AP Notes (pg 1 of 7) **Conquering Net Ionic Equations - Question #4** Name_____Per____

AP equation sets are found in the free-response section of the AP test. You are given three equations. The equations are of mixed types. The section is worth 15 points and is 15 % of the free response grade. Free response is 55% of the total AP test grade.

Each equation is worth a total of 5 points. One point is given for the correct reactants and two points for all correct products. If a reaction has three products, one point is given for two correct products and two points for all correct products. Leaving in the spectator ions will result in one point deduction on the equation set (not 1 point per problem). One point for balancing, and the 5th point for answering the associated question correctly. You should *not* write down physical state symbols (aq, s, ppt, L, g ... etc)

The best way to prepare for the equation section of the AP test is to practice *lots* of equations. The equation sets are similar and some equations show up year after year. When you are reading an equation, first try to classify it by type to help you predict the products.

All AP equations "work" so you do not need to decide if it is a valid reaction. In each case, a reaction will occur. These equations need to be written in net ionic form. All spectator ions must be left out and all ions must be written in ionic form. All molecular substances and non-soluble compounds must be written together (not ionized!). Know your solubility rules!!!

Special considerations concerning solubility rules:

- $Ca(OH)_2$, $Sr(OH)_2$, are moderately soluble and can be written together or as ions. Watch for clues in the question.
  - ✓ $Ba(OH)_2$ is generally considered soluble and $Mg(OH)_2$ and $Be(OH)_2$ are considered insoluble.
- Weak acids, such as acetic acid or hydrofluoric acid, are *not* ionized and must be written as molecules.
- Solids, pure liquids, and gases are written as molecules
- A *saturated* solution is written in ionic form while a *suspension* is written together as a molecule.

Solubility Rules

1. Strong electrolytes (100% ionized) and written as ions, which leads to spectator ions that must be left out of the equation:
2. Know your 7 strong Acids: HCl, HBr, HI, H_2SO_4, HNO_3, $HClO_4$, $HClO_3$
3. Strong Bases: Hydroxides of group IA and IIA (Ba, Sr, Ca are marginally soluble, Be and Mg are insoluble)
4. Soluble Salts: according to the Quickie Table Below (ionic compounds: metal/nonmetal)

ALWAYS SOUBLE IF IN A COMPOUND	EXCEPT WITH
NO_3^-, Alkali ions, NH_4^+, $C_2H_3O_2^-$, ClO_4^-, ClO_3^-	No Exceptions
Cl^- , Br^- , I^-	Pb, Ag, Hg_2^{2+}
SO_4^{2-}	Pb, Ag, Hg_2^{2+} Ca, Sr, Ba

5. If it does not fit one of the three rules above, assume it is INSOLUBLE or a WEAK ELECTROLYTE (and written together). (This won't always be correct, but will cover most of the situations.)
6. Also, GASES, PURE LIQUIDS, and SOLIDS are non-electrolytes.
7. Remember the *phantoms* − molecules that decompose into gases when they are a product.
   - H_2CO_3 decomposes into H_2O and $CO_{2(g)}$
   - NH_4OH decomposes into H_2O and $NH_{3(g)}$
   - H_2SO_3 decomposes into H_2O and $SO_{2(g)}$
   - H^+ with S^{2-} produces a gas, $H_2S_{(g)}$

Polyatomic Ions - If you memorize the shaded ions (and learn their companions), you will be in great shape.

per− (1 more O)	−ate	−ite (1 less O)	hypo− (2 less O)
	nitrate NO_3^-	nitrite NO_2^{1-}	
	sulfate SO_4^{2-}	sulfite SO_3^{2-}	
	phosphate PO_4^{3-}	phosphite PO_3^{3-}	
perchlorate ClO_4^-	chlorate ClO_3^-	chlorite ClO_2^-	hypochlorite ClO^-
perbromate BrO_4^-	bromate BrO_3^-	bromite BrO_2^-	hypobromite BrO^-
periodate IO_4^-	iodate IO_3^-	iodite IO_2^-	hypoiodite IO^-

