MCAT REVIEW SHEETS

Questions or Comments? Contact MileDown.MD@Gmail.com

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$^{A}_{Z}X$

A = Mass number = protons + neutrons
Z = Atomic number = # of protons

Note: Atomic Weight = weighted average

Scientist Contributions

Rutherford Model: 1911. Electrons surround a nucleus.

Bohr Model: 1913. Described orbits in more detail.
Farther orbits = ↑Energy
Photon emitted when n↓, absorbed when n↑

→ AHED Mnemonic
Absorb light
Higher potential
Excited
Distant from nucleus

Heisenberg Uncertainty: It is impossible to know the momentum and position simultaneously.

Hund's Rule: e^- only double up in orbitals if all orbitals first have 1 e^-.

Pauli Exclusion Principle: Paired e^- must be $+\frac{1}{2}, -\frac{1}{2}$.

Diamagnetic vs. Paramagnetic

Diamagnetic: ↑↓ All electrons are paired
REPELLED by an external magnetic field

Paramagnetic: ↑ 1 or more unpaired electrons
PULLED into an external magnetic field

Follow Hund's rule to build the atom's electron configuration. If 1 or more orbitals have just a single electron, the atom is *paramagnetic*. If there are no unpaired electrons, then the atom is *diamagnetic*.

Examples:
He = $1s^2$ = **diamagnetic** and will repel magnetic fields.
C = $1s^2 2s^2 2p^2$ = **paramagnetic** and will be attracted to magnetic fields.

Constants

Avogadro's Number: $6.022 \times 10^{23} = 1 \text{ mol}$

Planck's (*h*): 6.626×10^{-34} J•s

Speed of Light (*c*) $3.0 \times 10^{8} \frac{\text{m}}{\text{s}}$

Light Energy

$E = \frac{hc}{\lambda}$ $\quad E = hf$

f = frequency
h = Planck's constant
c = speed of light

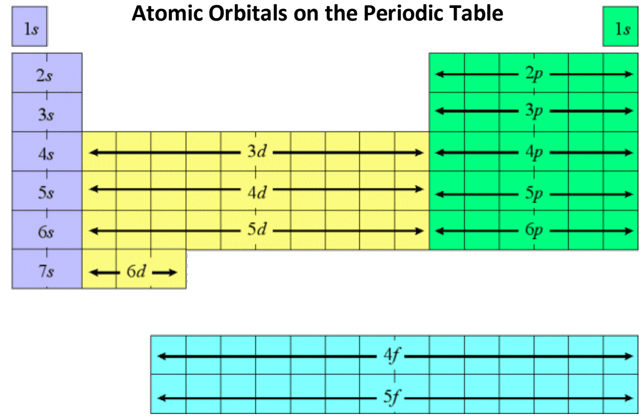
Quantum Numbers

Quantum Number	Name	What it Labels	Possible Values	Notes
n	Principal	e^- energy level or shell number	1, 2, 3, ...	Except for d- and f-orbitals, the shell # matches the row of the periodic table.
l	Azimuthal	3D shape of orbital	0, 1, 2, ..., n-1	0 = *s* orbital 1 = *p* orbital 2 = *d* orbital 3 = *f* orbital 4 = *g* orbital
m_l	Magnetic	Orbital sub-type	Integers $-l \rightarrow +l$	
m_s	Spin	Electron spin	$+\frac{1}{2}, -\frac{1}{2}$	

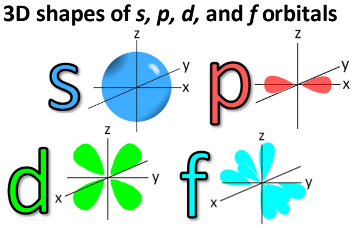
Maximum e^- in terms of n = $2n^2$
Maximum e^- in subshell = $4l + 2$

Free Radical: An atom or molecule with an unpaired electron.

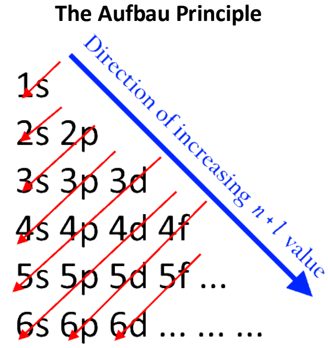
Atomic Orbitals on the Periodic Table

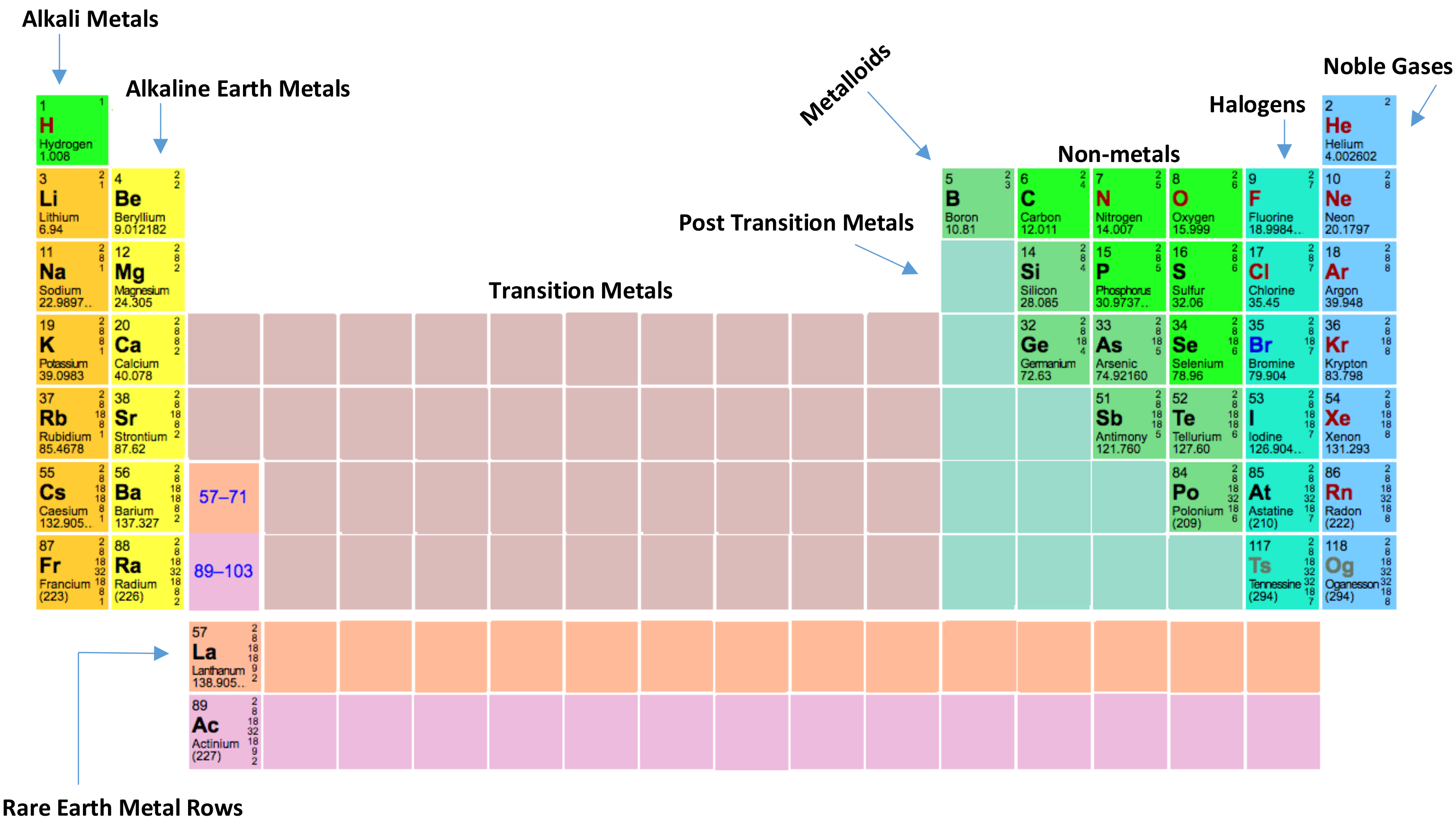


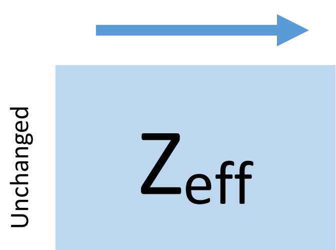
3D shapes of *s, p, d,* and *f* orbitals



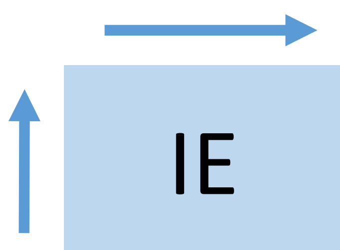
The Aufbau Principle



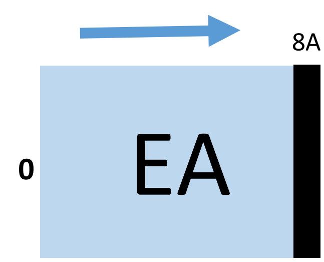




Pull between nucleus & valence e^-

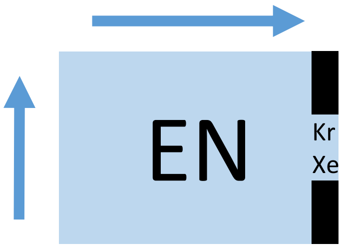


Lose e^-
1^{st} Ionization energies



Noble Gases have no affinity for e^-. It would take energy to force an e^- on them

Gain e^-
$\Delta H_{rxn} < 0$ when gaining e^-
but EA is reported as positive value

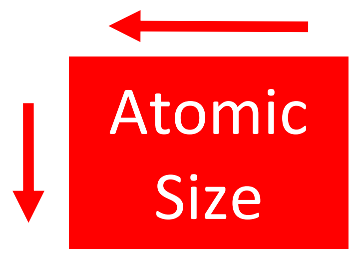


Of the Noble Gases, only Kr and Xe have an EN

Force the atom exerts on an e^- in a bond

Common Electronegativities

	H	C	N	O	F
Exact	2.20	2.55	3.04	3.44	3.98
≈	2.0	2.5	3.0	3.5	4.0



Only trend this direction
Cations < Neutral < Anions

Bond Type According to ΔEN

0 ⟷ Nonpolar covalent **0.5** ⟷ Polar covalent **1.7** ⟶ Ionic

Covalent Bonds

Covalent Bond: Formed via the sharing of electrons between two elements of similar EN.

Bond Order: Refers to whether a covalent bond is a single, double, or triple bond. As bond order increases *bond strength*↑, *bond energy*↑, *bond length*↓.

Nonpolar Bonds: ΔEN < 0.5.

Polar Bonds: ΔEN is between 0.5 and 1.7.

Coordinate Covalent Bonds: A single atom provides both bonding electrons. Most often found in Lewis acid-base chemistry.

Ionic Bonds

Ionic Bond: Formed via the transfer of one or more electrons from an element with a relatively low IE to an element with a relatively high electron affinity ΔEN > 1.7.

Cation: POSITIVE +

Anion: NEGATIVE –

Crystalline Lattices: Large, organized arrays of ions.

Intermolecular Forces

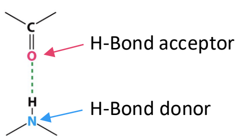
Strength ↑

Hydrogen O-H, N-H, F-H

Dipole-Dipole

London Dispersion

Note: *Van de Waals* Forces is a general term that includes Dipole-Dipole forces and London Dispersion forces.



Sigma and Pi Bonds

— 1 σ

= 1 σ 1 π

≡ 1 σ 2 π

Formal Charge

Formal Charge = valence e^- – dots – sticks

Dots: Nonbonding e^-

Sticks: Pair of bonding electrons

Valence Shell Electron Pair Repulsion Theory (VSEPR)

Electronic Geometry: Bonded and lone pairs treated the same.

Molecular Shape: Lone pairs take up less space than a bond to another atom.

Hybridization	e^- Groups Around Central Atom	Bonded Pairs	Lone Pairs	Electronic Geometry	Molecular Shape	Bond Angle
Sp	2	2 1	0 1	Linear	Linear Linear	180°
Sp^2	3	3 2 1	0 1 2	Trigonal Planar	Trig Planar Bent Linear	120°
Sp^3	4	4 3 2 1	0 1 2 3	Tetrahedral	Tetrahedral Trig Pyramidal Bent Linear	109.5°
Sp^3d	5	5 4 3 2	0 1 2 3	Trigonal Bipyramidal	Trigonal Bipyramidal Seesaw T-Shaped Linear	90° & 120°
Sp^3d^2	6	6 5 4	0 1 2	Octahedral	Octahedral Square Pyramidal Square Planar	90°

Equivalents & Normality

Equivalent Mass: Mass of an acid that yields 1 mole of H^+ or mass of a base that reacts with 1 mole of H^+.

GEW = $\frac{\text{molar mass}}{\text{mol } H^+ \text{ or } e^-}$

Equivalents = $\frac{\text{mass of compound}}{\text{GEW}}$

Normality = $\frac{\text{Eq}}{\text{L}}$

For acids, the # of equivalents (n) is the # of H^+ available from a formula unit.

Molarity = $\frac{\text{normality}}{\text{mol } H^+ \text{ or } e^-}$

Naming Ions

For elements (usually metals) that can form more than one positive ion, the charge is indicated by a Roman numeral in parentheses following the name of the element

Fe^{2+}	Iron(II)
Fe^{3+}	Iron(III)
Cu^{+}	Copper(I)
Cu^{2+}	Copper(II)

Older method: –ous and –ic to the atoms with lesser and greater charge, respectively

Fe^{2+}	Ferrous
Fe^{3+}	Ferric
Cu^{+}	Cuprous
Cu^{2+}	Cupric

Monatomic anions drop the ending of the name and add –ide

H^-	Hydride
F^-	Fluoride
O^{2-}	Oxide
S^{2-}	Sulfide
N^{3-}	Nitride
P^{3-}	Phosphide

Oxyanions = polyatomic anions that contain oxygen.
MORE Oxygen = –ate
LESS Oxygen = –ite

NO_3^-	Nitrate
NO_2^-	Nitrite
SO_4^{2-}	Sulfate
SO_3^{2-}	Sulfite

In extended series of oxyanions, prefixes are also used.
MORE Oxygen = Hyper- (per-)
LESS Oxygen = Hypo-

ClO^-	Hypochlorite
ClO_2^-	Chlorite
ClO_3^-	Chlorate
ClO_4^-	Perchlorate

Polyatomic anions that gain H^+ to for anions of lower charge add the word Hydrogen or dihydrogen to the front.

HCO_3^-	Hydrogen carbonate or bicarbonate
HSO_4^-	Hydrogen sulfate or bisulfate
$H_2PO_4^-$	Dihydrogen phosphate

Compound Formulas

Empirical: Simplest whole-number ratio of atoms.

Molecular: Multiple of empirical formula to show exact # of atoms of each element.

Types of Reactions

Combination: Two or more reactants forming one product
$2H_{2\,(g)} + O_{2\,(g)} \rightarrow 2H_2O_{\,(g)}$

Decomposition: Single reactant breaks down
$2HgO_{\,(s)} \rightarrow 2Hg_{\,(l)} + O_{2\,(g)}$

Combustion: Involves a fuel, usually a hydrocarbon, and $O_{2\,(g)}$
Commonly forms CO_2 and H_2O
$CH_{4\,(g)} + 2O_{2\,(g)} \rightarrow CO_{2\,(g)} + H_2O_{\,(g)}$

Single-Displacement: An atom/ion in a compound is replaced by another atom/ion
$Cu_{\,(s)} + AgNO_{3\,(aq)} \rightarrow Ag_{\,(s)} + CuNO_{3\,(aq)}$

Double-Displacement: (metathesis) Elements from two compounds swap places
$CaCl_{2\,(aq)} + 2AgNO_{3\,(aq)} \rightarrow Ca(NO_3)_{2\,(aq)} + 2AgCl_{\,(s)}$

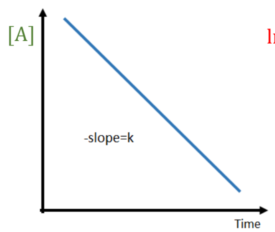
Neutralization: A type of double-replacement reaction
Acid + base → salt + H_2O
$HCl_{\,(aq)} + NaOH_{\,(aq)} \rightarrow NaCl_{\,(aq)} + H_2O_{\,(l)}$

Acid Names

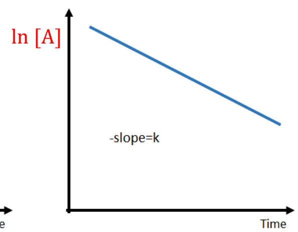
-ic: Have one MORE oxygen than -ous.

-ous: Has one FEWER oxygen than -ic.

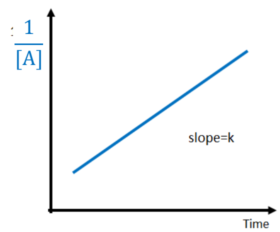
m	Order	Rate Law	Integrated Rate Law	Half Life	Units of Rate Constant
0	zeroth order	$R = k$	$[A] = [A]_0 - k\,t$	$t_{\frac{1}{2}} = \frac{[A]_0}{2\,k}$	$\frac{M}{s}$
1	first order	$R = k\,[A]$	$[A] = [A]_0 \times e^{-k\,t}$	$t_{\frac{1}{2}} = \frac{\ln(2)}{k}$	$\frac{1}{s}$
2	second order	$R = k\,[A]^2$	$\frac{1}{[A]} = \frac{1}{[A]_0} + kt$	$t_{\frac{1}{2}} = \frac{1}{k\,[A]_0}$	$\frac{1}{M\,s}$



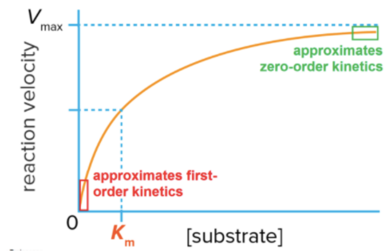
Zeroth Order Reaction



First Order Reaction



Second Order Reaction



Reaction Order and Michaelis-Menten Curve: At low substrate concentrations, the reaction is approximately FIRST-ORDER. At very high substrate concentration, the reaction approximates ZERO-ORDER since the reaction ceases to depend on substrate concentration.

Types of Reactions

Combination: Two or more reactants forming one product.
$2H_2\,_{(g)} + O_2\,_{(g)} \rightarrow 2H_2O\,_{(g)}$

Decomposition: Single reactant breaks down.
$2HgO\,_{(s)} \rightarrow 2Hg\,_{(l)} + O_2\,_{(g)}$

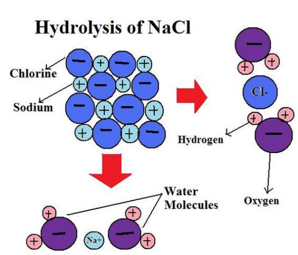
Combustion: Involves a fuel, usually a hydrocarbon, and $O_2\,_{(g)}$.
Commonly forms CO_2 and H_2O.
$CH_4\,_{(g)} + 2O_2\,_{(g)} \rightarrow CO_2\,_{(g)} + H_2O\,_{(g)}$

Single-Displacement: An atom or ion in a compound is replaced by another atom or ion.
$Cu\,_{(s)} + AgNO_3\,_{(aq)} \rightarrow Ag\,_{(s)} + CuNO_3\,_{(aq)}$

Double-Displacement: (metathesis) Elements from two compounds swap places.
$CaCl_2\,_{(aq)} + 2AgNO_3\,_{(aq)} \rightarrow Ca(NO_3)_2\,_{(aq)} + 2AgCl\,_{(s)}$

Neutralization: A type of double-replacement reaction.
Acid + base → salt + H_2O
$HCl\,_{(aq)} + NaOH\,_{(aq)} \rightarrow NaCl\,_{(aq)} + H_2O\,_{(l)}$

Hydrolysis: Using water to break the bonds in a molecule.



Gibbs Free Energy

$\Delta G = E_a - E_{a\,rev}$

$-\Delta G$ = Exergonic

$+\Delta G$ = Endergonic

Equations

Arrhenius: $k = A \times e^{\frac{-E_a}{RT}}$

Definition of Rate: For $aA + bB \rightarrow cC + dD$

$$\text{Rate} = -\frac{\Delta[A]}{a\Delta t} = -\frac{\Delta[B]}{b\Delta t} = \frac{\Delta[C]}{c\Delta t} = \frac{\Delta[D]}{d\Delta t}$$

Rate Law: $\text{rate} = k\,[A]^x\,[B]^y$

Radioactive Decay: $[A]_t = [A]_0 \times e^{kt}$

Reaction Mechanisms

Overall Reaction: $A_2 + 2B \rightarrow 2AB$

Step 1:	$A_2 + B \rightarrow A_2B$	slow
Step 2:	$A_2B + B \rightarrow 2AB$	fast

A_2B is an intermediate
Slow step is the rate determining step

Arrhenius Equation

Arrhenius: $k = A \times e^{\frac{-E_a}{RT}}$

k = rate constant
A = frequency factor
E_a = activation energy
R = gas constant = $8.314\,\frac{J}{mol\,K}$
T = temp in K

Trends: $\uparrow A \Rightarrow \uparrow k$

$\uparrow T \Rightarrow \uparrow k$ (Exponent gets closer to 0. Exponent becomes less negative)

Equilibrium Constant

$aA + bB \rightleftharpoons cC + dD$

Equilibrium Constant (K_{eq}): $K_{eq} = \frac{[C]^c\,[D]^d}{[A]^a\,[B]^b}$

Reaction Quotient (Q_c): $Q_c = \frac{[C]^c\,[D]^d}{[A]^a\,[B]^b}$

Exclude pure solids and liquids

Kinetic (E_a) and Thermodynamic (ΔG) Control

Kinetic Products: HIGHER in free energy than thermodynamic products and can form at *lower temperatures*. "Fast" products because they can form more quickly under such conditions.

Thermodynamic Products: LOWER in free energy than kinetic products, more stable. Slower but more spontaneous (more negative ΔG)

Reaction Quotient

$Q < K_{eq}$ $\Delta G < 0$, reaction $\rightarrow$

$Q = K_{eq}$ $\Delta G = 0$, equilibrium

$Q > K_{eq}$ $\Delta G > 0$, reaction $\leftarrow$

Le Châtelier's Principle

If a stress is applied to a system, the system shifts to relieve that applied stress.

Example: Bicarbonate Buffer

$CO_{2\,(g)} + H_2O_{(l)} \rightleftharpoons H_2CO_{3\,(aq)} \rightleftharpoons H^+_{(aq)} + HCO_3^-{}_{(aq)}$

$\downarrow$pH $\Rightarrow$ $\uparrow$respiration to blow off CO_2

$\uparrow$pH $\Rightarrow$ $\downarrow$respiration, trapping CO_2

Systems and Processes

Isolated System: Exchange neither matter nor energy with the environment.

Closed System: Can exchange energy but not matter with the environment.

Open system: Can exchange BOTH energy and matter with the environment.

Isothermal Process: Constant temperature.

Adiabatic Process: Exchange no heat with the environment.

Isobaric Process: Constant pressure.

Isovolumetric: (isochoric) Constant volume.

States and State Functions

State Functions: Describe the physical properties of an equilibrium state. Are pathway independent. Pressure, density, temp, volume, enthalpy, internal energy, Gibbs free energy, and entropy.

Standard Conditions: 298 K, 1 atm, 1 M
Note that in gas law calculations, Standard Temperature and Pressure (STP) is 0°C, 1 atm.

Fusion: Solid → liquid

Freezing: Liquid → solid

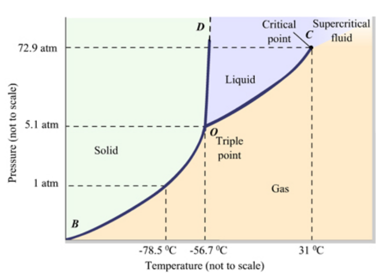
Vaporization: Liquid → gas

Sublimation: Solid → gas

Deposition: Gas → solid

Triple Point: Point in phase diagram where all 3 phases exist.

Supercritical Fluid: Density of gas = density of liquid, no distinction between those two phases.



Gibbs Free Energy (*G*)

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

ΔH	**ΔS**	**Outcome**
+	+	Spontaneous at HIGH temps
+	-	Non-spontaneous at all temps
-	+	Spontaneous at all temps
-	-	Spontaneous at LOW temps

Note: Temperature dependent when ΔH and ΔS have same sign.

Temperature (*T*) and Heat (*q*)

Temperature (*T*): Scaled measure of average kinetic energy of a substance.

Celsius vs Fahrenheit: $°F = (\frac{9}{5}°C) + 32$

0°C = 32°F	*Freezing Point H_2O*
25°C = 75°F	*Room Temp*
37°C = 98.6°F	*Body Temp*

Heat (*q*): The transfer of energy that results from differences of temperature. Hot transfers to cold.

Enthalpy (*H*)

Enthalpy (*H*): A measure of the potential energy of a system found in intermolecular attractions and chemical bonds.

Phase Changes: Solid → Liquid → Gas: ENDOTHERMIC since gases have more heat energy than liquids and liquids have more heat energy than solids.

Gas → Liquid → Solid: EXOTHERMIC since these reactions release heat.

Hess's Law: Enthalpy changes are additive.

<u>ΔH°_{rxn} from heat of formations</u>

$$\Delta H^{\circ}_{\mathrm{rxn}} = \Delta H^{\circ}_{\mathrm{products}} - \Delta H^{\circ}_{\mathrm{reactants}}$$

<u>ΔH°_{rxn} from bond dissociation energies</u>

$$\Delta H^{\circ}_{\mathrm{rxn}} = \Delta H^{\circ}_{\mathrm{reactants}} - \Delta H^{\circ}_{\mathrm{products}}$$

Entropy (*S*)

Entropy (*S*): A measure of the degree to which energy has been spread throughout a system or between a system and its surroundings.

$$\Delta S = \frac{q_{\mathrm{rev}}}{T}$$

<u>Standard entropy of reaction</u>

$$\Delta S^{\circ}_{\mathrm{rxn}} = \Delta S^{\circ}_{\mathrm{f,products}} - \Delta S^{\circ}_{\mathrm{f,reactants}}$$

Note: Entropy is maximized at equilibrium.

Gibbs Free Energy (*G*)

Gibbs Free Energy (*G*): Derived from enthalpy and entropy.

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

<u>Standard Gibbs free energy of reaction</u>

$$\Delta G^{\circ}_{\mathrm{rxn}} = \Delta G^{\circ}_{\mathrm{f,products}} - \Delta G^{\circ}_{\mathrm{f,reactants}}$$

<u>From equilibrium constant K_{eq}</u>

$$\Delta G^{\circ}_{\mathrm{rxn}} = -RT\ln(K_{\mathrm{eq}})$$

<u>From reaction quotient *Q*</u>

$$\Delta G_{\mathrm{rxn}} = \Delta G^{\circ}_{\mathrm{rxn}} + RT\ln(Q)$$

$$\Delta G_{\mathrm{rxn}} = RT\ln\left(\frac{Q}{K_{\mathrm{eq}}}\right)$$

$\Delta G < 0$: Spontaneous

$\Delta G = 0$: Equilibrium

$\Delta G > 0$: Non-spontaneous

Ideal Gases

Ideal Gas: Theoretical gas whose molecules occupy negligible space and whose collisions are perfectly elastic. Gases behave ideally under reasonably ↑temperatures and ↓pressures.

