Unit 4 Notes Chemical Reactions

CH 3, 4

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Introduction to reactions

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Physical change
- Composition stays the same
- Properties change
- Phase change, separate mixtures

Chemical change
- Composition changes
- New substances
- Typically produce heat, light, gas, precipitate, color change

Solutions

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- Homogeneous mixture with solute(s) and solvent
  - Solute—substance present in smaller amount
  - Solvent—substance present in larger amount

Solutions

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- Examples:

Solution	Solvent	Solute
Soda (l)	H_2O (l)	Sugar (s), CO_2 (g)
Air (g)	N_2 (g)	O_2, CO_2, Ar,
Solder (s)	Sn (s)	Pb (s)

Electrolytes

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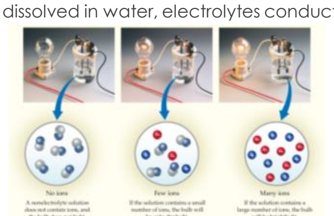
- When dissolved in water, electrolytes conduct electricity



Electrolytes

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- Strong electrolytes completely dissociate in water
  - $NaCl(s) \rightarrow Na^+(aq) + Cl^-(aq)$
- Weak electrolytes partially dissociate in water
  - $CH_3COOH(aq) \leftrightarrow CH_3COO^-(aq) + H^+(aq)$
- Non electrolytes do not dissociate in water, molecules just separate from each other
  - $C_6H_{12}O_6(s) \rightarrow C_6H_{12}O_6(aq)$

Solubility rules (need to know #1-3 for AP)

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1. All nitrates are soluble
2. Alkali metals ions and NH_4^+ ions are soluble
3. Halides are soluble except Ag^+, Pb^{2+}, and Hg_2^{2+}
4. Most sulfates are soluble, except Pb^{2+}, Ba^{2+}, Hg_2^{2+}, and Ca^{2+}
5. Most hydroxides and sulfides are slightly soluble (insoluble), except Ca^{2+}, Sr^{2+}, Ba^{2+}
6. Most carbonates, chromates, and phosphates are insoluble

Strong electrolytes

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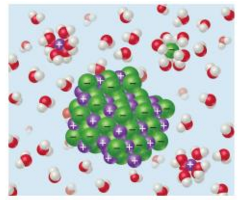
- All soluble ionic compounds
- Strong acids (HCl, HBr, HI, $HClO_3$, $HClO_4$, HNO_3, H_2SO_4)
  - Hydrochloric, hydrobromic, hydroiodic, chloric, perchloric, nitric, sulfuric



Strong electrolytes

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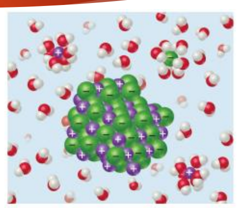
- Strong bases (soluble hydroxides)



Weak electrolytes

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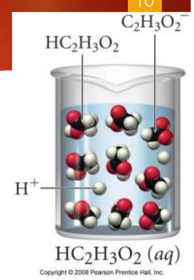
- Acids that are not strong acids (like CH_3COOH, HF, etc)
- NH_3 (weak electrolyte base)
- H_2O



Non-electrolytes

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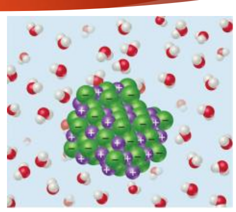
- Insoluble ionic salts



Electrolytes and conductivity

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- Conductivity increases with the concentration of ions present in the solution.
- No ions means no conductivity

Practice 1
Strong, weak, or nonelectrolyte?

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1. Lead (II) iodide
2. Hydrochloric acid
3. Sodium hydroxide
4. Nitrous acid
5. Ammonium phosphate
6. Silver chloride
7. Magnesium hydroxide
8. Copper (II) sulfate
9. Calcium carbonate
10. Acetic acid

Equations

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- Balanced equations represent processes
  - Write an equation for boiling water
  - Write an equation for the combustion of propane, C_3H_8.
- Must balance eqns because of conservation of matter/mass

Types of equations

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- Molecular equations show complete chemical formulas of reactants and products
  - $BaCl_2(aq) + K_2SO_4(aq) \rightarrow BaSO_4(s) + 2\ KCl(aq)$
  - Skeleton equations are unbalanced

