AP **Predicting Reactions** Name [redacted]

Know: Nomenclature (including names of polyatomic ions)
Solubility rules
Which elements are diatomic (HOFBrINCl **and also At**)
Charges of common transition metal ions
Fe is +2 or 3; Pb is +2 or 4; Sn is +2 or +4; Cu is +1 or 2; Ni is +2 or 3; Cr is +2, 3, or 6;
A halogen is an element from 7A

Types of Reactions: (UCE Rounds in parenthesis.)

1. **Combustion**
2. **Synthesis (or Combination)** (Round 2)
3. **Decomposition** (Round 2)
4. **Single Displacement** (Round 3)
5. **Double Displacement** (Round 4 – 6)
6. **Organic Reactions** (Round 1)
7. **Hydrolysis** (Round 7)
8. **Redox** (Round 11)
9. **Electrolysis** (Round 12)
10. **Complex ion reactions** (Round 13)

1. **Combustion** – results in forming the oxide of the elements of the compound
   a) Hydrocarbons or alcohols combine with oxygen to form CO_2 and H_2O
      Ex. Ethanol is burned in air
      $C_2H_5OH + O_2 \rightarrow H_2O + CO_2$
   b) Nonmetallic hydrides (a hydride is a compound with a H^- anion) combine with oxygen to form nonmetal oxides and water
      Ex. Gaseous silane, SiH_4. is burned in oxygen.
      $SiH_4 + O_2 \rightarrow H_2O + SiO_2$
   c) Nonmetallic sulfides combine with oxygen to from nonmetal oxides and sulfur dioxide
      Ex. Carbon disulfide vapor is burned with excess oxygen
      $CS_2 + O_2 \rightarrow CO_2 + SO_2$
   d) Ammonia combines with limited oxygen to produce NO and H_2O and with excess oxygen to produce NO_2
      Ex. Ammonia is ignited in a closed container with limited air
      $NH_3 + O_2 \rightarrow H_2O + NO$

2. **Synthesis (or Combination)** (UCE Round 2) – two reactants result in a single product
   a) Metal oxide + water → base
      Ex. Solid calcium oxide is added to water
      $CaO + H_2O \rightarrow Ca^{2+} + OH^-$ $Ca(OH)_2$ is ionized because it is a strong base in water.
   b) Nonmetal oxide + water → ternary acid
      Ex. Sulfur dioxide gas is bubbled through water
      $SO_2 + H_2O \rightarrow H_2SO_3$
   c) Metal oxide + nonmetal oxide → ternary salt
      Ex. Powdered magnesium oxide is added to a container of carbon dioxide
      $MgO + CO_2 \rightarrow MgCO_3$

X 3. **Decomposition** (UCE Round 2) – one reactant becomes several products
   a) Metallic hydroxide → metal oxide + water
      Ex. Magnesium hydroxide is heated
      $Mg(OH)_2 \rightarrow MgO + H_2O$

b) Ternary acid → nonmetal oxide + water
Ex. Sulfuric acid is heated
$H_2SO_4 \rightarrow SO_2 + H_2O$

c) Ternary salt → metal oxide + nonmetal oxide
Ex. Sodium nitrate is strongly heated
$NaNO_3 \rightarrow Na_2O + NO_2$

d) Metallic chlorates → metallic chlorides + oxygen
Ex. Potassium chlorate is heated
$KClO_3 \rightarrow KCl + O_2$

e) Electrolysis decomposes compound into its elements
Ex. A current of electricity is passed through water
$H_2O \rightarrow H_2 + O_2$

f) Hydrogen peroxide → water + oxygen
Ex. Hydrogen peroxide is heated slightly
$H_2O_2 \rightarrow H_2O + O_2$

g) Metallic carbonates → metal oxides + carbon dioxide
Ex. Copper (II) carbonate is heated
$CuCO_3 \rightarrow CuO + O_2$

h) Ammonium carbonate → ammonia (NH_3) + water + carbon dioxide
$(NH_4)_2CO_3 \rightarrow NH_3 + H_2O + CO_2$

4. Single displacement (UCE Round 3) – One element is displaced by another element (metals displace metals and nonmetals displace nonmetals)

Examples:

Zinc metal reacts with tin (II) sulfate solution
$Zn + Sn^{2+} \rightarrow Sn + Zn^{2+}$

Chlorine gas reacts with sodium bromide solution
$Cl_2 + Br^- \rightarrow Br_2 + Cl^-$

Potassium reacts with water
$K + H_2O \rightarrow K^+ + OH^- + H_2$

Magnesium turnings are added to a solution of iron (III) chloride
$Mg + Fe^{3+} \rightarrow Mg^{2+} + Fe$

5. Double Displacement (a.k.a. Metathesis) (UCE Round 4–6) **General Formula: AB + CD → AD + CB**

a) Neutralization – Acid + Base → Water + Salt
Ex. Hydrofluoric acid and magnesium hydroxide solutions are mixed (Weak Acid – Weak Base)
$HF + Mg(OH)_2 \rightarrow H_2O + MgF_2$