STP: 273 K (0°C), 1 atm

1 mol Gas: At STP 1 mol of gas = 22.4 L

Units: $1 \text{ atm} = 760 \text{ mmHg} = 760 \text{ torr} = 101.3 \text{ kPa} = 14.7 \text{ psi}$

Ideal Gas Law

$$PV = nRT \qquad R = 8.314 \frac{\text{J}}{\text{mol K}}$$

Density of Gas: $\rho = \frac{m}{V} = \frac{PM}{RT}$

Combined Gas Law: $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ (*n* is constant)
$V_2 = V_1\left(\frac{P_1}{P_2}\right)\left(\frac{T_2}{T_1}\right)$

Avogadro's Principle: $\frac{n}{V} = k$ or $\frac{n_1}{V_1} = \frac{n_2}{V_2}$ (*T* and *P* are constant)

Boyle's Law: $PV = k$ or $P_1V_1 = P_2V_2$ (*n* and *T* are constant)

Charles's Law: $\frac{V}{T} = k$ or $\frac{V_1}{T_1} = \frac{V_2}{T_2}$ (*n* and *P* are constant)

Gay-Lussac's Law: $\frac{P}{T} = k$ or $\frac{P_1}{T_1} = \frac{P_2}{T_2}$ (*n* and *V* are constant)

Other Gas Laws

Dalton's Law: $P_T = P_A + P_B + P_C + \ldots$
(total pressure from partial pressures)

Dalton's Law: $P_A = X_A P_T$ (*X* = mol fraction)
(partial pressure from total pressure)

Henry's Law: $[A] = k_H \times P_A$ or $\frac{[A]_1}{P_1} = \frac{[A]_2}{P_2} = k_H$

Diatomic Gases

Exist as diatomic molecules, never a stand-alone atom. Includes H_2, N_2, O_2, F_2, Cl_2, Br_2, and I_2

Mnemonic: "**H**ave **N**o **F**ear **O**f **I**ce **C**old **B**eer"

Real Gases

Real gases deviate from ideal behavior at ↓temperature & ↑pressure

At Moderately ↑*P*, ↓*V*, or ↓*T*: Real gases will occupy *less volume* than predicted by the ideal gas law because the particles have intermolecular attractions.

At Extremely ↑*P*, ↓*V*, or ↓*T*: Real gases will occupy *more volume* than predicted by the ideal gas law because the particles occupy physical space.

Van der Waals Equation of State: $\left(P + \frac{n^2a}{V^2}\right)(V - nb) = nRT$

a corrects for attractive forces
b corrects for volume of the particles themselves

Kinetic Molecular Theory

Avg Kinetic Energy of a Gas: $KE = \frac{1}{2} m v^2 = \frac{3}{2} K_B T \qquad K_B = 1.38 \times 10^{-23} \frac{\text{J}}{\text{K}}$

$(KE \propto T)$

↑*T* = molecules move FASTER
↑molar mass = molecules move SLOWER

Root-Mean-Square Speed: $u_{rms} = \sqrt{\frac{3RT}{M}}$

Diffusion: The spreading out of particles from [high] → [low]

Effusion: The mvmt of gas from one compartment to another through a small opening under pressure

Graham's Law: $\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}$

↓molar mass = diffuse/effuse FASTER
↑molar mass = diffuse/effuse SLOWER

		1 H 1.008			
					2 He 4.00
5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
31 Ga 69.72	32 Ge 72.61	33 As 74.92	34 Se 76.96	35 Br 79.90	36 Kr 83.80
49 In 114.8	50 Sn 118.71	51 Sb 121.75	52 Te 127.60	53 I 126.90	54 Xe 131.29
81 Tl 204.4	82 Pb 207.2	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)

The 7 Diatomic Gases

Terminology

Solution: Homogenous mixture. *Solvent* particles surround *solute* particles via electrostatic interactions.

Solvation or Dissolution: The process of dissolving a solute in solvent. Most dissolutions are endothermic, although dissolution of gas into liquid is exothermic.

Solubility: Maximum amount of solute that can be dissolved in a solvent at a given temp.

Molar Solubility: Molarity of the solute at saturation.

Complex Ions: Cation bonded to at least one ligand which is the e^- pair donor. It is held together with coordinate covalent bonds. Formation of complex ions ↑solubility.

Solubility in Water: Polar molecules (with +/- charge) are attracted to water molecules and are hydrophilic. Nonpolar molecules are repelled by water and are hydrophobic.

Polar = Hydrophilic
Nonpolar = Hydrophobic

Concentration

% by mass: $\frac{\text{mass solute}}{\text{mass solution}} \times 100\%$

Mole Fraction: $X_A = \frac{\text{moles solute}}{\text{total moles}}$

Molarity: $M = \frac{\text{moles solute}}{\text{liters of solution}}$

Molality: $C_m = \frac{\text{moles solute}}{\text{kg of solvent}}$ Can also just be a lowercase m

Normality: $N = \frac{\text{\# of equivalents}}{\text{liters of solution}}$ For acids, the # of equivalents (n) is the # of H^+ available from a formula unit.

Dilutions: $M_1 V_1 = M_2 V_2$

Solutions Equilibria

Saturated solutions are in equilibrium at that particular temperature.

Solubility Product Constant: Equilibrium expression for something that dissolves. For substance A_aB_b, $K_{sp} = [A]^a[B]^b$

Ion Product: $IP = [A]^a[B]^b$
$IP < K_{sp}$ unsaturated
$IP = K_{sp}$ saturated at equilibrium
$IP > K_{sp}$ supersaturated, precipitate

Formation or Stability Constant: K_f. The equilibrium constant for complex formation. Usually much greater that K_{sp}.

Common Ion Effect: ↓solubility of a compound in a solution that already contains one of the ions in the compound. The presence of that ion shifts the dissolution reaction to the left, decreasing its dissociation.

Chelation: When a central cation is bonded to the same ligand in multiple places. Chelation therapy sequesters toxic metals.

Solubility Rules

Soluble

Na^+, K^+, NH_4^+

NO_3^-

Cl^-, Br^-, I^- Except with Pb^{2+}, Hg_2^{2+}, Ag^+, Cu^+

SO_4^{2-} Except with Ca^{2+}, Sr^{2+}, Ba^{2+}, Pb^{2+}, Hg_2^{2+}, Ag_2^{2+}

Insoluble

S_2^- Except with Na^+, K^+, NH_4^+, Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}

O_2^- Except with Na^+, K^+, Sr^{2+}, Ba^{2+}

OH^- Except with Na^+, K^+, Ca^{2+}, Sr^{2+}, Ba^{2+}

CrO_4^{2-} Except with Na^+, K^+, Mg^{2+}, NH_4^+

PO_4^{3-} & CO_3^{2-} Except with Na^+, K^+, NH_4^+

Colligative Properties

Colligative Properties: Physical properties of solutions that depend on the concentration of dissolved particles but not on their chemical identity.

Raoult's Law: Vapor pressure depression. $P_A = X_A P_A^\circ$

The presence of other solutes ↓evaporation rate of solvent, thus ↓P_{vap}.

Boiling Point Elevation: $\Delta T_b = i\, K_b\, C_m$

i = ionization factor
K_b = boiling point depression constant
C_m = molal concentration

Freezing Point Depression: $\Delta T_f = i\, K_f\, C_m$

K_f = freezing point depression constant

Osmolarity: The number of individual particles in solution. Example: NaCl dissociates completely in water, so $1\text{ M NaCl} = 2\ \frac{\text{osmol}}{\text{liter}}$

Osmotic Pressure: "Sucking" pressure generated by solutions in which water is drawn into solution.

$\pi = i\, M\, R\, T$

i = van't Hoff factor
M = molar concentration of solute
R = gas constant
T = temperature

Definitions

Arrhenius Acid: Donates H^+ (same definition as Brønsted acid)

Arrhenius Base: Donates OH^-

Brønsted-Lowry Acid: Donates H^+ (same definition as Arrhenius acid)

Brønsted-Lowry Base: Accepts H^+

Lewis Acid: Accepts e^- pair

Lewis Base: Donates e^- pair

Note: All Arrhenius acids/bases are Brønsted-Lowry acids/bases, and all Brønsted-Lowry acid/bases are Lewis acids/bases; however, the converse of these statements is not necessarily true.

Amphoteric Species: Species that can behave as an acid or a base. Amphiprotic = amphoteric species that specifically can behave as a Brønsted-Lowry acid/base.

Polyprotic Acid: An acid with multiple ionizable H atoms.

Properties

Water Dissociation Constant: $K_w = 10^{-14}$ at 298 K
$K_w = K_a \times K_b$

pH and pOH: $pH = -\log[H^+]$ $[H^+] = 10^{-pH}$
$pOH = -\log[OH^-]$
$pH + pOH = 14$

p scale value approximation: $-\log(n \times 10^{-m})$
$\text{p value} \approx -(m + 0.n)$

Strong Acids/Bases: Dissociate completely

Weak Acids/Bases: Do not completely dissociate

Acid Dissociation Constant: $K_a = \frac{[H_3O^+][A^-]}{[HA]}$ $pK_a = -\log(K_a)$

Base Dissociation Constant: $K_b = \frac{[B^+][OH^-]}{[BOH]}$ $pK_b = -\log(K_b)$

$pK_a + pK_b = pK_w = 14$

Conjugate Acid/Base Pairs: Strong acids & bases / weak conjugate
Weak acids & bases / weak conjugate

Neutralization Reactions: Form salts and (sometimes) H_2O

Buffers

Buffer: Weak acid + conjugate salt
Weak base + conjugate salt

Buffering Capacity: The ability of a buffer to resist changes in pH. Maximum buffering capacity is within 1 pH point of the pK_a.

Henderson-Hasselbalch Equation: $pH = pK_a + \log\frac{[A^-]}{[HA]}$

When $[A^-] = [HA]$ at equivalence point, log(1) = 0, so $pH = pK_a$

$pOH = pK_b + \log\frac{[B^+]}{[HOH]}$

Polyvalence & Normality

Equivalent: 1 mole of the species of interest.

Normality: Concentration of equivalents in solution.

Polyvalent: Can donate or accept multiple equivalents.

Example: 1 mol H_3PO_4 yields 3 mol H^+. So, 2 M H_3PO_4 = 6 N.

Titrations

Half-Equivalence Point: (midpoint) The midpoint of the buffering region, in which half the titrant has been protonated or deprotonated. $[HA] = [A^-]$ and $pH = pK_a$ and a buffer is formed.

Equivalence Point: The point at which equivalent amounts of acid and base have reacted. $N_1 V_1 = N_2 V_2$

pH at Equivalence Point: Strong acid + strong base, pH = 7
Weak acid + strong base, pH > 7
Weak base + strong acid, pH < 7
Weak acid + weak base, pH > or < 7 depending on the relative strength of the acid and base

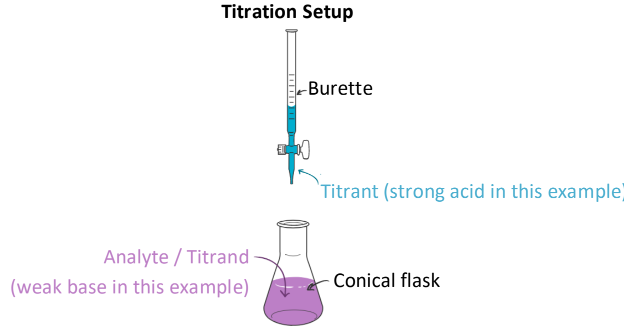
Indicators: Weak acids or bases that display different colors in the protonated and deprotonated forms. The indicator's pK_a should be close the pH of the *equivalence point*.

Tests: *Litmus*: Acid = red; Base = blue; Neutral = purple
Phenolphthalein: pH 8.2 = colorless; pH 10 = red
Methyl Orange: pH 3.1 = red; pH 4.4 = yellow
Bromophenol Blue: pH 3 = yellow; pH 4.6 = blue

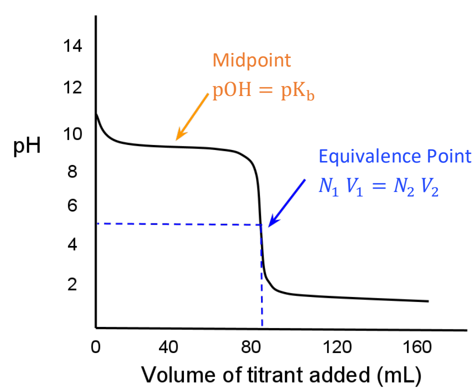
Endpoint: When indicator reaches full color.

Polyvalent Acid/Base Titrations: Multiple buffering regions and equivalence points.

Titration Setup



Titration Curve
When titrating a weak base with a strong acid



Definitions

Oxidation: Loss of e^-

Reduction: Gain of e^-

With Respect to Oxygen Transfer: Oxidation is GAIN of oxygen
Reduction is LOSS of oxygen

Oxidizing Agent: Facilitates the oxidation of another compound. Is itself reduced

Reducing Agent: Facilitates the reduction of another compound. Is itself oxidized

Balancing via Half-Reaction Method

- Separate the two half-reactions
- Balance the atoms of each half-reaction. Start with all elements besides H and O. In acidic solution, balance H and O using water and H^+. In basic solution, balance H and O using water and OH^-
- Balance the charges of each half-reaction by adding e^- as necessary
- Multiply the half-reactions as necessary to obtain the same number of e^- in both half-reactions
- Add the half-reactions, canceling out terms on both sides
- Confirm that the mass and charge are balanced

Oxidation # Rules

- Any free element or diatomic species = 0
- Monatomic ion = the charge of the ion
- When in compounds, group 1A metals = +1; group 2A metals = +2
- When in compounds, group 7A elements = -1, unless combined with an element of greater EN
- H = +1 unless it is paired with a less EN element, then = -1
- O = -2 except in peroxides, when it = -1, or in compounds with more EN elements
- The sum of all oxidation numbers in a compound must = overall charge

Net Ionic Equations

Complete Ionic Equation: Accounts for all of the ions present in a reaction. Split all aqueous compounds into their relevant ions. Keep sold salts intact.

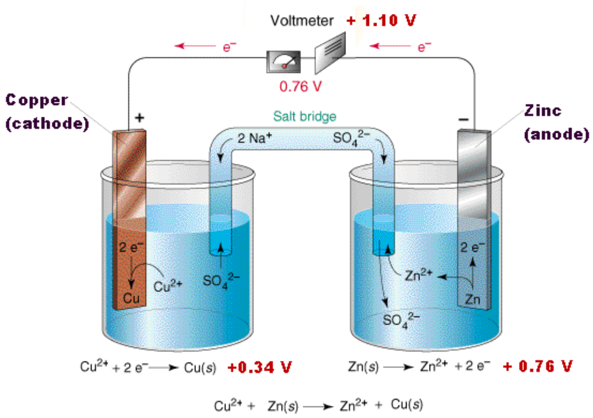
Net Ionic Equation: Ignores spectator ions

Disproportionation Reactions: (dismutation) A type of REDOX reaction in which one element is both oxidized and reduced, forming at least two molecules containing the element with different oxidation states

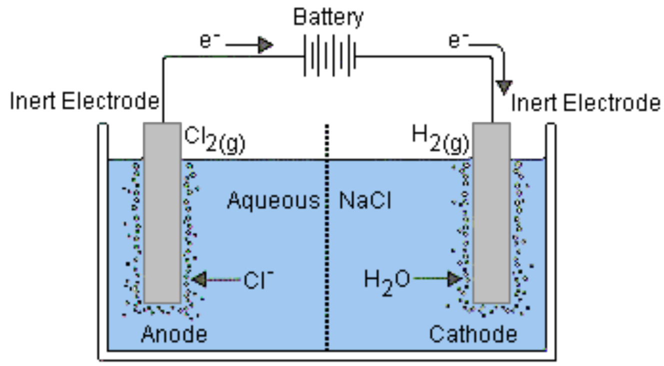
REDOX Titrations: Similar in methodology to acid-base titrations, however, these titrations follow transfer of charge

Potentiometric Titration: A form of REDOX titration in which a voltmeter measures the electromotive force of a solution. No indicator is used, and the equivalence point is determined by a sharp change in voltage

Galvanic Cell



Electrolytic Cell



Electrochemical Cells

Anode: Always the site of oxidation. It attracts anions.

Cathode: Always the site of reduction. It attracts cations.

Red Cat = Reduction at the Cathode

e⁻ Flow Anode → Cathode

Current Flow: Cathode → Anode

Galvanic Cells: (Voltaic) House spontaneous reactions. -ΔG, +Emf, $+E^\circ_{cell}$
Anode = NEG, Cathode = POS

Electrolytic Cells: House non-spont reactions. +ΔG, -Emf, $-E^\circ_{cell}$
Anode = POS, Cathode = NEG

Concentration Cells: Specialized form of galvanic cell in which both electrodes are made of the same material. It is the concentration gradient between the two solutions that causes mvmt of charge.

Rechargeable Batteries: Can experience charging (electrolytic) and discharging (galvanic) states.

Lead-Acid: Discharging: Pb anode, PbO_2 cathode in a concentrated sulfuric acid solution. Low energy density.

Ni-Cd: Discharging: Cd anode, NiO(OH) cathode in a concentrated KOH solution. Higher energy density than lead-acid batteries.

NiMH: More common than Ni-Cd because they have higher energy density.

Cell Potentials

Reduction Potential: Quantifies the tendency for a species to gain e⁻ and be reduced. More positive E_{red} = greater tendency to be reduced.

Standard Reduction Potential: E°_{red}. Calculated by comparison to the standard hydrogen electrode (SHE).

Standard Electromotive Force: E°_{cell}. The difference in standard reduction potential between the two half-cells.

Galvanic Cells: $+E^\circ_{cell}$

Electrolytic Cells: $-E^\circ_{cell}$

Emf & Thermodynamics

Electromotive force and change in free energy always have OPPOSITE signs.

When $+E^\circ_{cell}$, then $-\Delta G^\circ$ - Galvanic cells

When $-E^\circ_{cell}$, then $+\Delta G^\circ$ - Electrolytic cells

When $E^\circ_{cell} = 0$, then $\Delta G^\circ = 0$ - Concentration cells

$$E^\circ_{cell} = E^\circ_{red,cathode} - E^\circ_{red,anode}$$

$$\Delta G^\circ = -n\,F\,E^\circ_{cell}$$

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

$$\Delta G = \Delta G^\circ + R\,T\ln(Q)$$

Faraday constant (F): 96,485 C

$1\ C = \frac{J}{V}$

Nernst Equation

Describes the relationship between the concentration of species in a solution under nonstandard conditions and the emf.

When $K_{eq} > 1$, then $+E^\circ_{cell}$

When $K_{eq} < 1$, then $-E^\circ_{cell}$

When $K_{eq} = 1$, then $E^\circ_{cell} = 0$

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

$$E_{cell} = E^\circ_{cell} - \frac{0.0592}{n}\log(Q)$$

IUPAC Naming Conventions

Step 1: Find the parent chain, the longest carbon chain that contains the highest-priority functional group.

Step 2: Number the chain in such a way that the highest-priority functional group receives the lowest possible number.

Step 3: Name the substituents with a prefix. Multiples of the same type receive (*di-*, *tri-*, *tetra-*, etc.).

Step 4: Assign a number to each substituent depending on the carbon to which it is bonded.

Step 5: Alphabetize substituents and separate numbers from each other by commas and from words by hyphens.

TABLE 3-3 Names of Straight-Chain Alkanes

Number of carbons (n)	Name	Formula (C_nH_{2n+2})	Number of carbons (n)	Name	Formula (C_nH_{2n+2})
1	Methane	CH_4	9	Nonane	C_9H_{20}
2	Ethane	C_2H_6	10	Decane	$C_{10}H_{22}$
3	Propane	C_3H_8	11	Undecane	$C_{11}H_{24}$
4	Butane	C_4H_{10}	12	Dodecane	$C_{12}H_{26}$
5	Pentane	C_5H_{12}	13	Tridecane	$C_{13}H_{28}$
6	Hexane	C_6H_{14}	20	Icosane	$C_{20}H_{42}$
7	Heptane	C_7H_{16}	30	Triacontane	$C_{30}H_{62}$
8	Octane	C_8H_{18}			

Hydrocarbons and Alcohols

Alkane: Hydrocarbon with no double or triple bonds.
Alkane = $C_nH_{(2n+2)}$

Naming: Alkanes are named according to the number of carbons present followed by the suffix –*ane*.

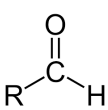
Alkene: Contains a double bond. Use suffix -ene.

Alkyne: Contains a triple bond. Use suffix –yne.

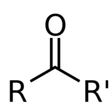
Alcohol: Contains a –OH group. Use suffix –ol or prefix hydroxy-. Alcohols have higher priority than double or triple bonds.

Diol: Contains 2 hydroxyl groups.
Geminal: Same side
Vicinal: If on adjacent carbons

Aldehydes and Ketones



Aldehyde



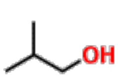
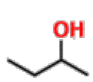
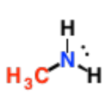
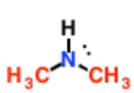
Ketone

Carbonyl Group: C=O. Aldehydes and ketones both have a carbonyl group.

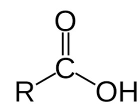
Aldehyde: Carbonyl group on terminal C.

Ketone: Carbonyl group on nonterminal C.

Primary, Secondary, and Tertiary

	1°	2°	3°
Alcohols:			
Amines:			

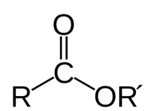
Carboxylic Acids & Derivatives



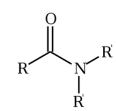
Carboxylic Acid

Carbonyl Group: The highest priority functional group because it contains 3 bonds to oxygen.

Naming: Suffix –oic acid.



Ester



Amide

Ester: Carboxylic Acid derivative where –OH is replaced with -OR.

Amide: Replace the –OH group of a carboxylic acid with an amino group that may or may not be substituted.

Structural Isomers

- Share only a molecular formula.
- Have different physical and chemical properties.

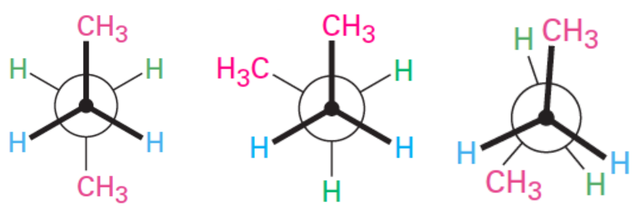
Stereoisomers

Compounds with atoms connected in the same order but differing in 3D orientation.

Chiral Center: Four different groups attached to a central carbon.

2^n Rule: $n = \#$ of chiral centers $\qquad \#$ of stereoisomers $= 2^n$

Conformational Isomers

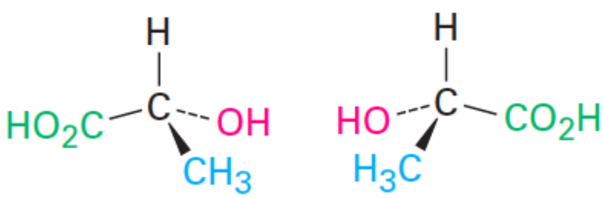


Anti **Gauche** **Eclipsed**

Differ by rotation around a single (σ) bond

Cyclohexane Substituents: *Equatorial*: In the plane of the molecule.
Axial: Sticking up/down from the molecule's plane.

Configurational Isomers



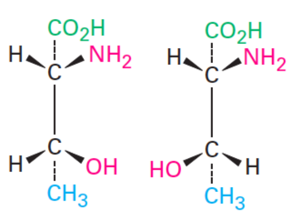
Enantiomers

Enantiomers: Nonsuperimposable mirror images. Opposite stereochemistry at every chiral carbon. Same chemical and physical properties, except for rotation of plane polarized light.

Optical Activity: The ability of a molecule to rotate plane-polarized light: d- or (+) = RIGHT, l- or (-) = LEFT.

Racemic Mixture: 50:50 mixture of two enantiomers. Not optically active because the rotations cancel out.

Meso Compounds: Have an internal plane of symmetry, will also be optically inactive because the two sides of the molecule cancel each other out.



Diastereomers

Diastereomers: Stereoisomers that are NOT mirror image.

Cis-Trans: A subtype of diastereomers. They differ at some, but not all, chiral centers. Different chemical and physical properties.

Relative & Absolute Configuration

Relative Configuration: Gives the stereochemistry of a compound in comparison to another compound. E.g. D and L.

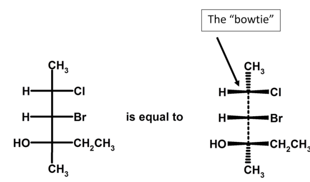
Absolute Configuration: Gives the stereochemistry of a compound without having to compare to other compounds. E.g. S and R.

Cahn-Ingold-Prelog Priority Rules: Priority is given by looking at atoms connected to the chiral carbon or double-bonded carbons; whichever has the highest atomic # gets highest priority.

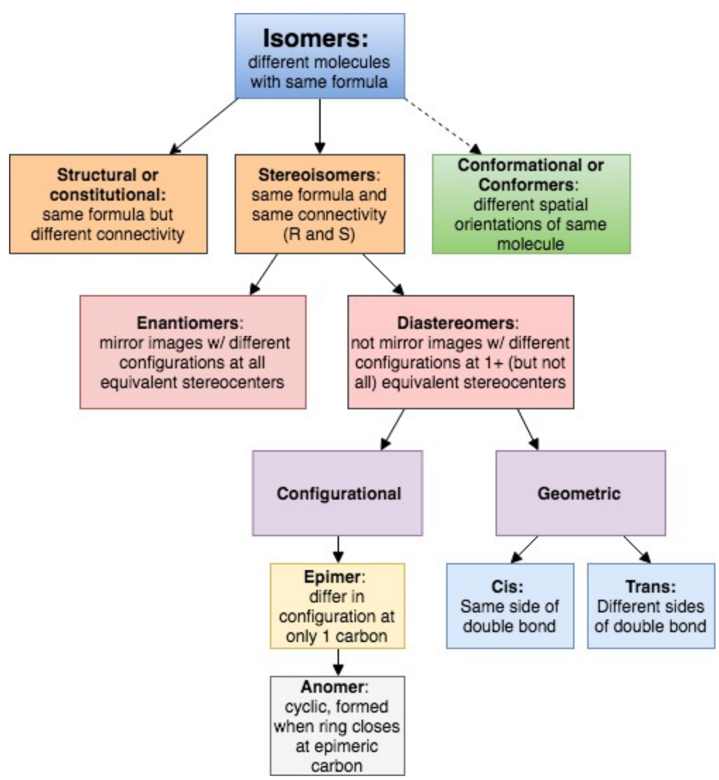
(Z) and (E) for Alkenes: (*Z*): Highest priority on same side.
(*E*): Highest priority on opposite sides.

(R) and (S) for Stereocenters: A stereocenter's configuration is determined by putting the lowest priority group in the back and drawing a circle from group 1-2-3.
(*R*): Clockwise
(*S*): Counterclockwise

Fischer Projection: Vertical lines go to back of page (dashes); horizontal lines come out of the page (wedges).



Altering Fischer Projection: Switching 1 pair of substituents inverts the stereochemistry; switching 2 pairs retains stereochemistry. Rotating entire diagram 90° inverts the stereochemistry; rotating 180° retains stereochemistry.



Atomic Orbitals & Quantum Numbers

Quantum Numbers: Describe the size, shape, orientation, and number of atomic orbitals in an element

Quantum Number	Name	What it Labels	Possible Values	Notes
n	Principal	e^- energy level or shell number	1, 2, 3, …	Except for d-orbitals, the shell # matches the row of the periodic table
l	Azimuthal	3D shape of orbital	0, 1, 2, …, n-1	0 = *s* orbital 1 = *p* orbital 2 = *d* orbital 3 = *f* orbital 4 = *g* orbital
m_l	Magnetic	Orbital sub-type	Integers $-l \rightarrow +l$	
m_s	Spin	Electron spin	$+\frac{1}{2}, -\frac{1}{2}$	

Maximum e^- in terms of n = $2n^2$
Maximum e^- in subshell = $4l + 2$

Molecular Orbitals

Bonding Orbitals: Created by head-to-head or tail-to-tail overlap of atomic orbitals of the same sign. ↓energy ↑stable

Antibonding Orbitals: Created by head-to-head or tail-to-tail overlap of atomic orbitals of opposite signs. ↑energy ↓stable

Single Bonds: 1 σ bond, contains 2 electrons

Double Bonds: 1 σ + 1 π
Pi bonds are created by sharing of electrons between two unhybridized p-orbitals that align side-by-side

Triple Bonds: 1 σ + 2 π

Multiple bonds are less flexible than single bonds because rotation is not permitted in the presence of a π bond. Multiple bonds are shorter and stronger than single bonds, although individual π are weaker than σ bonds

Hybridization

***sp*³:** 25% *s* character and 75% *p* character
Tetrahedral geometry with 109.5° bond angles

sp²: 33% *s* character and 67% *p* character
Trigonal planar geometry with 120° bond angles

sp: 50% *s* character and 50% *p* character
Linear geometry with 180° bond angles

Resonance: Describes the delocalization of electrons in molecules that have conjugated bonds

Conjugation: Occurs when single and multiple bonds alternate, creating a system of unhybridized *p* orbitals down the backbone of the molecule through which π electrons can delocalize

Acids and Bases

Lewis Acid: e^- acceptor. Has vacant orbitals or + polarized atoms.

Lewis Base: e^- donor. Has a lone pair of e^-, are often anions.

Brønsted-Lowry Acid: Proton donors.

Brønsted-Lowry Base: Proton acceptor.