Types of equations

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- Complete ionic equations show all soluble strong electrolytes as ions
  - $Ba^{2+}(aq) + 2\ Cl^-(aq) + 2\ K^+(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s) + 2\ K^+(aq) + 2\ Cl^-(aq)$
- Net ionic equations includes only ions and molecules involved in reaction
  - Ignores spectator ions (play no direct role in reaction)
  - $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$

Practice 2: Write molecular, complete ionic, and net ionic equations

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1. Iron (III) sulfate and lithium hydroxide
2. Silver nitrate and potassium phosphate
3. Hydrochloric acid and barium hydroxide
4. Sodium chloride and silver nitrate

Particulate representations

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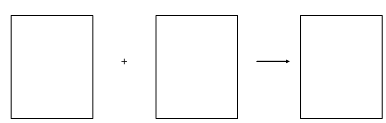
- Sodium chloride(*aq*) and silver nitrate(*aq*) →



Physical and chemical changes

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- Chemical changes typically involve breaking and/or making chemical bonds
  - $CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$
  - What bonds are broken? What bonds are made?

Physical and chemical changes

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- Physical changes involve changes in intermolecular interactions
  - H_2O (l) → H_2O (g)
  - What intermolecular interactions are changed?

Physical and chemical changes

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- NaCl(*aq*) → Na^+(*aq*) + Cl^-(*aq*)
  - Physical or chemical change?
  - What happens to chemical bonds?
  - What happens to intermolecular interactions?

Stoichiometry

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- Use balanced equations
- Atoms are always conserved
- Explains the changes in amounts of reactants and products

Practice 3 Stoichiometry

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1. A piece of aluminum foil 5.11 inches x 3.23 inches x 0.0381 inches is dissolved in excess HCl(*aq*). How many grams of H_2(*g*) are produced? (BTW, the density of aluminum is 2.70 g/cm^3) 3.12 g H_2

Practice 3 Stoichiometry

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2. Years of experience have proven that the percent yield for the following reaction is 74.3%

   $Hg + Br_2 \rightarrow HgBr_2$

   a. If 10.0 g of Hg and 9.00 g of Br_2 are reacted, what mass of $HgBr_2$ will be produced? 13.3 g
   b. If the reaction did go to completion, what mass of excess reagent would be left? 1.03 g Br_2

Practice 4
Stoichiometry with gas laws

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1. A sample of solid CaO is placed in a 1.00 L vessel containing CO_2 gas at a pressure of 730. torr and a temperature of 25˚C. The CO_2 reacts with the CaO, forming $CaCO_3$. When the reaction is complete, the pressure of the remaining CO_2 is 150. torr.
   a. Write the balanced equation.
   b. How many moles of CO_2 reacted? 0.0312 mol
   c. What mass of $CaCO_3$ should have formed? 3.12 g

Practice 4
Stoichiometry with gas laws

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2. Gaseous ammonia and gaseous hydrochloric acid react to form solid ammonium chloride.
   a. Write the equation.
   b. What volume of ammonia at 1.50 atm and 25C is required to produce 50.0 g of ammonium chloride? 15.2 L

Titration

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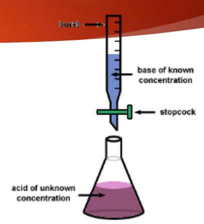
- Technique used to determine the concentration of an analyte
- Titrate has known concentration, reacts specifically with analyte



Titration

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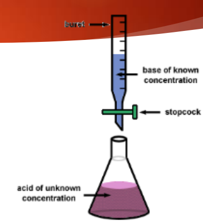
- Equivalence point—analyte is consumed by titrating
- End point—visual change indicating equivalence point



Acid-base titration

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- HCl(*aq*) + NaOH(*aq*) → NaCl(*aq*) + HOH(*l*) {aka H_2O}
- 45.7 mL of 0.500 M NaOH is used to titrate a 25.0 mL sample of HCl solution with unknown concentration. What is the concentration of HCl? 0.914 M HCl