once you memorize bromate, you'll know the iodate and iodate series

Exceptions
hydroxide OH^-
cyanide CN^-
peroxide O_2^{2-}
ammonium NH_4^+

oxyen, O with an oxidation state = −1

Odd Companions or No Companion	
acetate $C_2H_3O_2^-$	
carbonate CO_3^{2-}	bicarbonate HCO_3^-
chromate CrO_4^{2-}	dichromate $Cr_2O_7^{2-}$
permanganate MnO_4^-	manganate MnO_4^{2-}
ferricyanide $Fe(CN)_6^{3-}$	ferrocyanide $Fe(CN)_6^{4-}$

not necessary to memorize, just shown for comparison

not necessary to memorize, as they do not show up on the AP exam but they are ions that we have used in class several times

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Double Replacement (metathesis)

Two compounds react to form two new compounds. No changes in oxidation numbers occur. All double replacement reactions must have a "driving force" that removes a pair of ions from solution. They may be removed by forming a precipitate, a gas, or molecular compound. If water forms, it's an acid/base reaction.

- **Formation of a precipitate:**
  A precipitate is an insoluble substance formed by the reaction of two aqueous substances. Two ions bond together so strongly that water can not pull them apart. You must know your solubility rules to write these net ionic equations!
  - *Solutions of silver nitrate and sodium sulfide are mixed.*

  $2Ag^+ + S^{2-} \rightarrow Ag_2S$

- **Formation of a gas:**

  Gases may form directly in a double replacement reaction such as H_2S or can form from the decomposition of a product such as H_2CO_3, H_2SO_3, or NH_4OH.
  - *Excess hydrochloric acid solution is added to a solution of sodium sulfite.*

    $2H^+ + SO_3^{2-} \rightarrow (H_2SO_3 \rightarrow) H_2O + SO_2$
  - *A solution of sodium hydroxide is added to a solution of ammonium nitrate.*

    $OH^- + NH_4^+ \rightarrow (NH_4OH \rightarrow) NH_3 + H_2O$
  - *Dilute sulfuric acid is added to a solution of sodium bicarbonate.*

    $H^+ + HCO_3^- \rightarrow (H_2CO_3 \rightarrow) H_2O + CO_2$
  - *Concentrated hydroiodic acid is added to solid copper(II) sulfide.*

    $2H^+ + CuS \rightarrow H_2S + Cu^{2+}$

- **Formation of a molecular substance (often an acid base neutralization):**

  When a molecular substance such as water or a weak acid is formed, ions are removed from solution and the reaction "works".
  - *Dilute solutions of lithium hydroxide and hydrobromic acid are mixed.*

    $OH^- + H^+ \rightarrow H_2O$ (Remember your strong acids - HBr, HCl, and HI are three of them, HF is not.)
  - *Dilute solutions of sodium fluoride and hydrobromic acid are mixed.*

    $F^- + H^+ \rightarrow HF$ (Remember HF is a weak acid, thus a molecule is formed.)
  - *Dilute solutions of potassium acetate and sulfuric acid are mixed.*

    $C_2H_3O_2^- + H^+ \rightarrow HC_2H_3O_2$ (Remember $HC_2H_3O_2$ is a weak acid, thus a molecule is formed.)
  - *Gaseous hydrofluoric acid reacts with solid silicon dioxide.*

    $4HF + SiO_2 \rightarrow SiF_4 + 2H_2O$

Acid/Base Neutralization

- **Acids react with bases to produce salts and water.**

One mole of hydrogen ions react with one mole of hydroxide ions to produce one mole of water. Watch out for information about quantities of each reactant! Remember which acids are strong (and thus ionize completely, except for concentrated sulfuric acid) and those acids which are weak (should be written as a molecule).