Amphoteric Molecules: Can act as either acids or bases, depending on reaction conditions.

K_a: Acid dissociation constant. A measure of acidity. It is the equilibrium constant corresponding to the dissociation of an acid, HA, into a proton and its conjugate base.

pK_a: An indicator of acid strength. pK_a decreases down the periodic table and increases with EN.
$\mathrm{p}K_\mathrm{a} = -\log(K_\mathrm{a})$

α-carbon: A carbon adjacent to a carbonyl.

α-hydrogen: Hydrogen connected to an α-carbon.

REDOX Reactions

Oxidation State: The charge an atom would have if all its bonds were completely ionic.

Oxidation: Raises oxidation state. Assisted by oxidizing agents.

Oxidizing Agent: Accepts electrons and is reduced in the process.

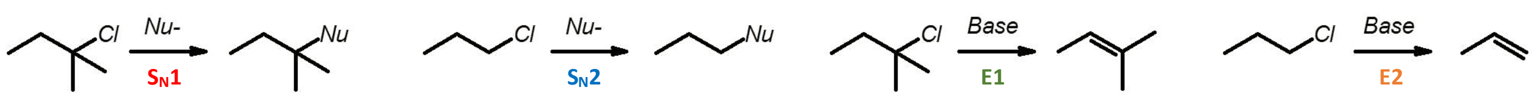
Reduction: Lowers oxidation state. Assisted by reducing agents.

Reducing Agent: Donates electrons and is oxidized in the process.

Chemoselectivity

Both nucleophile-electrophile and REDOX reactions tend to act at the highest-priority (most oxidized) functional group.

One can make use of steric hindrance properties to selectively target functional groups that might not primarily react, or to protect functional groups.



Nucleophiles, Electrophiles and Leaving Groups

Nucleophiles: "Nucleus-loving". Contain lone pairs or π bonds. They have ↑EN and often carry a NEG charge. Amino groups are common organic nucleophiles.

Nucleophilicity: A kinetic property. The nucleophile's strength. Factors that affect nucleophilicity include charge, EN, steric hindrance, and the solvent.

Electrophiles: "Electron-loving". Contain a + charge or are positively polarized. More positive compounds are more electrophilic.

Leaving Group: Molecular fragments that retain the electrons after heterolysis. The best LG can stabilize additional charge through resonance or induction. Weak bases make good LG.

S_N1 Reactions: Unimolecular nucleophilic substitution. 2 steps. In the 1st step, the LG leaves, forming a carbocation. In the 2nd step, the nucleophile attacks the planar carbocation from either side, leading to a racemic mixture of products.
$\text{Rate} = k\,[\text{substrate}]$

S_N2 Reactions: Bimolecular nucleophilic substitution. 1 concerted step. The nucleophile attacks at the same time as the LG leaves. The nucleophile must perform a backside attack, which leads to inversion of stereochemistry. (*R*) and (*S*) is also changed if the nucleophile and LG have the same priority level. S_N2 prefers less-substituted carbons because steric hindrance inhibits the nucleophile from accessing the electrophilic substrate carbon.
$\text{Rate} = k\,[\text{nucleophile}]\,[\text{substrate}]$

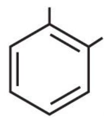
Solvents	
Polar Aprotic	**Polar Protic**
S_N2	S_N1
E2	E1
Polar Aprotic solvents DMF, DMSO, Acetone, Ethyl Acetate	Polar Protic solvents Acetic Acid, H_2O, ROH, NH_3

Substrate	Reaction	
1°	S_N2:	Weak base as nucleophile. Or strong unhindered base as nucleophile.
	E2:	Strong / bulky nucleophile plus a beta-H
2°	S_N2:	Weak base as nucleophile; e.g. CN^- or Acetate
	E2:	Strong nucleophile; e.g. OH^- or stronger. Or anything hindered. Will always need a beta-H.
3°	S_N2:	No S_N2 reaction
	E2:	Basic conditions with a beta-H
	S_N1:	Acidic or neutral conditions and NO Beta-H ⇒ good yield. If there is a beta-H, there will be a mix of S_N1 / E1.
	E1:	Competes with Sn1 in neutral or basic conditions. ↑temp = E1 major product ↓temp = S_N1 major product

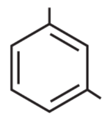
Description & Properties

Alcohols: Have the general form ROH and are named with the suffix *–ol*. If they are NOT the highest priority, they are given the prefix *hydroxy-*

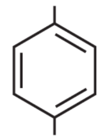
Phenols: Benzene ring with –OH groups attached. Named for the relative position of the –OH groups:



ortho



meta

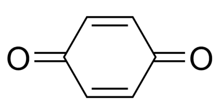


para

- Alcohols can hydrogen bond, raising their boiling and melting points
- Phenols are more acidic than other alcohols because the aromatic ring can delocalize the charge of the conjugate base
- Electron-donating groups like alkyl groups decrease acidity because they destabilize negative charges. EWG, such as EN atoms and aromatic rings, increase acidity because they stabilize negative charges

Reactions of Phenols

Quinones: Synthesized through oxidation of phenols. Quinones are resonance-stabilized electrophiles. Vitamin K_1 (*phylloquinone*) and Vitamin K_2 (the *menaquinones*) are examples of biochemically relevant quinones



Quinone

Hydroxyquinones: Produced by oxidation of quinones, adding a variable number of hydroxyl gruops

Ubiquinone: Also called *coenzyme Q*. Another biologically active quinone that acts as an electron acceptor in Complexes I, II, and III of the electron transport chain. It is reduced to *ubiquinol*

Reactions of Alcohols

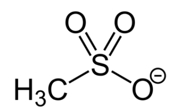
Primary Alcohols: Can be oxidized to aldehydes only by *pyridinium chlorochromate* (PCC); they will be oxidized all the way to carboxylic acids by any stronger oxidizing agents

Secondary Alcohols: Can be oxidized to ketones by any common oxidizing agent

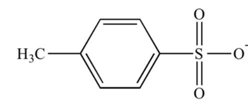
Alcohols can be converted to *mesylates* or *tosylates* to make them better leaving groups for nucleophilic substitution reactions

Mesylates: Contain the functional group $–SO_3CH_3$

Tosylates: Contain the functional group $–SO_3C_6H_4CH_3$



Mesylate

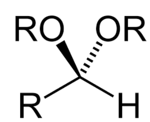


Tosylate

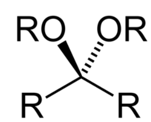
Aldehydes or ketones can be protected by converting them into *acetals* or *ketals*

Acetal: A 1° carbon with two –OR groups and an H atom

Ketal: A 2° carbon with two –OR groups



Acetal

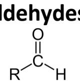


Ketal

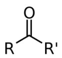
Deprotection: The process of converting an *acetal* or *ketal* back to a carbonyl by catalytic acid

Description and Properties

Aldehydes: Are terminal functional groups containing a carbonyl bonded to at least one hydrogen. Nomenclature: suffix *–al* and prefix *oxo-*. In rings, they are indicated by the suffix *–carbaldehyde*.

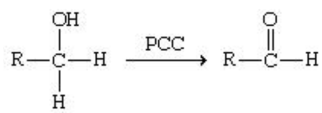


Ketones: Internal functional groups containing a carbonyl bonded to two alkyl chains. In nomenclature, they use the suffix *–one* and the prefix *oxo-* or *keto-*.



Carbonyl: A carbon-oxygen double bond. The reactivity of a carbonyl is dictated by the polarity of the double bond. The carbon has a δ^+ so it is electrophilic. Carbonyl containing compounds have a ↑BP than equivalent alkanes due to dipole interactions. Alcohols have ↑BP than carbonyls due to hydrogen bonding.

Oxidation: Aldehydes and ketones are commonly produced by oxidation of primary and secondary alcohols, respectively. Weaker, anhydrous oxidizing agents like *pyridinium chlorochromate (PCC)* must be used for synthesizing aldehydes, or the reaction will continue oxidizing to a carboxylic acid.



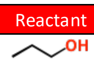
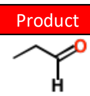
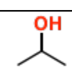
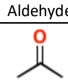
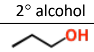
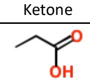
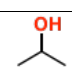
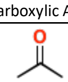
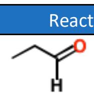
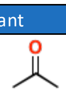
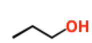
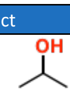
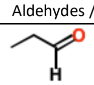
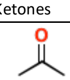
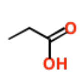
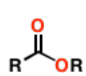
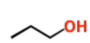
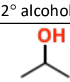
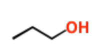
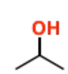
1° Alcohol **Aldehyde**

Oxidation-Reduction Reactions

Aldehydes: Aldehydes can be *oxidized* to carboxylic acids using an oxidizing agent like $KMnO_4$, CrO_3, Ag_2O, or H_2O_2. They can be *reduced* to primary alcohols via hydride reagents ($LiAlH_4$, $NaBH_4$).

Ketones: Ketones cannot be further *oxidized*, but can be *reduced* to secondary alcohols using the same hydride reagents.

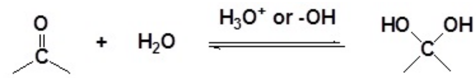
Common Oxidizing / Reducing Agents

Oxidizing Agent	Reactant	Product
PCC	 1° alcohol	 Aldehyde
	 2° alcohol	 Ketone
$KMnO_4$ or $H_2Cr_2O_4$	 1° alcohol	 Carboxylic Acid
	 2° alcohol	 Ketone
Reducing Agent	**Reactant**	**Product**
$NaBH_4$	  Aldehydes / Ketones	 1° alcohol  2° alcohol
$LiAlH_4$ (LAH)	 Aldehydes  Ketones  Carboxylic Acid  Ester	 1° alcohol  2° alcohol  1° alcohol  2° alcohol

Nucleophilic Addition Reactions

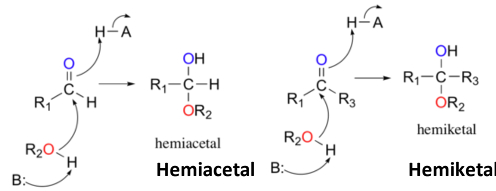
When a nucleophile attacks and forms a bond with a carbonyl carbon, electrons in the π bond are pushed to the oxygen atom. If there is no good leaving group (aldehydes and ketones), the carbonyl will remain open and is protonated to form an alcohol. If there is a good leaving group (carboxylic acid and derivatives), the carbonyl will reform and kick off the leaving group.

Hydration Rxns: Water adds to a carbonyl, forming a *geminal diol*.



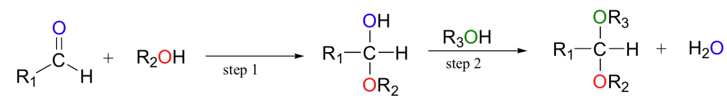
Aldehyde or Ketone ***Gem*-diol**

Aldehyde + Alcohol: When one equivalent of alcohol reacts with an aldehyde, a *hemiacetal* is formed. When the same rxn occurs with a ketone, a *hemiketal* is formed.



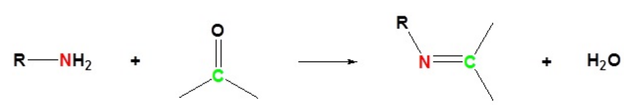
Hemiacetal **Hemiketal**

When another equivalent of alcohol reacts with a hemiacetal (via nucleophilic substitution), an *acetal* is formed. When the same reaction occurs with a hemiketal, a *ketal* is formed.

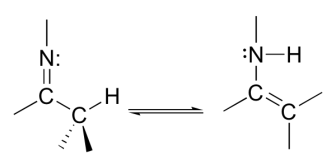


Hemiacetal **Acetal**

Nitrogen + Carbonyl: Nitrogen and nitrogen derivatives react with carbonyls to form *imines*, oximes, hydrazones, and semicarbazones. Imines can tautomerize to form *enamines*.

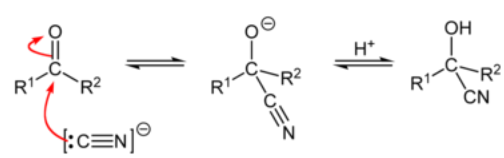


1° Amine **Aldehyde or Ketone** **Imine**



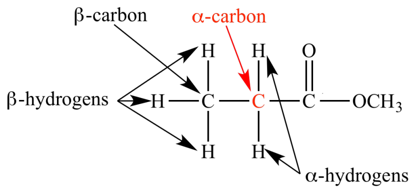
Imine **Enamine**

HCN + Carbonyl: Hydrogen cyanide reacts with carbonyls to form *cyanohydrins*.



General Principles

α-carbon: The carbon adjacent to the carbonyl is the α-carbon. The hydrogens attached to the α-carbon are the **α-hydrogens**.

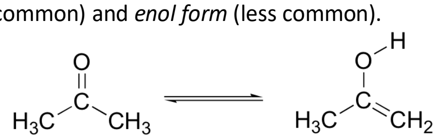


α-hydrogens: Relatively acidic and can be removed by a strong base. The e^- withdrawing O of the carbonyl weakens the C-H bonds on α-hydrogens. The **enolate** resulting from deprotonation can be stabilized by resonance with the carbonyl.

Ketones: Ketones are less reactive toward nucleophiles because of steric hindrance and α-carbanion de-stabilization. The presence of an additional alkyl group crowds the transition step and increases energy. The alkyl group also donates e^- density to the carbanion, making it less stable.

Enolate Chemistry

Keto / Enol: Aldehydes and ketones exist in both *keto form* (more common) and *enol form* (less common).



keto form of acetone **enol** form of acetone

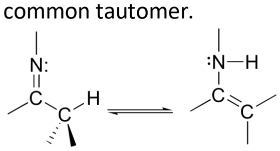
Tautomers: Isomers that can be interconverted by moving a hydrogen and a double bond. Keto / Enol are tautomers.

Michael Addition: An enolate attacks an α,β-unsaturated carbonyl, creating a bond.

Kinetic Enolate: Favored by fast, irreversible reactions at LOW TEMP, with strong, sterically hindered bases.

Thermodynamic Enolate: Favored by slower, reversible reactions at HIGH TEMP with weaker, smaller bases.

Enamines: Tautomers of *imines*. Like enols, enamines are the less common tautomer.

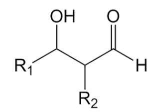


imine enamine

Aldol Condensation

The aldehyde or ketone acts as both nucleophile and electrophile, resulting in the formation of a C-C bond in a new molecule called an *aldol*.

Aldol: Contains both aldehyde and an alcohol. "Ald – ol"

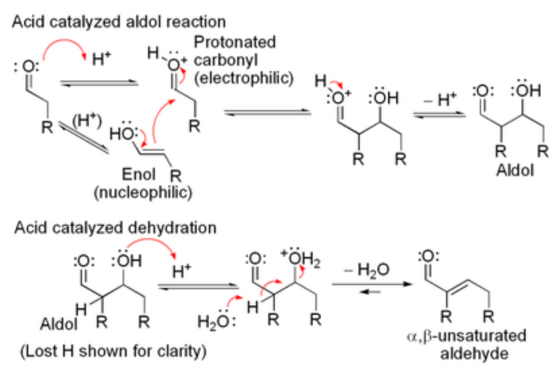


Aldol Nucleophile: The nucleophile is the enolate formed from the deprotonation of the α-carbon.

Aldol Electrophile: The electrophile is the aldehyde or ketone in the form of the keto tautomer.

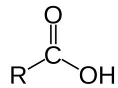
Dehydration: After the aldol is formed, a dehydration reaction (loss of water molecule) occurs. This results in an α,β-unsaturated carbonyl.

Retro-Aldol Reactions: Reverse of aldol condenstations. Catalyzed by heat and base. Bond between α- and β-carbon is cleaved.



Description and Properties

Carboxylic acids contain a carbonyl and a hydroxyl group connected to the same carbon. They are always terminal groups.

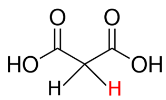


Nomenclature: Suffix **–oic acid**. Salts are named with the suffix **–oate**, and dicarboxylic acids are **–dioic acids**

Physical Properties: Carboxylic acids are polar and hydrogen bond well, resulting in high BP. They often exist as *dimers* in solution.

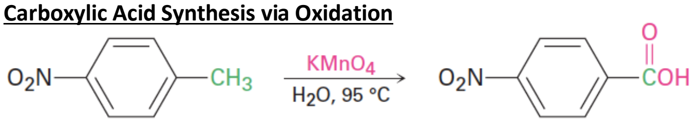
Acidity: The acidity of a carb acid is enhanced by the resonance between its oxygen atoms. The acidity can be further enhanced by substituents that are electron-withdrawing, and decreased by substituents that are electron-donating

β-dicarboxylic Acids: Like other 1,3-dicarbonyl compounds, they have an α-hydrogen that is also highly acidic

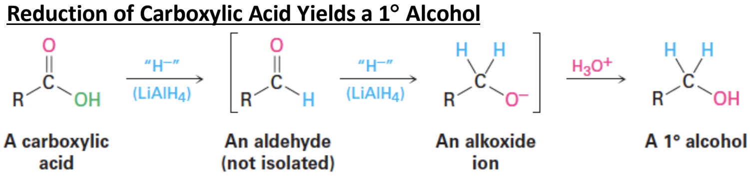


α-proton is the most acidic due to resonance

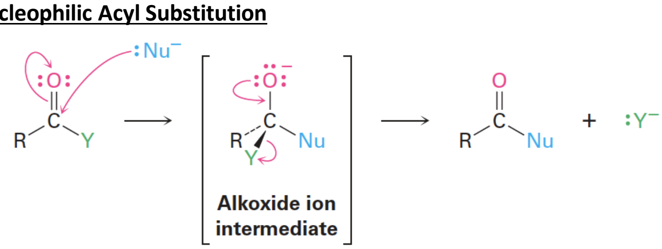
Carboxylic Acid Synthesis via Oxidation



Reduction of Carboxylic Acid Yields a 1° Alcohol



Nucleophilic Acyl Substitution



Acid Halide Synthesis

Reactions of Carboxylic Acids

Oxidation: Carboxylic acids can be made by the oxidation of 1° alcohols or aldehydes or the oxidation of 1° or 2° alkyl groups using an oxidizing agent like $KMnO_4$, $Na_2Cr_2O_7$, $K_2Cr_2O_7$, or CrO_3.

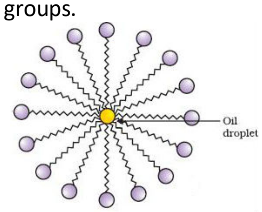
Nucleophilic Acyl Substitution: A common reaction in carboxylic acids. Nucleophile attacks the electrophilic carbonyl carbon, opening the carbonyl and forming a tetrahedral intermediate. The carbonyl reforms, kicking off the L.G.

Nucleophiles: *Ammonia / Amine*: Forms an amide. Amides are given the suffix **–amide**. Cyclic amides are called **lactams**.
Alcohol: Forms an ester. Esters are given the suffix **–oate**. Cyclic esters are called **lactones**.
Carboxylic Acid: Forms an anhydride. Both linear and cyclic anhydrides are given the suffix **anyhydride**.

Reduction: Carboxylic acids can be reduced to a 1° alcohol with a strong reducing agent like LiAlH4. Aldehyde intermediates are formed, but are also reduced to 1° alcohols. $NaBH_4$ is not strong enough to reduce a carboxylic acid

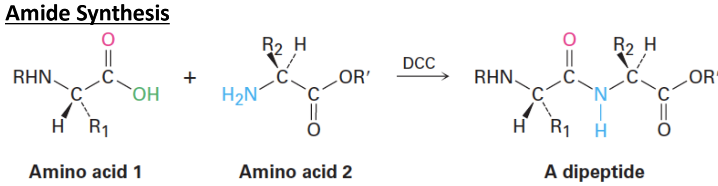
Decarboxylation: β-dicarboxylic acids and other β-keto acids can undergo spontaneous decarboxylation when heated, losing a carbon as CO_2. This reaction proceeds via a six-membered cyclic intermediate

Saponification: Mixing long-chain carboxylic acids (fatty acids) with a strong base results in the formation of a salt we call soap. Soaps contain a hydrophilic carboxylate head and hydrophobic alkyl chain tail. They organize in hydrophilic environments to form *micelles*. A micelle dissolves nonpolar organic molecules in its interior, and can be solvated with water due to its exterior shell of hydrophilic groups.

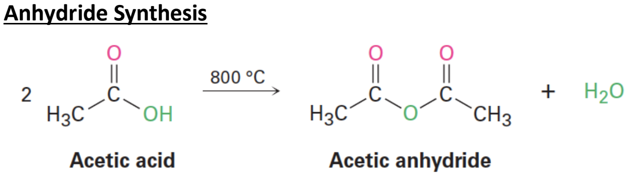


Micelle: Polar heads, non-polar tails. The non-polar tails dissolve non-polar molecules such as grease

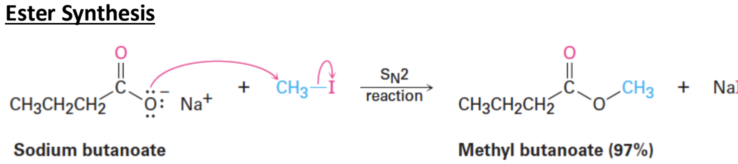
Amide Synthesis



Anhydride Synthesis

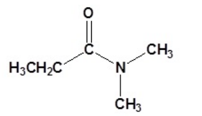


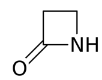
Ester Synthesis



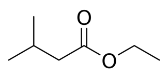
Amides, Esters, and Anhydrides

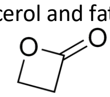
Amides: The condensation product of carboxylic acid and ammonia or an amine. Amides are given the suffix **–amide**. The alkyl groups on a substituted amide are written at the beginning of the name with the prefix **N-**. Cyclic amides are called **lactams**, named with the Greek letter of the carbon forming the bond with the N.


N,N-Dimethylpropanamide

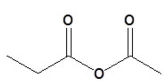

β-Lactam

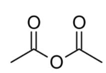
Esters: The condensation products of carboxylic acids with alcohols, i.e., a *Fischer Esterification*. Esters are given the suffix **–oate**. The esterifying group is written as a substituent, without a number. Cyclic esters are called **lactones**, named by the number of carbons in the ring and the Greek letter of the carbon forming the bond with the oxygen. Triacylglycerols include three ester bonds between glycerol and fatty acids.

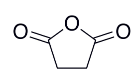

Isopropyl butanoate


β-Propiolactone

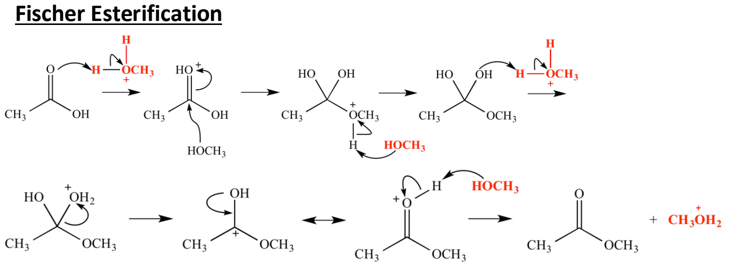
Anhydrides: The condensation dimers of carboxylic acids. Symmetric anhydrides are named for the parent carb acid, followed by **anhydride**. Asymmetric anhydrides are named by listing the parent carb acids alphabetically, followed by **anhydride**. Some cyclic anhydrides can be synthesized by heating dioic acids. Five- or six-membered rings are generally stable.


Ethanoic propanoic anhydride

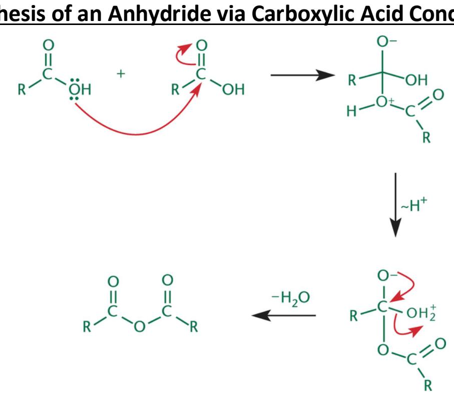

Ethanoic anhydride


Succinic anhydride

Fischer Esterification



Synthesis of an Anhydride via Carboxylic Acid Condensation



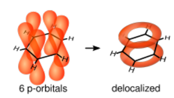
Reactivity Principles

In Nu⁻ substitution reactions, reactivity is:
acid chloride > anhydrides > esters > amides > carboxylate

Steric Hindrance: Describes when a reaction cannot proceed (or significantly slows) because substituents crowd the reactive site. *Protecting groups*, such as acetals, can be used to increase steric hindrance or otherwise decrease the reactivity of a particular portion of a molecule

Induction: Refers to uneven distribution of charge across a σ bond because of differences in EN. The more EN groups in a carbonyl-containing compound, the *greater* its reactivity

Conjugation: Refers to the presence of alternating single and multiple bonds, which creates delocalized π electron clouds above and below the plane of the molecule. Electrons experience resonance through the unhybridized p-orbitals, increasing stability. Conjugated carbonyl-containing compounds are *more* reactive because they can stabilize their transition states.



Conjugation in Benzene

Ring Strain: Increased stain in a molecule can make it more reactive. β-lactams are prone to hydrolysis because they have significant ring strain. **Ring strain** is due to torsional strain from eclipsing interactions and angle strain form compression bond angles below 109.5°

Nucleophilic Acyl Substitution Reactions

All carboxylic acid derivatives can undergo nucleophilic substitution reactions. The rates at which they do so is determined by their relative reactivities.

Cleavage: Anhydrides can be cleaved by the addition of a *nucleophile*. Addition of *ammonia* or an *amine* results in an amide and a carboxylic acid. Addition of an *alcohol* results in an ester and a carboxylic acid. Addition of *water* results in two carboxylic acids.

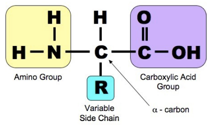
Transesterification: The exchange of one esterifying group for another on an ester. The attacking nucleophile is an alcohol.

Amides: Can be hydrolyzed to carboxylic acids under strongly acidic or basic conditions. The attacking nucleophile is water or the hydroxide anion.

Ring Strain: Increased stain in a molecule can make it more reactive. β-lactams are prone to hydrolysis because they have significant ring strain. **Ring strain** is due to torsional strain from eclipsing interactions and angle strain form compression bond angles below 109.5°

Amino Acids, Peptides, and Proteins

Amino Acid: The α-carbon of an amino acid is attached to four groups: an amino group, a carboxyl group, a hydrogen atom, and an R group. It is chiral in all amino acids except *glycine*.



All amino acids in eukaryotes are L-amino acids. They all have (S) stereochemistry except *cysteine*, which is (R).

Amphoteric: Amino acids are amphoteric, meaning they can act as acids or bases. Amino acids get their acidic characteristics from carboxylic acids and their basic characteristics from amino groups. In neutral solution, amino acids tend to exist as *zwitterions* (dipolar ions).

Aliphatic: Non-aromatic. Side chain contains only C and H. Gly, Ala, Val, Leu, Ile, Pro. Met can also be considered aliphatic.

Peptide Bonds: Form by *condensation* reactions and can be cleaved *hydrolytically*. Resonance of peptide bonds restricts motion about the C-N bond, which takes on partial double bond character. A strong acid or base is needed to cleave a peptide bond. Formed when the N-terminus of an AA nucleophilically attacks the C-terminus of another AA.

Polypeptides: Made up of multiple amino acids linked by peptide bonds. Proteins are large, folded, functional polypeptides.

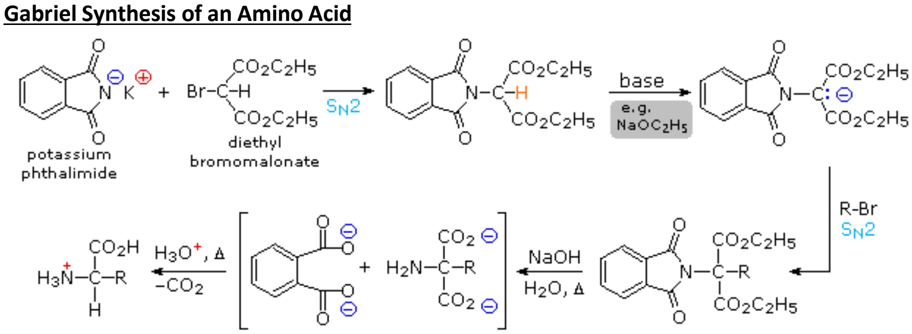
Synthesis of α-Amino Acids

Biologically, amino acids are synthesized in many ways. In the lab, certain standardized mechanisms are used.

