Note: Summaries are most helpful post-content review.

Gold Standard MCAT General Chemistry Review: Stoichiometry

- Mole - Atomic and Molecular Weights

For element:

$$\text{moles} = \frac{\text{weight of sample in grams}}{\text{GAW}}$$

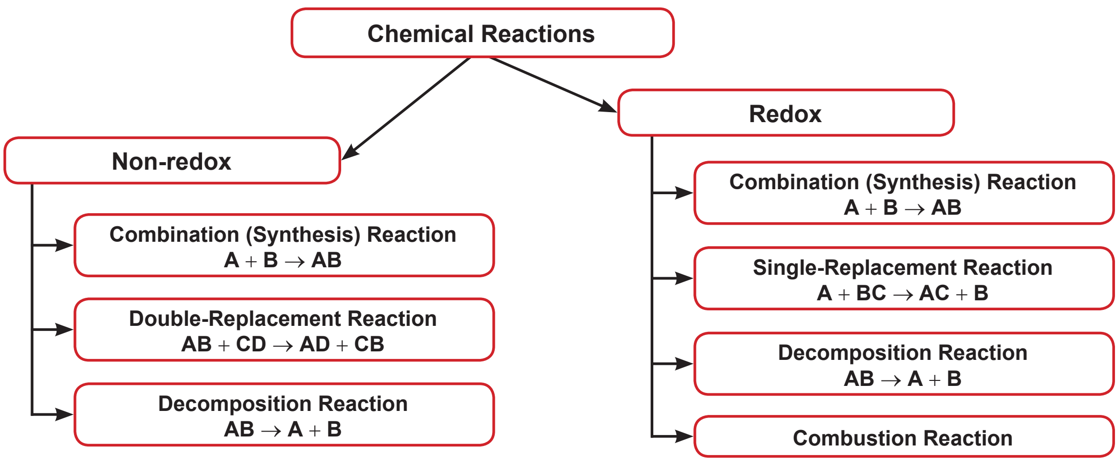
1 mol = 6.02×10^{23} atoms

For compound:

$$\text{moles} = \frac{\text{weight of sample in grams}}{\text{GMW}}$$

1 mol = 6.02×10^{23} molecules

- Categories of Chemical Reactions



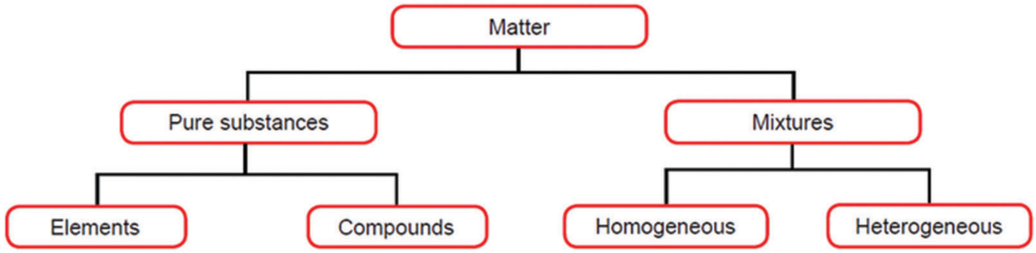
Note: Any reaction that does not involve the transfer of electrons (= change in oxidation numbers) qualifies as a non-redox reaction. Combination reactions qualify as non-redox reactions when all reactants and products are compounds and the oxidation numbers do not change. Decomposition reactions qualify as non-redox reactions when all reactants and products are compounds and the oxidation numbers do not change.

- Oxidation Numbers, Redox Reactions, Oxidizing vs. Reducing Agents
  - Here are the general rules:
    - In elementary substances, the oxidation number of an uncombined element is zero
    - In monatomic ions the oxidation number of the elements that make up this ion is equal to the charge of the ion
    - In a neutral molecule the sum of the oxidation numbers of all the elements that make up the molecule is zero
  - Some useful oxidation numbers to memorize
    - For H: +1, except in metal hydrides where it is equal to -1
    - For O: -2 in most compounds; In peroxides (e.g. in H_2O_2) the oxidation number for O is -1, it is +2 in OF_2 and -1/2 in superoxides
    - For alkali metals: +1
    - For alkaline earth metals: +2
    - Aluminium always has an oxidation number of +3 in all its compounds

