, Na⁺, K⁺, Rb⁺, Cs⁺, NH₄⁺</td>
<td>PO₄³⁻</td>
<td>Li⁺, Na⁺, K⁺, Rb⁺, Cs⁺, NH₄⁺</td>
<td></td>
</tr>
<tr>
<td>NO₃⁻</td>
<td>CO₂⁻</td>
<td>Li⁺, Na⁺, K⁺, Rb⁺, Cs⁺, NH₄⁺</td>
<td></td>
</tr>
<tr>
<td>Cl⁻, Br⁻, I⁻</td>
<td>CrO₄²⁻</td>
<td>Li⁺, Na⁺, K⁺, Rb⁺, Cs⁺, NH₄⁺, Mg²⁺</td>
<td></td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>CrO₄²⁻</td>
<td>OH⁻</td>
<td>Li⁺, Na⁺, K⁺, Rb⁺, Cs⁺, NH₄⁺, (Ca(OH)₂, Sr(OH)₂, and Ba(OH)₂ are slightly soluble)</td>
</tr>
<tr>
<td>ClO₃⁻, ClO₄⁻</td>
<td>C₂O₄²⁻</td>
<td>S²⁻</td>
<td>Li⁺, Na⁺, K⁺, Rb⁺, Cs⁺, NH₄⁺, (MgS, CaS, and BaS are slightly soluble)</td>
</tr>
<tr>
<td>CH₃COO⁻</td>
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</table>

ELECTROLYTES: A chemical that produces ions; more ions → more electrical current/better conductor  
*Strong-Electrolyte:* Produces large numbers of ions: soluble ionic compounds (e.g., NaCl); strong acids (e.g., HBr); strong bases (e.g., NaOH); bright light in conductivity experiment  
*Weak-Electrolyte:* Produces small quantity of ions: weak acids (e.g., CH₃COOH); weak bases (e.g., NH₃); dim light in conductivity experiment

Nonelectrolyte: Produces no ions: insoluble ionic compounds (e.g., AgCl); molecular compounds (e.g., sugar); no light in conductivity experiment  
(Reminder: Ionic Compounds: Metal + nonmetal (or polyatomic ion); Molecular Compounds: 2 nonmetals)

CONDUCTIVITY – how well a solution can pass an electrical current; more ions → greater conductivity;  
(molecular compounds → no ions!); Strong
HOW TO WRITE REACTIONS

1. Overall or Molecular Reaction: All compounds are written in a molecular form; no ions.
   1. If needed, given names → translate names into reactant formulas.
   2. Write products by switching reactant parts in ionic or acid/base reactions. For combustion reactions products are CO₂ and H₂O. When writing products, use only one reactant part (anion/cation) even if there is more than one reactant part on the reactant side (i.e., product parts should initially have a subscript of 1).
   3. Assign charges to product parts.
   4. Balance product formulas by adding subscripts as needed.
   5. Balance the overall reaction.

Example 1: Calcium nitrate and sodium phosphate are mixed; write the molecular reaction.
   1. calcium nitrate + sodium phosphate: Ca(NO₃)₂ + Na₃PO₄ → (translate names into formulas)
   2. Ca(NO₃)₂ + Na₃PO₄ → CaPO₄ + NaNO₃ (switch partners; use only 1 reactant part in products; i.e., 3 Na on the left side but 1 Na on the right side to start)
   3. Ca(NO₃)₂ + Na₃PO₄ → Ca⁺₂PO₄⁻³ + Na⁺¹NO₃⁻¹ (assign charges to product parts)
   4. Ca(NO₃)₂ + Na₃PO₄ → Ca₃(PO₄)₂ + Na₃(NO₃)₁ (balance product formulas with subscripts using charges)
   5. 3Ca(NO₃)₂ + 2Na₃PO₄ → Ca₃(PO₄)₂ + 6NaNO₃ (balance reaction with coefficients); this is the molecular rxn

Answer 1: Molecular reaction: 3Ca(NO₃)₂(aq) + 2Na₃PO₄(aq) → Ca₃(PO₄)₂(s) + 6NaNO₃(aq)

2. Complete Ionic Reaction: Break the appropriate compounds into aqueous ions

   Break up into ions if chemical is: 1. Soluble Ionic (metal+nonmetal/polyatomic ion & solubility rules), 2. Strong Acid (memorized), or 3. Strong Base (memorized)

   Exception: H₂CO₃(aq) → H₂O(l) + CO₂(g) (used with gas-forming reactions)

Example 2: Calcium nitrate and sodium phosphate are mixed (same as Example 1 above so start with molecular reaction); what is the complete ionic reaction?
   Molecular reaction: 3Ca(NO₃)₂(aq) + 2Na₃PO₄(aq) → Ca₃(PO₄)₂(s) + 6NaNO₃(aq)
   Ca(NO₃)₂ – soluble + ionic → break-up; Na₃PO₄ – soluble + ionic → break-up;  
   Ca₃(PO₄)₂ – insoluble + ionic → don’t break-up; NaNO₃ – soluble + ionic → break-up

   Note 1: the “3” in front of Ca(NO₃)₂ acts on both the Ca⁺² and the NO₃⁻;
   Note 2: not written as 3(NO₃)₂⁻; (NO₃)₂ = implies the 2 NO₃⁻ are bonded together (they’re not bonded together!); 6NO₃⁻ = implies 6 separate NO₃⁻;
   Note 3: polyatomic ions are treated as a group and are not broken apart; it is 6NO₃⁻ and not 6N + 18O

Answer 2: Complete ionic reaction: 3Ca⁺²(aq) + 6NO₃⁻(aq) + 6Na⁺(aq) + 2PO₄⁻³(aq) → Ca₃(PO₄)₂(s) + 6Na⁺(aq) + 6NO₃⁻(aq)

3. Net Ionic Reaction: Ions that "react" are included; other ions (Spectator Ions) are not included

Example 3: Calcium nitrate and sodium phosphate are mixed (same as Example 1 above so start with complete ionic reaction); what is the net ionic reaction?