Strecker Synthesis: Generates an amino acid from an aldehyde. An aldeyhyde is mixed with ammonium chloride (NH_4Cl) and potassium cyanide. The ammonia attacks the carbonyl carbon, generating an imine. The imine is then attacked by the cyanide, generating an aminonitrile. The aminonitrile is hydrolyzed by two equivalents of water, generating an amino acid.

Gabriel Synthesis: Generates an amino acid from potassium phthalimide diethyl bromomalonate, and an alkyl halide. Phthalimide attacks the diethyl bromomalonate, generating a phthalimidomalonic ester. The phthalimidomalonic ester attacks an alkyl halide, adding an alkyl group to the ester. The product is hydrolyzed, creating phthalic acid (with two carboxyl groups) and converting the esters into carboxylic acids. One carboxylic acid of the resulting 1,3-dicarbonyl is removed by decarboxylation.

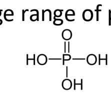
Gabriel Synthesis of an Amino Acid



Phosphorus-Containing Compounds

Phosphoric Acid: Sometimes referred to as a **phosphate group** or **inorganic phosphate**, denoted $\mathbf{P_i}$. At physiological pH, inorganic phosphate includes molecules of both hydrogen phosphate (HPO_4^{2-}) and dihydrogen phosphate ($H_2PO_4^-$).

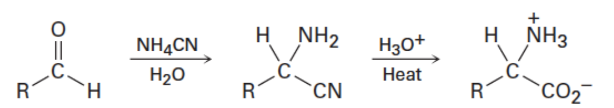
Phosphoric Acid Structure: Contains 3 hydrogens, each with a unique p*K*a. The wide variety in p*K*a values allows phosphoric acid to act as a buffer over a large range of pH values.



Phosphodiester Bonds: Phosphorus is found in the backbone of DNA, which uses phosphodiester bonds. In forming these bonds, a **pyrophosphate** (**PP**$_i$, $P_2O_7^{4-}$) is released. Pyrophosphate can then be hydrolyzed to two inorganic phosphates. Phosphate bonds are high energy because of large negative charges in adjacent phosphate groups and resonance stabilization of phosphates.

Organic Phosphates: Carbon containing compounds that also have phosphate groups. The most notable examples are nucleotide triphosphates (such as ATP or GTP) and DNA.

Strecker Synthesis of an Amino Acid



An α-amino acid

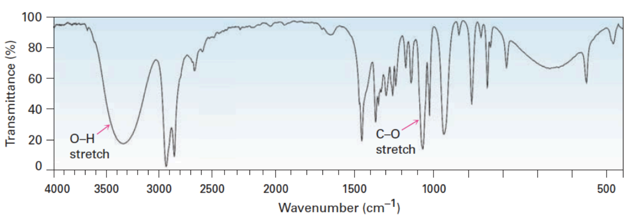
Infrared Spectroscopy

Measures absorption of infrared light, which causes molecular vibration (stretching, bending, twisting, and folding). Plotted as *% transmittance* vs. *wavenumber* ($\frac{1}{\lambda}$).

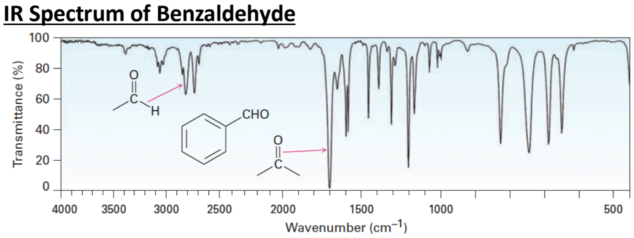
Peaks to Know for MCAT:

Bond	Range (cm^{-1})	Peak Type
N-H	3300	Sharp
O-H	3000 - 3300	Broad
C≡O, C≡N	1900 – 2200	Medium
C=O	1750	Sharp
C=C	1600 – 1680	Weak

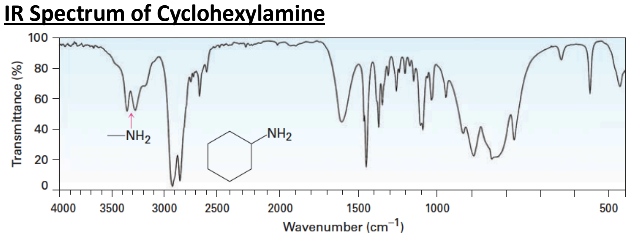
IR Spectrum of Cyclohexanol



IR Spectrum of Benzaldehyde



IR Spectrum of Cyclohexylamine



Ultraviolet Spectroscopy

UV spectroscopy is most useful for studying compounds containing double bonds and/or heteroatoms with lone pairs that create conjugated systems.

Measures the absorption of UV light, which causes movement of electrons between molecular orbitals. UV spectra are generally plotted as percent transmittance or absorbance vs. Wavelength.

HOMO & LUMO: To appear on a UV spectrum, a molecule must have a small enough energy difference between its HOMO and LUMO to permit an electron to move from one orbital to the other. The smaller the difference between HOMO and LUMO, the longer the wavelengths a molecule can absorb.

Nuclear Magnetic Resonance Spectroscopy

NMR spectroscopy measures alignment of nuclear spin with an applied magnetic field, which depends on the magnetic environment of the nucleus itself. It is useful for determining the structure (connectivity) of a compound, including functional groups.

Generally plotted as frequency vs. absorption energy. They are standardized by using chemical shift (δ), measured in parts per million (ppm) of spectrophotometer frequency.

TMS: NMR spectra are calibrated using tetramethylsilane (TMS), which has a chemical shift of 0 ppm

Integration: Area under the curve. Proportional to the number of protons contained under the peak.

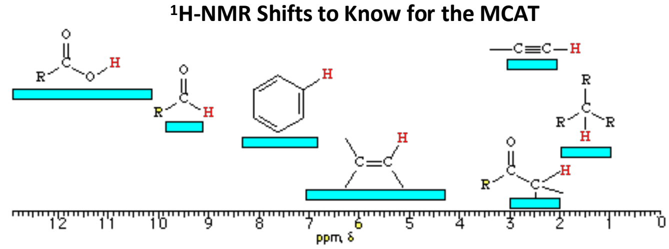
Deshielding: Occurs when electron-withdrawing groups pull electron density away from the proton's nucleus, allowing it to be more easily affected by the magnetic field. Deshielding moves a peak further downfield

Downfield: LEFT. Deshielded by EWG or EN atom nearby.

Upfield: RIGHT. More shielded, by EDG or less EN atom nearby.

Spin-Spin Coupling: When hydrogens are on adjacent atoms, they interfere with each other's magnetic environment, causing spin-spin coupling (splitting). A proton's (or a group of protons') peak is split into n+ 1 subpeaks, where n is the number of protons that are three bonds away from the proton of interest. Splitting patterns include *doublets*, *triplets*, and *multiplets*.

^{1}H-NMR Shifts to Know for the MCAT



Mass Spectrometry

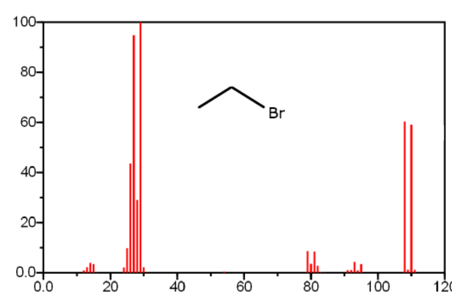
Used to determine the molecular weight and aid in determining molecular structure. The charged molecule collides with an electron, resulting in the ejection of an electron from the molecule, making it a radical.

Base Peak: Tallest peak (not always the intact molecule)

Molecular Ion Peak: Peak that represents the molecule.

M+1 Peak: Relative abundance of ^{13}C. Found in relative abundance of 1.1%. So, if M+1 has an m/z value of 4.4, that means there are 4 carbons. 4.4/1.1 = 4.

M+2 Peak: Relative abundance of either ^{81}Br or ^{37}Cl.
Br has a 1:1 ratio relative to the M peak.
Cl has a 3:1 ratio relative to the M peak.



Mass Spec of Bromoethane. M^+ has similar intensity as M+2.

Solubility-Based Methods

Extraction: Combines two immiscible liquids, one of which easily dissolves the compound of interest.

Nonpolar Layer: Organic layer, dissolves nonpolar compounds.
Polar Layer: Aqueous (water) layer. Dissolves compounds with hydrogen bonding or polarity.

Wash: The reverse of an extraction. A small amount of solute that dissolves impurities is run over the compound of interest.

Filtration: Isolates a solid (residue) from a liquid (filtrate)

Gravity Filtration: Use when the product of interest is in the filtrate. Hot solvent is used to maintain solubility.
Vacuum Filtration: Used when the product of interest is the solid. A vacuum is connected to the flask to pull the solvent through more quickly.

Recrystallization: The product is dissolved in a minimum amount of hot solvent. If the impurities are more soluble, the crystals will reform while the flask cools, excluding the impurities.

Chromatography

* See appendix for detailed information

Separates two or more molecules from a mixture. Includes *liquid chromatography*, *gas chromatography*, *size-exclusion chromatography*, *ion-exchange chromatography*, *affinity chromatography*, and *thin-layer chromatography*.

Distillation

Distillation: Separates liquids according to differences in their boiling points. The liquid with the lowest BP vaporizes first and is collected as the *distillate*.

Simple Distillation: Can be used if the boiling points are under 150°C and are at least 25°C apart.

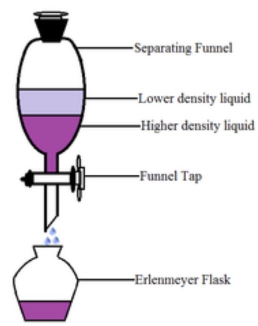
Vacuum Distillation: Should be used if the boiling points are over 150°C to prevent degradation of the product. The vacuum lowers the air pressure, which decreases the temp the liquid must reach in order to boil.

Fractional Distillation: Should be used if the boiling points are less than 25°C apart because it allows more refined separation of liquids by BP.

<u>Most Experiments</u>

Organic on top

Aqueous on bottom



Extraction: Polar solutes dissolve in the aqueous layer. Non-polar solutes dissolve in the organic layer.

Parts of Cell

Nucleoid Region: DNA region in prokaryotes.

Nucleolus: Makes ribosomes. Sits in nucleus, no membrane.

Peroxisomes: Collect and break down material.

Rough ER: Accept mRNA to make proteins.

Smooth ER: Detox & make lipids.

Golgi Apparatus: Modify / distribute proteins. Only in eukaryotes.

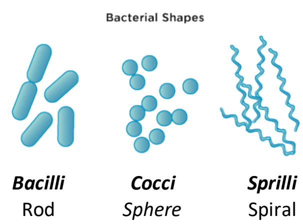
<u>Vesicular Transport</u>	<u>Cisternal Maturation</u>
COPII → forward COPI ← return	Vesicles travel in retrograde New Cis made Cis/Medial/Trans/Exit

Peroxisomes: Collect and break down material.

Centrioles: 9 groups of microtubules, pull chromosomes apart.

Lysosomes: Demo & Recycling center. Made by Golgi. Single membrane.

Plasmids: In prokaryotes. Carry DNA not necessary for survival.



Bacteria

Obligate Aerobe: Requires O_2.

Obligate Anaerobe: Dies in O_2.

Facultative Anaerobe: Toggle between Aerobic / Anaerobic.

Aerotolerant Anaerobe: Does not use O_2 but tolerates it.

Gram + is PURPLE, THICK peptidoglycan/lipoteichoic acid cell wall.

Gram – is PINK-RED, THIN peptidoglycan cell wall & an outer membrane.

Eukaryote vs. Prokaryote

Eukaryote	**Prokaryote**
ETC in mitochondria	ETC in cell membrane
Large ribosomes	Small ribosomes
Reproduce via mitosis	Reproduce via binary fission
	Plasmids carry DNA material. May have *virulence factors*. Plasmids that integrate into genome are *Episomes*

Miscellaneous

Prions: Infectious proteins. Trigger misfolding. α-helical → β-pleated sheets. ↓Solubility.

Viroid: Plant pathogens.

Cytoskeleton

Microfilaments: Actin

Microtubules: Tubulin

Intermediate Filaments: Keratin = Vimentin; Desmin = Lamin

Tissues

Epithelia: Parenchyma (functional parts of organ).
Simple: One layer.
Stratified: Multiple layers.
Pseudostratified: One layer (looks mult, but really just 1).
Cuboidal: Cube shape.
Columnar: Long and narrow.
Squamous: Flat, scale-like.

Connective: Stroma (support, extracellular matrix). Bone, cartilage, tendon, blood.

Genetic Recombination

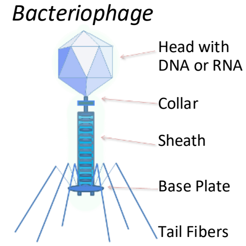
Transformation: Gets genetic info from environment.

Conjugation: Transfer of genetic info via conjugation bridge.
$F^+ \rightarrow F^-$ or Hfr → recipient

Transduction: Transfer using bacteriophage.

Transposons: Genetic info that can insert/remove themselves.

Bacteriophage



Viruses

Capsid: Protein Coat.

Envelope: Some have lipid envelope.

Virion: Individual virus particles.

Bacteriophage: Bacteria virus. Tail sheath injects DNA / RNA.

Viral Genome: May be DNA or RNA. Single or double stranded.

If Single Strand: *Positive Sense*: Can be translated by host cell.
Negative Sense: RNA replicase must synthesize a complimentary strand, which can then be translated.

Retrovirus: Single stranded RNA. Reverse transcriptase needed to make DNA.

Bacteriophage Life Cycles: *Lytic*: Virions made until cell lyses.
Lysogenic: Virus integrates into genome as provirus or prophage. Goes dormant until stress activates it.

Cell Cycle

G_1: Decide if it is time to divide. Make organelles.

G_0: A cell will enter G_0 if it DOES NOT need to divide.

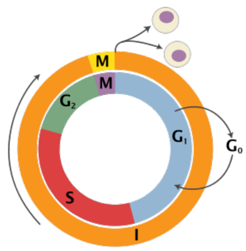
Restriction Point: DNA checked. P53 in charge.

S: DNA replicated.

G_2: Check / repair / die.

Checkpoint: Check organelles & cell size. P53 in charge.

M: Mitosis and cytokinesis.



Growth Signals

Positive Growth Signals:
1) CDK + Cyclin create a complex
2) Phosphorylate Rb to Rb + P
3) Rb changes shape, releases E2F
4) Cell division continues

Negative Growth Signals:
1) CDK inhibitors block phosphorylation of Rb
2) So, E2F stays attached
3) Cell cycle halts

Sex Chromosomes

Sex determined by 23rd pair of chromosomes. XX = female. XY = Male.

X-Linked Disorders: Males express, females can be carriers

Y-Chromosome: Little genetic info. SRY gene = "Sorry you're a male"

Male Reproductive System

Semen: Sperm + seminal fluid.

Bulbourethral Glands: Makes viscous fluid to clean out urethra.

Seminal Vesicles & Prostate Gland: Make alkaline fluid to help sperm survive acidic environment of female reproductive tract.

SEVE(N) UP sperm pathway mnemonic

Seminiferous tubules: Site of spermatogenesis. Nourished by Sertoli Cells.

Epididymis: Stores sperm. Sperm gain motility.

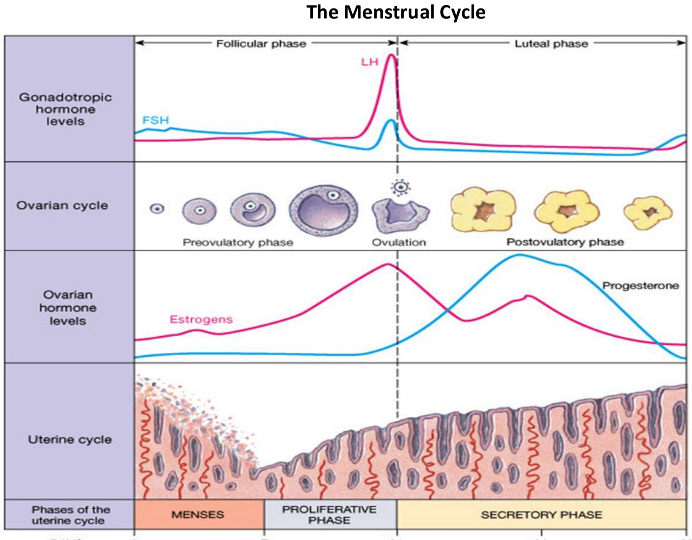
Vans deferens: Raise / lower testes.

Ejaculatory duct:

Urethra:

Penis:

The Menstrual Cycle



Mitosis

- PMAT
- Ploidy of 2n throughout

Prophase: DNA condenses. Centrioles migrate to opposite poles and microtubules form. Nuclear envelope disappears.

Metaphase: "Meet in the middle". Chromosomes meet in middle.

Anaphase: "Apart". Sister chromatids separate and move to opposite poles.

Telophase: Chromosomes decondense. Nuclear membrane forms. Cytokinesis occurs.

Meiosis

- PMAT x 2

Nondisjunction: When sister chromatids don't separate properly during anaphase. Results in aneuploidy.

Prophase I: Chromosomes condense, nuclear membrane dissolves, homologous chromosomes form bivalents, crossing over occurs.

Metaphase I: Spindle fibers from opposing centrosomes connect to bivalents (at centromeres) and align them along the middle of the cell.

Anaphase I: Homologous pairs move to opposite poles of the cell. This is disjunction and it accounts for the Law of Segregation.

Telophase I: Chromosomes decondense, nuclear membrane MAY reform, cell divides (cytokinesis), forms two haploid daughter cells of unequal sizes.

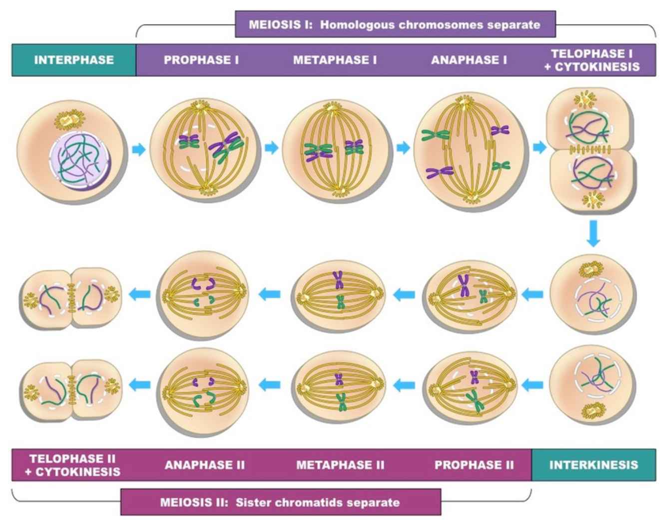
Prophase II: Chromosomes condense, nuclear membrane dissolves, centrosomes move to opposite poles (perpendicular to before).

Metaphase II: Spindle fibers from opposing centrosomes attach to chromosomes (at centromere) and align them along the cell equator.

Anaphase II: Spindle fibers contract and separate the sister chromatids, chromatids (now called chromosomes) move to opposite poles.

Telophase II: Chromosomes decondense, nuclear membrane reforms, cells divide (cytokinesis) to form four haploid daughter cells.

Meiosis Diagram



Female Reproductive System

Ovaries: Have follicles that produce ova. Controlled by FSH and LH.

Oogenesis: Production of female gametes.

Estrogen: Response to FSH. Develops rep tract, thickens uterine wall.

Progesterone: Response to LH. Maintains / protects endometrium. "Estrogen establishes; progesterone protects the endometrium".

Pathway: Egg → peritoneal sac → fallopian tube / oviduct

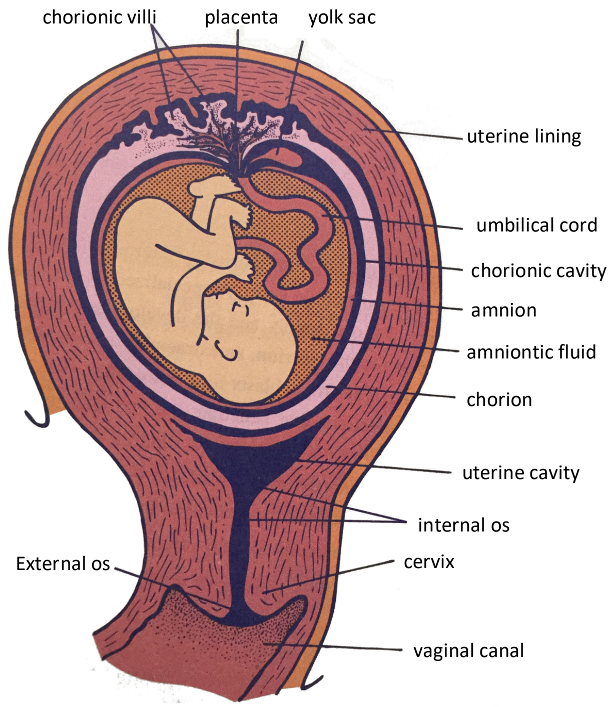
Gonadotropin-Releasing Hormone (GnRH)

FSH: Follicle Stimulating Hormone.
Males: Triggers spermatogenesis, stimulates Sertoli Cells.
Females: Stimulates development of ovarian follicles.

LH: Luteinizing Hormone.
Males: Causes interstitial cells to make testosterone.
Females: Induces ovulation.

1 Fertilization

Occurs in the Ampulla of fallopian tube.
Sperm's Acrosomal enzymes penetrate corona radiate & zona pellucia.
Acrosomal enzymes inject pronucleus.
Cortical reaction releases Ca^{2+} which depolarizes ovum membrane and makes it impenetrable.



2 Morula

- Early. Solid mass of cells

3 Blastula

- Implants in endometrial lining
- Fluid filled blastocoel
- Trophoblast → Chorion / placenta
- Inner Cell Mass → Organism

4 Gastrulation

- Archenteron leads to blastopore

Ectoderm: Nervous system, skin, hair, nails, mouth, anus.
"Atract-oderm": Skin, hair are things people are attracted to.

Mesoderm: Muscoskeleton, circulatory system, gonads, adrenal cortex.
"Move-oderm": Involved in moving things such as muscles, RBC, steroids.

Endoderm: Endocrine glands, GI tract, respiratory tract, bronchi, bladder, stomach.
"In-doderm": Things that are inside.

Twins

Fraternal = dizygotic
Identical = monozygotic

Cell Specialization

Determination: Cells commit to a function

Differentiation: Follows determination. Selectively transcribe genes appropriate for cell's specific function

5 Neurulation

Mesoderm develops a Notochord. Notochord induces Ectoderm.

Ectoderm → Neural folds → Neural tube
Neural folds ↓ Neural crest cells ↓ Peripheral nervous system
Neural tube ↓ Central nervous system

Induction

Group of cells influence the fate of nearby cells. Mediated by *inducers*, which are commonly *growth factors*.

Stem Cells

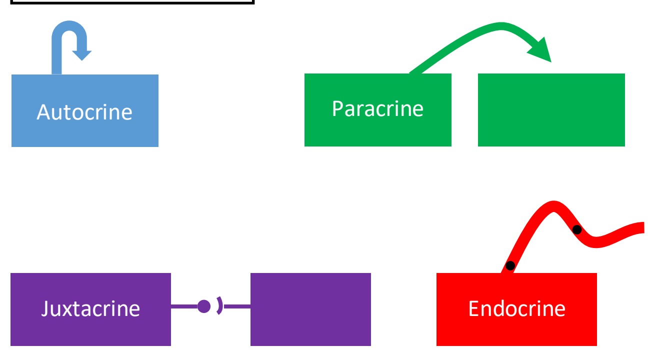
Totipotent: "Total", can be any type of cell

Pluripotent: Can be any cell except those found in placental structures

Multipotent: More specialized. Can be multiple types of cells

*Adult stem cells are multipotent and require treatment w/ transcription factors

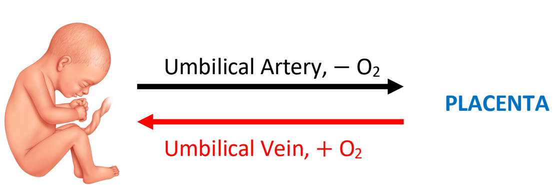
Cell Signaling



Fetal Circulation

Fetal Hemoglobin (HbF): ↑O_2 affinity than HbA

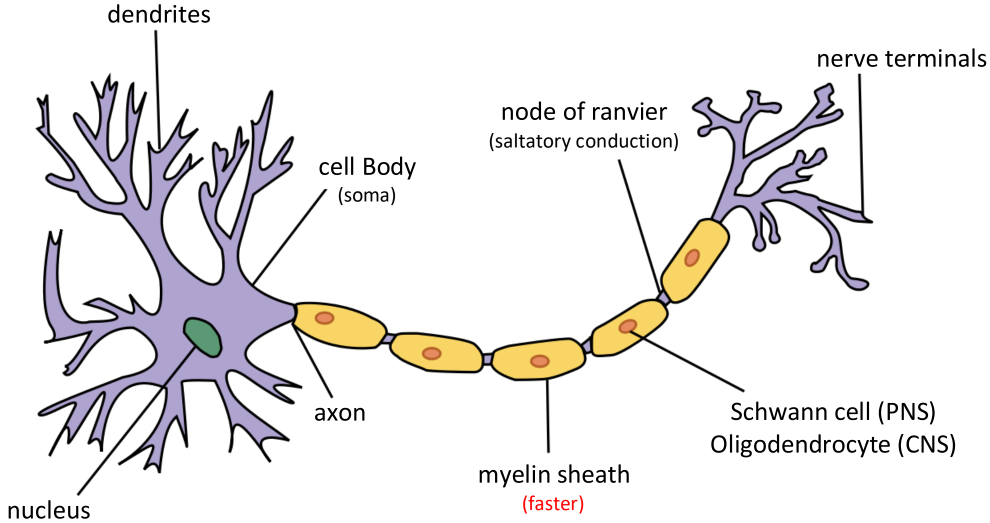
O_2 and CO_2 exchange via diffusion



Fetal Shunts

Skip Lungs: Foramen ovule: R atrium → L atrium
Ductus Arteriousus: Pulmonary artery → Aorta

Skip Liver: Umbilical vein → inferior vena cava



Neurons

Afferent: Ascend spinal cord

Interneurons: Between other neurons

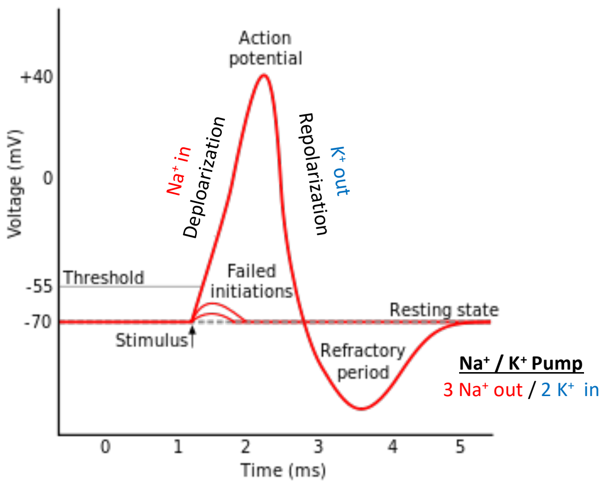
Efferent: Exit spinal cord

Summations

Temporal: Same space / Different time

Spatial: Different space / Same time

Action Potential



Glial Cells

Astrocytes: Blood-brain barrier. Controls solutes moving from bloodstream → nervous tissue.

Ependymal Cells: The barrier between cerebrospinal fluid and interstitial fluid of the CNS.

Microglia: Digest waste in CNS.

Schwann Cells: PNS, makes myelin.

Oligodendrocytes: CNS, makes myelin.

White / Grey Matter

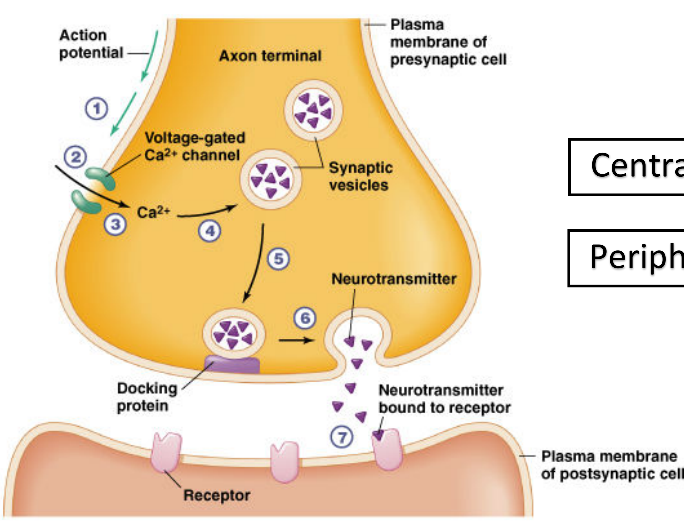
White Matter: Myelinated sheaths.