Common Redox Agents

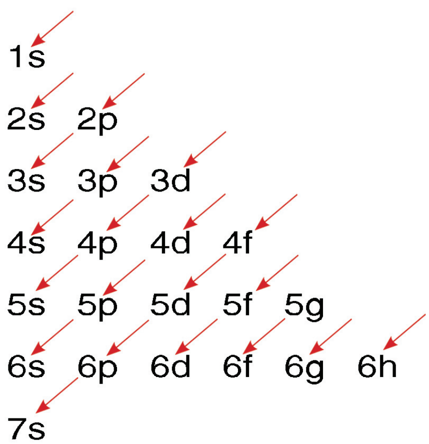
Reducing Agents	Oxidizing Agents
* Lithium aluminium hydride ($LiAlH_4$) * Sodium borohydride ($NaBH_4$) * Metals * Ferrous ion (Fe^{2+})	* Iodine (I_2) and other halogens * Permanganate (MnO_4) salts * Peroxide compounds (i.e. H_2O_2) * Ozone (O_3); osmium tetroxide (OsO_4) * Nitric acid (HNO_3); nitrous oxide (N_2O)

- Mixtures



Gold Standard MCAT General Chemistry Review: Electronic Structure & The Periodic Table

- Conventional Notation for Electronic Structure



The order for filling atomic orbitals: Follow the direction of successive arrows moving from top to bottom.

- Metals, Nonmetals and Metalloids

*General Characteristics of metals, nonmetals and metalloids

Metals	Nonmetals	Metalloids
Hard and shiny	Gases or dull, brittle solids	Appearance will vary
3 or less valence electrons	5 or more valence electrons	3 to 7 valence electrons
Form + ions by losing e^-	Form − ions by gaining e^-	Form + and/ or − ions
Good conductors of heat and electricity	Poor conductors of heat and electricity	Conduct better than nonmetals, but not as well as metals

*These are general characteristics. There are exceptions beyond the scope of the exam.

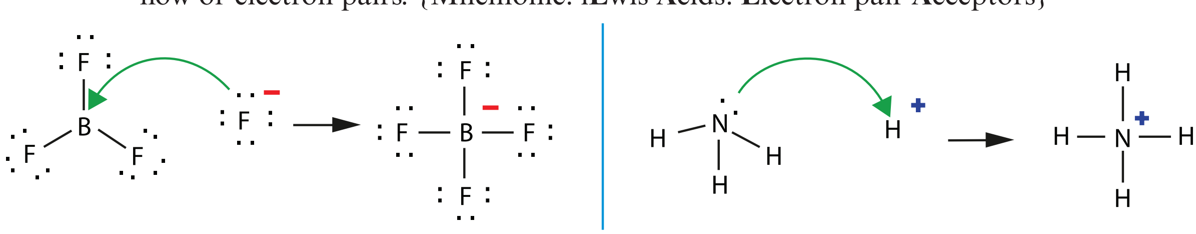
Gold Standard MCAT General Chemistry Review: Bonding

- Partial Ionic Character
  - This polar bond will also have a dipole moment given by:

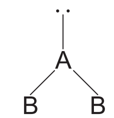
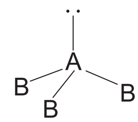
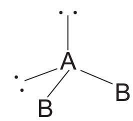
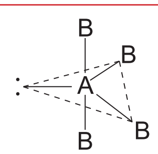
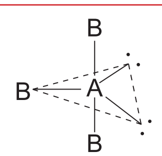
$$D = q \cdot d$$

where q is the charge and d is the distance between these two atoms.