Ex. Hydrochloric acid and sodium hydroxide solutions are mixed. (Strong Acid – Strong Base)
$H^+ + OH^- \rightarrow H_2O$

Ex. Acetic acid solutions reacts with solid potassium hydroxide
$CH_3COOH + KOH \rightarrow K^+\ CH_3COO^- + H_2O$

b) Precipitation – forming an insoluble product i.e. $Ag^+ + Cl^- \rightarrow AgCl$
Ex. Aqueous solutions of silver nitrate and sodium iodide are mixed
$Ag^+ + I^- \rightarrow AgI$

Ex. Solid aluminum chloride is added to an aqueous solution of potassium chromate
$AlCl_3 + CrO_4^{2-} \rightarrow Al_2(CrO_4)_3 + Cl^-$

c) Gas Forming – produces a gas **Know: $H_2CO_3 \rightarrow H_2O + CO_2$ and $H_2SO_3 \rightarrow H_2O + SO_2$**

Ex. A solution of hydrofluoric acid is mixed with solid magnesium carbonate

$HF + MgCO_3 \rightarrow H_2CO_3 + MgF_2 \rightarrow H_2O + CO_2 + MgF_2$

Ex. Excess hydrochloric acid solution is added to a solution of potassium sulfite.

$H^+ + SO_3^{2-} \rightarrow H_2O + SO_2$

Ex. Calcium carbonate crystals are added to a solution of hydrochloric acid

$CaCO_3 + H^+ \rightarrow H_2O + CO_2 + Ca^{2+}$

- Less common examples
  - Phosphorus halides (i.e. PF_3) react with water to make an acid of phosphorus (H_3PO_4) and a binary acid containing hydrogen (i.e. HF) $PF_3 + H_2O \rightarrow H_3PO_4 + HF$
    $PBr_3 + H_2O \rightarrow H_3PO_4 + H^+ + Br^-$
  - Group 1A and 2A nitrides (i.e. Mg_3N_2) react with water to make the metallic hydroxide (i.e. $Mg(OH)_2$) and ammonia (NH_3) $Mg_3N_2 + H_2O \rightarrow Mg(OH)_2 + NH_3$
    $Na_3N + H_2O \rightarrow Na^+ + OH^- + NH_3$

6. Organic Reactions (Round 1)

a) Addition reaction – hydrogen or halogen is added to a compound with a multiple bond. The hydrogen or halogen breaks the multiple bond and bonds with the carbon compound.

Ex. Fluorine gas is bubbled through ethene.

$F_2 + CH_2{=}CH_2 \rightarrow CH_2F{-}CH_2F$

b) Substitution reaction – when an atom (often a halogen) is added

Ex. Methane gas is mixed with chlorine gas.

$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$

c) Organic Combustion reaction – when an organic compound reacts with oxygen gas (O_2) to produce water (H_2O) and carbon dioxide (CO_2)

Ex. Ethane burns in air.

$C_2H_6 + O_2 \rightarrow CO_2 + H_2O$

d) Esterification reaction – when a carboxylic acid (R-COOH) is combined with an (R'-OH) alcohol to make an ester (R-COO-R') and water (H_2O)

Ex. Propanoic acid is reacted with ethanol

$CH_3CH_2COOH + CH_3CH_2OH \rightarrow CH_3CH_2COOCH_2CH_3 + H_2O$

7. Hydrolysis (UCE Round 7) – compounds reacting with water

Watch for soluble salts that contain anions of weak acids (the anion is a conjugate base) or cations of weak bases (the cation is a conjugate acid).

<u>Examples</u>:

1.0 M sodium acetate is added to water

$CH_3COO^- + H_2O \rightarrow CH_3COOH + OH^-$

Solid ammonium chloride is added to water

$NH_4Cl + H_2O \rightarrow NH_3 + H_3O^+ + Cl^-$

8. Redox – (a.k.a. oxidation-reduction) (UCE Round 11) – change in charges (oxidation state)

Keywords to look for:

- Common oxidizers or reducers (on tables below)
- "acidified" or "acid added"

Less common things to look for:

- Hydrides of 1A and Ca, Ba, or Sr dissolve in water to make hydroxides and H_2 gas.
  i.e. $NaH + H_2O \rightarrow Na^+ + OH^- + H_2$ or $BaH_2 + H_2O \rightarrow Ba^{2+} + OH^- + H_2$
- One element can be both oxidized and reduced

Common Oxidizers	What they produce
MnO_2 in acid solution	Mn^{2+}
MnO_4^- in acid solution	Mn^{2+}
MnO_4^- in neutral or basic solution	MnO_2
$Cr_2O_7^{2-}$ in acid	Cr^{3+}
HNO_3, concentrated	NO_2
Halogens, diatomic i.e. F_2	Halide ions i.e. F^-
H_2SO_4, hot, concentrated	SO_2