Sulfuric acid (a strong acid) can be written as H^+ and SO_4^{2-} or as H^+ and HSO_4^-

- *A solution of dilute sulfuric acid is added to a solution of barium hydroxide until the same number of moles of each compound as been added.*

  $H^+ + SO_4^{2-} + Ba^{2+} + OH^- \rightarrow BaSO_4 + H_2O$

- **Watch out for acids or bases that should be written as a molecule, such as weak acids or bases and gases.**
  - *A dilute solution of ammonia is added to a dilute solution of hydrochloric acid*

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

  - *Acetic acid solution is added to an aqueous solution of sodium hydroxide.*

    $HC_2H_3O_2 + OH^- \rightarrow H_2O + C_2H_3O_2^-$

  - *Hydrogen sulfide gas is bubbled through excess sodium hydroxide solution.*

    $H_2S + OH^- \rightarrow H_2O + S^{2-}$

  - *A suspension of magnesium hydroxide is added to a dilute solution of hydrochloric acid.*

    $Mg(OH)_2 + 2H^+ \rightarrow 2H_2O + Mg^{2+}$

- **Watch out for substances that can react with water before reacting with an acid or a base. (See the anyhdride section on next page) These are easier if though of as two step reactions, making the acid first, then neutralizing, though it is written all as one.**
  - *Sulfur dioxide gas is bubbled into an excess of a saturated solution of calcium hydroxide.*

    $SO_2 + Ca^{2+} + OH^- \rightarrow CaSO_3 + H_2O$ (SO_2 + water in the solution ➙ H_2SO_3 which reacts with $Ca^{2+} + OH^-$ ➙ $CaSO_3 + H_2O$)

Single Replacement

- Reaction where one element displaces another in a compound. One element is oxidized and another is reduced.
- Generic: $A + BC \rightarrow B + AC$
  - **Active metals replace less active metals or hydrogen (in acid or water).**

    The more easily oxidized metal replaces the less easily oxidized metal. The metal with the most negative reduction potential will be the most active, because that metal does not want to be reduce, it prefers to be oxidized. You will have a reduction potential chart during the free response.

    - *Magnesium turnings are added to a solution of nickel(III) chloride.*

      $3Mg + 2Ni^{3+} \rightarrow 2Ni + 3Mg^{2+}$ (This reaction must be balanced for charge since electrons lost/gained must be equal.)

    - *Nickel is added to hydrochloric acid.*

      $Ni + 2H^+ \rightarrow Ni^{2+} + H_2$

    - *Sodium is added to water.*

      $2Na + 2H_2O \rightarrow 2Na^+ + 2OH^- + H_2$ (Remember that some metals can replace hydrogen in water. You may find it useful to think of water as HOH)

  - **Active nonmetals replace less active nonmetals from their compounds in aqueous solution.**

    Each halogen will displace less electronegative (heavier) halogens from their binary salts.

    - *Chlorine gas is bubbled into a solution of potassium iodide.*

      $Cl_2 + 2I^- \rightarrow I_2 + 2Cl^-$

  - **Tricky redox reactions that appear to be ordinary single replacement reactions**:

    Hydrogen reacts with a hot metallic oxide to produce the elemental metal and water.

    - *Hydrogen gas is passed over hot zinc oxide.*

      $H_2 + ZnO \rightarrow Zn + H_2O$

    Metal sulfides react with oxygen to produce the metallic oxide and sulfur dioxide.

    - *Oxygen gas is passed over hot calcium sulfide.*

      $3O_2 + 2CaS \rightarrow 2CaO + 2SO_2$

Anhydrides

- Anhydride means "without water".
- Water is a reactant in each of these equations.
  - **Nonmetallic oxides (aka: acidic anhydrides) plus water yield acids. (Keep it simple and choose the acid in which the nonmetal will have the same oxidation number.)**
    - *Carbon dioxide is bubbled into water.*

      $CO_2 + H_2O \rightarrow H_2CO_3$
  - **Metallic oxides (aka: basic anhydrides) plus water yield bases.**
    - *Solid sodium oxide is added to water.*

      $Na_2O + H_2O \rightarrow 2Na^{+1} + 2OH^-$ (Think of water as HOH and it looks like a single replacement reaction.)
  - **Metallic hydrides plus water yield metallic hydroxides and hydrogen gas. (This is a redox disproportionation reaction.)**
    - *Solid sodium hydride is added to water.*