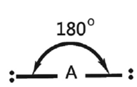
- Lewis Acids and Lewis Bases
  - The Lewis acid BF_3 and the Lewis base NH_3. Notice that the green arrows follow the flow of electron pairs. {Mnemonic: l**E**wis **A**cids: **E**lectron pair **A**cceptors}



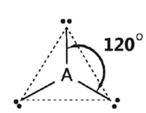
- Valence Shell Electronic Pair Repulsions (VSEPR Models)
  - Geometry of simple molecules in which the central atom A has one or more lone pairs of electrons (= e⁻)

Total number of e⁻ pairs	Number of lone pairs	Number of bonding pairs	Electron Geometry, Arrangement of e⁻ pairs	Molecular Geometry (Hybridization State)	Examples
3	1	2	 Trigonal planar	Bent (sp^2)	SO_2
4	1	3	 Tetrahedral	Trigonal pyramidal (sp^3)	NH_3
4	2	2	 Tetrahedral	Bent (sp^3)	H_2O
5	1	4	 Trigonal bipyramidal	Seesaw (sp^3d)	SF_4
5	2	3	 Trigonal bipyramidal	T-shaped (sp^3d)	ClF_3

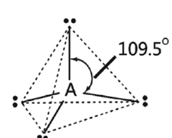
Note: dotted lines only represent the overall molecular shape and not molecular bonds. In brackets under "Molecular Geometry" is the hybridization.



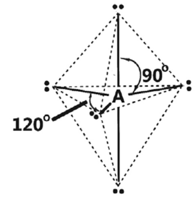
linear arrangement of 2 electron pairs around central atom A



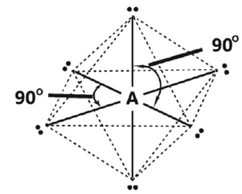
trigonal planar arrangement of 3 electron pairs around central atom A



tetrahedral arrangement of 4 electron pairs around central atom A



trigonal bipyramidal arrangement of 5 electron pairs around central atom A

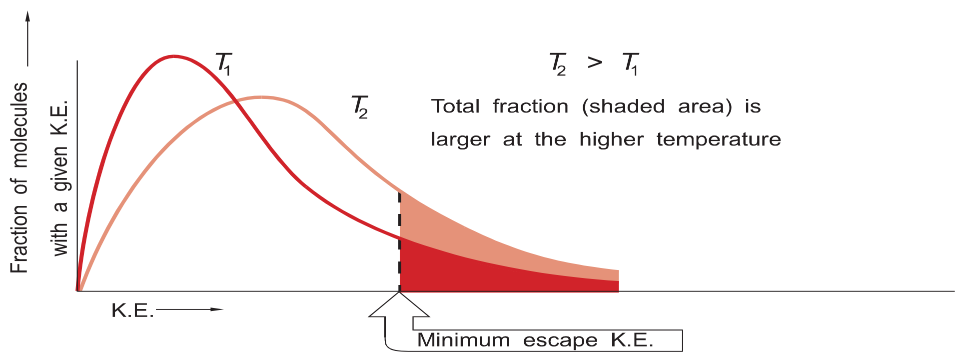


octahedral arrangement of 6 electron pairs around central atom A

Molecular arrangement of electron pairs around a central atom A. Dotted lines only represent the overall molecular shape and not molecular bonds.

