Writing and Predicting Products of Chemical Reactions:

AP Chemistry Exam Question 4 of Section II (Free Response)

"4. For each of the following three reactions, in part (i) write a BALANCED equation and in part (ii) answer the question about the reaction. In part (i), coefficients would be in terms of lowest whole numbers. Each of the reactions occurs in aqueous solution unless otherwise indicated."

"Represent substances in solution as ions if the substance is extensively ionized. Omit formulas for any ions or molecules that are unchanged by the reaction (spectator ions). In all cases a reaction occurs!" (You will never have all the substances be subtracted out in the net ionic equation).

Scoring the question: This is 10% of your score for Section II (Free Response)

Each of the three reactions is worth a maximum of 5 points. (15 pts total)

One point is given if the **reactants** are correct.

Two points are given if the **products** are correct.

If the equation is correct but the charge on ions is incorrect, 1 point is deducted.

One point is given for correct **balancing**.

One point is given for the correct **answer to the question**.

The kinds of question they may ask might be:

1. What type of reaction is it and why?
2. For precipitation reactions - What is the color of the product?
3. For redox reactions - What are the oxidation states?
   - What are the oxidizing or reducing agents?
   - What would happen if the acid was diluted? (The use of a *concentrated* acid is an indicator that the reaction is redox).
4. For acid-base reactions – What's the pH be after the reaction?
   - What indicator might be used?
   - What type of salt is produced (acidic or basic)?
   - Write the conjugate acid/base pairs.
   - Write the ka expression.
   - Is the substance a strong or weak acid or base?
5. In general: Is the product soluble?
   - How could the gas produced be recovered?
   - What is a good test for a particular gas produced?
   - What color is one of the substances?
     - **DON'T use *clear* for *colorless*!! NOT the same!
   - Is it an endo or exothermic reaction?
   - What is the Lewis Dot structure of .....?
   - What is the change in entropy?
   - Is the reaction reversible?

Need to know:

A). When to write the formulas of compounds in ion or unionized form (see handout by this name) and also how to write a net ionic equation:

1. Solubility rules for salts (soluble salts ionize, insoluble ones don't)
2. Rules for Acids and Bases (strong acids & bases ionize, weak ones don't)

B). Driving forces for a chemical reaction:

1. Production of a **precipitate** (insoluble, non-ionizing solid product) –ppt rxns
   Keq > 1 because Ksp < 1
2. Production of **water** (molecular, non-ionizing product) ex. acid/base rxns
3. Production of a **weak (or non-) electrolyte** (non-ionizing product)
   Keq > 1 because Ksp < 1
4. Production of a **gas** (molecular, non-ionizing product)
   Loss of a gas product continually shifts equilibrium to the right.
5. **Electron transfer** (one element loses & one gains electrons) - redox rxns
   If the electrode potential (E) for the reducing half-reaction is more negative than that for the oxidizing half-reaction.

C). Hints In General:

1. For compounds with two cations, the first cation is removed first.
ex. $NaHCO_3$ --> $Na^+ + HCO_3^-$

2. For polyprotic acids (more than one H^+), one H^+ is removed per reaction.
ex. H_3PO_4 --> $H^+ + H_2PO_4^-$ $\qquad$ H_2SO_4 --> $H^+ + HSO_4^-$
$H_2PO_4^-$ --> $H^+ + HPO_4^{-2}$ $\qquad$ HSO_4^- --> $H^+ + SO_4^{-2}$
HPO_4^{-2} --> $H^+ + PO_4^{-3}$

3. Typical reactions of some anions and a cation that produce gases:
CO_3^{-2} in the presence of H^+(acid) generally reacts to produce $CO_2(g) + H_2O$
SO_3^{-2} in the presence of H^+ generally reacts to produce $SO_2(g) + H_2O$
NO_2^{-1} in the presence of H^+ generally reacts produce $NO_2(g) + NO(g) + H_2O$
NH_4^+ in the presence of OH^- generally reacts to produce $NH_3(g) + H_2O$

4. It may be helpful to write H_2O as HOH to see how it reacts.

5. Acetic acid (ethanoic acid) may be written as $HC_2H_3O_2$ or as CH_3COOH.

D). Types of reactions:

Non-Redox Reactions - No change in oxidation numbers occur:
(double replacement / double displacement / metathesis reactions)

1. Precipitation **(formation of a precipitate, an insoluble or non-ionizing solid product from 2 aqueous reactants)**

A solution of mercury(I) nitrate is added to a solution of potassium chloride.

$Hg_2^{+2} + Cl^- \rightarrow Hg_2Cl_2$

2. ***Acid-Base Reactions*** (Arrhenius, Bronsted-Lowry, or Lewis Acids & Bases)

An **acid** is any compound that can release a H+ whether it is strong or weak.

A **base** is any compound that can bond to a H+ whether strong or weak.

Excess hydrochloric acid is added to a solution of sodium hydroxide.