   Complete ionic reaction: 3Ca⁺²(aq) + 6NO₃⁻(aq) + 6Na⁺(aq) + 2PO₄⁻³(aq) → Ca₃(PO₄)₂(s) + 6Na⁺(aq) + 6NO₃⁻(aq)
   Cancel out spectator ions from Complete Ionic Reaction (Na⁺ and NO₃⁻); watch for H₂CO₃ (not in this reaction); if everything cancels out → No reaction!

Answer 3: Net ionic reaction: 3Ca⁺²(aq) + 2PO₄⁻³(aq) → Ca₃(PO₄)₂(s) [Na⁺(aq), NO₃⁻(aq) were canceled – spectator ions]

Example 4: Write the molecular, complete ionic, and net ionic reactions for the reaction of acetic acid with barium hydroxide.

Answer 4: Molecular rxn: Step 1: names → formulas: CH₃COOH (memorized) + Ba(OH)₂ → (assign charges, balance reactants → H⁺¹CH₃COO⁻¹ + Ba⁺²(OH⁻¹)₂)
   Step 2: switch partners; use only 1: CH₃COOH + Ba(OH)₂ → HOH + Ba(CH₃COO)
   Step 3: assign charges to products: CH₃COOH + Ba(OH)₂ → H⁺¹OH⁻¹ + Ba⁺²CH₃COO⁻¹
   Step 4: balance product formulas: CH₃COOH + Ba(OH)₂ → HOH (= H₂O) + Ba(CH₃COO)₂
   Step 5: balance reaction: Molecular reaction: 2CH₃COOH(aq) + Ba(OH)₂(aq) → 2HOH(l) + Ba(CH₃COO)₂(aq)

   Complete ionic reaction: Step 1: break strong acids (SA), strong bases (SB), and soluble ionic compounds into ions; don’t break up weak acids (WA), weak bases (WB), insoluble ionic compounds, or molecular compounds
   CH₃COOH – WA → don’t break up; Ba(OH)₂ – SB → break up; HOH = H₂O – molecular compound → don’t break up;
   Ba(CH₃COO)₂ – ionic (has a metal and a polyatomic ion) and is soluble (has CH₃COO⁻) → break up:

   Complete ionic rxn: 2CH₃COOH(aq) + Ba⁺²(aq) + 2OH⁻(aq) → 2H₂O(l) + Ba⁺²(aq) + 2CH₃COO⁻(aq)

   Net ionic reaction: Step 1: cancel out ions on both sides of the reaction: 2CH₃COOH + 2OH⁻ → 2H₂O + 2 CH₃COO⁻
   Simplify reaction coefficients if possible (divide all coefficients by 2): Net ionic reaction: CH₃COOH(aq) + OH⁻(aq) → H₂O(l) + CH₃COO⁻(aq)

   Molecular reaction: 2CH₃COOH(aq) + Ba(OH)₂(aq) → 2HOH(l) + Ba(CH₃COO)₂(aq)

   Complete ionic reaction: 2CH₃COOH(aq) + Ba⁺²(aq) + 2OH⁻(aq) → 2H₂O(l) + Ba⁺²(aq) + 2CH₃COO⁻(aq)

   Net ionic reaction: CH₃COOH(aq) + OH⁻(aq) → H₂O(l) + CH₃COO⁻(aq)
1. **Precipitation:** 2 aqueous/soluble ionic compounds "switch" partners and produce a solid (precipitate)

   Example 5: Write the molecular, complete ionic, and net ionic reaction for: Ba(NO₃)₂(aq) + K₂SO₄(aq) →

   Answer 5: Ba(NO₃)₂(aq) + K₂SO₄(aq) → BaSO₄(s) + 2KNO₃(aq) (molecular reaction)

   Ba²⁺(aq) + 2NO₃⁻(aq) + 2K⁺(aq) + SO₄²⁻(aq) → BaSO₄(s) + 2K⁺(aq) + 2NO₃⁻(aq) (complete ionic reaction)

   (Ba(NO₃)₂ → soluble ionic → break up; K₂SO₄ → soluble ionic → break up; KNO₃ → soluble ionic → break up; BaSO₄ → insoluble ionic → don’t break up)

   Ba²⁺(aq) + SO₄²⁻(aq) → BaSO₄(s) (net ionic reaction)

2. **Acid/Base (neutralization): Acid + Base → H₂O + salt** (salt = ionic compound that is usually soluble)

   Example 6: Write the molecular, complete ionic, and net ionic reaction for: 2HNO₃(aq) + Ba(OH)₂(aq) → (strong acid + strong base)

   Answer 6: 2HNO₃(aq) + Ba(OH)₂(aq) → 2H₂O(l) + Ba(NO₃)₂(aq) (molecular reaction)

   2H⁺(aq) + 2NO₃⁻(aq) + Ba²⁺(aq) + 2OH⁻(aq) → 2H₂O(l) + Ba²⁺(aq) + 2NO₃⁻(aq) (complete ionic reaction)