Gold Standard MCAT General Chemistry Review: Phases & Phase Equilibria

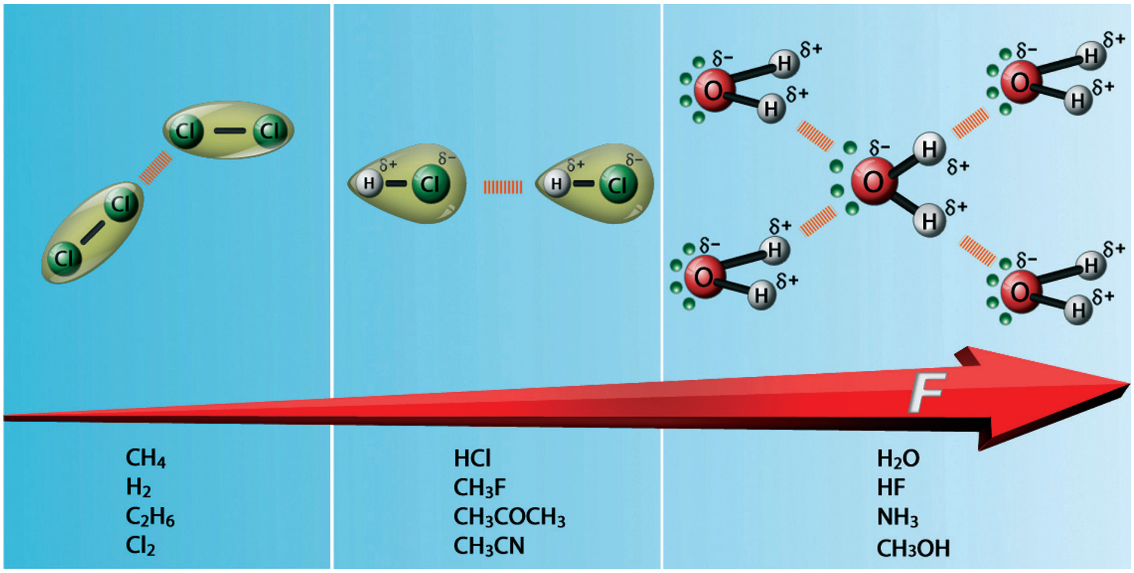
- Standard Temperature and Pressure, Standard Molar Volume
  - 0 °C (273.15 K) and 1.00 atm (101.33 kPa = 760 mmHg = 760 torr); these conditions are known as the standard temperature and pressure (STP). {Note: the SI unit of pressure is the pascal (Pa).}
  - The volume occupied by one mole of any gas at STP is referred to as the standard molar volume and is equal to 22.4 L.
- Kinetic Molecular Theory of Gases (A Model for Gases)
  - The average kinetic energy of the particles ($KE = 1/2\ mv^2$) increases in direct proportion to the temperature of the gas ($KE = 3/2\ kT$) when the temperature is measured on an absolute scale (i.e. the Kelvin scale) and k is a constant (the Boltzmann constant).



The Maxwell Distribution Plot

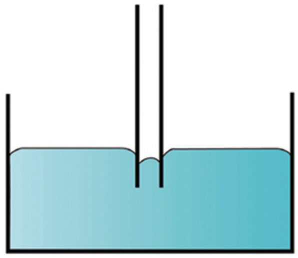
Graham's Law (Diffusion and Effusion of Gases)	Combined Gas Law
$\frac{Rate_1}{Rate_2} = \sqrt{\frac{M_2}{M_1}}$	$\frac{P_1V_1}{T_1} = k = \frac{P_2V_2}{T_2}$ (at constant mass)
Charles' Law	**Ideal Gas Law**
$V = Constant \times T$ or $V_1/V_2 = T_1/T_2$	$PV = nRT$ since m/V is the density (d) of the gas: $P = \frac{dRT}{M}$
Boyle's Law	**Partial Pressure and Dalton's Law**
$V = Constant \times 1/P$ or $P_1V_1 = P_2V_2$	$P_T = P_1 + P_2 + \ldots + P_i$ Of course, the sum of all mole fractions in a mixture must equal one: $\Sigma X_1 = 1$
Avogadro's Law	**The partial pressure (P_i) of a component of a gas mixture is equal to:**
$V/n = Constant$ or $V_1/n_1 = V_2/n_2$	$P_i = X_i P_T$

- Liquid Phase (Intra- and Intermolecular Forces)

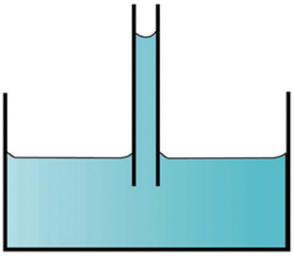


Van Der Waal's forces (weak) and hydrogen bonding (strong). London forces between Cl_2 molecules, dipole-dipole forces between HCl molecules and H-bonding between H_2O molecules. Note that a partial negative charge on an atom is indicated by δ- (delta negative), while a partial positive charge is indicated by δ+ (delta positive). Notice that one H_2O molecule can potentially form 4 H-bonds with surrounding molecules which is highly efficient. The preceding is one key reason that the boiling point of water is higher than that of ammonia, hydrogen fluoride, or methanol.