Practice 5
Titrations

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1. 45.00 mL of 2.5 M NaOH is used to titrate 15.0 mL of an unknown concentration of HCl to its endpoint. What is the molarity of the HCl? 7.5M
2. A 50.00 mL sample of aqueous $Ca(OH)_2$ is titrated to its endpoint with 34.66 mL of 0.0980 M nitric acid for neutralization. What is $[Ca(OH)_2]$? 0.0340 M $Ca(OH)_2$

Practice 5
Titrations

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3. 75 mL of 0.25M HCl is mixed with 225 mL of 0.055 M $Ba(OH)_2$. What is the concentration of the excess H^+ or OH^-? 0.020 M OH^-

Types of reactions

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- Synthesis/combination
- Decompositon
- Combustion
- Single replacement
- Double replacement

$\left.\begin{array}{l}\text{Single replacement}\\ \text{Double replacement}\end{array}\right\}$ Metathesis

Types of reactions

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Combination/Synthesis	A + B ⇨ AB
Decomposition	AB ⇨ A + B
Combustion	$C_xH_yO_z + O_2$ ⇨ $CO_2 + H_2O$
SR (metathesis)	A + BC ⇨ B + AC
DR (metathesis)	AB + CD ⇨ AD + CB

New types of reactions

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- Precipitation reactions
  - Insoluble product is formed (see rules for non electrolytes)
  - $Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$

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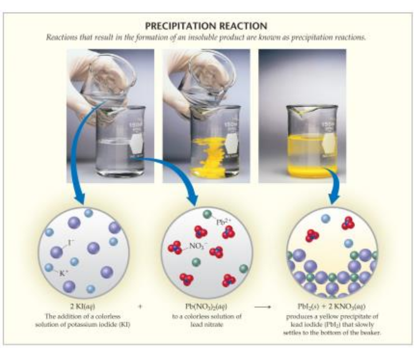

Precipitation reactions

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- Write formulas for the products
- Use solubility rules to predict the solubility of products
- Reaction occurs when 1 or more product is insoluble

Practice 6
Precipitation reactions

1. $K_3PO_4(aq)$ + $Ca(NO_3)_2(aq)$ →
2. $CaCl_2(aq)$ + $Na_2CO_3(aq)$ →
3. A solution of sodium phosphate is added to a solution of aluminum nitrate
4. Solutions of silver nitrate and magnesium chloride are combined
5. A solution of copper (II) sulfate is added to a solution of lithium hydroxide

New types of reactions

- Acid-base reactions
  - DR with acids and bases
  - Proton is transferred in reaction
  - $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$
  - H_2O can act as acid or base
    - $H_2O \rightarrow H^+ + OH^-$ Acid
    - $H_2O + H^+ \rightarrow H_3O^+$ Base

Practice 7
Acid-base reactions

1. Calcium hydroxide reacts with hydrochloric acid
2. Acetic acid reacts with sodium hydroxide
3. Nitric acid reacts with sodium sulfide (one product is a gas)
4. Sulfuric acid reacts with sodium hydrogen carbonate (H_2CO_3 is unstable and decomposes to H_2O and CO_2)

New types of reactions

- Oxidation-reduction reactions (redox)
  - Electrons transferred between reactants
  - Indicated by changes in oxidation numbers
  - Combustion is also redox

Oxidation numbers rules

- Atoms in elemental form have ox # of 0
- Ions have same ox # as charge
- Oxygen is usually -2 (-1 in peroxides)
- Hydrogen is usually +1 (-1 when bonded to metals)
- Halogens are usually -1 (except with O)
- Sum of oxidation #s in a compound = charge of compound

Practice 8
Oxidation numbers

- Assign oxidation numbers to each atom in the following compounds:
  - O_2, HCl, Al_2O_3, $SnBr_4$, $Pb(NO_3)_2$, CH_4, CO_2, Li_2O, HNO_3, $Cr_2O_7^{2-}$, $NaBH_4$, WO_4^{2-}, SnF_2, CO_3^{2-}

Acid-base reactions
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- Brønsted-Lowry acids are proton donors
  - HCl loses H^+ and becomes Cl^-
  - HCl ⇨ H^+ + Cl^-
- Brønsted-Lowry bases are proton acceptors
  - OH^- + H^+ ⇨ HOH (H_2O)
  - NH_3 + H^+ ⇨ NH_4^+