Common Reducers	What they produce
Metal element	Metal ion
Halide ions	Halogens, diatomic
Sulfite (SO_3^{2-})	Sulfate (SO_4^{2-})
Nitrite (NO_2^-)	Nitrate (NO_3^-)
H_2O_2	O_2
$C_2O_4^{2-}$	CO_2

Examples:

Magnesium metal is added to dilute nitric acid
$Mg + H^+ + NO_3^- \rightarrow Mg^{2+} + NO_2 + H_2O$

Solution of iron (II) nitrate is added to an acidified solution of potassium permanganate
$Fe^{2+} + MnO_4^- + H^+ \rightarrow Mn^{2+} + Fe^{3+} + H_2O$

Solutions of potassium iodide, potassium iodate, and dilute sulfuric acid are mixed
$I^- + IO_3^- + H^+ \rightarrow I_2 + H_2O$

A piece of iron is added to a solution of iron (III) sulfate
$Fe + Fe^{3+} \rightarrow Fe^{2+}$

Solid lithium hydride is placed in water
$LiH + H_2O \rightarrow Li^+ + OH^- + H_2$

9. Electrolysis (Round 12) – where an electric current is passed through a solution and one kind of ion is oxidized and another kind of ion is reduced.

Reductions:

A cation may be reduced to its metal. $M^{x+} \rightarrow M(s)$
Water can be reduced to hydrogen and hydroxide. $H_2O \rightarrow H_2 + OH^-$

Which will happen?

- Transition (B-groups) metal ions are easier to reduce than water, so if you have a transition metal in water, the metal ions will be reduced to the solid neutral metal.
- Representative (A-groups) metal ions are harder to reduce than water, so if you have a representative metal in water the water will be reduced and the representative metal will stay as ions.

Oxidations:

An anion may be oxidized to its nonmetal. $N^{y-} \rightarrow N$ or (N_2 if it is diatomic)
Water can be oxidized to oxygen and hydrogen ions. $H_2O \rightarrow O_2 + H^+$

Which will happen?

- It is easier to oxidize chloride, bromide, and iodide to their ions than it is to oxidize water, so if any of these three are in water their ions will be produced.
- However, fluorine and all of the polyatomic ions are harder to oxidize than water, so if only these ions are in water the water will be oxidized instead of the ions

Ex. Aqueous calcium chloride is electrolyzed.
What could be reduced: Ca^{2+} and H_2O
Ca^{2+} is an A-group (and therefore harder to reduce than water) so the H_2O will be reduced to H_2
What could be oxidized?
Cl^- and H_2O → Cl^- is easier to oxidize than H_2O so, Cl^- will be oxidized to Cl_2
Rxn: $H_2O + Cl^- \rightarrow H_2 + OH^- + Cl_2$

Ex. Aqueous zinc sulfate is electrolyzed.
What could be reduced: Zn^{2+} and H_2O → Zn^{2+} is easier so, $Zn^{2+} \rightarrow Zn$
What could be oxidized? SO_4^{-2} and H_2O → H_2O is easier so, $H_2O \rightarrow O_2 + H^+$
Rxn: $Zn^{2+} + H_2O \rightarrow Zn + O_2 + H^+$

Ex. Molten calcium phosphide is electrolyzed. (Note: Molten means liquid. There is no water present!)
What could be reduced: Ca^{2+} → no other choices so, $Ca^{2+} \rightarrow Ca$
What could be oxidized? P^{-3} → no other choices so, $P^{3-} \rightarrow P$
Rxn: $Ca_3P_2 \rightarrow Ca + P$

10. Complex ion reactions (UCE Round 13) – a reaction where a coordinate compound and a ligand react to make a complex ion

a) The formation of a Complex occurs when you add excess source of ligand to transition metal. Keywords such as "excess" and "concentrated" of compounds containing ligands indicates a formation of a complex ion.

Complex ions are compounds where ligands are bonded to a central atom that is a transition metal (or Al).
Ligands are normally OH^- or NH_3 or Cl^- (but could also be CN^- (cyanide) and SCN^- (thiocyanate).
In the complex, the number of ligands is normally twice the charge of the metal ion.

General Form:
where the transition metal (or Al) is represented by M
and the ligand is represented by L.
$M^{+x} + L \rightarrow [M(L)_{2x}]^{\text{net charge}}$

Ex. A concentrated solution of ammonia is added to a solution of copper (II) chloride
$Cu^{2+} + NH_3 \rightarrow [Cu(NH_3)_4]^{2+}$ (I will also accept $Cu(NH_3)_4^{2+}$ as well.)

b) Breakup of complex by adding an acid which makes a metal ion and the species that is formed when hydrogen ions from the acid reacts with the ligand
Ex. Tetrammine copper (II) ions are reacted with nitric acid
$[Cu(NH_3)_4]^{2+} + H^+ \rightarrow NH_4^+ + Cu^{2+}$