   (HNO₃ → strong acid → break up; Ba(OH)₂ → strong base → break up; Ba(NO₃)₂ → soluble ionic → break up; H₂O → molecular → don’t break up)

   H⁺(aq) + OH⁻(aq) → H₂O(l) (net ionic reaction; this net ionic reaction is for SA + SB; not WA or WB)

   Example 7: Write the molecular, complete ionic, and net ionic reaction for: 2CH₃COOH(aq) + Sr(OH)₂(aq) → (weak acid + strong base)

   Answer 7: 2CH₃COOH(aq) + Sr(OH)₂(aq) → 2H₂O(l) + Sr(CH₃COO)₂(aq) (molecular reaction)

   2H⁺(aq) + Sr²⁺(aq) + 2OH⁻(aq) → 2H₂O(l) + Sr²⁺(aq) + 2CH₃COO⁻(aq) (complete ionic reaction)

   (CH₃COOH → weak acid → don’t break up; Sr(OH)₂ → strong base → break up; Sr(CH₃COO)₂ → soluble ionic → break up; H₂O → molecular → don’t break up)

   HF(aq) + OH⁻(aq) → H₂O(l) + CH₃COO⁻(aq) (net ionic reaction for weak acid + strong base)

3. **Gas-Forming:** produces a gas

   - Carbon dioxide gas, CO₂: acid (H⁺) + CO₃²⁻(aq) → H₂O(l) + CO₂(g)
   - Sulfur dioxide gas, SO₂: acid (H⁺) + SO₃²⁻(aq) → H₂O(l) + SO₂(g)
   - Dihydrogen sulfide gas, H₂S: acid (H⁺) + S²⁻(aq) → H₂S(g)

4. **Hydrogen gas, H₂:** metal(s) + H₂O(l) or acid (H⁺) → M⁺(aq) + OH⁻(aq) + H₂(g) (this is also a redox reaction)

   Example 8: Write the molecular, complete ionic, and net ionic reaction for: 2HCl(aq) + Na₂CO₃(aq) →

   Answer 8: 2HCl(aq) + Na₂CO₃(aq) → H₂O(l) + CO₂(g) + 2NaCl(aq) (molecular reaction not yet finished)

   the H₂O₂(aq) breaks up; H₂O₂(aq) → H₂O(l) + CO₂(g) to yield an overall molecular reaction:

   2HCl(aq) + Na₂CO₃(aq) → H₂O(l) + CO₂(g) + 2NaCl(aq) (molecular reaction finished)

   2H⁺(aq) + 2Cl⁻(aq) + 2Na⁺(aq) + CO₃²⁻(aq) → H₂O(l) + CO₂(g) + 2Na⁺(aq) + 2Cl⁻(aq) (complete ionic reaction)

   (HCl → strong acid → break up; Na₂CO₃ → soluble ionic → break up; NaCl → soluble ionic → break up; H₂O → molecular → don’t break up; CO₂ → molecular → don’t break up)

   2H⁺(aq) + CO₃²⁻(aq) → H₂O(l) + CO₂(g) (net ionic reaction)

5. **Combustion: a type of redox reaction:** Hydrocarbon (H and C only) reacting with O₂ to form H₂O and CO₂

   CₓHᵧ + O₂(g) → CO₂(g) + H₂O(g) (unbalanced)

   Example 9: Write the molecular, complete ionic, and net ionic reaction for: 2C₈H₁₈(g) + 25O₂(g) →

   Answer 9: 2C₈H₁₈(g) + 25O₂(g) → 16CO₂(g) + 18H₂O(g) (molecular reaction)

   2C₈H₁₈(g) + 25O₂(g) → 16CO₂(g) + 18H₂O(g) (complete ionic reaction)

   (C₈H₁₈O₂ → molecular → don’t break up)

   2C₈H₁₈(g) + 25O₂(g) → 16CO₂(g) + 18H₂O(g) (net ionic reaction)

6. **Redox: oxidation numbers change** for elements as they go from reactants to products (see below)

   **Displacement: metal + (acid or metal salt) → metal salt + metal/element**

   A + BX → AX + B

   Example 10: Write the molecular, complete ionic, and net ionic reaction for: Mg(s) + 2HCl(aq) →

   Answer 10: Mg(s) + 2HCl(aq) → MgCl₂(aq) + H₂(g) (molecular reaction)

   Mg(s) + 2H⁺(aq) → Mg²⁺(aq) + H₂(g) (net ionic reaction)

   (Note: When an acid is in a redox reaction and forms H₂(g), this reaction is sometimes classified as a gas-forming reaction!)
REDOX – Reduction-Oxidation; redox reactions occur when there is a change in oxidation number
Oxidation reaction cannot occur without reduction reactions and vice-versa
LEO the lion goes GER (LEO - Lose Electrons Oxidation; GER - Gain Electrons Reduction)
  Reducing agent - that which causes something else to be reduced;
  oxidizing agent is the chemical that is oxidized
Oxidizing agent - that which causes something else to be oxidized;
  oxidizing agent is the chemical that is reduced

1. ASSIGNING OXIDATION NUMBERS - Bookkeeping of electrons
1. Elements in elemental form
2. In a compound:
   a. Group 1A (Li, Na,..) +1 (always)
   b. Group 2A (Be, Mg,..) +2 (always)
   c. F -1 (always)
   d. H +1 (usually; can also be -1 with MH; e.g., NaH)
   e. O -2 (usually; can also be: -1 with O²⁻, e.g., H₂O₂; -1/2 with O²⁺, e.g., KO₂; +1 with F, e.g., F₂O₂)