      $NaH + H_2O \rightarrow Na^+ + OH^- + H_2$
  - **Phosphorus halides react with water to produce an acid of phosphorus (phosphorous acid or phosphoric acid - the oxidation numbers will remain the same) and a hydrohalic acid.**
    - *Phosphorus tribromide is added to water.*

      $PBr_3 + 3H_2O \rightarrow H_3PO_3 + 3H^+ + 3Br^-$
  - **Group I&II nitrides react with water to produce the metallic hydroxide and ammonia.**
    - *Solid calcium nitride is added to water.*

      $Ca_3N_2 + 6H_2O \rightarrow 3Ca^{2+} + 6OH^- + 2NH_3$ (Since calcium hydroxide is slightly soluble, you could write it as a compound as well. $Ca_3N_2 + 6H_2O \rightarrow 3Ca(OH)_2 + 2NH_3$
  - **Amines (weak base) react with water to produce alkyl-ammonium ions and hydroxide ions.**
    - *Methylamine gas is bubbled into distilled water.*

      $CH_3NH_2 + H_2O \rightarrow CH_3NH_3^+ + OH^-$

Complex Ion Reactions

Vocabulary

- **Ligand** - any particle with an unshared pair of electrons that can bond to a metal ion
- **Complex ion (coordination complex)** - the combination of a central metal ion and its ligands
- **Coordination compound** - a neutral compound containing complex ions

  $[Co(NH_3)_6]Cl_3$ is a coordination compound

  $[Co(NH_3)_6]^{3+}$ is the complex ion

  NH_3 is the ligand

Common complex ions formed in AP equations		
Ligand	**Complex Ion**	**Name**
NH_3, ammonia	$[Ag(NH_3)_2]^+$	diammine silver ion
	$[Cu(NH_3)_4]^{2+}$	tetrammine copper(II) ion
OH^-, hydroxide ion	$[Al(OH)_4]^-$	tetrahydroxo aluminate ion
	$[Zn(OH)_4]^{2-}$	tetrahydroxo zincate ion
SCN^-, thiocyanate ion	$[FeSCN]^{2+}$	(mono) thiocyano iron(III) ion
CN^-, cyanide ion	$[Ag(CN)_2]^-$	dicyano argentate ion

- **When the reaction adds excess of some reactant, a complex is often formed**
  - An excess of sodium hydroxide solution is added to a solution of aluminum chloride

    $4OH^- + Al^{3+} \rightarrow [Al(OH)_4]^-$
- **Excess acid will remove the complexed ammonia (amine) because the acid reacts with the weak base ammonia**
  - Excess dilute nitric acid is added to a solution containing the tetraaminenickel(II) ion

    $4H^+ + [Ni(NH_3)_4]^{2+} \rightarrow 4NH_4^+ + Ni^{2+}$
- **Excess ammonia will produce a complex ion**
  - Silver chloride is dissolved in excess ammonia solution

    $AgCl + 2NH_3 \rightarrow [Ag(NH_3)_2]^+ + Cl^-$

Decomposition Reactions

Reaction in which a compound breaks down into two or more elements or compounds. Heat, electrolysis, or a catalyst is usually necessary.

- **A compound may break down to produce two elements (always a redox reaction).**
  - *Molten sodium chloride is electrolyzed.*

    $2NaCl \rightarrow 2Na + Cl_2$
- **A compound may break down to produce an element and a compound (also a redox reaction).**
  - *A solution of hydrogen peroxide is decomposed catalytically.*

    $2H_2O_2 \rightarrow 2H_2O + O_2$
- **A compound may break down to produce two compounds (not usually a redox reaction).**
  - *Solid magnesium carbonate is heated.*

    $MgCO_3 \rightarrow MgO + CO_2$

Rules worth memorizing

- *Metallic carbonates* break down to yield metallic oxides and carbon dioxide. (Reverse is a synthesis.)
- *Metallic chlorates* break down to yield metallic chlorides and oxygen.
- *Hydrogen peroxide* decomposes into water and oxygen.
- Don't forget the phantoms:
  - ✓ *Ammonium carbonate* decomposes into ammonia, water and carbon dioxide.
  - ✓ *Sulfurous acid* decomposes into water and sulfur dioxide.
  - ✓ *Carbonic acid* decomposes into water and carbon dioxide.