Grey Matter: Cell bodies and dendrites. Unmyelinated.

Brain: White deep / Grey outer

Spinal Cord: Grey deep / White outer

Synapse



Neurotransmitter removed from synaptic cleft via either:

- Breakdown by enzymes
- Reuptake
- Diffusion out of cleft

Reflex Arcs

Monosynaptic: Sensory neuron → motor neuron

Polysynaptic: Sensory → interneuron → motor

Central Nervous System

- Brain & Spinal Cord

Peripheral Nervous System

Somatic

Voluntary
Sensory: *Afferent*
Motor: *Efferent*

Autonomic

Sympathetic

Fight / Flight
Relax bronchi
Blood to locomotion
↓Peristalsis

Neurotransmitters:
Preganglionic: Acetylcholine
Postganglionic: Epi / Norepi

Parasympathetic

Rest / Digest
Reduce bronchi
Conserve energy
↑Peristalsis

Neurotransmitters:
Preganglionic: Acetylcholine
Postganglionic: Acetylcholine

Peptide Hormones

Made of amino acids

1) Cleaved from larger polypeptide
2) Golgi modifies & activates hormone
3) Put in vesicles released via exocytosis
4) Polar – cannot pass through membrane, so uses extracellular receptor like GPCR
   Common 2nd messengers: cAMP, Ca^{2+}, IP_3

Ex: Insulin

Steroid Hormones

- **Made in Gonads & Adrenal Cortex, from Cholesterol**
- Don't dissolve, must be carried by proteins
- Non-polar, so CAN pass through membrane
- They activate nuclear receptors
- Direct action on DNA

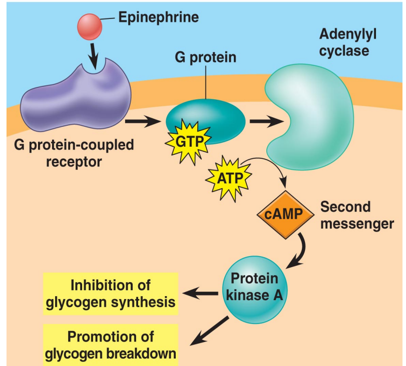
Ex: Estrogen / Testosterone / Cortisol

Amino Acid-Derivative Hormones

Share traits from both peptide & steroid hormones

Ex: Catecholamines use GPCR, Thyroxine bind intracellularly

G-Protein Coupled Receptor (GPCR)



Notes: Epinephrine is a ligand 1st messenger. At the end of the GPCR process, Phosphodiesterase deactivates cAMP and GTP hydrolyzed back to GDP.

Direct vs. Tropic Hormones

Direct Hormones: Act directly on target tissue/organ. Ex: Insulin.

Tropic Hormones: Require an intermediary. They only affect other endocrine tissues. Ex: GnRH and LH are both tropic.

Diabetes

Type 1: No insulin, so glucose is not able to enter cells.

Type 2: Desensitized insulin receptors. Glucose unable to enter cells.

Endocrine Organs & Hormones

* See appendix for more details on each hormone

Hypothalamus

GnRH ⇒ ↑FSH + ↑LH
GHRH ⇒ ↑GH
TRH ⇒ ↑TSH
CRH ⇒ ↑ACTH
Dopamine (PIF) ⇒ ↓Prolactin
ADH & Oxytocin: Produced in hypothalamus, released from posterior pituitary

Pancreas

Insulin ⇒ βeta islets, ↓Glucose
Glucagon ⇒ αlpha islets, ↑Glucose
Somatostatin (GHIH) ⇒ δelta islets
↓Insulin, ↓Glucagon

Gonads

Testosterone in Testes
Estrogen / **Progesterone** in ovaries

Pineal Gland

Melatonin controls circadian rhythm

Anterior Pituitary

"FLAT PEG" mnemonic

FSH ⇒ Male: Spermatogenesis
Females: Growth of ovarian follicles
LH ⇒ Males: Testosterone
Females: Induces ovulation
ACTH ⇒ Synth & release glucocorticoids from adrenal cortex
TSH ⇒ Synth & release triiodothyronine and thyroxine from thyroid
Prolactin ⇒ ↑Milk
Endorphins ⇒ ↓Pain
GH ⇒ ↑Growth in bone/muscle
↑Glucose in bone/muscle

Thyroid Gland

T_4 & T_3 ⇒ made by follicle cells
↑basal metabolic rate
Calcitonin ⇒ Made by parafollicular (c) cells
↑Ca^{2+} in bone
↓Ca^{2+} in blood
↓Ca^{2+} absorption in gut
↑Ca^{2+} excretion from kidneys

Parathyroid Glands

PTH ⇒ ↓Ca^{2+} in bone
↑Ca^{2+} in blood
↑Ca^{2+} absorption in gut
↓Ca^{2+} excretion in kidneys
Bone breakdown releases Ca^{2+}
Activates Vitamin D (Calcitriol)

Posterior Pituitary

ADH ⇒ ↓H_2O output in urine
vasoconstriction
Oxytocin ⇒ ↑Uterine contractions
↑Milk
↑Bonding behavior
POSITIVE FEEDBACK

Adrenal Cortex

Glucocorticoids: Cortisol / Cortisone
↑Glucose
↓Protein synthesis
↓Immune system
Mineralocorticoids: Aldosterone
↓K^+ in blood
↑Na^+ in blood
↑H_2O in blood due to osmosis
↑blood pressure
Androgens: Converted to **Testosterone** and **Estrogen** in the gonads.

Adrenal Medulla

Catecholamines

Epinephrine: Anti-histamine
↑Heart rate
↑BP
Norepinephrine: ↑Heart rate
↑BP

Air Pathway

Nares of nose: Nostrils

Pharynx: Food / air
Warmed / humidified
Vibrissae filter

Larynx: Air ONLY
Epiglottis covering
2 vocal cords

Trachea: Ciliated epithelium collect debris.

Bronchi: Ciliated epithelium collect debris.

Bronchioles:

Alveoli: Sacs where diffusion occurs. Surfactant REDUCES surface tension preventing collapse.

LUNGS → Pulmonary Veins, + O_2 → (heart)
LUNGS ← Pulmonary Artery, - O_2 ← (heart)

Spirometer

Measures lung capacity
CAN NOT measure TOTAL volume

Total Lung Capacity: Maximum volume of air in the lungs.

Residual Volume: Residual after exhalation (air stays in lungs to keep alveoli from collapsing).

Vital Capacity: Difference between minimum and maximum volume of air in the lungs.

Tidal Volume: Volume inhaled and exhaled in a normal breath.

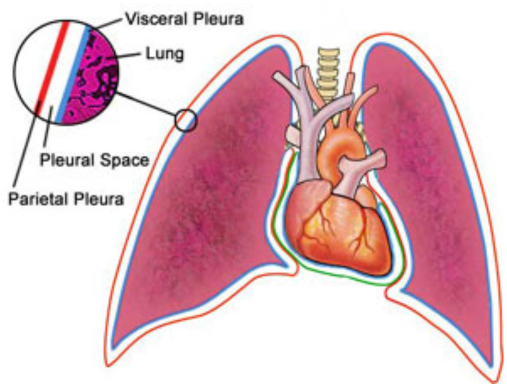
Expiratory Reserve Volume: Volume of additional air that can be forcibly exhaled following normal exhalation.

Inspiratory Reserve Volume: Volume of additional air that can be forcibly inhaled following normal inhalation.

Medulla Oblongata

↑[CO_2] ⇒ Hypercarbia / hypercapria
↑respiration (exchanging gases)
↓[O_2] ⇒ Hypoxemia
↑ventilation (air in/out)

Pleurae Membranes



Inhalation

Negative pressure breathing

Active process

Diaphragm & External Intercostal muscles contract

↑intrapleural space, ↑thoracic cavity, ↓pressure

↑lung volume, ↓lung pressure

Air rushes in

Exhalation

Passive process

Muscles relax

↓lung volume, ↑lung pressure

Air leaves lungs

Active Exhalation: Internal intercostal & abdominal muscles help force air out

Protection from Pathogens

Vibrissae: In pharynx

Mucous Membranes

Mucociliary Escalator

Lysozymes: In nasal cavity/saliva. Attack Gram + peptidoglycan

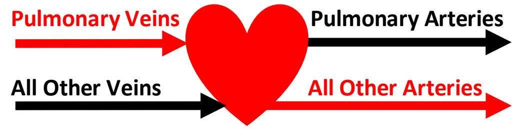
Mast Cells: Antibiotics on surface. Inflammation. Allergic reactions

Bicarbonate Buffer

$$CO_{2\,(g)} + H_2O_{\,(l)} \rightleftharpoons H_2CO_{3\,(aq)} \rightleftharpoons H^+_{\,(aq)} + HCO_3^-{}_{\,(aq)}$$

↓pH ⇒ ↑respiration to blow off CO_2

↑pH ⇒ ↓respiration, trapping CO_2



Blood Pathway

Deoxygenated → Oxygenated →

R Atrium → (Tricuspid Valve) → R Ventricle → (Pulmonary Valve) → Pulmonary Artery → Lungs → Pulmonary Veins → L Atrium → (Mitral Valve) → L Ventricle → (Aortic Valve) → Aorta → Arteries → Arterioles → Capillaries → Venules → Veins → Venae Cavae → R Atrium

Electrical Conduction

SA Node (Pacemaker) → AV Node → Bundle of His → Purkinje Fibers

"Stab **A B**ig **P**ickle" acrostic

Blood Pressure

Systole Ventricular contraction, AV valves close

Diastole Ventricular relaxation, SV close, blood atria → ventricles

Normal BP: $\frac{90}{60} \to \frac{120}{80}$ Maintained by baroreceptors and chemoreceptors

↑BP ⇒ ↑ANP (atrial natriuretic peptide)

↓BP ⇒ ↑Aldosterone, ↑ADH (vasopressin)

↑Osmolarity ⇒ ↑ADH

Cardiac Output = Heart Rate x Stroke Volume. $CO = HR \times SV$

Blood Type

Antigens: Surface proteins on RBCs

Rh Factor: Rh^+ is dominant. An Rh^- person will only create anti-Rh antibodies after exposure to Rh^+ blood

Blood Type	Antigens Produced	Antibodies Produced	Donate To	Receive From
A - I^A	A	Anti-B	A, AB	A, O
B - I^B	B	Anti-A	B, AB	B, O
AB - I^AI^B	A and B	None	AB only	A, B, AB, O (universal recipient)
O - i	none	Anti-A and Anti-B	A, B, AB, O (universal donor)	O only

Coagulation

When the endothelial lining of a blood vessel is damaged, the *collagen* and *tissue factor* underlying the endothelial cells are exposed.

Prothrombin → Thrombin
Fibrinogen → Fibrin

Clots are broken down by Plasmin

Vasculature

Arteries: Thick, ↑muscular, elastic, allows for recoil and helps propel blood forward.

Arterioles: Small muscular arteries.

Capillaries: 1 cell thick endothelial wall, easy diffusion of gases (O_2 CO_2) and waste (NH_3, urea).

Veins: THIN wall, inelastic. May stretch to accommodate lots of blood, but do not have recoil. Surrounding muscles help pump blood through. Contain valves.

Venules: Small veins

Blood

- Considered a connective tissue.

Erythrocytes (RBCs): Formed in bone marrow. No nucleus, mitochondria, or organelles. Contain Hemoglobin to carry O_2.

Hematocrit: % of blood composed of RBCs.

Leukocytes (WBCs): Immune system. Formed in bone marrow. *Granular Leukocytes*: Neutrophils, eosinophils, and basophils = nonspecific immunity, inflammatory reactions *Agranulocytes*: Lymphocytes = specific immunity, monocytes digest foreign matter (if monocytes leave bloodstream for organ they are called macrophages)

Thrombocytes (Platelets): Cell fragments. Coagulation.

Fluid Balance

Hydrostatic Pressure: Blood against vessel walls. Generated by heart contraction and elasticity of arteries.

Osmotic Pressure: "Sucking" pressure generated by solutes as they draw H_2O into the bloodstream.

Oxygen: Carried by hemoglobin.

CO_2: Some carried by hemoglobin, most exist in the bloodstream as bicarbonate HCO_3^-.

<u>Bicarbonate Buffer</u>

$$CO_{2\,(g)} + H_2O_{\,(l)} \rightleftharpoons H_2CO_{3\,(aq)} \rightleftharpoons H^+_{\,(aq)} + HCO^-_{3\,(aq)}$$

↓pH ⇒ ↑respiration to blow off CO_2

↑pH ⇒ ↓respiration, trapping CO_2

Structure

Innate Immunity: Defenses that are always active but NON-SPECIFIC. Skin, mucus, stomach acid, tears etc.

Adaptive Immunity: Defenses that take time to activate and are SPECIFIC to the invader.

Innate Immune System

Non-cellular innate defenses:

Skin: Physical barrier. Secretes antimicrobial enzymes like *defensins*

Mucus: On mucous membranes. Traps pathogens. In respiratory system mucous is propelled upward by cilia via *mucociliary escalator*

Lysozymes: In tears and saliva. Antimicrobial compound

Complement System: Can punch holes in the cell walls of bacteria making them osmotically unstable, leading to lysis. Also triggers opsonization.

Interferons: Given off by virally infected cells. Interfere with viral replication and dispersion

Cellular innate defenses:

Macrophages: Ingest pathogens and present them on MHC-II. Secrete *Cytokines*

MHC-I: Present in all nucleated cells. Displays *endogenous antigen* to cytotoxic T-cells $CD8^+$ cells.

MHC-II: Present in professional antigen-presenting cells (macrophages, dendritic cells, some B-cells, and certain activated epithelial cells). Displays *exogenous antigen* to helper T-Cells $CD4^+$ cells.

Dendritic cells: Antigen-presenting cells in the skin

Natural Killer Cells: Attack cells low on MHC, including virally infected cells and cancer cells

Granulocytes: *Neutrophils*: Activated by bacteria, conduct phagocytosis.
Eosinophil: Activated by parasites & allergens ↑histamines
Basophils: Activated by allergens, inhibit blood clotting.

Lymphatic System

- Circulatory system that consists of one-way vessels with intermittent lymph nodes
- Provides for mounting immune responses
- Connects to the cardiovascular system via the *thoracic duct* in the posterior chest
- Equalizes fluid distribution, transports fats and fat-soluble compounds in *chylomicrons*
- *Edema* results when the lymphatic system is overwhelmed and can't drain excess fluid from tissues

Adaptive Immune System

Humoral Immunity: Centers on antibody production by B-Cells. Kills antigens while they are floating around in the fluid (humor).

B-Lymphocytes: (B-cells) Made and mature in bone marrow. Activated in spleen or lymph nodes. Express antibodies on its cell surface.

Antibodies (Ig): Produced by plasma cells, which are activated B-Cells. Target an antigen. Contain 2 heavy chains and 2 light chains. Constant region & variable region. Tip of variable region is the antigen-binding region.

Hypermutation: Activated antibodies' antigen-binding region mutates to improve specificity of the antibody produced. 5 diff isotypes (IgM, IgD, IgG, IgE, IgA)

Opsonize: Antibodies mark pathogens for destruction.

Agglutination: Pathogens clump together into insoluble complexes. Caused by opsonizing pathogens.

Memory B-Cells: Lie in wait for a second exposure to pathogen. Secondary response is more rapid and vigorous.

Cell-Mediated (Cytotoxic) Immunity: Centers on T-Cells. Responds to cells once they have been infected by the antigen.

T-Lymphocytes: (T-cells) Made in bone marrow, mature in Thymus. Coordinate immune system and directly kill infected cells. Cell-mediated immune ty.

Positive/Negative Selection: Maturation of T-Cells. Facilitated by *thymosin*. Occurs in Thymus.
Positive Selection: Mature only T-cells that can respond to the presentation of antigen on MHC.
Negative Selection: Causes apoptosis in T-cells that are self-reactive

Helper T-Cells : T_h or $CD4^+$. Respond to antigen on MHC-II. Coordinate rest of the immune system, secreting *lymphokines* to activate immune defense.
T_h1 – secrete *interferon gamma*
T_h2 – activate B-Cells, in parasitic infections

Cytotoxic T-cells: T_c, CTL, or $CD8^+$. "Killer cells". Respond to antigen on MCH-I and kill virally infected cells

Suppressor T-Cells: T_{reg}. Down regulate the immune response after an infection and promote self-tolerance. Defective suppressor T-Cells lead to autoimmune conditions.

Memory T-Cells: Serve a similar function to memory B-Cells

Autoimmune Conditions: A self-antigen is recognized as foreign, and the immune system attacks normal cells

Allergic Reactions: Nonthreatening exposures incite an inflammatory response

Immunization: Induces active immunity (activation of B-Cells that produce antibodes)

Passive Immunity: Transfer of antibodies to an individual. Breast milk.

Overview

Intracellular Digestion: The oxidation of glucose and fatty acids to make energy.

Extracellular Digestion: Process by which nutrients are obtained from food. Occurs in alimentary canal.

Mechanical Digestion: Physical breakdown of large food molecules into smaller particles.

Chemical Digestion: The enzymatic cleavage of chemical bonds such as the peptide bonds of proteins or the glycosidic bonds of starches.

Peristalsis: Rhythmic contractions of the gut tube.
↑parasympathetic nervous system
↓sympathetic nervous system

Digestive Pathway

Oral Cavity → Pharynx → Esophagus → Stomach → Small Intestine → Large Intestine → Rectum

Oral Cavity

Mastication starts the mechanical digestion. Salivary *amylase* and *lipase* stat the chemical digestion of food. Food is formed into a *bolus* and swallowed.

Pharynx

Connects the mouth to the esophagus. The *epiglottis* prevents food from entering the *larynx*.

Esophagus

Propels food to the stomach using *peristalsis*. Top third has skeletal muscle and is under somatic control. Bottom third has smooth muscle, middle third has combo of both. The middle & bottom are under autonomic control.

Stomach

An acidic (pH = 2) environment. Four parts: *fundus*, *body*, *antrum* and *pylorus*. The enzyme pepsin chemically breaks down proteins.

Secretory cells that line the stomach

Mucous Cells: Produce bicarbonate-rich mucus to protect stomach wall from acid.

Chief Cells: Secrete *pepsinogen*, a protease activated by the acidic environment.

Parietal Cells: Secrete HCl and *intrinsic factor*, which is needed for vitamin B_{12} absorption.

G-Cells: Secrete *gastrin*, a peptide hormone that ↑HCl secretion & gastric motility.

After processing in the stomach, food particles are now called *chyme*. *Chyme* exits through *pyloric sphincter* → *duodenum*.

Feeding Behavior Hormones

ADH & Aldosterone: ↑thirst

Glucagon & Ghrelin: ↑hunger

Leptin & Cholecystokinin: ↑satiety

Duodenum

First part of small intestine. A basic (pH = 8.5) environment. Site of the majority of chemical digestion.

Enzymes in Duodenum

Disaccharidases: Brush-border enzymes that break down *maltose*, *isomaltose*, *lactose*, and *sucrose* into monosaccharides.

Aminopeptidase & Dipeptidase: Brush-border peptidases.

Enteropeptidase: Activates trypsinogen and procarboxypeptidases.

Hormones in Duodenum

Secretin: Peptide hormone. Stimulates release of pancreatic juices and slows motility.

Cholecystokinin: Stimulates bile release from gallbladder, release of pancreatic juices, and satiety.

Absorption and Defecation

The *jejunum* and *ileum* of the small intestine are primarily involved in absorption. The small intestine is lined with *villi*, which are covered with *microvilli*.

Villi: *Capillary Bed*: Absorbs water-soluble nutrients.
Lacteal: Absorbs fat, sends to lymphatic system.

Vitamin Absorption: *Fat-Soluble*: Only A,D,E,K; enter lacteal.
Water-Soluble: All others; enter plasma directly.

Large Intestine – absorbs H_2O and salts, forms feces

Cecum: Outpocketing that accepts fluid from small intestine through *ileocecal valve*. Site of attachment of the appendix.

Colon: Ascending / transverse / descending / sigmoid

Gut Bacteria: Produce vitamin K and biotin (vitamin B_7).

Accessory Organs

- Originate from endoderm

Pancreas: Acinar Cells produce pancreatic juices that contain bicarbonate, *pancreatic amylase*, *pancreatic peptidases*, and *pancreatic lipase*.

Liver: Synthesizes *bile*, *albumin* and *clotting factors*. Process nutrients. Detox: NH_3 → Urea, as well as alcohol & drugs. Liver receives blood from the abdominal portion of digestive tract via *Hepatic Portal Vein*.

Gallbladder: Stores & concentrates *bile*. CCK stimulates bile release into biliary tree, which merges with pancreatic duct.

Excretory (urine) Pathway

Bowman's space → proximal convoluted tubule → descending limb of the loop of Henle → ascending limb of the loop of Henle → distal convoluted tubule → collecting duct → renal pelvis → ureter → bladder → urethra

Kidney

Kidney: Contains a cortex and medulla. Produces urine which dumps into the ureter at the renal pelvis. Urine is then collected in the bladder until it is excreted through the urethra.

Nephron: Functioning unit of the kidney.

Renal Portal System: Two capillary beds in series (glomeruli & nephron). Blood flow: renal artery → afferent arterioles → glomeruli → efferent arteriole → vasa recta, which surround nephron → renal vein.

Filtration: Bowman's capsule moves solutes from blood → filtrate. Direction and rate determined by hydrostatic and oncotic pressure differentials between the glomerulus and Bowman's space.

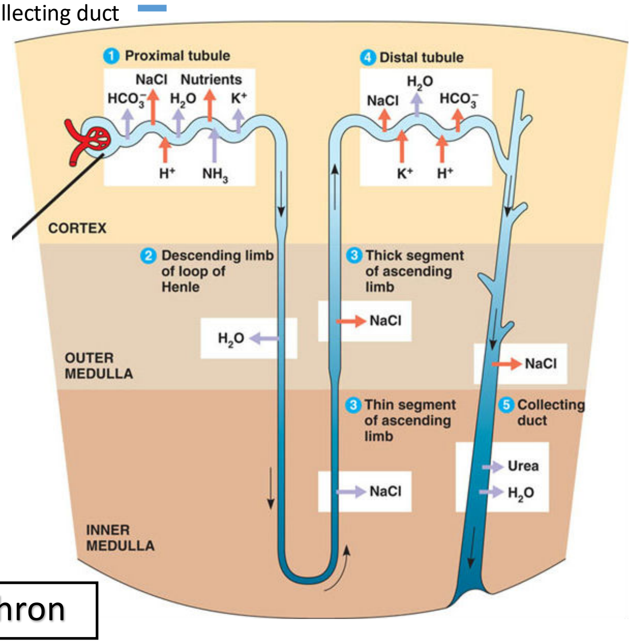
Secretion: The movement of solutes from blood → filtrate anywhere other than Bowman's capsule.

Reabsorption: The mvmt of solutes from filtrate → blood.

pH: Kidney can regulate pH with bicarbonate and H^+.

Aldosterone: Steroid hormone synthesized in Adrenal Cortex in response to Angiotensin 2 or high [K^+]. It is derived from cholesterol. Increases Na^+ reabsorption in the distal convoluted tubule and collecting duct, thereby increasing H_2O reabsorption. Result: ↑BP but no change in blood osmolarity

ADH (Vasopressin): Peptide hormone synthesized by hypothalamus and released by posterior pituitary. ↑permeability of the collecting duct to H_2O, which ↑H_2O reabsorption. Result: ↑BP and ↓blood osmolarity, concentrated urine.



Nephron

Proximal Convoluted Tubule (PCT): Site of bulk reabsorption of glucose, amino acids, soluble vitamins, salt, and H_2O. Site of secretion for H^+, K^+, NH_3, and urea

Descending Limb of the Loop of Henle: Permeable to H_2O but NOT salt; therefore, as the filtrate moves into the more osmotically concentrated *renal medulla*, water is reabsorbed from the filtrate.

Countercurrent Multiplier System: The *vasa recta* and *nephron* flow in opposite directions, creating a countercurrent multiplier system that allows maximal reabsorption of water

Ascending Limb of the Loop of Henle: Permeable to salt but NOT to H_2O; therefore, salt is reabsorbed both passively and actively. The diluting segment is in the outer medulla; because salt is actively reabsorbed in this site, the filtrate becomes hypotonic compared to the blood

Distal Convoluted Tubule (DCT): Responsive to aldosterone and is a site of salt reabsorption and waste product excretion, like the PCT.

Collecting Duct: Responsive to both aldosterone and ADH. Has variable permeability, which allows reabsorption of the right amount of H_2O depending on the body's needs.

Bladder

Detrusor Muscle: Muscular lining of bladder. Parasympathetic control

Internal Urethral Sphincter: Smooth muscle. Parasympathetic control

External Urethral Sphincter: Skeletal muscle. Voluntary control

Skin

- Epidermis / Dermis / Hypodermis (subcutaneous layer)

Epidermis: *Stratum Basale*: Stem cells → keratinocytes
Stratum Spinosum: Lagerhans cells
Stratum Granulosum: Keratinocytes die
Stratum Luciderm: Only on thick, hairless skin
Stratum Corneum: Mult thin layers, flat keratinocytes

Langerhans Cells: Macrophages that are antigen-presenting cells in skin

Melanin: Produced by Melanocytes. Protects skin from DNA damage caused by ultraviolet radiation

Dermis: Papillary layer and reticular layer. Sensory:
Merkel Cells: Deep pressure & texture
Free Nerve Endings: Pain
Meissner's Corpuscles: Light touch
Ruffini Endings: Stretch
Pacinian Corpuscles: Deep pressure & vibration

Hypodermis: Fat and connective tissue. Connects skin to body

Thermo-regulation: *Sweating*: Evaporative cooling
Piloerection: Warming
Shivering: Warming
Vasodilation / Vasoconstriction: Cool / warm

Skeletal Muscle

- Support & movement, blood propulsion, thermoregulation, striated
- Voluntary (somatic) control
- Polynucelated

Red Fibers: Slow twitch. Support (dark meat). Carry out oxidative phosphorylation.

White Fibers: Fast-twitch. Active (white meat). Anaerobic metabolism.

Smooth Muscle

- Respiratory, reproductive, cardiovascular, digestive
- Involuntary (autonomic) control
- Uninucleated
- Can display myogenic activity without neural input

Cardiac Muscle

- Contractile tissue of the heart
- Involuntary (autonomic) control
- Uninucleated (sometimes binucleated)
- Can display myogenic activity
- Cells connected with *intercalated discs* that contain *gap junctions*

Skeletal System

- Derived from mesoderm

Axial Skeleton: Skull, vertebral column, ribcage, hyoid bone.
Appendicular Skeleton: Bones of limbs, pectoral girdle, pelvis.

Compact Bone: Strength and density.

Spongy Bone: (cancellous) Lattice-like structure of bony spicules known as trabeculae. Cavities filled with bone marrow.

Bone Marrow: *Red*: Filled with hematopoietic stem cells.
Yellow: Fat

Long Bones: Shafts called diaphysis that flare to form metaphyses and that terminate in epiphyses. Epiphyses contain epiphyseal (growth) plate.

Periosteum: Connective tissue that surrounds bone.

Ligaments: Attach bones to other bones.

Tendons: Attach bones to muscles.

Bone Matrix: Concentric rings called *lamellae* around a central *Haversian* or *Volkmann's canal*. This structural unit is called an *Osteon* or *Haversian system*. Between rings are *lacunae*, where *osteocytes* reside, which are connected with *cancaliculi*.

Bone Remodeling: *Osteoblasts* build bone, *osteoclasts* resorb bone.
Parathyroid Hormone: ↑resorption of bone ↑[blood Ca^{2+}].
Vitamin D: ↑resorption of bone, ↑[blood Ca^{2+}].
Calcitonin: ↑bone formation, ↓[Ca^{2+}] in blood.

Cartilage: Firm & elastic. Matrix is *chondrin*. Secreted by *chondrocytes*. Vascular and is NOT innervated.