3. Sum Rule: Sum of all the oxidation numbers = total charge on compound
   Example 11: Assign oxidation numbers to all atoms in N₂O₄.
   Answer 11: Assign O = -2 → Sum Rule: 2(N) + 4(-2) = 0; 2(N) + (-8) = 0; 2N = +8; N = +4

   Example 12: Assign oxidation numbers to all atoms in PO₄⁻³.
   Answer 12: Assign O = -2 → Sum Rule: 1(P) + 4(-2) = -3; 1(P) + (-8) = -3; P = +5

   Example 13: Assign oxidation numbers to all atoms in CuSO₄.
   Answer 13: Two unknowns: Cu and S; break into 2 parts and look for a polyatomic ion: Cu and SO₄; assign charges (not oxidation numbers) to SO₄ → -2 → SO₄⁻² (memorized); therefore, Cu → Cu²⁺ since entire compound, CuSO₄, is neutral (+2 + (-2) = 0); Cu²⁺ has ox num = +2; Cu = +2;
   SO₄⁻²: Assign O = -2 → Sum Rule: 1(S) + 4(-2) = -2; 1(S) + (-8) = -2; S = +6

2. OXIDIZED, REDUCED, OXIDIZING AGENT, REDUCING AGENT
If oxidation number get more positive ⇒ oxidized
If oxidation number get more negative ⇒ reduction
Chemical oxidized = reducing agent; Chemical reduced = oxidizing agent;
Chemical oxidized, Chemical reduced, Oxidizing agent, Reducing agent = reactants only; no products

Example 14: Identify which chemical is oxidized, reduced, oxidizing agent, and reducing agent in the following reaction:
Cu(s) + 2HNO₃(aq) → CuO(s) + 2NO₂(g) + H₂O(l)
Answer 14: Assign oxidation numbers to all elements in all chemicals:
Cu(s) + 2HNO₃(aq) → CuO(s) + 2NO₂(g) + H₂O(l)
Note where the change in oxidation number occurs as the reactants become products:
Cu: 0 → +2 → increasing oxidation number → oxidized; N: +5 → +4 → decreasing oxidation number → reduced
The chemical that is oxidized (Cu) is also the reducing agent = Cu(s); the chemical that is reduced (HNO₃) is also the oxidizing agent = HNO₃

3. ID A REDOX RXN
Redox reaction occurs when oxidation numbers change in a reaction
  • If rxn is an acid/base, precipitation, or gas-forming rxn (such as HCO₃⁻/CO₃²⁻ + acid/H⁺) – it’s not a redox rxn
  • If rxn has an element on one side and that element is in a compound on the other side of the rxn – it’s nearly always a redox rxn
  • If rxn is a combustion rxn – it’s a redox rxn
4. METAL ACTIVITY SERIES (skip if not covered)
when the metal is above another metal cation – reaction occurs: metal is oxidized to a cation and metal cation forms a metal solid (e.g., Mn(s) and Fe^{2+}(aq) – see chart below);
when the metal is below a metal cation – no reaction occurs (e.g., Cu(s) and Cr^{3+}(aq) – see chart below)

<table>
<thead>
<tr>
<th>Metal Activity Series – Table 3.4 (just a few reactions shown here)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reaction Occurs</strong> when metal is <strong>above</strong> the cation</td>
</tr>
<tr>
<td>Fe(s) → Fe^{2+}(aq) + 2e^-</td>
</tr>
<tr>
<td>Cr(s) → Cr^{3+}(aq) + 3e^-</td>
</tr>
<tr>
<td>H_2(g) → 2H^+(aq) + 2e^-</td>
</tr>
<tr>
<td>Cu(s) → Cu^{2+}(aq) + 2e^-</td>
</tr>
<tr>
<td><strong>No Reaction Occurs</strong> when metal is <strong>below</strong> the cation</td>
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<td>Fe(s) → Fe^{2+}(aq) + 2e^-</td>
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<td>H_2(g) → 2H^+(aq) + 2e^-</td>
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<tr>
<td>Cu(s) → Cu^{2+}(aq) + 2e^-</td>
</tr>
</tbody>
</table>

Example 15: For each reaction, if it occurs write the balanced reaction. If it does not occur, write “No reaction occurs”.

**Answer 15:**

a. Mn(s) + FeBr_2(aq) → **Answer:** Mn(s) + FeBr_2(aq) → MnBr_2(aq) + Fe(s)

These 2 reactions from the Activity Series occur: Mn(s) → Mn^{2+}(aq) and Fe^{2+}(aq) → Fe(s) because Mn(s) is up and to the left of Fe^{2+} (see table above)

b. 2Cr(s) + 6HBr(aq) → **Answer:** 2Cr(s) + 6HBr(aq) → 2CrBr_3(aq) + 3H_2(g)

These 2 reactions from the Activity Series occur: Cr(s) → Cr^{3+}(aq) and 2H^+(aq) → H_2(g) because Cr(s) is up and to the left of H^+ (see table above)

c. Cu(s) + Cr^{3+}(aq) → **Answer:** No reaction occurs: Cu(s) + Cr^{3+}(aq) → No Reaction because Cu(s) is below and to the left of Cr^{3+} (see table above)