- Surface Tension
  - PE is directly proportional to the surface area (A)
  - PE = gA; g = surface tension
  - g = F/l; F = force of contraction of surface; l = length along surface

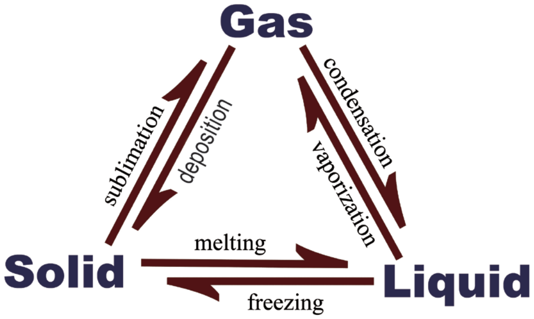


(a) cohesive > adhesive

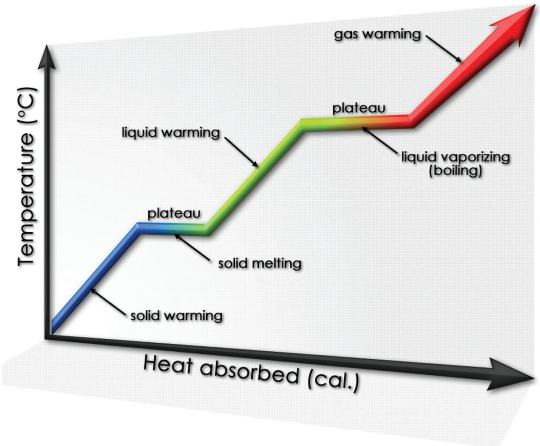


(b) adhesive > cohesive

- Phase Changes



- Phase Diagrams



Gold Standard MCAT General Chemistry Review: Solution Chemistry

- Vapor-Pressure Lowering (Raoult's Law)

$$P = P^{\circ}X_{solvent}$$

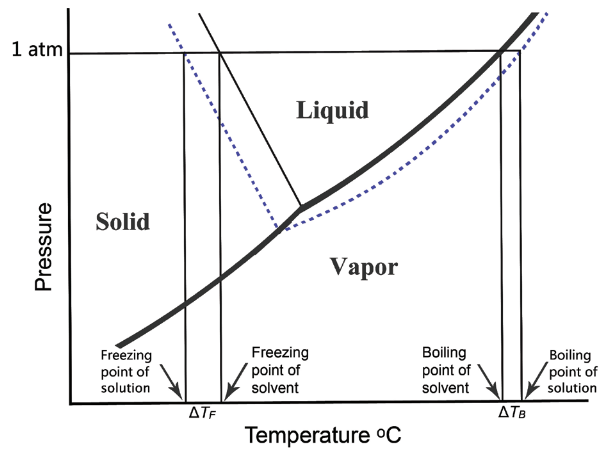
where P = vapor pressure of solution
P° = vapor pressure of pure solvent (at the same temperature as P)

- Osmotic Pressure

$$\Pi = i\,MRT$$

where R = gas constant per mole
T = temperature in degrees K and
M = concentration of solute (mole/liter)
i = Van't Hoff factor

- Boiling-Point Elevation and Freezing-Point Depression



Phase diagram of water demonstrating the effect of the addition of a solute
$\Delta T_B = iK_b m$
$\Delta T_F = iK_F m$

- Ions in Solution
  - Ions that are positively charged = <u>cations</u>; ions that are negatively charged = <u>anions</u>
  - *Mnemonic: anions are negative ions*
  - The word "aqueous" simply means containing or dissolved in water

Common Anions					
F^-	Fluoride	OH^-	Hydroxide	ClO^-	Hypochlorite
Cl^-	Chloride	NO_3^-	Nitrate	ClO_2^-	Chlorite
Br^-	Bromide	NO_2^-	Nitrite	ClO_3^-	Chlorate
I^-	Iodide	CO_3^{2-}	Carbonate	ClO_4^-	Perchlorate
O^{2-}	Oxide	SO_4^{2-}	Sulfate	SO_3^{2-}	Sulfite
S^{2-}	Sulfide	PO_4^{3-}	Phosphate	CN^-	Cyanide
N^{3-}	Nitride	$CH_3CO_2^-$	Acetate	MnO_4^-	Permanganate

Common Cations			
Na^+	Sodium	H^+	Hydrogen
Li^+	Lithium	Ca^{2+}	Calcium
K^+	Potassium	Mg^{2+}	Magnesium
NH_4^+	Ammonium	Fe^{2+}	Iron (II)
H_3O^+	Hydronium	Fe^{3+}	Iron (III)