Joints: *Immovable:* Fused together to form sutures.
Movable: Strengthened by ligaments and contain a synovial capsule.
Synovial Fluid: Secreted by synovium, lubricates joints.

Fetus: Bones form from cartilage through *endochondroal ossification.* Skull bones form directly from *mesenchyme* in *intramembranous ossification*.

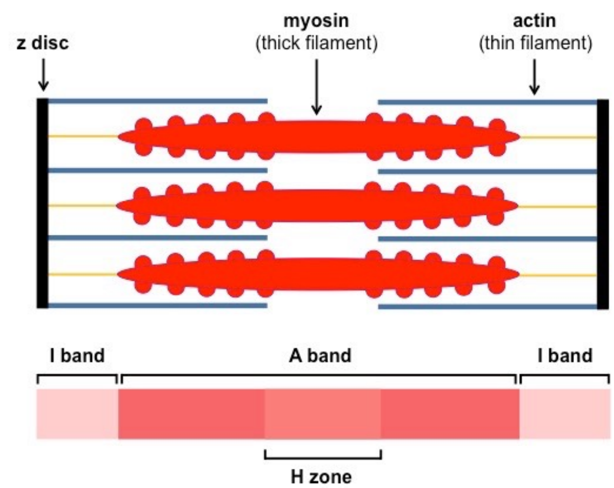
Sarcomeres

- Basic contractile unit of striated muscle
- THICK myosin and THIN actin filaments
- *Troponin* & *tropomyosin* found on the thin filament and regulate actin-myosin interactions
  - *Z-lines:* Define the boundary of each sarcomere
  - *M-line:* Middle of sarcomere
  - *I-band:* Only actin filaments.
  - *H-zone:* Only myosin filaments.
  - *A-band:* Contains both actin and myosin. Only part that maintains a constant size during contraction.
- Sarcomeres attach end-to-end to become *myofibrils*. Each *myocyte* contains many *myofibrils*

Sarcoplasmic Reticulum: Ca^{2+} filled modified endoplasmic reticulum.

Sarcolemma: Cell membrane of a myocyte.

T-tubules: Connected to sarcolemma. Carry signals.



Contraction / Relaxation

- Begins at neuromuscular junction, where the efferent neuron release acetylcholine that binds to receptors on the sarcolemma, causing depolarization
- Depolarization spreads down sarcolemma to T-tubules, triggering the release of Ca^{2+}
- Ca^{2+} binds to troponin, causing a shift in tropomyosin and exposure of the myosin-binding sites on the actin filament
- Shortening of the sarcomere occurs as myosin heads bind to the exposed sites on actin, forming cross bridges and pulling the actin filament along the thick filament. "Sliding filament model"
- Muscles relax when acetylcholine is degraded by acetylcholinesterase, terminating the signal and allowing Ca^{2+} to return to the SR.
- ATP binds to myosin head, allowing it to release form actin

Simple Twitch: Single muscle fiber responds to brief stimulus.

Frequency Summation: Addition of multiple simple twitches before the muscle has a chance to fully relax.

Oxygen Debt: Difference between O_2 needed and O_2 present.

Creatine Phosphate: Adds a phosphate group to ADP, forming ATP.

Myoglobin: Heme-containing protein that is a muscular oxygen reserve.

Definitions

Alleles: Alternative forms of a gene. Dominant allele only requires 1 copy in order to be expressed. Recessive allele requires two copies in order to be expressed.

Genotype: The combination of alleles one has at a given locus.
Homozygous: Having two of the same allele.
Heterozygous: Having two different alleles.

Phenotype: The observable manifestation of a genotype.

Dominance: *Complete*: Only one dominant allele.
Codominance: More than one dominant allele.
Incomplete: No dominant alleles; heterozygotes have intermediate phenotypes.

Penetrance: The proportion of individuals carrying a particular allele that also express an associated phenotype.

Expressivity: The varying phenotypic outcomes of a genotype.

Genetic Leakage: Flow of genes between species via *hybrid* offspring.

Genetic Drift: When the composition of the gene pool changes as a result of chance.

Founder Effect: Bottlenecks that suddenly isolate a small population; inbreeding.

Taxonomic Rank: Kingdom, phylum, class, order, family, genus, species. "**K**ing **P**hillip **C**ame **O**ver **F**rom **G**reat **S**pain"

Mendel's Laws

Law of Segregation: An organism has two alleles for each gene, which segregate during Anaphase I. Because of this, gametes carry only one allele for a trait.

Law of Independent Assortment: The inheritance of one allele does not influence the probability of inheriting a given allele for a different trait (except for linked genes).

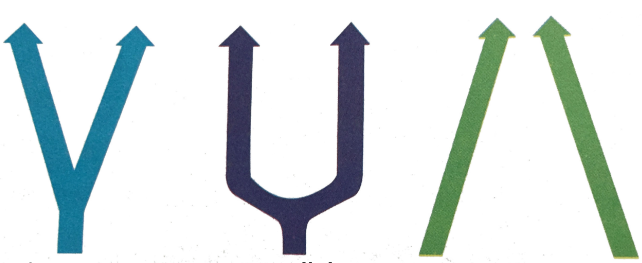
Experiments

Experiments to support DNA as genetic material.

Griffith: Demonstrated transformation. Heat-killed smooth (virulent) strain of bacteria still transformed rough strain into smooth.

Avery-MacLeod-McCarty: Degradation of DNA led to a cessation of bacterial transformation. Degradation of proteins did not.

Hershey-Chase: Confirmed DNA is the genetic material because only radiolabeled DNA could be found in bacteriophage-infected bacteria.



Nucleotide Mutations

Point Mutations: The substituting of one nucleotide for another.

Frameshift Mutations: Moving the 3 letter reading frame.

Results: *Silent*: No effect on the protein.
Missense: Replace one amino acid with another.
Nonsense: A stop codon replaces an amino acid.
Insertion/Deletion: Shift in the reading frame, leading to a change in all downstream amino acids.

Chromosomal Mutations

Much larger mutations, affecting whole segments of DNA.

Results: *Deletion*: A large segment of DNA is lost.
Duplication: A segment of DNA is copied multiple times.
Inversion: A segment of DNA is reversed.
Insertion: A segment of DNA is moved from one chromosome to another.
Translocation: A segment of DNA is swapped with a segment of DNA from another chromosome.

Analytical Techniques

Punnett Squares: Monohybrid cross accounts for 1 gene. Dihybrid crosses account for two genes. Sex-linked cross is linked to the X chromosome.

Recombination Frequency: The likelihood of two alleles being separated during crossing over in meiosis. Farther = ↑likely

Hardy-Weinberg Principle: If a population meets certain criteria (aimed at a lack of evolution), then the allele frequencies will remain constant.

Hardy-Weinberg Equation: $P + q = 1$ $P^2 + 2Pq + q^2 = 1$ — P = dominant allele freq, q = recessive allele freq

Evolution

Natural Selection: The mechanism for evolution is *natural selection*.

Modern Synthesis Model: Neo-Darwinism. Mutation and recombination are mechanisms of variation. Differential reproduction.

Inclusive Fitness: If a population meets certain criteria (aimed at a lack of evolution), then the allele frequencies will remain constant.

Punctuated Equilibrium: Considers evolution to be a very slow process with intermittent rapid bursts of evolutionary activity.

Mode of Natural Selection: *Stabilizing Selection*: Keeps phenotypes in a narrow range, excluding extremes.
Directional Selection: Moves the average phenotype toward an extreme.
Disruptive Selection: Moves toward two different phenotypes at the extremes, can lead to speciation.
Adaptive Radiation: Rapid emergence of multiple species from a common ancestor, each has a *niche*.

Isolation: Reproductively isolated from each other by *pre-* or *postzygotic* mechanisms.

Molecular Clock Model: The degree of difference in the genome between two species is related to the amount of time since the two species broke off from a common ancestor.

Amino Acids Found in Proteins

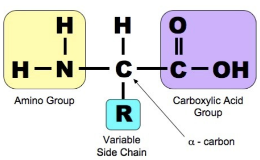
* See appendix for full AA chart

Amino Acids: A molecule with 4 groups attached to a central (α) carbon: an amino group, a carboxylic acid group, a hydrogen atom, and an R Group. The R Group determines function of that amino acid.

Stereochemistry: The stereochemistry of the α-carbon is L for all chiral amino acids in eukaryotes. (carbohydrates are D-config). All chiral amino acids except *cysteine* have (*S*) configuration and all amino acids are chiral except for *Glycine*.

Hydrophobic & Hydrophilic: Amino acids with long alkyl chains are hydrophobic. Those with charges are hydrophilic. All others fall in somewhere in between.

Structure of an Amino Acid



Acid-Base Chemistry of Amino Acids

Amphoteric: Amino acids can act as a base or an acid.

pK$_a$: The pH at which half of the species is deprotonated; [HA] = [A$^-$].

pH: ↓pH ⇒ amino acid is fully *protonated*
pH ≈ pI ⇒ amino acid is a neutral *zwitterion*
↑pH ⇒ amino acid is fully *deprotonated*

Isoelectric Point: (pI) The pH at which an amino acid is in zwitterion form; the charges cancel out to make a neutral molecule.

pK_{a1} = carboxyl grp
pK_{a2} = amine grp
pK_{a3} = side chain

For no side chain: $pI = \frac{1}{2}(pK_{a1} + pK_{a2})$

For a NEUTRAL side chain: $pI = \frac{1}{2}(pK_{a1} + pK_{a2})$

For a BASIC side chain: $pI = \frac{1}{2}(pK_{a2} + pK_{a3})$

For an ACIDIC side chain: $pI = \frac{1}{2}(pK_{a1} + pK_{a3})$

Titration: Midpoint: $pH = pK_a$
Equivalence Point: $pH = pI$

Peptide Bond Formation and Hydrolysis

Terminology: *Dipeptide*: 2 residues
Tripeptide: 3 residues
Oligopeptides: Less than 20 residues
Polypeptides: Greater than 20 residues

Formation: Forming a peptide bond is a dehydration reaction. The nucleophilic amino group of one amino acid attacks the electrophilic carbonyl group of another amino acid.

Amide Bonds: The C-N bond of a peptide bond. Rigid due to resonance.

Breaking: Breaking a peptide bond is a hydrolysis reaction.

1° and 2° Protein Structure

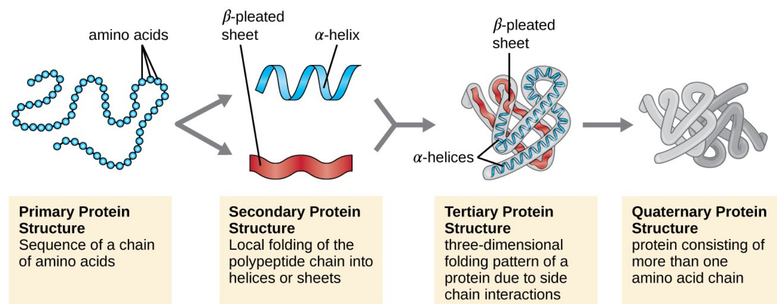
1° Structure: Linear sequence of amino acids in a peptide. Stabilized by peptide bonds. The AA sequence is written N-terminus to C-terminus. N-terminus is POSITIVELY charged due to $-NH_3^+$.

2° Structure: The local structure of neighboring amino acid. Is stabilized by hydrogen bonding between amino groups and nonadjacent carboxyl groups.

α-helices: A common 2° structure. Clockwise coils around a central axis.

β-pleated sheets: A common 2° structure. Rippled strands that can be parallel or antiparallel.

Proline: Can interrupt 2° structure because of its rigid cyclic structure.



Note: Denaturing is when a protein (or nucleic acid) loses its 4°, 3°, and 2° structures due to breaking non-covalent interactions such as H-bonds, hydrophobic interactions, and dipole-dipole interactions.

3° and 4° Protein Structure

3° Structure: 3-D shape of a single polypeptide chain, and is stabilized by hydrophobic interactions, acid-base interactions, H-bonds, and disulfide bonds.

Hydrophobic Interactions: Push hydrophobic R groups to the interior or a protein, which increases entropy of the surrounding water molecules and creates a negative Gibbs free energy.

Disulfide Bonds: Occur when two *cysteine* molecules are oxidized and create a covalent bond between their thiol groups. This forms *cystine*.

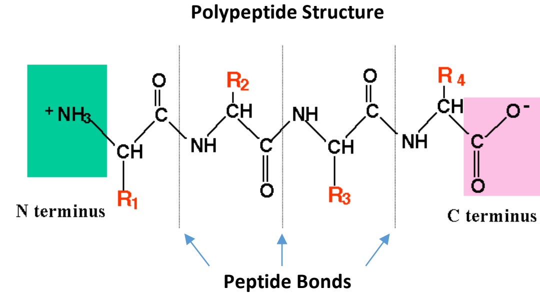
4° Structure: The interaction between peptides in proteins that contain multiple subunits.

Conjugated Proteins: Proteins with covalently attached molecules.

Prosthetic Group: The attached molecule in a conjugated protein. Can be a metal ion, vitamin, lipid, carbohydrate, or nucleic acid.

Denaturation: The loss of 3-D structure. Caused by heat or solute concentration.

Polypeptide Structure



Enzymes as Biological Catalysts

Enzymes: Biological catalysts that are unchanged by the reactions they catalyze & are reusable. Enzymes DO NOT alter the ΔG or ΔH, nor the final equilibrium position. They only change the rate of reaction by altering the mechanism. Catalyze both the FORWARD & REVERSE reactions.

Exergonic Rxns: Release energy; ΔG is negative.

Endergonic Rxns: Require energy; ΔG is positive.

Oxidoreductases: REDOX reactions that involve the transfer of e^-.

Transferases: Move a functional group from one molecule to another.

Hydrolases: Catalyze cleavage with the addition of H_2O.

Lyases: Catalyze cleavage without the addition of H_2O and without the transfer of e^-. The reverse reaction (synthesis) is often more important biologically.

Isomerases: Catalyze the interconversion of isomers, including both constitutional isomers and stereoisomers.

Ligases: Join two large biomolecules, often of the same type.

Lipases: Catalyze the hydrolysis of fats. Dietary fats are broken down into fatty acids and glycerol or other alcohols.

Kinases: ADD a phosphate group. A type of transferase.

Phosphatases: REMOVE a phosphate group. A type of transferase.

Phosphorylases: Introduces a phosphate group into an organic molecule, notably glucose.

Enzyme Kinetics

Saturation Kinetics: As ↑[S] ⇒ ↑rxn rate, until a max value is reached.

Graphical Plots: *Michaelis-Menten*: Hyperbolic curve
Lineweaver-Burk: Line

K_m The [S] at which an enzyme runs at half its V_{max}.
$$K_m = \frac{K_{-1} + K_2}{K_1}$$

V_{max}: The maximum rate at which an enzyme can catalyze a reaction. This is when all enzyme active sites are saturated with substrate.

Michaelis–Menten Equation: $V_0 = V_{max} \frac{[S]}{[S]+K_m}$

Cooperative Enzymes: Display a sigmoidal curve because of the change in activity with substrate binding.

Mechanisms of Enzyme Activity

Enzymes act by stabilizing the transition state, providing a favorable microenvironment, or bonding with the substrate molecules.

Active Site: The site of catalysis.

Lock & Key Theory: The enzyme and substrate are exactly complementary and fit together like a key into a lock.

Induced Fit Theory: The enzyme and substrate undergo conformational changes to interact fully.

Cofactors: Metal cation that is required by some enzymes.

Coenzyme: Organic molecule that is required by some enzymes.

Effects of Local Conditions on Enzymes

Temp and pH: Can affect an enzyme's activity *in vivo*; changes in temperature and pH can result in denaturing of the enzyme and loss of activity do to loss of 2°, 3°, or 4° structure.

Salinity: *In vitro*, salinity can impact the action of enzymes.

Regulation of Enzymes

* See appendix for detailed information on enzyme inhibition

Feedback Inhibition: An enzyme is inhibited by high levels of a product from later in the same pathway.

Reversible Inhibition: The ability to replace the inhibitor with a compound of greater affinity or to remove it using mild laboratory treatment.

Competitive Inhibition: When the inhibitor is similar to the substrate and binds at the active site, blocking the substrate from binding. Can be overcome by adding more substrate. V_{max} is unchanged, K_m increases.

Uncompetitive Inhibition: When the inhibitor binds only with the enzyme-substrate complex. V_{max} and K_m both decrease.

Noncompetitive Inhibition: When the inhibitor binds with equal affinity to the enzyme and the enzyme-substrate complex. V_{max} decreases, K_m is unchanged.

Mixed Inhibition: When the inhibitor binds with unequal affinity to the enzyme and the enzyme-complex. V_{max} decreases, K_m is increased or decreased depending on if the inhibitor has a higher affinity for the enzyme or enzyme-substrate complex.

Irreversible Inhibition: Alters the enzyme in such a way that the active site is unavailable for a prolonged duration or permanently.

Suicide Inhibitor: A substrate analogue that binds IRREVSERIBLY to the active site via a covalent bond.

Allosteric Effecter: Binds at the allosteric site and induces a change in the conformation of the enzyme so the substrate can no longer bind to the active site. Displays cooperativity, so it does not obey Michaelis-Menten kinetics.

Positive Effectors: Exert a positive effect, ↑activity.
Negative Effectors: Exert a negative effect, ↓activity.

Homotropic Effector: An allosteric regulator that IS ALSO the substrate. Ex: O_2 is a homotropic allosteric regulator of hemoglobin.

Heterotropic Effector: An allosteric regulator molecule that is DIFFERENT from the substrate.

Phosphorylation: Covalent modification with phosphate.
Catabolism: Phosphorylated = active
Anabolism: Phosphorylated = inactive

Glycosylation: Covalent modification with carbohydrate.

Zymogens: Precursor to an enzyme. Secreted in an inactive form and are activated by cleavage.

Reaction scheme for Michaelis-Menten enzyme activity. To simplify things, we assume that almost none of the product reverts back to ES, which is true at the start of the reaction. This is why K_{-2} is omitted from the reaction scheme shown below.

$$\mathrm{E} + \mathrm{S} \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} \mathrm{ES} \xrightarrow{k_2} \mathrm{E} + \mathrm{P}$$

Cellular Functions

Structural Proteins: Compose the cytoskeleton, anchoring proteins, and much of the extracellular matrix. The most common structural proteins are *collagen, elastin, keratin, actin,* and *tubulin.* They are generally fibrous in nature.

Motor Proteins: Have one or more heads capable of force generation through a conformational change. They have catalytic activity, acting as ATPases to power mvmt. Common applications include muscle contraction, vesicle mvmt within cells, and cell motility. Examples include: *myosin*, *kinesin*, and *dynein*.

Binding Proteins: Bind a specific substrate, either to sequester it in the body or hold its concentration at steady state.

Cell Adhesion Molecules (CAM): Allow cells to bind to other cells or surfaces.

Cadherins: Calcium dependent glycoproteins that hold similar cells together.

Integrins: Have two membrane-spanning chains and permit cells to adhere to proteins in the extracellular matrix.

Selectins: Allow cells to adhere to carbohydrates on the surfaces of other cells and are most commonly used in the immune system.

Antibodies: Immunoglobulins, Ig. Used by the immune system to target a specific *antigen*, which may be a protein on the surface of a pathogen or a toxin. The variable region is responsible for antigen binding.

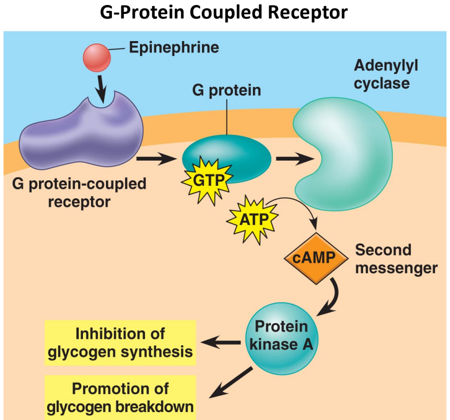
Biosignaling

Ion Channels: Can be used for regulating ion flow into or out of a cell.
Ungated Channels: Always open.
Voltage-Gated Channels: Open within a range of membrane potentials.
Ligand-Gated Channels: Open in the presence of a specific binding substance, usually a hormone or neurotransmitter.

Enzyme-Linked Receptors: Participate in cell signaling through extracellular ligand binding and initiation of 2nd messenger cascades.

G Protein-Coupled Receptors: GPCR has a membrane-bound protein called the G-Protein (α, β, γ subunits). The 1st messenger ligand initiates the 2nd messenger and the cascade response.

G-Protein Coupled Receptor



Notes: Epinephrine is a ligand 1st messenger. At the end of the GPCR process, Phosphodiesterase deactivates cAMP and GTP hydrolyzed back to GDP.

Protein Isolation

* See appendix for detailed information

Electrophoresis: Uses a gel matrix to observe the migration of proteins in responses to an electric field .

Native PAGE: Maintains the protein's shape, but results are difficult to compare because the mass / charge ratio differs for each protein.

SDS-PAGE: Denatures the proteins and masks the native charge so that comparison of size is more accurate, but functional protein cannot be recaptured from the gel.

Isoelectric Focusing: Separates proteins by their isoelectric point (pI); the protein migrates toward an electrode until it reaches a region of the gel where pH = pI of the protein.

Chromatography: Separates protein mixtures on the basis of their affinity for a stationary phase or a mobile phase.

Column Chromatography: Uses beads of a polar compound (stationary phase) with a nonpolar solvent (mobile phase).

Ion-Exchange Chromatography: Uses a charged column and a variably saline eluent.

Size-Exclusion Chromatography: Relies on porous beads. Larger molecules elute first because they are not trapped in the small pores.

Affinity Chromatography: Uses a bound receptor or ligand and an eluent with free ligand or a receptor for the protein of interest.

Protein Analysis

Structure: Primarily determined through x-ray crystallography after the protein is isolated, although NMR can also be used.

Amino Acid Sequence: Determined using the *Edman Degradation*.

Concentration: Determined colorimetrically, either by UV spectroscopy or through a color change reaction. *Bradford Assay*, *BCA Assay*, and *Lowry Reagent Assay* each test for protein and have different advantages and disadvantages. The *Bradford Protein Assay* is most common. It uses a color change from brown-green → blue.

Beer-Lambert Law: $\text{Absorbance} = \varepsilon C l$

ε = extinction coefficient C = concentration
l = path length in cm

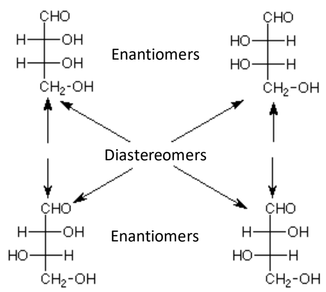
Carbohydrate Classification

Nomenclature: 3 carbons: Trioses, 4 carbons: Tetroses, etc. Some common names: glucose, fructose & galactose.

D and L: Based on the D- and L- forms of glyceraldehyde. Look at the highest numbered chiral carbon, -OH on right = D-sugars, -OH on left = L-sugars. Nearly all carbohydrates in nature are in the D-configuration. Compared to amino acids, which are found in the L-confiduration.

Enantiomers: Stereoisomers that are non-superimposable mirror images of each other. D and L forms of the same sugar.

Diastereomers: Any stereoisomer that is not an enantiomer.
Epimers: Subtype of diastereomers that differ at exactly one chiral carbon.
Anomers: A subtype of epimers that differ at the anomeric carbon.



Monosaccharides

Monosaccharides: Single carbohydrate units, with glucose as the most commonly observed monomer. Can undergo oxidation/reduction, esterification, and glycoside formation

Aldoses: Oxidized into aldonic acids, reduced to alditols

Sugar as Reducing Agent: Sugars that can be oxidized are reducing agents themselves. Can be detected by reacting with *Tollen's* or *Benedict's* reagents

Deoxy Sugars: -H replaces –OH

Esterification: Sugars react with carboxylic acids and their derivatives, forming esters

Phosphorylation: A phosphate ester is formed by transferring a phosphate group from ATP onto the sugar. This rxn is similar to esterification

Glycoside Formation: The basis for building complex carbohydrates and requires the anomeric carbon to link to another sugar

Cyclic Sugar Molecules

Cyclization: Describes the ring formation of carbohydrates from their straight-chain forms.

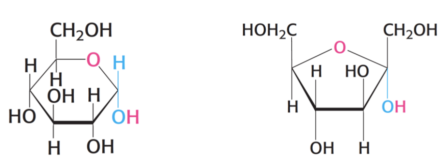
Anomeric Carbon: The new chiral center formed in ring closure; it was the carbon containing the carbonyl in the straight-chain form.

α-anomers: Have the –OH on the anomeric carbon *trans* to the free $–CH_2OH$ group.

β-anomers: Have the –OH on the anomeric carbon *cis* to the free $–CH_2OH$ group.

Haworth Projections: Represent 3D structure of a monosaccharide.

Mutarotation: Spontaneous shift from one anomeric form to another with the straight-chain form as an intermediate.



β-D-Glucose **α-D-Fructose**

Examples of Cyclic Sugar Molecules

Complex Carbohydrates

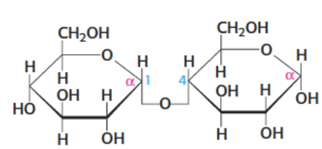
Disaccharides: Form as a result of glycosidic bonding between two monosaccharide subunits. Common examples: sucrose, lactose, maltose.

Polysaccharides: Formed by repeated monosaccharide or polysaccharide glycosidic bonding.

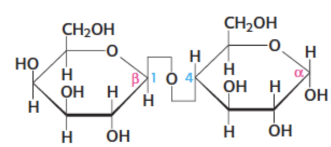
Cellulose: The main structural component for plant cell walls. Main source of fiber in human diet.

Starches: Main energy storage form for plants.
Amylose: Unbranched
Amylopectin: Branched

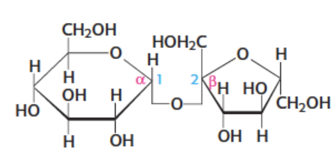
Maltose:
(glucose + glucose with alpha glycosidic bond)



Lactose:
(galactose + glucose with beta glycosidic bond)



Sucrose:
(glucose + fructose with alpha glycosidic bond)



Structural Lipids

Characteristics: Lipids are insoluble in water and soluble in nonpolar organic solvents.

Phospholipids: Amphipathic and form the bilayer of membranes. Contain a hydrophilic (polar) head and hydrophobic (nonpolar) tails. The head is attached by a *phosphodiester linkage*, and determines the function of the phospholipid.

Saturation: Saturation of the fatty acid tails determines the fluidity of the membrane. Saturated fatty acid = less fluid.

Glycerophospholipids: Phospholipids that contain a glycerol backbone.

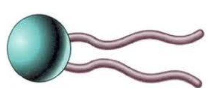
Sphingolopids: Contain a *sphingosine* backbone. Many (but not all) sphingolipid are also phospholipids with a phosphodiester bond. These are *sphingophospholipids*.

Sphingomyelins: The major class of *sphingophospholipids* and contain a phosphatidylcholine or phohsphatidylethanolamine head group. Part of the myelin sheath.

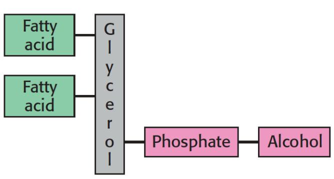
Glycosphingolipids: Attached to sugar moieties instead of a phosphate group. *Cerebrosides* have 1 sugar connected to sphingosine. *Globosides* have 2 or more.

Gangliosides: Contain oligosaccharides with at least 1 terminal *N-acetylneuraminic* acid (NANA).

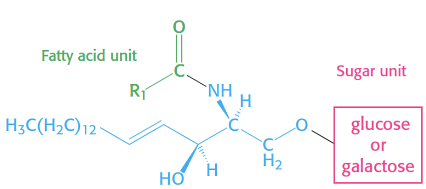
Waxes: Contain long-chain fatty acids esterified to long-chain alcohols. Used as protection against evaporation and parasites in plants and animals.



Phospholipid
Polar head, nonpolar tails



Schematic of a phospholipid. May use glycerol or sphingosine for the backbone



Cerebroside: A type of glycolipid. Any lipid linked to a sugar is a **glycolipid**

Signaling Lipids

Terpenes: Odiferous steroid precursors made from *isoprene*. One terpene unit (monoterpene) contains 2 isoprene units.

Terpenoids: Derived from terpenes via oxygenation or backbone rearrangement. Odorous characteristics.