1. Balance the following equations.

   a. Mg(s) + SiO_2(s) → MgO(s) + Si(s)  
   b. Ca(s) + N_2(g) → Ca_3N_2(s)  
   c. CH_3OH(l) + O_2(g) → CO_2(g) + H_2O(l)  
   d. CaCl_2(s) + Na_2CO_3(s) → CaCO_3(s) + NaCl(s)  
   e. P_4O_{10}(s) + H_2O(l) → H_3PO_4(aq)  
   f. C_6H_6(l) + O_2(g) → CO_2(g) + H_2O(l)

2. Write and balance a reaction from the description given (recall combustion refers to the reaction of a hydrocarbon with O_2(g) to produce water, H_2O(l), and carbon dioxide, CO_2). Include phases [(aq), (s), (l), (g)].

   a. pentane (C_5H_{12}(l)) is combusted  
   b. ethylene (C_2H_4(g)) is combusted  
   c. sodium metal reacts with oxygen gas  
   d. calcium metal reacts with solid phosphorus

3. Write the balanced molecular reactions from each description. Include phases [(aq), (s), (l), (g)].

   a. Solid dinitrogen pentoxide reacts with water to form aqueous nitric acid.  
   b. Solid ammonium nitrate decomposes to form gaseous dinitrogen monoxide and water.  
   c. Solid manganese(II) carbonate breaks down to form solid manganese(II) oxide and carbon dioxide.

4. Write balanced molecular reactions for each of the following. Include phases [(aq), (s), (l), (g)].

   a. HCl(aq) and Ba(OH)_2(aq)  
   b. AgNO_3(aq) and NaBr(aq)  
   c. H_2O(l) is decomposed into its elements
5. a. What are the six common strong acids and six common strong bases (give name/chemical formula)?
b. Identify (name and chemical formula) one common weak acid and one common weak base.

6. Identify each type of reaction as either acid-base, gas-forming, or precipitation reaction.
   a. 2KI(aq) + Pb(NO₃)₂(aq) ®
   b. Na₂S(aq) + 2HCl(aq) ®
   c. HCl(aq) + NaOH(aq) ®
   d. K₂SO₃(aq) + 2HNO₃(aq) ®
   e. Cd(NO₃)₂(aq) + H₂S(g) ®
   f. HF(aq) + NaOH(aq) ®
   g. K₂CO₃(aq) + 2CH₃COOH(aq) ®
   h. 2Li(s) + 2H₂O(l) ®

Note: The above question could also be asked using names rather than formulas which makes those questions more challenging:
   a. potassium iodide(aq) + lead(II) nitrate(aq) ®
   b. sodium sulfide(aq) + hydrochloric acid(aq) ®
   c. hydrochloric acid(aq) + sodium hydroxide(aq) ®
   d. potassium sulfite(aq) + nitric acid(aq) ®
   e. cadmium(II) nitrate(aq) + dihydrogen sulfide(g) ®
   f. hydrofluoric acid(aq) + sodium hydroxide(aq) ®
   g. potassium carbonate(aq) + acetic acid(aq) ®
   h. lithium(s) + water(l) ®

7. Use the reactions below to answer the following 3 questions.
   a. sulfuric acid(aq) + barium hydroxide(aq) ®
   b. acetic acid(aq) + sodium carbonate(aq) ®
   c. ammonia(aq) + hydrochloric acid(aq) ®
   d. lead(II) nitrate(aq) + sodium sulfide(aq) ®
   e. sodium sulfide(aq) + hydrochloric acid(aq) ®

I. Select all reactions above that will lead to a precipitation reaction.
II. Select all reactions above that are a weak base reacting with a strong acid.
III. Select all reactions above that are an example of a gas-forming reaction?

8. Which reaction is a weak acid reacting with a weak base reaction?
   a. HCl(aq) + NaOH(aq) ® H₂O(l) + NaCl(aq)
   b. AgNO₃(aq) + NaCl(aq) ® AgCl(s) + NaNO₃(aq)
   c. CH₃COOH(aq) + LiOH(aq) ® NaCH₃COO(aq) + H₂O(l)
   d. HF(aq) + NH₃(aq) ® NH₄⁺(aq) + F⁻(aq)

9. Identify the following chemicals when they are dissolved into water as a strong, weak, or nonelectrolyte.
   a. NaCl   b. HCl   c. CH₃COOH   d. sugar   e. BaSO₄
   f. NH₃   g. H₂SO₄   h. NaOH   i. HF

10. Write the balanced net ionic reaction for each of the following. If no reaction occurs, write no reaction. Include phases [(aq), (s), (l), (g)]. (Hint: Start by writing a molecular reaction, then a complete ionic, and then a net ionic – it’s long to do it this way but it is also instructive.)
    a. An aqueous solution of potassium chloride, KCl(aq), is combined with an aqueous solution of silver(I) nitrate, AgNO₃(aq), to yield an insoluble precipitate.
    b. Aqueous Pb(NO₃)₂(aq) and aqueous NaI(aq) are combined to yield an insoluble precipitate.
    c. A solution of hydrochloric acid, HCl(aq), and a solution of potassium hydroxide, KOH(aq) are combined.
    d. A balloon containing oxygen gas and hydrogen gas is combusted.
    e. Aqueous barium chloride and aqueous potassium sulfate are mixed together to yield an insoluble precipitate.
11. Which of the following compounds will form a solution that will have the light bulb in the conductivity experiment not shine bright?
   a. NaCl       b. KOH       c. NH₄CH₃COO      d. HClO₄      e. none of the above