$H^+ + OH^- \rightarrow H_2O$

Excess hydrochloric acid is added to a solution of sodium hydrogen sulfite.

$H^+ + HSO_3^- \rightarrow H_2O + SO_2$

a). Hydrolysis - addition of water to salts of weak acids, salts of weak bases, or transition metals

$CN^- + H_2O \rightarrow HCN + OH^-$

$S^{-2} + H_2O \rightarrow HS^- + OH^-$

$NH_4^+ + H_2O \rightarrow NH_3 + H_3O^+$

$Al^{+3} + H_2O \rightarrow Al(OH)_2^+ + H_3O^+$

b). Metal Oxides (Basic Anhydrides) + Water --> Bases (metal oxides)

$MgO + H_2O \rightarrow Mg(OH)_2$

c). Nonmetal Oxides (Acidic Anhydrides) + Water --> Acids (non-metal oxides)

$N_2O_5 + H_2O \rightarrow H^+ + NO_3^-$

3. ***Complexation*** (non-redox reactions involving the synthesis or decomposition of a compound with complex ions)

A complex ion is an ion containing one or more molecules or ions bonded to a central transition metal. Some common complex ions are:

$Cu(NH_3)_4^{+2}$ $Ni(NH_3)_4^{2+}$ $Zn(NH_3)_4^{+2}$ $Ag(NH_3)^{2+}$ $FeSCN^{+2}$ $Pb(OH)_3^-$ $Al(OH)_4^-$ $Zn(OH)_4^{-2}$ $Cr(OH)_4^-$

When in doubt as to the coordination number (number of ligands attached to the transition metal), double the charge on the ion.

Some common ligands are:

NH_3 OH^- I^- CO

Much of the behavior of the reactions can be rationalized on the basis of Lewis acid/base theory. Below the NH_3 has an unshared electron pair, is electron rich and can donate an e- pair (Lewis base). The Cr+3 is electron deficient and can accept electron pairs (Lewis acid).

Excess 3M ammonia solution is added to solution of chromium(III) nitrate

$Cr^{+3} + NH_3 \rightarrow Cr(NH_3)_6^{+3}$

4. *Redox Reactions* – rxns with **oxidation/reduction, electron transfer**

A. Synthesis (Addition or Combination)

metallic element + nonmetallic element --> ionic compound

A piece of solid copper metal is covered with powdered sulfur in a crucible and heated until the sulfur melts around the copper.

$Cu + S \rightarrow Cu_2S$ or CuS

B. Decomposition (One compound --> elements +/or simpler compounds)

Metallic carbonates --> metallic oxides + CO2
Metallic chlorates --> metallic chlorides + O2
Metallic hydroxides --> metallic oxides + water (reverse of basic anhydride)
Acids --> nonmetallic oxide + water (reverse of acidic anhydride)

Solid potassium chlorate is heated in a test tube.

$KClO_3 \rightarrow KCl + O_2$

C. Single Replacement (element + compound --> element + compound)

A zinc strip is placed in a solution of copper(II) chloride.

$Zn + Cu^{+2} \rightarrow Zn^{+2} + Cu$

D. Combustion (Burning) Nonmetal compounds react with oxygen to produce nonmetal oxides.

carbon --> carbon dioxide
hydrogen --> water
nitrogen --> nitrogen dioxide

Methanol is burned in the presence of air.

$CH_3OH + O_2 \rightarrow CO_2 + H_2O$

E. Redox By Commonly Used "Agents"

Common Oxidizing Agents are:	Reduced To:
NO_3^-	NO
MnO_4^-	Mn^{+2} (acid), MnO_2 (base)
H_2O_2	H_2O
$Cr_2O_7^{-2}$, CrO_4^{-2}	Cr^{+3} (acid), $Cr(OH)_3$ (base)
IO_3^-	I^-
ClO_3^-	Cl^-
BrO_3^-	Br^-
Sn^{+4}	Sn^{+2}
Fe^{+3}	Fe^{+2}
F_2	F^-
Cl_2	Cl^-
Br_2	Br^-
O_2	H_2O or OH^-
MnO_2	Mn^{+2}
PbO_2	Pb^{+2}

Common Reducing Agents are:	**Oxidized To:**
H_2O_2	O_2
SO_3^{-2}	SO_4^{-2}
SO_2	SO_4^{-2}
$S_2O_3^{-2}$	SO_4^{-2}, $S_2O_6^{-2}$ with I_2
	S and $SO_2(g)$ with H^+
H_2	H^+
Metal M^0	M^+
I^-	I_2
Zn	Zn^{+2}
Al	Al^{+3}
Sn^{+2}	Sn^{+4}
Fe^{+2}	Fe^{+3}
$C_2O_4^{-2}$	CO_2
H_2S	S

A strip of zinc metal is added to a solution of copper(II) nitrate.

$Zn + Cu^{+2} \rightarrow Zn^{+2} + Cu$

Chlorine gas is bubbled through a solution of sodium iodide.

$Cl_2 + I^- \rightarrow I_2 + Cl^-$