Addition (aka Synthesis) Reactions

Two or more elements or compounds combine to form a single product.

- **A Group IA or IIA metal may combine with a nonmetal to make a salt.**
  - *A piece of lithium metal is dropped into a container of nitrogen gas.*

    $6Li + N_2 \rightarrow 2Li_3N$
- **When an element combines with a compound, you can usually sum up all of the elements on the product side.**
  - *Phosphorus trichloride is reacted with chlorine gas.*

    $PCl_3 + Cl_2 \rightarrow PCl_5$
- **Two compounds combine to form a single product.**
  - *Sulfur dioxide gas is passed over solid calcium oxide.*

    $SO_2 + CaO \rightarrow CaSO_3$
  - *The gases boron trifluoride and ammonia are mixed. (This is the classic Lewis acid/base reaction.)*

    $BF_3 + NH_3 \rightarrow H_3NBF_3$
- **Two nonmetals may combine to form a molecular compound. The oxidation number of the less electronegative element is often variable depending upon conditions. Generally, a higher oxidation state of one nonmetal is obtained when reacting with an excess of the other nonmetal.**
  - *Phosphorus is reacted with a limited amount of chlorine gas.*

    $P_4 + 6Cl_2 \rightarrow 4PCl_3$ (in a limited amount of Cl_2)
  - *Phosphorus is reacted with excess chlorine gas.*

    $P_4 + 10Cl_2 \rightarrow 4PCl_5$ (in excess Cl_2)

Combustion

Reaction of some chemical with oxygen to produce oxide compounds.

- **Hydrocarbons, carbohydrates, or alcohols combine with oxygen to form carbon dioxide and water.**
  - *Ethanol is burned completely in air.*

    $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$
- **Metals react with oxygen to form their metallic oxide**
  - *Sodium metal react with oxygen*

    $2Na + O_2 \rightarrow 2Na_2O$
- **Nonmetallic sulfides combine with oxygen to form oxides and sulfur dioxide.**
  - *Carbon disulfide vapor is burned in excess oxygen.*

    $CS_2 + 2O_2 \rightarrow CO_2 + 2SO_2$
- **Nonmetallic hydrides combine with oxygen to form oxides and water.**
  - *Dinitrogen tetrahydride is burned completely in air.*

    $N_2H_4 + O_2 \rightarrow 2NO_2 + 2H_2O$
- **Ammonia combines with *limited* oxygen to produce NO and water**

  ✓ **and with *excess* oxygen to produce NO_2 and water.**
  - *Ammonia is reacted with excess oxygen in the presence of a catalyst*

    $4NH_3 + 7O_2 \rightarrow 4NO_2 + 6H_2O$

Simple Organic

Organic compounds likely to be used in net ionic equations.

group name	situation	generic formula	examples
alkanes, -ane	saturated with hydrogens, all single bonds	C_nH_{2n+2}	propane, C_3H_8
alkenes, -ene	double bond	C_nH_{2n}	ethene, C_2H_4
alkynes, -yne	triple bond	C_nH_{2n-2}	pentyne, C_5H_8
benzene	6 carbon ring with alternating double bonds	C_6H_6	
alcohol, -ol (aka ...-yl alcohol)	an -H replaced with an -OH	$C_nH_{2n+1}OH$	hexanol, $C_6H_{13}OH$
carboxylic acid, ...-oic acid	an -H replaced with a -COOH	$C_{n-1}H_{2n-1}COOH$	butanoic acid, C_3H_7COOH aka butyl alcohol
ether	an O between two carbons		dimethyl ether, H_3COCH_3

Prefixes that indicate the number of carbons:

1. meth-
2. eth-
3. prop-
4. but-
5. pent-
6. hex-
7. hept-
8. oct-
9. non-
10. dec-