12. Assign the oxidation numbers for each element present.
   a. Na   b. Fe   c. Cl₂  d. Li⁺  e. Br⁻  f. NO   g. NO₂  h. NaCl  i. NaNO₃  j. PO₄⁻³  k. H₂O  l. NO₃⁻
   m. H₂SO₄  n. Ca(NO₃)₂  o. S₂O₃⁻²  p. CO₃⁻²  q. MnSO₄  r. Cr₃(PO₄)₂  s. CuNO₃  t. NH₄NO₃

13. Identify what is being oxidized, reduced, what the oxidizing agent is, and what the reducing agent is. (Hint: When assigning oxidation numbers you don’t use the stoichiometric coefficients.)
   a. 8S²⁻(aq) + 16NO₃⁻(aq) + 32H⁺(aq) → 16NO₂(g) + S₈(s) + 16H₂O
   b. NO₃⁻(aq) + Cr(s) + 4H⁺(aq) → NO(g) + Cr³⁺(aq) + 2H₂O(l)
   c. 2MnO₄⁻(aq) + 5SO₂(g) + 2H₂O(l) → 5SO₄²⁻(aq) + 2Mn²⁺(aq) + 4H⁺(aq)
   d. 8Hg₂²⁺ + 8H₂S → 16Hg + S₈ + 16H⁺

14. A white compound is found and is either Pb(NO₃)₂ or Ba(NO₃)₂. Which one of the following compounds could be used when dissolved in water and the unknown white compound to determine the identity of the unknown compound?
   a. HNO₃       b. HCl       c. AgNO₃       d. ClO₄       e. C₂H₅OH (ethanol)

15. A white compound is found and is either K₂CO₃ or AgNO₃. Which one of the following compounds could be used with water and the unknown white compound to determine the identity of the unknown compound?
   a. BaCl₂      b. NaClO₄     c. Li₂SO₄     d. CaI₂     e. HNO₂

16. (skip if not covered) Using the metal activity series shown on the prior page above (see Table 3.4 in the text), complete the reactions below by writing the molecular and net ionic reactions.
   a. Ni(s) + HBr(aq) →
   b. Al(s) + AgNO₃(aq) →
   c. Fe(s) + Zn(NO₃)₂(aq) →
   d. Mg(s) + SnSO₄(aq) →

ANSWERS
1. a. 2Mg(s) + SiO₂(s) → 2MgO(s) + Si(s)
    b. 3Ca(s) + N₂(g) → Ca₃N₂(s)
    c. 2CH₃OH(l) + 3O₂(g) → 2CO₂(g) + 4H₂O(l)
    d. CaCl₂(s) + Na₂CO₃(s) → CaCO₃(s) + 2NaCl(s)
    e. P₄O₁₀(s) + 6H₂O(l) → 4H₃PO₄(aq)
    f. 2C₆H₆(l) + 15O₂(g) → 12CO₂(g) + 6H₂O(l)

2. a. C₅H₁₂(l) + 8O₂(g) → 5CO₂(g) + 6H₂O(g)
    b. C₂H₄(g) + 3O₂(g) → 2CO₂(g) + 2H₂O(g)
    c. 4Na(s) + O₂(g) → 2Na₂O(s)
    d. 3Ca(s) + 2P(s) → Ca₃P₂(s)
3. a. \( \text{N}_2\text{O}_5(\text{s}) + \text{H}_2\text{O}(\text{l}) \rightarrow 2\text{HNO}_3(\text{aq}) \)
   b. \( \text{NH}_4\text{NO}_3(\text{s}) \rightarrow \text{N}_2\text{O}(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \)
   c. \( \text{MnCO}_3(\text{s}) \rightarrow \text{MnO}(\text{s}) + \text{CO}_2(\text{g}) \)

4. a. \( 2\text{HCl}(\text{aq}) + \text{Ba(OH)}_2(\text{aq}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + \text{BaCl}_2(\text{aq}) \)
   b. \( \text{AgNO}_3(\text{aq}) + \text{NaBr}(\text{aq}) \rightarrow \text{AgBr}(\text{s}) + \text{NaNO}_3(\text{aq}) \)
   c. \( 2\text{H}_2\text{O}(\text{l}) \rightarrow \text{O}_2(\text{g}) + 2\text{H}_2(\text{g}) \)

5. a. \( \text{Acids: HCl}/\text{hydrochloric acid, HBr}/\text{hydrobromic acid, HI}/\text{hydroiodic acid, H}_2\text{SO}_4}/\text{sulfuric acid, HNO}_3}/\text{nitr} \text{ic acid, HClO}_4}/\text{perchloric acid}; \text{ Bases: LiOH}/\text{lithium hydroxide, NaOH}/\text{na} \text{dium hydroxide, KOH}/\text{potassium hydroxide, Ca(OH)}_2}/\text{calcium hydroxide, Sr(OH)}_2}/\text{strontium hydroxide, Ba(OH)}_2}/\text{barium hydroxide}; \)
   b. \( \text{Weak acid: CH}_3\text{COOH}/\text{acetic acid}; \text{ Weak Base: NH}_3}/\text{ammonia} \)