Common Anions and Cations

- Units of Concentration
  - Molarity (M): moles of solute/liter of solution (solution = solute + solvent)
  - Normality (N): one equivalent per liter
  - Molality (m): one mole/1000g of solvent
  - Molal concentrations are not temperature-dependent as molar and normal concentrations are
  - Density (ρ): Mass per unit volume at the specified temperature
  - Osmole (Osm): The number of moles of particles (molecules or ions) that contribute to the osmotic pressure of a solution
  - Osmolarity: osmoles/liter of solution
  - Osmolality: osmoles/kilogram of solution
  - Mole Fraction: amount of solute (in moles) divided by the total amount of solvent and solute (in moles)
  - Dilution: $M_iV_i = M_fV_f$

- Solubility Product Constant, the Equilibrium Expression

$$AgCl\ (s) \rightleftharpoons Ag^+\ (aq) + Cl^-\ (aq)$$

$$K_{sp} = [Ag^+][Cl^-]$$

Because the K_{sp} product always holds, precipitation will not take place unless the product of $[Ag^+]$ and $[Cl^-]$ exceeds the K_{sp}.

- Solubility Rules
  1. All salts of alkali metals are soluble.
  2. All salts of the ammonium ion are soluble.
  3. All chlorides, bromides and iodides are water soluble, with the exception of Ag^+, Pb^{2+}, and Hg_2^{2+}.
  4. All salts of the sulfate ion (SO_4^{2-}) are water soluble with the exception of Ca^{2+}, Sr^{2+}, Ba^{2+}, and Pb^{2+}.
  5. All metal oxides are insoluble with the exception of the alkali metals and CaO, SrO and BaO.
  6. All hydroxides are insoluble with the exception of the alkali metals and Ca^{2+}, Sr^{2+}, Ba^{2+}.
  7. All carbonates (CO_3^{2-}), phosphates (PO_4^{3-}), sulfides (S^{2-}) and sulfites (SO_3^{2-}) are insoluble, with the exception of the alkali metals and ammonium.

Gold Standard MCAT General Chemistry Review: Acids & Bases

- Acids

$$K_a = [H^+][A^-]/[HA]$$

STRONG	WEAK
Perchloric $HClO_4$	Hydrocyanic HCN
Chloric $HClO_3$	Hypochlorous HClO
Nitric HNO_3	Nitrous HNO_2
Hydrochloric HCl	Hydrofluoric HF
Sulfuric H_2SO_4	Sulfurous H_2SO_3
Hydrobromic HBr	Hydrogen Sulfide H_2S
Hydriodic HI	Phosphoric H_3PO_4
Hydronium Ion H_3O^+	Benzoic, Acetic and other Carboxylic Acids

- Bases

$$K_b = [HB^+][OH^-]/[B]$$

  - Strong bases include any hydroxide of the group 1A metals
  - The most common weak bases are ammonia and any organic amine.

- Conjugate Acid-Base Pairs
  - The acid, HA, and the base produced when it ionizes, A-, are called a conjugate acid-base pair.

- Water Dissociation

$$K_w = [H^+][OH^-] = 1.0 \times 10^{-14}$$

- Salts of Weak Acids and Bases

$$K_a \times K_b = K_w$$

- Buffers

$$pH = pK_a + \log([salt]/[acid])$$

$$pOH = pK_b + \log([salt]/[base])$$

- The pH Scale

$$pH = -\log_{10}[H^+]$$

$$pOH = -\log_{10}[OH^-]$$

at 25°C, pH + pOH = 14.0

- Properties of Logarithms

1. $\log_a a = 1$
2. $\log_a M^k = k \log_a M$
3. $\log_a(MN) = \log_a M + \log_a N$
4. $\log_a(M/N) = \log_a M - \log_a N$
5. $10^{\log_{10}(M)} = M$

Gold Standard MCAT General Chemistry Review: Thermodynamics

- The First Law of Thermodynamics

$$\Delta E = Q - W$$

  - heat absorbed by the system: $Q > 0$
  - heat released by the system: $Q < 0$
  - work done by the system on its surroundings: $W > 0$
  - work done by the surroundings on the system: $W < 0$