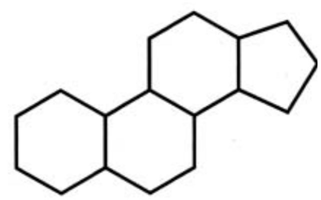
Steroids: Contain 3 cyclohexane rings and 1 cyclopentane.

Steroid Hormones: Have high-affinity receptors, work at low concentrations, and affect gene expression and metabolism.

Cholesterol: A steroid important to membrane fluidity and stability; and serves as a precursor to many other molecules.

Prostaglandins: Are autocrine and paracrine signaling molecules that regulate cAMP levels. Affect smooth muscle contraction, body temp, sleep-wake cycle, fever, pain.

Vitamins A, D, E, & K: Fat soluble vitamins
Vitamin A: Carotene, vision.
Vitamin D: Cholecalciferol, bone formation.
Vitamin E: Tocopherols, antioxidants.
Vitamin K: Phylloquinone & menaquinones. Forms prothrombin, a clotting factor.



Steroid

Energy Storage

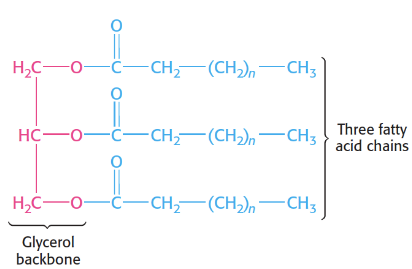
Triacylglycerols: Storage form of fatty acids. Contain 1 glycerol attached to 3 fatty acids by ester bonds. Very hydrophobic so do not carry additional water weight.

Adipocytes: Animal cells used specifically for storage of large triacylglycerol deposits.

Free Fatty Acids: Unesterified fatty acids that travel in the bloodstream. Salts of free fatty acids are soaps.

Saponification: The ester hydrolysis of triacylglycerols using a strong base like sodium or KOH.

Micelle: Can dissolve a lipid-soluble molecule in its fatty acid core, and washes away with water because of its shell of carboxylate head groups.



Triacylglycerol

Nucleic Acid Structure

Nucleic acids are polymers of nucleotides. Types include Deoxyribonucleic Acid (DNA) and Ribonucleic Acid (RNA).

1° Structure: Linear sequence of nucleotides.

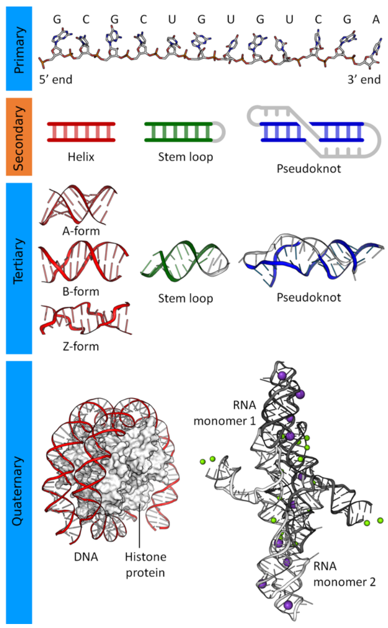
2° Structure: Interactions between bases within the same molecule. In DNA, the bases are held together by hydrogen bonds. 2° structure is responsible for the shape of nucleic acid.

RNA 2° structure has 4 basic elements: Loops, helices, bulges, and junctions. Loops include stem-loops (hairpin loops), tetraloops, and psuedoknots.

3° Structure: The location of the atoms in 3D space.

4° Structure: Interactions of nucleic acids with other molecules. Example: Chromatin interacting with histones.

Nucleic Acid Structure: Includes DNA structure and RNA structure.



DNA Structure

* See appendix for full diagram

DNA: Deoxyribonucleic Acid. A macromolecule that stores genetic information in all living organisms.

Nucleoside: 5-carbon sugar + nitrogenous base. NO PHOSPHATE groups.

Nucleotide: A nucleoside with 1 to 3 phosphate groups added. Nucleotides in DNA contain *deoxyribose*; in RNA they contain *ribose*. Adenine (A), Thymine (T), Guanine (G), Cytosine (C), Uracil (U). In RNA, U replaces T, so A pairs with U via 2 h-bonds.

Watson-Crick Model: Backbone of alternating sugar/phosphate groups. Always read 5' → 3'. Two strands with antiparallel polarity wound into a double helix.

Nitrogenous Bases: *Purines*: Adenine and Guanine. Made of two rings.
Pyrimidines: Cytosine, Thymine, Uracil. Made of one ring.

Chargaff's Rules: # of Purines = # of Pyrimidines. A = T; C = G

B-DNA vs Z-DNA: Most DNA is B-DNA, forming a right-handed helix. Low concentrations of Z-DNA, with a zigzag shape, may be seen with high GC-content or high salt concentration.

Denature / Reannealed: *Denatured*: Pulled apart
Reannealed: Brought back together

DNA Replication

* See appendix for full diagram

DNA Replication: The process of producing an identical replica of a DNA molecule. Occurs in the S (synthesis) phase of the cell cycle.

DNA Repair

Oncogenes: Develop from mutations of *proto-oncogenes*, and promote cell cycling. May lead to cancer.
Oncogenes = stepping on gas pedal

Tumor Suppressor Genes: Code for proteins that reduce cell cycling or promote DNA repair.
Mutated Tumor Suppressor genes = cutting the brakes

Proofreading: DNA Polymerase proofreads its work and excises incorrectly matched bases. The daughter strand is identified by its lack of methylation and corrected accordingly.

Mismatch Repair: Occurs during G2 phase using the genes MSH2 and MLH1.

Nucleotide Excision Repair: Fixes helix-deforming lesions of DNA such as Thymine dimers. A cut-and-patch process. Excision Endonuclease.

Base Excision Repair: Fixes nondeforming lesions of the DNA helix such as cytosine deamination by removing the base, leaving *apurinic/apyrimidinic* (AP) site. *AP Endonuclease* then removes the damaged sequence, which can be filled in with the correct bases.

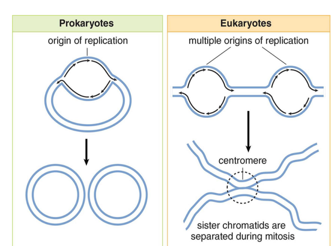
Eukaryotic Chromosome Organization

46 chromosomes in human cells. DNA is wound around **histone proteins** to form **nucleosomes**, which may be stabilized by another histone protein. As a whole, DNA and its associated histones make up **chromatin** in the nucleus.

Chromatin: *Heterochromatin*: Dark, dense, and silent
Euchromatin: Light, uncondensed, and expressed

Telomeres: Ends of chromosomes. Contain high GC-content to prevent unraveling of the DNA. During replication, telomeres are shortened, but this can be partially reversed by telomerase.

Centromeres: Located in the middle of chromosomes and hold sister chromatids together until they are separated during anaphase in mitosis. High GC-content to maintain a strong bond between chromatids.



Acrocentric Chromosome: When the centromere is located near one end of the chromosome and not in the middle.

Recombinant DNA and Biotechnology

Recombinant DNA: DNA composed of nucleotides from 2 different sources

Hybridization: The joining of complementary base pair sequences.

Polymerase Chain Reaction (PCR): See appendix for details

Electrophoresis: See appendix for details

The Genetic Code

Central Dogma: States that DNA is transcribed to RNA, which is translated to protein.

Degenerate Code: Allows for multiple codons to encode for the same amino acid.

Start / Stop Codons: *Initiation (start)*: AUG
Termination (stop): UAA, UGA, UAG

Wobble: 3rd base in the codon. Allows for mutations to occur without effects in the protein. __ __ ?
Wobble base pairings are less stable.

Point Mutations: *Silent*: Mutations with no effect on protein synthesis. Usually found in the 3rd base of a codon.
Nonsense (truncation): Mutations that produce a premature STOP codon.
Missense: Mutations that produce a codon that codes for a DIFFERENT amino acid.

Frameshift Mutations: Result from a nucleotide addition or deletion, and change the reading frame of subsequent codons.

RNA: Similar to DNA except: Ribose sugar instead of deoxyribose. Uracil instead of thymine. Single stranded instead of double stranded.

3 Types of RNA: *Messenger RNA (mRNA)*: Transcribed from DNA in the nucleus, it travels into the cytoplasm for translation.
Transfer RNA (tRNA): Brings in amino acids and recognizes the codon on the mRNA using its anticodon.
Ribosomal RNA (rRNA): Makes up the ribosome and is enzymatically active.

Translation

* See appendix for full diagram

tRNA: Translates the codon into the correct amino acid.

Ribosomes: Factories where translation (protein synthesis) occurs.
Eukaryotes: 80s ribosomes
Prokaryotes: 70s ribosomes

Initiation: Prokaryotes: When the 30S ribosome attaches to the *Shine-Delgarno Sequence* and scans for a start codon; it lays down N-formylmethionine in the P site of the ribosome.

Eukaryotes: When the 40S ribosome attaches to the 5′ cap and scans for a start codon; it lays down methionine in the P site of the ribosome.

Elongation: The addition of a new aminoacyl-tRNA into the A site of the ribosome and transfer of the growing polypeptide chain form the tRNA in the P site to the tRNA in the A site. The now uncharged tRNA pauses in the E site before exiting the ribosome.

Termination: Occurs when the codon in the A site is a stop codon; *release factor* places a water molecule on the polypeptide chain and thus releases the protein.

Posttranslational Modifications: Folding by *chaperones*. Formation of quaternary structure. Cleavage of proteins or signal sequences. Covalent addition of other biomolecules (phosphorylation, carboxylation, glycosylation, prenylation).

DNA Ligase: Fuse the DNA strands together to create one strand.

Transcription

* See appendix for full diagram

Helicase: Unwinds the DNA double helix.

RNA Polymerase II: Binds to the TATA box within the promoter region of the gene (25 base pairs upstream from first transcribed base).

hnRNA: Collective term for the unprocessed mRNA in nucleus.

Posttranscriptional Modification: The process in eukaryotic cells where primary transcript RNA is converted into mature RNA. Introns cut out.

Exons: Exit the nucleus and form mRNA.
Introns: Spliced out so they stay in nucleus. Introns also enable alternative splicing.

Alternative splicing: Usually introns are cut away and exons remain, but alternative splicing might change that. A certain exon may be cut out, or an intron may stay. This allows for the RNA segment to code for more than one gene.

5′ Cap and Poly-A tail are added to the mRNA. The cap and tail stabilize mRNA for translation.

Prokayotic cells can increase the variability of gene products from one transcript though *polycistronic genes*, starting transcription in different sites within the gene leads to different gene products.

Control of Gene Expression in Prokaryotes

Jacob-Monod Model: Explains how *Operons* work.

Operons: Inducible or repressible clusters of genes transcribed as a single mRNA.

Inducible Systems: Bonded to a *repressor* under normal conditions; they can be turned on by an *inducer* pulling the repressor form the *operator site*. Example: *Lac* operon.

Repressible Systems: Transcribed under normal conditions; they can be turned off by a corepressor coupling with the repressor and the binding of this complex to the operator site. Example: *Trp* operon

Control of Gene Expression in Eukaryotes

Transcription Factors: Search for promoter and enhancer regions in the DNA, then bind to the DNA and recruit RNA polymerase.

Promotors: Are within 25 base pairs of the transcription start site.

Enhancers: Are more than 25 base pairs away from the transcription start site.

Modification of chromatin structure affects the ability of transcriptional enzymes to access the DNA through *histone acetylation* (increases accessibility) or *DNA methylation* (decreases accessibility).

Fluid Mosaic Model

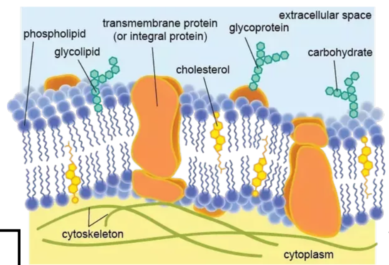
Accounts for the presence of lipids, protein, and carbohydrates in a dynamic, semisolid plasma membrane that surrounds cells

Phospholipid Bilayer: Each phospholipid has a hydrophilic head and hydrophobic tail. They are arranged so the heads are facing outward and the tails make up the inside of the membrane. Proteins are embedded in the bilayer

Lipid Rafts: Lipids move freely in the plane of the membrane and can assemble into *lipid rafts*

Flippases: Specific membrane proteins that maintain the bidirectional transport of lipids between the layers of the phospholipid bilayer in cells

Proteins & Carbohydrates: May also move within the membrane, but are slowed by their relatively large size



Membrane Components

Lipids: The primary membrane component, both by mass and mole fraction

Triacylglycerols & Fatty Acids: Act as phospholipid precursors and are found in low levels in the membrane

Glycerophospholipids: Replace one fatty acid with a phosphate group, which is often linked to other hydrophilic groups

Cholesterol: Is present in large amounts and contributes to membrane fluidity and stability
↓temp = INCREASE fluidity
↑temp = DECREASE fluidity

Waxes: Present in very small amounts, if at all; they are most prevalent in plants and function in waterproofing and defense

Transmembrane Proteins: A type of integral protein that spans the entire membrane. They are often glycoproteins.

Embedded Proteins: Are most likely part of a catalytic complex or involved in cellular communication

Membrane-Associated Proteins: May act as recognition molecules or enzymes

Carbohydrates: Can form a protective *glycoprotein coat* and also function in cell recognition

Ligands: Extracellular ligands can bind to membrane receptors, which function as channels or enzymes in second messenger pathways

Gap Junctions: Allow for rapid exchange of ions and other small molecules between adjacent cells

Tight Junctions: Prevent solutes from leaking into the space between cells via a *paracellular* route, but do not provide intercellular transport

Desmosomes & Hemidesmosomes: *Desmosomes* bind adjacent cells by anchoring to their cytoskeletons. *Hemidesmosomes* are similar, but their main function is to attach epithelial cells to underlying structures

Membrane Transport

Concentration Gradients: All transmembrane movement is based on concentration gradients. The gradient tells us whether the process is passive or active

Osmotic Pressure: A colligative property. It is the pressure applied to a pure solvent to prevent osmosis and is used to express the concentration of the solution. It can be conceptualized as a "sucking" pressure in which a solution is drawing water in, proportional to its concentration

$$\pi = i\,M\,\mathrm{R}\,T$$

Passive Transport: Does not require energy because the molecule is moving down its concentration gradient.

Simple Diffusion: A form of passive transport. Small, nonpolar molecules passively move form an area of high concentration to an area of low concentration until equilibrium is achieved

Osmosis: A form of passive transport. Describes the diffusion of water across a selectively permeable membrane

Facilitated Diffusion: A form of passive transport. Uses transport proteins to move impermeable solutes across the cell membrane

Active Transport: Requires energy in the form of ATP or an existing favorable ion gradient

Primary Active Transport: Uses ATP or another energy molecule to directly power the transport of molecules across a membrane

Secondary Active Transport: "Coupled transport". Harnesses the energy released by one particle going *down* its electrochemical gradient to drive a different particle *up* its gradient.
Symport: Both particles flow the same direction
Antiport: The particles flow in opposite directions

Endocytosis & Exocytosis: Methods of engulfing material into the cells or releasing material out of the cell.
Pinocytosis: Ingestion of liquids via vesicles
Phagocytosis: Ingestion of larger solid materials

Specialized Membranes

Membrane Potential: (V_m) Maintained by the Na^+/K^+ pump and leak channels. Resting potential of most cells is between -40 and -80 mV

Nernst Equation: The electrical potential created by one ion can be calculated using the Nernst Equation.

$$E = \frac{\mathrm{R}\,T}{z\,\mathrm{F}}\ln\left(\frac{[\text{ion}]_{\text{outside}}}{[\text{ion}]_{\text{inside}}}\right) = \frac{61.5}{z}\log\left(\frac{[\text{ion}]_{\text{outside}}}{[\text{ion}]_{\text{inside}}}\right)$$

Goldman-Hodgkin-Katz Voltage Eq: Resting potential of a membrane at physiological temp can be calculated using the *Goldman-Hodgkin-Katz Voltage Equation*, which is derived from the Nernst equation.

$$V_m = 61.5\log\left(\frac{P_{Na^+}\times[Na^+]_{\text{outside}} + P_{K^+}\times[K^+]_{\text{outside}} + P_{Cl^-}\times[Cl^-]_{\text{inside}}}{P_{Na^+}\times[Na^+]_{\text{inside}} + P_{K^+}\times[K^+]_{\text{inside}} + P_{Cl^-}\times[Cl^-]_{\text{outside}}}\right)$$

Mitochondrial Membranes: The *outer mitochondrial membrane* is highly permeable to metabolic molecules and small proteins.
The *inner mitochondrial membrane* surrounds the mitochondrial matrix, where the citric acid cycle produces electrons used in the ETC. The inner mito membrane does not contain cholesterol.

Glucose Transport

GLUT 2: Found in liver (for glucose storage) and pancreatic β-islet cells (as part of the glucose sensor). Has ↑K_m

GLUT 4: Found in adipose tissue and muscle. Stimulated by insulin. Has ↓K_m

Glycolysis

* See appendix for full diagram

Glucose + $2NAD^+$ + 2ADP + 2P → 2Pyruvate + 2ATP + 2NADH + $2H^+$

Important enzymes:

Glucokinase: (irreversible) Converts *glucose* to *glucose 6-phosphate* in the pancreatic β-islet cells as part of the glucose sensor.

Hexokinase: (irreversible) Converts *glucose* to *glucose 6-phosphate* in in peripheral tissues. Inhibited by its product G 6-P.

Phosphofructokinase-1: (irreversible) PFK-1. Phosphorylates *fructose 6-phospate* to *fructose 1,6-bisphosphate* in the **rate-limiting step**. Activated by AMP and *fructose 2,6-bisphosphate*. Inhibited by ATP and citrate.

Phosphofructokinase-2: PFK-2. Produces *fructose 2,6-bisphosphate* that activates PFK-1. It is activated by insulin; inhibited by glucagon.

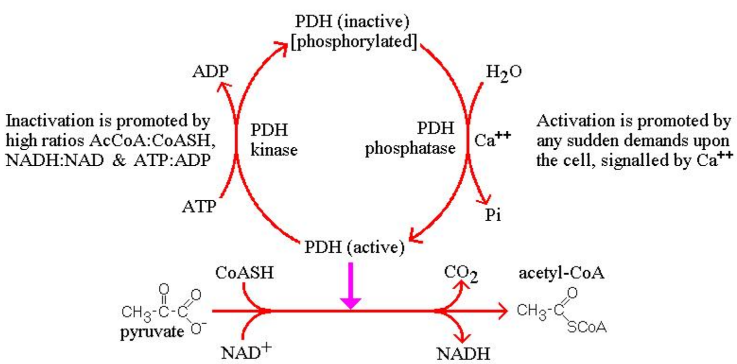
Glyceraldehyde-3-phosphate dehydrogenase: Produces NADH, which can feed into the electron transport chain.

Pyruvate Kinase: (irreversible) Perform substrate-level phosphorylation, placing an inorganic phosphate onto ADP to form ATP.

The **NADH** produced in glycolysis is oxidized by the mitochondrial electron transport chain when O_2 is present. If O_2 or mitochondria are absent, the NADH produced in glycolysis is oxidized by cytoplasmic *lactate dehydrogenase*. Examples include RBCs and skeletal muscle.

Pyruvate Dehydrogenase

A complex of enzymes that convert pyruvate to Acetyl-CoA right before the citric acid cycle. It is stimulated by insulin and inhibited by acetyl-CoA.



Glycogenesis and Glycogenolysis

* See appendix for full diagram

Glycogenesis: The production of glycogen using two main enzymes: *Glycogen Synthase*, and *Branching Enzyme*. Occurs in the liver and muscle cells. Glycogen is stored in liver.

Glycogen Synthase: Creates α-1,4 glycosidic bonds between glucose.

Branching Enzyme: Creates branches with α-1,6 glycosidic bonds.

Glycogenolysis: The breakdown of glycogen using two main enzymes: *Glycogen Phosphorylase*, and *Debranching Enzyme*.

Glycogen Phosphorylase: Removes single glucose 1-phosphate molecules by breaking α-1,4 glycosidic bonds. In the liver, it is activated by glucagon to prevent low blood sugar. In exercising skeletal muscle, it is activated by epinephrine and AMP to provide glucose for the muscle itself.

Debranching Enzyme: Moves a block of oligoglucose from the branch and connects it to the chain using an α-1,4 glycosidic bond. It also removes the branchpoint, which is connected via an α-1,6 glycosidic bond, releasing a free glucose molecule.

Gluconeogenesis

* See appendix for full diagram

Occurs in both the cytoplasm and mitochondria, predominantly in the liver with a small contribution from the kidneys. Most gluconeogenesis is simply the reverse of glycolysis, using the same enzymes. The 3 irreversible steps of glycolysis must be bypassed by different enzymes.

Pyruvate Carboxylase: Converts pyruvate to oxaloacetate, which is converted to PEP by PEPCK. Together, these two enzymes bypass pyruvate kinase. Pyruvate carboxylase is activated by Acetyl-CoA. PEPCK is activated by glucagon and cortisol.

Fructose-1,6-bisphosphatase: Converts fructose 1,6-bisphosphate to fructose 6-phosphate, bypassing phosphofructokinase-1. This is the rate-limiting step of gluconeogenesis. It is activated by ATP and glucagon. Inhibited by AMP and insulin.

The Pentose Phosphate Pathway

Also known as the *hexose monophosphate (HMP) shunt*, it occurs in the cytoplasm of most cells. Glucose 6-Phosphate enters the pathway and the products are NADPH, sugars for biosynthesis, and glycolysis intermediates.

Rate-Limiting Enzyme: Glucose-6-phosphate dehydrogenase (G6PD), which is activated by $NADP^+$ and insulin and inhibited by NADPH.

Other Monosaccharides

Galactose: Comes from *lactose* in milk. Trapped in the cell by *galactokinase*, and converted to 1-phosphate via *galactose-1-phosphate uridyltransferase* and an epimerase.

Fructose: Comes from honey, fruit, and sucrose. Trapped in the cell by *fructokinase*, then cleaved by *aldolase B* to form glyceraldehyde and DHAP.

Acetyl-CoA

Acetyl-CoA: Contains a high-energy thioester bond that can be used to drive other reactions when hydrolysis occurs.

Acetyl-CoA Formation: Can be formed from fatty acids, which enter the mitochondria using carriers. The fatty acid couples with CoA in the cytosol to form fatty *acyl-CoA*, which moves to the intermembrane space. The acyl (fatty acid) group is transferred to *carnitine* to form *acyl-carnitine*, which crosses the inner membrane. The acyl group is transferred to a mitochondrial CoA to re-form fatty acyl-CoA, which can undergo β-oxidation to form acetyl-CoA.

Can also be formed from the carbon skeletons of ketogenic amino acids, ketone bodies, and alcohol.

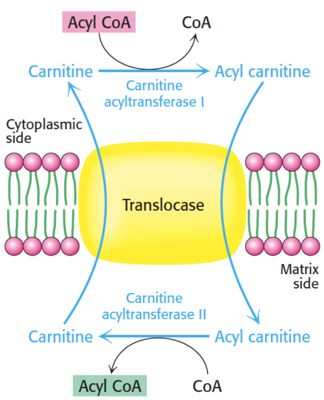
Pyruvate Dehydrogenase (PDH): Oxidizes pyruvate, creating CO_2; it requires thiamine pyrophosphate (vitamin B_1, TPP) and Mg^{2+}.

Dihydrolipoyl Transacetylase: Oxidizes the remaining two-carbon molecule using lipoic acid, and transfers the resulting acetyl group to CoA, forming acetyl-CoA.

Dihydrolipoyl Dehydrogenase: Uses FAD to reoxidize lipoic acid, forming $FADH_2$. This $FADH_2$ can later transfer electrons to NAD^+, forming NADH that can feed into the electron transport chain.

Pyruvate Dehydrogenase Kinase: Phosphorylates PDH when ATP or acetyl-CoA levels are high, turning it off.

Pyruvate Dehydrogenase Phosphatase: Dephosphorylates PDH when ADP levels are high, turning it on.



Acyl Carnitine Translocase: Mechanism for Acyl CoA to enter the mitochondrial matrix. The mitochondrial matrix is where Acyl CoA can undergo β-oxidation to form Acetyl-CoA.

Oxidative Phosphorylation

Proton-Motive Force: The electrochemical gradient generated by the electron transport chain across the inner mitochondrial membrane. The intermembrane space has a higher concentration of protons than the matrix; this gradient stores energy, which can be used to form ATP via *chemiosmotic coupling*.

ATP Synthase: The enzyme responsible for generating ATP from ADP and P_i
F_0 Portion: An ion channel, allowing H^+ to flow down the gradient from the intermembrane space to the matrix
F_1 Portion: Uses the energy released by the gradient to phosphorylate ADP into ATP.

Reactions of the Citric Acid Cycle

* See appendix for full diagram

Citric Acid Cycle: Takes place in the mitochondrial matrix. Its main purpose is to oxidize carbons in intermediates to CO_2 and generate high-energy electron carriers (NADH and $FADH_2$) and GTP.

Citrate Synthase: Couples acetyl-CoA to oxaloacetate and then hydrolyzes the resulting product, forming *citrate* and CoA-SH. This enzyme is regulated by negative feedback from ATP, NADH, succinyl-CoA and citrate.

Aconitase: Isomerizes citrate to *isocitrate*.

Isocitrate Dehydrogenase: Oxidizes and decarboxylates isocitrate to form *α-ketoglutarate*. This enzyme generates the first CO_2 and first NADH of the cycle. As the rate-limiting step of the citric acid cycle, it is heavily regulated: ATP and NADH are inhibitors; ADP and NAD^+ are activators.

α-Ketoglutarate Dehydrogenase Complex: Acts similarly to PDH complex, metabolizing α-ketoglutarate to form *succinyl-CoA*. This enzyme generates the second CO_2 and second NADH of the cycle. It is inhibited by ATP, NADH, and succinyl-CoA; it is activated by ADP and Ca^{2+}.

Succinyl-CoA Synthesis: Hydrolyzes the thioester bond in succinyl-CoA to form *succinate* and *CoA-SH*. This enzyme generates the one GTP generated in the cycle.

Succinate Dehydrogenase: Oxidizes succinate to form *fumarate*. This flavoprotein is anchored to the inner mitochondrial membrane because it requires FAD, which is reduced to form the one $FADH_2$ generated in the cycle.

Fumarase: Hydrolyzes the alkene bond of fumarate, forming *malate*.

Malate Dehydrogenase: Oxidizes malate to *oxaloacetate*. This enzyme generates the third and final NADH of the cycle.

The Electron Transport Chain

* See appendix for full diagram

Electron Transport Chain: Takes place on the matrix-facing surface of the inner mitochondrial membrane. NADH donates electrons to the chain, which are passed from one complex to the next. As the ETC progresses, reduction potentials increase until oxygen, which has the highest reduction potential, receives the electrons.

Complex I: NADH-CoQ Oxidoreductase. Uses an iron-sulfur cluster to transfer electrons from NADH to flavin mononucleotide (FMN), and then to CoQ, forming $CoQH_2$. 4 H^+ ions are translocated by Complex I.

Complex II: Succinate-CoQ Oxidoreductase. Uses an iron-sulfur cluster to transfer electrons from succinate to FAD, and then to CoQ, forming $CoQH_2$. No H^+ pumping occurs at complex II.

Complex III: $CoQH_2$-Cytochrome *C* Oxidoreductase. Uses an iron-sulfur cluster to transfer elcetrons form $CoQH_2$ to heme, forming cytochrome *C* as part of the Q cycle. 4 H^+ ions are translocated by complex III.

Complex IV: Cytochrome *C* Oxidase. Uses cytochromes and Cu^{2+} to transfer electrons in the form of hydride ions (H^-) from cytochrome *c* to oxygen, forming water. 2 H^+ ions are translocated by complex IV.

NADH cannot cross the inner mitochondrial membrane. Therefore, one of two available shuttle mechanisms to transfer electrons in the mitochondrial matrix must be used.

Glycerol 3-Phosphate Shuttle: Electrons are transferred from NADH to DHAP, forming glycerol 3-phosphate. These electrons can then be transferred to mitochondrial FAD, forming $FADH_2$.

Malate-Aspartate: Electrons are transferred from NADH to oxaloacetate, forming malate. Malate can then cross the inner mitochondrial membrane and transfer the electron to mitochondrial NAD^+, forming NADH.

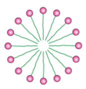
Lipid Digestion and Absorption

Mechanical Digestion: Mechanical digestion of lipids occurs primarily in the mouth and stomach.