6. a. precipitation \( \{2\text{KI}(\text{aq}) + \text{Pb(NO}_3)_2(\text{aq}) \rightarrow 2\text{KNO}_3(\text{aq}) + \text{PbI}_2(\text{s})\} \)
   b. gas-forming \( \{\text{Na}_2\text{S}(\text{aq}) + 2\text{HCl}(\text{aq}) \rightarrow 2\text{NaCl}(\text{aq}) + \text{H}_2\text{S}(\text{g})\} \)
   c. acid/base \( \{\text{HCl}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l}) + \text{NaCl}(\text{aq})\} \)
   d. gas-forming \( \{\text{K}_2\text{SO}_3(\text{aq}) + 2\text{HNO}_3(\text{aq}) \rightarrow 2\text{KNO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{SO}_2(\text{g})\} \)
   e. precipitation \( \{\text{Cd(NO}_3)_2(\text{aq}) + \text{H}_2\text{S}(\text{g}) \rightarrow \text{CdS}(\text{s}) + \text{HNO}_3(\text{aq})\} \)
   f. acid/base \( \{\text{HF}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{NaF}(\text{aq}) + \text{H}_2\text{O}(\text{l})\} \)
   g. gas-forming \( \{\text{K}_2\text{CO}_3(\text{aq}) + 2 \text{CH}_3\text{COOH}(\text{aq}) \rightarrow 2\text{KCH}_3\text{COO}(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})\} \)
   h. gas-forming \( \{2\text{Li}(\text{s}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow 2\text{LiOH}(\text{aq}) + \text{H}_2(\text{g})\} \)

7. I. a, d \{solubility rules: PbS insoluble; BaSO_4 insoluble\}
   II. c \{NH_3 is a weak base (memorized); HCl is a strong acid (memorized)\}
   III. b, e \{“b”: 2H^+(aq) + CO_3^{2-}(aq) \rightarrow H_2CO_3(aq) \rightarrow H_2O(l) + CO_2(g); “e”: S^{2-}(aq) + 2H^+(aq) \rightarrow H_2S(g)\}

8. d \{“a” = strong acid + strong base; “b” = precipitation; “c” = weak acid + strong base\}

9. \{To determine the answers below here is part of the information needed:
   metal+nonmetal or containing a polyatomic ion \rightarrow ionic;
   only 2 nonmetals \rightarrow molecular;
   strong acids \rightarrow memorized;
   strong bases \rightarrow memorized;
   chemicals that are acids (start with H or contain –COOH) but are not strong acids \rightarrow weak acids;
   NH_3 is a weak base \rightarrow memorized;
   soluble or insoluble \rightarrow from solubility rules
   ionic + soluble, strong acids, strong bases \rightarrow strong electrolytes (light bulb is on brightly)
   weak acids, weak bases \rightarrow weak electrolytes (light bulb is on but dimly)
   molecule compounds, ionic + insoluble \rightarrow nonelectrolytes (light bulb is not on)\}
   a. strong \{soluble ionic compound \rightarrow strong electrolyte\}
   b. strong \{strong acid \rightarrow strong electrolyte\}
   c. weak \{weak acid \rightarrow weak electrolyte\}
   d. non \{molecular compound \rightarrow non-electrolyte\}
   e. non \{insoluble ionic compound \rightarrow non-electrolyte\}
   f. weak \{weak base \rightarrow weak electrolyte\}
   g. strong \{strong acid \rightarrow strong electrolyte\}
   h. strong \{strong base \rightarrow strong electrolyte\}
   i. weak \{weak acid \rightarrow weak electrolyte\}
10. a. Molecular: KCl(aq) + AgNO₃(aq) → AgCl(s) + KNO₃(aq)

Complete Ionic: K⁺(aq) + Cl⁻(aq) + Ag⁺(aq) + NO₃⁻(aq) → AgCl(s) + K⁺(aq) + NO₃⁻(aq)

{KCl – soluble ionic compound = break up; AgNO₃ – soluble ionic compound = break up;
AgCl(s) – insoluble ionic compound = don’t break up; KNO₃ – soluble ionic compound = break up}

Net Ionic: Ag⁺(aq) + Cl⁻(aq) → AgCl(s)

b. Molecular: Pb(NO₃)₂(aq) + 2NaI(aq) → PbI₂(s) + 2NaNO₃(aq)

Complete Ionic: Pb⁺²(aq) + 2NO₃⁻(aq) + 2Na⁺(aq) + 2I⁻(aq) → PbI₂(s) + 2Na⁺(aq) + 2NO₃⁻(aq)

{Pb(NO₃)₂ – soluble ionic compound = break up; NaI – soluble ionic compound = break up;
PbI₂(s) – insoluble ionic compound = don’t break up; NaNO₃ – soluble ionic compound = break up}

Net Ionic: Pb⁺²(aq) + 2I⁻(aq) → PbI₂(s)

c. Molecular: HCl(aq) + KOH(aq) → H₂O(l) + KCl(aq)

Complete Ionic: H⁺(aq) + Cl⁻(aq) + K⁺(aq) + OH⁻(aq) → H₂O(l) + K⁺(aq) + Cl⁻(aq)

{HCl – strong acid = break up; KOH – strong base = break up; H₂O – molecular compound = don’t break up;
KCl – soluble ionic compound = break up}

Net Ionic: H⁺(aq) + OH⁻(aq) → H₂O(l)

d. Molecular, Complete Ionic, and Net Ionic: 2H₂(g) + O₂(g) → 2H₂O(g)

e. Molecular: BaCl₂(aq) + K₂SO₄(aq) → BaSO₄(s) + 2KCl(aq)

Complete Ionic: Ba⁺²(aq) + 2Cl⁻(aq) + 2K⁺(aq) + SO₄²⁻(aq) → BaSO₄(s) + 2K⁺(aq) + 2Cl⁻(aq)

{BaCl₂ – soluble ionic compound = break up; K₂SO₄ – soluble ionic compound = break up;
BaSO₄(s) – insoluble ionic compound = don’t break up; KCl – soluble ionic compound = break up}