- Temperature Scales

$$0\ K = -273.13\ °C.$$

$$(X\ °F - 32) \times 5/9 = Y\ °C$$

- State Functions
  - W can be determined experimentally by calculating the area under a pressure-volume curve

	Work	Heat	Changes in internal energy
1st tranf.	w	0	$-w$
2nd transf.	$W = w + q$	q	$-w$

Gold Standard MCAT General Chemistry Review: Enthalpy & Thermochemistry

- Heat of Reaction: Basic Principles
  - A reaction during which heat is released is said to be exothermic (ΔH is negative).
  - If a reaction requires the supply of a certain amount of heat it is endothermic (ΔH is positive).

$$\Delta H_{OVERALL} = \Delta H_1 + \Delta H_2$$

$$\Delta H^\circ_{reaction} = \Sigma \Delta H_f^\circ{}_{(products)} - \Sigma \Delta H_f^\circ{}_{(reactants)}$$

- Bond Dissociation Energies and Heats of Formation

$$\begin{aligned}\Delta H^\circ_{(reaction)} &= \Sigma \Delta H_{(bonds\ broken)} + \Sigma \Delta H_{(bonds\ formed)} \\ &= \Sigma BE_{(reactants)} - \Sigma BE_{(products)}\end{aligned}$$

- Calorimetry

$$Q = mC(T_2 - T_1)$$

$$Q = m\,L$$

- The Second Law of Thermodynamics
  - For any spontaneous process, the entropy of the universe increases which results in a greater dispersal or randomization of the energy ($\Delta S > 0$).

- Entropy

$$\Delta S^\circ_{reaction} = \Delta S^\circ_{products} - \Delta S^\circ_{reactants}$$

- Free Energy

$$\Delta G = \Delta H - T\Delta S$$

  - A reaction carried out at constant pressure is spontaneous if: $\Delta G < 0$
  - It is not spontaneous if: $\Delta G > 0$
  - It is in a state of equilibrium (reaction spontaneous in both directions) if: $\Delta G = 0$

Gold Standard MCAT General Chemistry Review: Rate Processes in Chemical Reactions

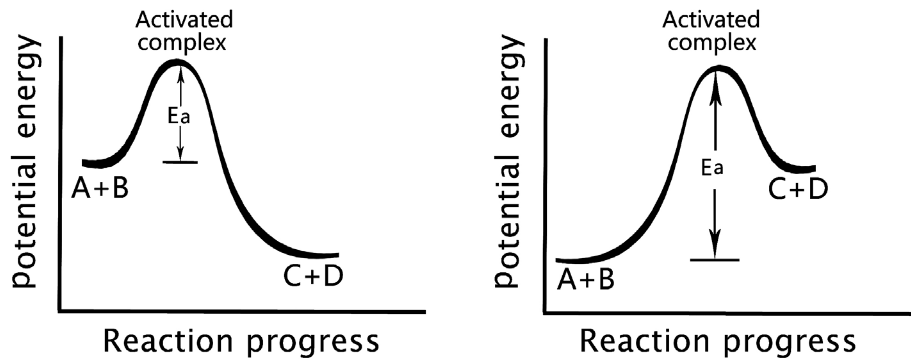
- Dependence of Reaction Rates on Concentration of Reactants

$$\text{rate} = k\,[A]^m\,[B]^n$$

  - [ ] is the concentration of the corresponding reactant in moles per liter
  - k is referred to as the rate constant
  - m is the order of the reaction with respect to A
  - n is the order of the reaction with respect to B
  - m+n is the overall reaction order