Acid-base reactions
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- Water can act as acid **and** base
- Conjugate base is the base after the acid donates a proton
- Conjugate acid is the acid after the base accepts a proton

Acid-base reactions
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$$HNO_2(aq) + H_2O(l) \rightleftharpoons NO_2^-(aq) + H_3O^+(aq)$$

Acid-base reactions
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$$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

Practice 9
Acid-base reactions
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- Identify the acid, base, conjugate acid, and conjugate base:

1. HBrO + H_2O → H_3O^+ + BrO^-
2. HSO_4^- + HCO_3^- → SO_4^{2-} + H_2CO_3
3. HSO_3^- + H_3O^+ → H_2SO_3 + H_2O

Redox reactions
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- Use ox # to determine which species is oxidized and which is reduced
- **LEO** says **GER**
  - **L**ose **E**lectrons **O**xidation
  - **G**ain **E**lectrons **R**eduction

Redox reactions

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- Which element is oxidized? Reduced?
- $N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g)$
- $P_4 + 10\ HClO + 6\ H_2O \rightarrow 4\ H_3PO_4 + 10\ HCl$

Practice 10 Redox reactions

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- Complete and balance the reaction. Then indicate which element is oxidized and which is reduced.

1. $Br_2(l) + K(s) \rightarrow$
2. $CH_3OH(l) + O_2(g) \rightarrow$
3. $Zn(s) + HCl(aq) \rightarrow$
4. $ZnCl_2(aq) + NaOH(aq) \rightarrow$

SR/redox activity series *not on AP exam*

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Metal	Oxidation Reaction
Lithium	$Li(s) \longrightarrow Li^+(aq) + e^-$
Potassium	$K(s) \longrightarrow K^+(aq) + e^-$
Barium	$Ba(s) \longrightarrow Ba^{2+}(aq) + 2e^-$
Calcium	$Ca(s) \longrightarrow Ca^{2+}(aq) + 2e^-$
Sodium	$Na(s) \longrightarrow Na^+(aq) + e^-$
Magnesium	$Mg(s) \longrightarrow Mg^{2+}(aq) + 2e^-$
Aluminum	$Al(s) \longrightarrow Al^{3+}(aq) + 3e^-$
Manganese	$Mn(s) \longrightarrow Mn^{2+}(aq) + 2e^-$
Zinc	$Zn(s) \longrightarrow Zn^{2+}(aq) + 2e^-$
Chromium	$Cr(s) \longrightarrow Cr^{3+}(aq) + 3e^-$
Iron	$Fe(s) \longrightarrow Fe^{2+}(aq) + 2e^-$
Cobalt	$Co(s) \longrightarrow Co^{2+}(aq) + 2e^-$
Nickel	$Ni(s) \longrightarrow Ni^{2+}(aq) + 2e^-$
Tin	$Sn(s) \longrightarrow Sn^{2+}(aq) + 2e^-$
Lead	$Pb(s) \longrightarrow Pb^{2+}(aq) + 2e^-$
Hydrogen	$H_2(g) \longrightarrow 2\ H^+(aq) + 2e^-$
Copper	$Cu(s) \longrightarrow Cu^{2+}(aq) + 2e^-$
Silver	$Ag(s) \longrightarrow Ag^+(aq) + e^-$
Mercury	$Hg(l) \longrightarrow Hg^{2+}(aq) + 2e^-$
Platinum	$Pt(s) \longrightarrow Pt^{2+}(aq) + 2e^-$
Gold	$Au(s) \longrightarrow Au^{3+}(aq) + 3e^-$

Ease of oxidation increases

Redox half reactions

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- Complete equation: $Ca(s) + HCl(aq) \rightarrow$
- Write net ionic equation:
- Which element is oxidized? Reduced?