Net Ionic: Ba⁺²(aq) + SO₄²⁻(aq) → BaSO₄(s)

11. e. {poor conductor of electricity = weak or non-electrolyte; “a”: soluble ionic compound = strong conductor/electrolyte;
“b”: strong base = strong conductor/electrolyte; “c”: soluble ionic compound = strong conductor/electrolyte;
“d”: strong acid = strong conductor/electrolyte}

12. a. Na = 0  b. Fe = 0  c. Cl = 0  d. Li = +1  e. Br = -1  f. O = -2, N = +2  g. O = -2, N = +4

h. Na = +1, Cl = -1  i. Na = +1, O = -2, N = +5  j. O = -2, P = +5  k. H = +1, O = -2  l. O = -2, N = +5

m. H = +1, O = -2, S = +6  n. Ca = +2, O = -2, N = +5  o. O = -2, S = +2  p. O = -2, C = +4

q. Mn = +2, S = +6, O = -2  {separate into Mn²⁺ and SO₄²⁻; solve each part separately}
r. Cr = +2, P = +5, O = -2  {separate into Cr³⁺ and PO₄³⁻; solve each part separately}
s. Cu = +1, N = 5, O = -2  {separate into Cu²⁺ and NO₃⁻; solve each part separately}
t. N = -3 (from NH₄⁺), H = +1, N = +5 (from NO₃⁻), O = -2  {separate into NH₄⁺ and NO₃⁻; solve each part separately}
13. a. \(S^{2-}\) is oxidized, \(NO_3^-\) is reduced, \(NO_3^-\) is the oxidizing agent, \(S^{2-}\) is the reducing agent

\{assign oxidation numbers and see what changes: S: -2 in \(S^{2-}\) \(\rightarrow\) 0 in \(S_8\) \(\rightarrow\) oxidation; N: +5 in \(NO_3^-\) \(\rightarrow\) +4 in \(NO_2\) \(\rightarrow\) reduction; since \(S^{2-}\) oxidized \(\rightarrow\) reducing agent; since \(NO_3^-\) reduced \(\rightarrow\) oxidizing agent\}

b. Cr is oxidized, \(NO_3^-\) is reduced, \(NO_3^-\) is the oxidizing agent, Cr is the reducing agent

\{assign oxidation numbers and see what changes: N: +5 in \(NO_3^-\) \(\rightarrow\) +2 in NO \(\rightarrow\) reduction; Cr: 0 in Cr \(\rightarrow\) +3 in \(Cr^{+3}\) \(\rightarrow\) oxidation; since Cr oxidized \(\rightarrow\) reducing agent; since \(NO_3^-\) reduced \(\rightarrow\) oxidizing agent\}

c. \(SO_2\) is oxidized, \(MnO_4^-\) is reduced, \(MnO_4^-\) is the oxidizing agent, \(SO_2\) is the reducing agent

\{assign oxidation numbers and see what changes: S: +4 in \(SO_2\) \(\rightarrow\) +6 in \(SO_4^{2-}\) \(\rightarrow\) oxidation; Mn: +7 in \(MnO_4^-\) \(\rightarrow\) +2 in \(Mn^{2+}\) \(\rightarrow\) reduction; since \(SO_2\) oxidized \(\rightarrow\) reducing agent; since \(MnO_4^-\) reduced \(\rightarrow\) oxidizing agent\}

d. \(H_2S\) is oxidized, \(Hg_2^{2+}\) is reduced, \(Hg_2^{2+}\) is the oxidizing agent, \(H_2S\) is the reducing agent

\{assign oxidation numbers and see what changes: S: -2 in \(H_2S\) \(\rightarrow\) 0 in \(S_8\) \(\rightarrow\) oxidation; Hg: +1 in \(Hg_2^{2+}\) \(\rightarrow\) 0 in Hg \(\rightarrow\) reduction; since \(H_2S\) oxidized \(\rightarrow\) reducing agent; since \(Hg_2^{2+}\) reduced \(\rightarrow\) oxidizing agent\}

14. b. \{HCl: \(Pb^{+2} + 2Cl^- \rightarrow PbCl_2(s)\) forms a precipitate; HCl: \(Ba^{+2} + 2Cl^- \rightarrow BaCl_2(aq)\) is soluble; hence, if HCl is added and a precipitate forms, then the unknown was \(Pb(NO_3)_2\) while if HCl is added and no precipitate forms, the unknown was \(Ba(NO_3)_2\); all the other choices will yield no reaction and hence would not distinguish between these two chemicals\}

e. \{HNO_2 will generate bubbles of \(CO_2(g)\); answers “a” and “d” will cause precipitation from both \(K_2CO_3\) and \(AgNO_3\) so it would not clarify what the unknown is.\}

16. a. \(Ni(s) + 2HBr(aq) \rightarrow H_2(g) + NiBr_2(aq)\) \{Ni(s) is up and to the left of \(H^+\)\}

b. \(Al(s) + 3AgNO_3(aq) \rightarrow 3Ag(s) + Al(NO_3)_3(aq)\) \{Al(s) is up and to the left of \(Ag^+\)\}

c. \(Fe(s) + Zn(NO_3)_2(aq) \rightarrow no reaction\) \{Fe(s) is below and to the left of \(Zn^{+2}\) \(\rightarrow\) No reaction!\}

d. \(Mg(s) + SnSO_4(aq) \rightarrow Sn(s) + MgSO_4(aq)\) \{Mg(s) is up and to the left of \(Sn^{+2}\)\}