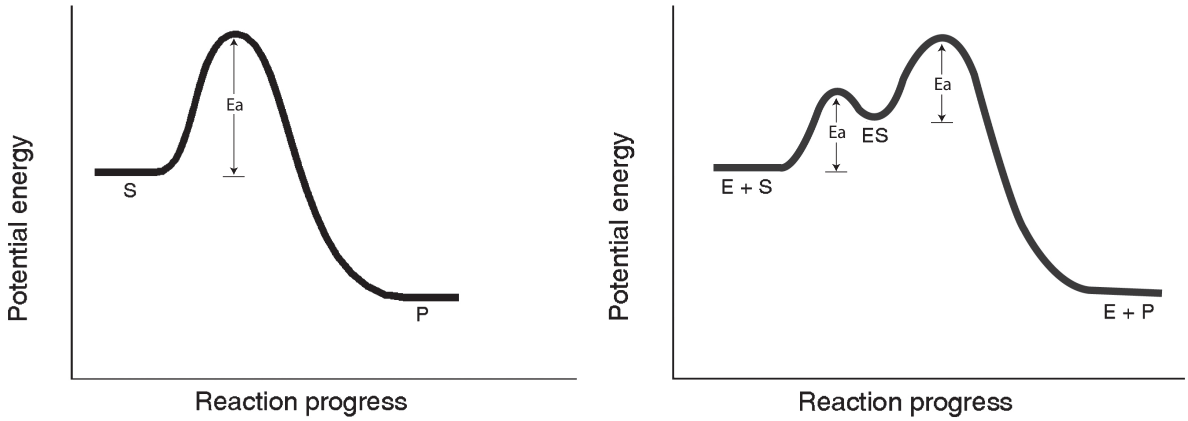
- Dependence of Reaction Rates upon Temperature

$$k = A\,e^{-Ea/RT}$$

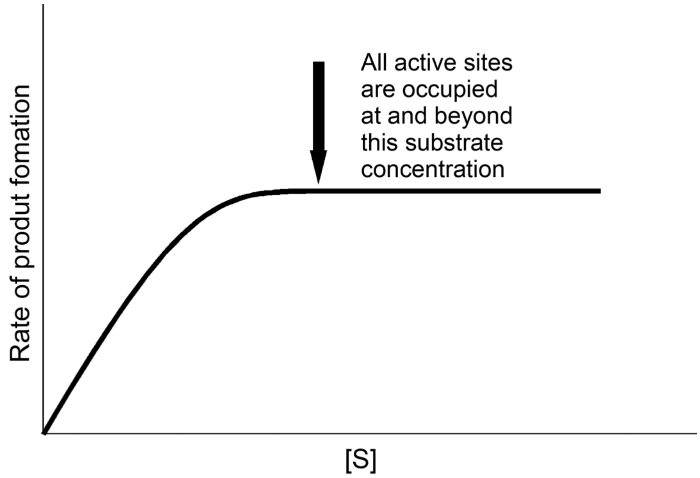


Potential Energy Diagrams: Exothermic vs. Endothermic Reactions

- Catalysis



Potential Energy Diagrams: Without and With a Catalyst



Saturation Kinetics

- Equilibrium in Reversible Chemical Reactions

$$aA + bB \rightleftharpoons cC + dD$$

$$K = \frac{[C]^c\,[D]^d}{[A]^a\,[B]^b}$$

  - {Note: Catalysts speed up the rate of reaction without affecting K_{eq}}

- Le Chatelier's Principle
  - Le Chatelier's principle states that whenever a perturbation is applied to a system at equilibrium, the system evolves in such a way as to compensate for the applied perturbation.
  - Relationship between the Equilibrium Constant and the Change in the Gibbs Free Energy

$$\Delta G^\circ = -R\,T\,ln\,K_{eq}$$

Gold Standard MCAT General Chemistry Review: Electrochemistry

- Generalities
  - The more positive the E° value, the more likely the reaction will occur spontaneously as written.
  - The strongest reducing agents have large negative E° values.
  - The strongest oxidizing agents have large positive E° values.
  - The oxidizing agent is reduced; the reducing agent is oxidized.
- Galvanic Cells
  - Mnemonic: LEO is A GERC
    - Lose Electrons Oxidation is Anode
    - Gain Electrons Reduction at Cathode
- Concentration Cell
  - Nernst equation

$$E_{cell} = E^\circ_{cell} - (RT/nF)(\ln Q)$$

- Faraday's Law
  - Faraday's law relates the amount of elements deposited or gas liberated at an electrode due to current.
  - One mole (= Avogadro's number) of electrons is called a faraday ($\mathfrak{F}$).
  - A faraday is equivalent to 96 500 coulombs.
  - A coulomb is the amount of electricity that is transferred when a current of one ampere flows for one second (1C = 1A . S).