Redox half reactions

53

- Complete equation:
  - $Ca(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2(g)$
- Write net ionic equation:
  - $Ca(s) + 2\ H^+(aq) \rightarrow Ca^{2+}(aq) + H_2(g)$
- Which element is oxidized? Ca Reduced? H

Redox half reactions

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- Separate the oxidization and reduction parts
  - $Ca \rightarrow Ca^{2+}$
  - $2\ H^+ \rightarrow H_2$
- Include electrons where needed
  - $Ca \rightarrow Ca^{2+} + 2\ e^-$
  - $2\ H^+ + 2\ e^- \rightarrow H_2$

Practice 11
Redox half reactions

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- Write the oxidation and reduction half reactions for the following:

1. $MnO_4^-(aq) + C_2O_4^-(aq) \rightarrow Mn^{2+}(aq) + 2\ CO_2(g)$
2. $Cr_2O_7^{2-}(aq) + 2\ Cl^-(aq) \rightarrow 2\ Cr^{3+}(aq) + Cl_2(g)$

Practice 11
Redox half reactions

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- Write the oxidation and reduction half reactions for the following:

1. $MnO_4^-(aq) + C_2O_4^-(aq) \rightarrow Mn^{2+}(aq) + 2\ CO_2(g)$

$MnO_4^-(aq) + 5e^- \rightarrow Mn^{2+}(aq)$

$C_2O_4^-(aq) \rightarrow 2\ CO_2(g) + 2e^-$

Practice 11
Redox half reactions

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- Write the oxidation and reduction half reactions for the following:

2. $Cr_2O_7^{2-}(aq) + 2\ Cl^-(aq) \rightarrow 2\ Cr^{3+}(aq) + Cl_2(g)$

$Cr_2O_7^{2-}(aq) + 6\ e^- \rightarrow 2\ Cr^{3+}(aq) + Cl_2(g)$

$2\ Cl^-(aq) \rightarrow Cl_2(g) + 2\ e^-$

Balance by half rxn in <u>acidic</u> conditions

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1. Separate into half reactions
2. Balance easy atoms (not H or O)
3. Balance oxygens by adding waters
4. Balance hydrogens by adding H^+
5. Balance charges by adding electrons
6. Multiply half rxns to cancel out electrons

Balance by half rxn in acidic conditions

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Example:

$Cr_2O_7^{2-}(aq) + Cl^-(aq) \rightarrow Cr^{3+}(aq) + Cl_2(g)$

$Cr_2O_7^{2-}(aq) + 6\ Cl^-(aq) + 14\ H^+ \rightarrow$
$2Cr^{3+}(aq) + 3\ Cl_2(g) + 7\ H_2O(l)$

Practice 12
Balance by half rxn in acidic conditions

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1. $Mn^{2+}(aq) + NaBiO_3(s) \rightarrow Bi^{3+}(aq) + MnO_4^-(aq) + Na^+(aq)$
2. $Cu(s) + NO_3^-(aq) \rightarrow Cu^{2+}(aq) + NO_2(g)$
3. $2Mn^{2+}(aq) + 5NaBiO_3(s) + 14H^+(aq) \rightarrow$
   $5Bi^{3+}(aq) + 2MnO_4^-(aq) + 5Na^+(aq) + 7H_2O(l)$
4. $Cu(s) + 2NO_3^-(aq) + 4H^+(aq) \rightarrow$
   $Cu^{2+}(aq) + NO_2(g) + 7H_2O(l)$

Balancing by half rxns in basic conditions

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Same steps as acidic solutions, but because it's in basic solution, not acidic, you can't have H^+. Neutralize all H^+ with OH- on both sides, then continue

Balancing by half rxns in basic conditions

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Example:

CN^-(*aq*)+ MnO_4^-(*aq*) → CNO^-(*aq*) + MnO_2(s)

$3CN^-$(*aq*)+ $2MnO_4^-$(*aq*) + H_2O(*l*)→
$3CNO^-$(*aq*) + $2MnO_2$(s) + $2OH^-$(*aq*)

Practice 13
Balancing by half rxns in basic conditions

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1. NO_2^-(*aq*) + Al(s) → NH_3(*aq*) + $Al(OH)_4^-$(*aq*)
2. $Cr(OH)_3$(s) + ClO^-(*aq*) → CrO_4^{2-}(*aq*) + Cl_2(*g*)
3. NO_2^-(*aq*) + 2Al(s) +$5H_2O$(*l*) + OH^-(*aq*)→
   NH_3(*aq*) + $2Al(OH)_4^-$(*aq*)
4. $2Cr(OH)_3$(s) + $6ClO^-$(*aq*) → $2CrO_4^{2-}$(*aq*) +
   $3Cl_2$(*g*) + $2H_2O$(*l*) + $2OH^-$(*aq*)