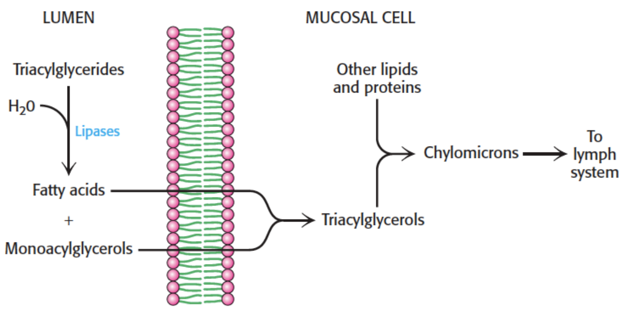
Chemical Digestion: Chemical digestion of lipids occurs in the small intestine and is facilitated by *bile*, *pancreatic lipase*, *colipase*, and *cholesterol esterase*.

Emulsification: Upon entry into the duodenum, emulsification occurs, which is the mixing of two normally immiscible liquids; in this case, fat and water. (A common example of an emulsion is oil-and-vinegar salad dressing). This increases the surface area of the lipid, which permits greater enzymatic interaction and processing. Emulsification is aided by bile salts.

Micelles: Water-soluble spheres with a lipid-soluble interior. Digested lipids may form micelles to be carried to the intestinal epithelium where they are absorbed across the plasma membrane.



Short vs. Long Chain Fatty Acids: *Short-chain fatty acids* are absorbed across the intestine into the blood. *Long-chain fatty acids* are absorbed as micelles and assembled into **chylomicrons** for release into the lymphatic system.



Lipid Mobilization and Transport

Lipid Mobilization: Lipids are mobilized from adipocytes by *hormone-sensitive lipase*. Lipids are mobilized from lipoproteins by *lipoprotein lipase*.

Chylomicrons: Transport dietary triacylglycerols, cholesterol, & cholesteryl esters from intestine to tissues. Uses the lymphatic system.

Lipoproteins: The transport mechanism for lipids.
Very-low-density: Liver → tissues.
Intermediate-density: Transition particle between lipoproteins.
Low-density: Bad. Moves cholesterol → tissues.
High-density: Good. Moves cholesterol → liver, exits body.

Apoproteins: Form the protein component of lipoproteins. They are receptor molecules that control interactions between lipoproteins.

Cholesterol Metabolism

Cholesterol may be obtained through dietary sources or through de novo synthesis in the liver

HMG-CoA Reductase: Synthesizes *mevalonate*. This is the rate limiting step of cholesterol synthesis

LCAT: Catalyzes the formation of cholesteryl esters for transport with HDL

CETP: Catalyzes the transition of IDL to LDL by transferring cholesteryl esters from HDL

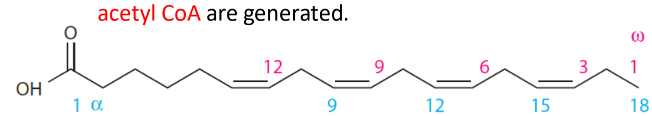
Fatty Acids and Triacylglycerols

Fatty Acids: Carboxylic acids with a long chain
Saturated: No double bonds
Unsaturated: One or more double bonds

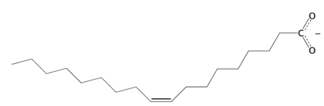
Fatty Acid Synthesis: Synthesized in cytoplasm from acetyl-CoA transported out of the mitochondria. Five steps: Activation, bond formation, reduction, dehydration, and a second reduction.

Arachidonate: Precursor to eicosanoid signaling molecules: prostaglandins, prostacyclins, & thromboxanes. Also precursor to leukotrienes.

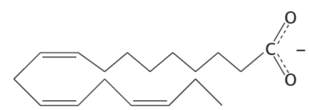
Fatty Acid Oxidation: Oxidation occurs in the mitochondria following transport by the *carnitine shuttle*. **β-oxidation** uses cycles of oxidation, hydration, oxidation, and thiolysis cleavage. The fatty acid chain is shortened by two carbon atoms. $FADH_2$, NADH, and acetyl CoA are generated.



The carboxylic acid is the α end. The ω carbon counting starts on the other end.



***Cis*-Oleate, a cis-Δ^9 fatty acid**
The cis bond prevents tight packing, which lowers the melting point.



α-Linolenate, an Omega-3 Fatty Acid
(3rd carbon from the ω end)

Ketone Bodies

Ketogenesis: Ketone bodies form via **ketogenesis** due to excess acetyl-CoA in the liver during a prolonged starvation state

Ketolysis: Regenerates acetyl-CoA for use as an energy source in peripheral tissues

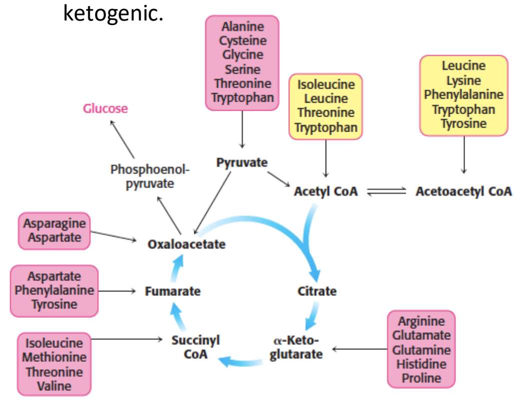
Energy Source: The brain can derive up to 2/3 of its energy from ketone bodies during prolonged starvation

Protein Catabolism

Protein digestion occurs primarily in the small intestine. Catabolism of cellular proteins occurs only under conditions of starvation. Amino acids released from proteins usually lose their amino group through deamination. The remaining carbon skeleton can be used for energy.

Glucogenic Amino Acids: Can be converted into glucose through gluconeogenesis. All but leucine and lysine.

Ketogenic Amino Acids: Can be converted into acetyl-CoA and ketone bodies. Leucine and lysine are the only amino acids that are solely ketogenic.



Fates of the amino acid carbon skeleton following protein catabolism

Thermodynamics and Bioenergetics

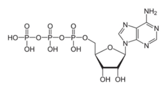
Open System: Matter & energy can be exchanged with the environment

Closed System: Only energy can be exchanged with the environment. No work is performed because pressure and volume remain constant. $\Delta\text{enthalpy} = \Delta\text{internal energy} = \text{heat exchange}$

Entropy: A measure of energy dispersion in a system

Change in Free Energy: *Standard Free Energy*, $\Delta G°$: The energy change that occurs at 1 M concentration, 1 atm, and 25°C.
Modified Standard State, $\Delta G°'$: Indicates physiological conditions. $[H^+] = 10^{-7} M$, so pH is 7.

The Role of ATP



ATP structure

ATP is a mid-level energy molecule. It contains high-energy phosphate bonds that are stabilized upon hydrolysis by resonance, ionization, and loss of charge repulsion.

Energy Source: ATP provides energy through *hydrolysis* and *coupling* to energetically unfavorable reactions. $\text{ATP} = 30\ \frac{\text{kJ}}{\text{mol}}$

Phosphoryl Group Transfers: ATP can donate a phosphate group to other molecules. For example, in Glycolysis, it donates a Phosphate group to glucose to form glucose 6-phosphate

Biological Oxidation and Reduction

Biological oxidation and reduction reactions can be broken down into component half-reactions. Half-reactions provide useful information about stoichiometry and thermodynamics

High Energy Electron Carriers: May be soluble or membrane-bound. Includes NADH, NADPH, $FADH_2$, ubiquinone, cytochromes, and glutathione.

Flovoproteins: A subclass of electron carriers that are derived from riboflavin (vitamin B_2). Examples: FAD and FMN

Metabolic States

Equilibrium: Equilibrium is an undesirable state for most biochemical reactions because organisms need to harness free energy to survive.

Postprandial State: Well-fed, absorptive. ↑Insulin. Anabolism prevails.

Postabsorptive State: Fasting. ↓Insulin. ↑glucagon and catecholamine. Transition to catabolism.

Prolonged Fasting: Starvation. ↑↑glucagon and catecholamine. Most tissues rely on fatty acids. 2/3 of brain activity can be derived from ketone bodies.

Integrative Metabolism

Calorimetry: Measures metabolic rates

Respiratory Quotient: RQ. Estimates the composition of fuel that is actively consumed by the body. $\text{RQ} = \frac{CO_2 \text{ produced}}{O_2 \text{ consumed}}$

Regulatory Hormones: *Ghrelin*: ↑appetite. (sight, sound, taste, smell of food)
Orexin: ↑appetite.
Leptin: ↓appetite by suppressing orexin production

Body Mass Index: $\text{BMI} = \frac{\text{mass}}{\text{height}^2}$

Hormonal Regulation of Metabolism

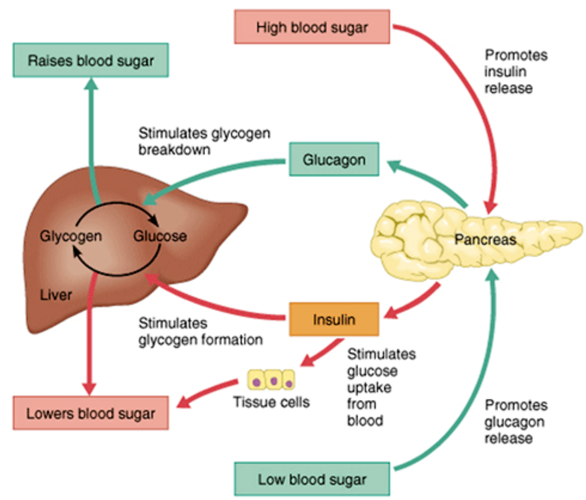
Insulin: Secreted by pancreatic β-cells, regulated by glucose
↓blood glucose by increasing cellular uptake
↑rate of anabolic metabolism

Glucagon: Secreted by pancreatic α-cells, stimulated by low glucose and high amino acid levels
↑blood glucose by promoting gluconeogenesis and glycogenolysis in the liver

Glucocorticoids: ↑blood glucose in response to stress by mobilizing fat stores and inhibiting glucose uptake. They increase the impact of glucagon and catecholamines. Ex: cortisol

Catecholamines: Promote glycogenolysis and ↑basal metabolic rate through sympathetic nervous system activity. "Adrenaline rush". Ex: epinephrine and norepinephrine

Thyroid Hormones: ↑basal metabolic rate, as evidenced by ↑O_2 consumption and heat production when they are secreted. T_3 is more potent than T_4, but has a shorter half-life and is available in lower concentrations in the blood. T_4 is converted to T_3 at the tissues. Thyroid hormones are tyrosine-based.



Tissue-Specific Metabolism

Liver: The most metabolically diverse tissue. Hepatocytes are responsible for the maintenance of blood glucose levels by glycogenolysis and gluconeogenesis in response to pancreatic hormone stimulation. The liver also processes lipids and cholesterol, bile, urea, and toxins.

Adipose Tissue: Stores lipids under the influence of insulin and releases them under the influence of epinephrine.

Skeletal Muscle: Skeletal muscle metabolism will differ depending on current activity level and fiber type.

Resting muscle: Conserves carbohydrates in glycogen stores and uses free fatty acids from the bloodstream.

Active muscle: May use anaerobic metabolism, oxidative phosphorylation of glucose, direct phosphorylation from creatine phosphate, or fatty acid oxidation, depending on fiber type and exercise duration.

Cardiac Muscle: Uses fatty acid oxidation in both the well-fed and fasting states.

Brain and Nervous Tissue: Consume only glucose in all metabolic states, except for prolonged fasts, where up to 2/3 of the brain's fuel may come from ketone bodies.

Researchers

Franz Gall: (1758 – 1828). Phrenology

Pierre Flourens: (1794 – 1867). Functions of major sections of the brain. Used extirpation to study parts of brain.

William James (1842 – 1910). *Functionalism*: How mental processes help individuals adapt to their environment.

John Dewey: (1859 – 1952). Functionalism

Paul Broca: (1824 – 1880). Studied people with legions in specific regions of brain. *Broca's Area*: Speech production.

Hermann von Helmholtz: (1821 – 1894). Speed of impulse. Made psychology a science.

Sir Charles Sherrington: (1857 – 1952). Synapses

Sigmund Freud: (1856 – 1939). Psychoanalytic perspective.

Nervous System Organization

Neurons: *Sensory*: Afferent, receptors → spinal cord
Interneurons: Between other neurons. Mainly CNS.
Motor: Efferent, CNS → muscles & glands

Reflex Arcs: Interneurons in spinal cord relay info to the source of stimuli while simultaneously routing it to the brain.

Central Nervous System CNS. Brain and spinal cord.

Peripheral Nervous System: PNS. Nervous tissue and fibers outside CNS
Somatic: Voluntary
Autonomic: Sympathetic = F/F, parasympathetic = R/D.

Influences of Behavior

Neurotransmitters: Released by neurons to carry a signal.

Acetylcholine: Used by somatic nervous system to move muscles. Also used by the parasympathetic and CNS.

Dopamine: Maintains smooth movements and steady posture.

Endorphins & Enkephalins: Natural pain killers.

Epinephrine & Norepinephrine: Maintain wakefulness and mediate F/F responses. Epinephrine tends to act as a hormone, norepinephrine a neurotransmitter.

γ-aminobutyric Acid (GABA): and **Glycine**. Inhibitory neurotransmitters. Act as brain "stabilizers".

Glutamate: Acts as an excitatory neurotransmitter.

Serotonin: Modulates mood, sleep, eating, and dreaming.

The endocrine system is tied to the nervous system through the hypothalamus and the anterior pituitary, and a few other **hormones**:

Cortisol: Stress hormone released by the adrenal cortex.

Testosterone & Estrogen: Mediate libido. Testosterone also ↑aggressive behavior. Both are produced in gonads, released by adrenal cortex.

Epinephrine & Norepinephrine: Released by adrenal medulla and cause physiological changes associated with the sympathetic nervous system.

Brain Organization

* See appendix for full diagram

Hindbrain: *Cerebellum*, *medulla oblongata*, *reticular formation*.

Midbrain: Inferior and superior *colliculi*.

Forebrain *Thalamus*, *hypothalamus*, *basal ganglia*, *limbic system*, *cerebral cortex*.

Methods of Study: Electroencephalography (EEG). Regional cerebral blood flow.

Forebrain

Thalamus: Relay station for sensory information.

Hypothalamus: Homeostasis & the 4 F's. Integrates with endocrine system.
Hypothalamus → hypophyseal portal → anterior pituitary

Basal Ganglia: Smooths movements and helps postural stability.

Limbic System: *Septal Nuclei*: Pleasure and addiction.
Amygdala: Fear and aggression.
Hippocampus: Emotion and memory.

Cerebral Cortex: Four lobes
Frontal: Executive function, impulse control, speech, motor.
Parietal: Touch, pressure, temp, pain, spatial processing.
Occipital: Visual
Temporal: Sound, speech perception, memory, emotion.

Cerebral Hemispheres: Left is analytic, language, logic, math. Usually dominant
Right is intuition, creativity, spatial processing.

Development

The nervous system develops through *neurulation*, in which the *notochord* stimulates overlying *ectoderm* to fold over, creating a *neural tube* topped with *neural crest cells*

Neural Tube: Becomes the CNS

Neural Crest Cells: Spread out throughout the body, differentiating into many different tissues.

Primitive Reflexes: Exist in infants and should disappear with age.
Rooting Reflex: Turns head toward stimulus.
Moro Reflex: Extends arms, response to falling sensation.
Babinski Reflex: Big toe is extended and other toes fan out in response to brushing on sole of foot.
Grasping Reflex: Grabs anything put into hands.

Developmental Milestones

- Gross and fine motor abilities progress head to toe and core to periphery
- Social skills shift from parent-oriented to other-oriented
- Language skills become increasingly complex

Definitions

Sensory Receptors: Sensory nerves that respond to stimuli.

Sensory Ganglia: Collection of cell bodies outside the CNS.

Projection Areas: Areas in the brain that analyze sensory input.

Absolute Threshold: The min of stimulus energy that will activate a sensory system.

Threshold of Conscious Perception: The minimum stimulus energy that will create a signal large enough in size and long enough in duration to be brought into awareness.

Difference Threshold: The min difference in magnitude between two stimuli before one can perceive this difference.

Weber's Law: Just Noticeable Difference (JND) for a stimulus is proportional to the magnitude of the stimulus.

Signal Detection Theory: Refers to the effects of nonsensory factors, such as experiences, motives, and expectations on perception of stimuli. Accounts for response bias.

Adaptation: Refers to a ↓ in response to a stimulus over time.

Vision

Cornea: Gathers and filters incoming light.

Iris: Controls size of pupil. Colored part of eye. Divides front of the eye into the *anterior* & *posterior* chamber. It contains 2 muscles, the *dilator* and constrictor *pupillae*.

Lens: Refracts incoming light to focus it on the retina.

Aqueous Humor: Produced by the *ciliary body*. Nourishes the eye and gives the eye its shape. Drains through the *canal of Schlemm*.

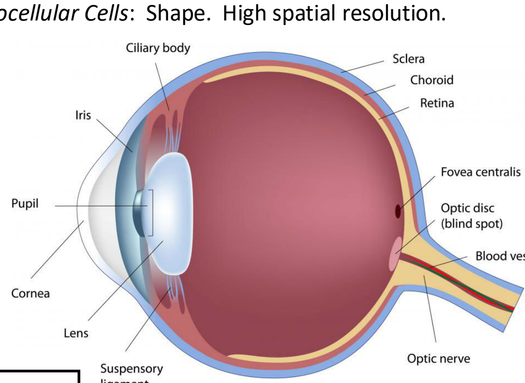
Retina: *Rods*: Detect light / dark. Contain rhodopsin.
Cones: Color. Short / medium / long. Cones are in the fovea, which is part of the macula. Pathway from retina:
Rods/Cones → bipolar cells → ganglion cells → optic nerve

Retinal Disparity: Space between eyes; allows for binocular vision and depth.

Horizontal & Amacrine Cells: Integrates signals from ganglion cells and performs edge-sharpening.

Support: *Vitreous* on inside. *Sclera* and *choroid* on outside.

Processing: *Parallel Processing*: Color, form, and motion at same time.
Cones: Color
Magnocellular Cells: Motion. High temporal resolution.
Parvocellular Cells: Shape. High spatial resolution.



Visual Pathway

eye → optic nerves → optic chiasm → optic tracts → lateral geniculate nucleus (LGN) → visual radiations → visual cortex

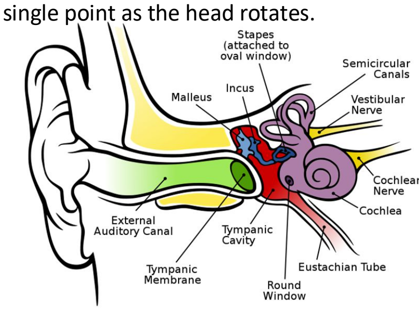
Hearing

Outer Ear: *Pinna* (*auricle*), *external auditory canal*, *tympanic membrane.*

Middle Ear: Connected to nasal cavity by *Eustachian tube*.
Ossicles: Acronym MIS and HAS.
Malleus: Hammer
Incus: Anvil
Stapes: Stirrup. Footplate of *stapes* rests in the oval window of cochlea.

Inner Ear: *Bony Labyrinth*: Filled with perilymph.
Membranous Labyrinth: Filled with endolymph.
Membranous labyrinth consists of *cochlea* (sound), *utricle* & *saccule* (linear acceleration) and *semicircular canals* (rotational acceleration & balance).

Projection Areas: *Superior Olive*: Localizes sound. Located in brain stem.
Inferior Colliculus: Startle reflex. Also used by both eyes and ears in the vestibulo-ocular reflex which keeps the eyes fixed on a single point as the head rotates.



Auditory Pathway

cochlea → vestibulocochlear nerve → medial geniculate nucleus (MGN) → auditory cortex

Other Senses

Smell: The detection of volatile or aerosolized chemicals by the *olfactory chemoreceptors* (*olfactory nerves*) in the *olfactory epithelium*. Smell info bypasses the thalamus.

Pheromones: Chemicals given off by animals that have an effect on social foraging, and sexual behavior.

Taste: The detection of dissolved compounds by *taste buds* in *papillae*. Sweet/sour/salty/bitter/umamai.

Somatosensation: Refers to the four touch modalities: Pressure, vibration, pain, temperature.

Two-Point Threshold: Minimum distance necessary between 2 points of stimulation on the skin such that the points will be felt as two distinct stimuli.

Physiological Zero: The normal temp of skin to which objects are compared to.

Nociceptors: Pain reception. Gate theory of pain. ↓JND for pain.

Kinesthetic Sense: Proprioception

Object Recognition

Top-Down Processing: The recognition of an object by memories and expectations. Little attention to detail. Uses background knowledge.

Bottom-Up Processing: Details → whole. Recognition of objects by feature detection. Not influenced by background knowledge.

Gestalt Principles: *Proximity*, *similarity*, *good continuation*, *subjective contours*, *closure*. All are governed by the *Law of Prägnanz*.

Learning

Habituation: Becoming used to a stimulus.

Dishabituation: When a 2nd stimulus intervenes causing a resensitization of the original stimulus.

Associative Learning: Pairing together stimuli / responses or behaviors / consequences.

Operant Conditioning: Behavior is changed through the use of consequences.
Reinforcement: Increases likelihood of behavior.
Punishment: Decreases likelihood of behavior.
Schedule: The schedule of reinforcement can be based on an amount of time or a ratio of behavior / reward, and can be either fixed or variable.

Positive Response: Adding something.
Negative Response: Removing something.

Extinction: According to operant conditioning, when a previously reinforced behavior is no longer reinforced, it goes extinct.

Shaping: In operant conditioning, shaping is a when behavior closer and closer to the target behavior is reinforced.

Classical Conditioning: With repetition, a neutral stimulus becomes a conditioned stimulus that produces a conditioned response.

Observational Learning or Modeling: The acquisition of behavior by watching others.

Operant (instrumental): Experimenter arranges relationship between a stimulus (the reinforcer) and a response. E.g. bar press ⇒ food

Classical (Pavlovian): Experimenter arranges a relationship between two stimuli (CS and US). E.g. tone ⇒ food

Memory

Encoding: The process of putting new info into memory. It can be *automatic* or *effortful*. *Semantic* encoding is stronger than both *acoustic* and *visual* encoding.

Sensory & Short Term Memory: Transient and based on neurotransmitter activity.

Working Memory: Requires STM, attention, and executive function to manipulate information.

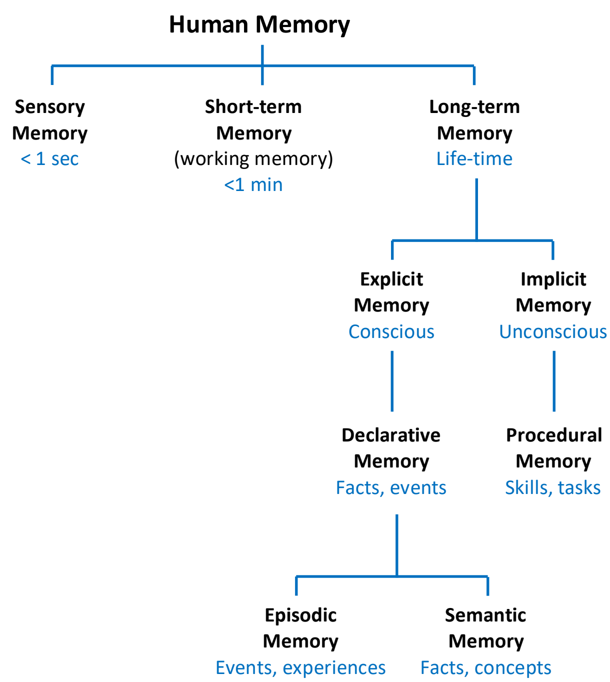
Long Term Memory: Requires elaborate rehearsal and is the result of increased neuronal connectivity.
Explicit (declarative) Memory: Accounts for memories that we must consciously recall with effort and focus.
Implicit (nondeclaritive) Memory: Accounts for acquired skills and conditioned responses to circumstances and stimuli.

Semantic Networks: Stores facts. Concepts are linked together based on similar meaning. Certain triggers will activate associated memories.

Retrieval: *Recognition* of info is stronger than *recall*. Retrieval is often based on *priming* interconnected nodes of the semantic network.

Diseases: *Alzheimers*: Degenerative brain disorder linked to a loss of acetylcholine in neurons that link to hippocampus. Causes dementia and memory loss.
Korsakoff's Syndrome: Memory loss caused by thiamine deficiency in the brain. Causes retrograde amnesia and anterograde amnesia. Another symptom is *confabulation*, the fabrication of vivid but fake memories.
Agnosia: Loss of ability to recognize objects, people, or sounds. Usually caused by physical damage to brain.

Interference: *Retroactive Interference*: New memories make you forget old memories.
Proactive Interference: Old memories interfere with learning new memories.



Cognition

Information Processing Model: The brain encodes, stores, and retrieves info much like a computer.

Piaget's Stages: Involve schemas and assimilation vs. accommodation.
Sensorimotor*:* 0 → 2 yrs. Child manipulates the environment to meet physical needs through circular reactions. *Object permanence* develops at the end of this stage.
Preoperational*:* 2 → 7 yrs. Pretend play, *symbolic thinking* so they learn to talk*, egocentrism* & *centration.*
Concrete Operational*:* 7 → 11 yrs. Understands the feelings of others. Conservation develops. Math.
Formal Operational*:* 11 years and older. Abstract thought and problem solving. Moral reasoning.

Problem-Solving

Types: *Trial-and-Error*
Algorithms
Deductive Reasoning: Form conclusions from rules.
Inductive Reasoning: Form conclusions from evidence.

Mental Set: A pattern of approach for a given problem.

Functional Fixedness: The tendency to use objects only in the way they are normally utilized. Creates barriers to problem-solving.

Heuristics: "Rules of thumb"

Availability Heuristic: When we make our decisions based on how easily similar instances can be imagined.

Representativeness Heuristic: The tendency to make decisions about actions / events based on our standard representations of the events.

Confirmation Bias: The tendency to focus on information that fits an individual's beliefs, while rejecting information that goes against those beliefs.

Gardner's Theory of Multiple Intelligences: 7 areas of intelligence: Linguistic, logical-mathematical, musical, visual-spatial, bodily-kinesthetic, interpersonal, intrapersonal.

Consciousness

Alertness: State of being awake and thinking. EEG shows BETA waves when alert or concentrating, ALPHA waves when awake but tired, eyes closed. BETA: ↑freq ↓amp; ALPHA: Synchronous

Sleep: More info on right

Hypnosis: Individuals appear to be in normal control of their faculties but are in a highly suggestible state. Used for pain control, psychological therapy, memory enhancement.

Meditation: Quieting of the mind. Used for relief of anxiety.

Consciousness-Altering Drugs

Depressants: Alcohol, barbiturates, benzodiazepines. They ↑GABA.

Stimulants Amphetamines, cocaine, ecstasy. ↑Dopamine, ↑norepinephrine, ↑serotonin at synaptic cleft.

Opiates & Opioids Heroin, morphine, opium, oxycodone & hydrocodone. Can cause death by respiratory depression.

Hallucinogens: LSD, peyote, mescaline, ketamine.

Mesolimbic Pathway: Mediates drug addiction. Includes nucleus accumbens, medial forebrain bundle, and ventral tegmental area. Dopamine is the main neurotransmitter.

Language

Phonology: The actual sound of speech.

Morphology: The building blocks of words.

Semantics: The meaning of words.

Syntax: Rules dictating word order.

Pragmatics: Changes in language delivery depending on context.

Theories of Language Development: *Nativist (biological) Theory*: Language acquisition is innate.
Learning (behaviorist) Theory: Language acquisition is controlled by operant conditioning and reinforcement by parents and caregivers.
Social Interactionist Theory: Language acquisition is caused by a motivation to communicate and interact with others.

Whorfian Hypothesis: *Linguistic Relativity*. The lens by which we view and interpret the world is created by language.

Broca's Area: Produces speech

Wernicke's Area: Language comprehension

Arcuate Fasciculus: Connects Broca's Area and Wernicke's Area.

Aphasia: Language deficit
Broca's Aphasia: Difficult to generate speech.
Wernicke's Aphasia: Lack of comprehension.
Conduction Aphasia: Can't repeat words.

Sleep

Beta – **A**lpha – **T**heta – **D**elta
BAT-D mnemonic for sequential order of brain waves.

Stage 1: Light sleep. THETA waves

Stage 2: Slightly deeper. THETA waves, sleep spindles, K complexes. ↓heart rate, ↓respiration, ↓temperature.

Stages 3 & 4 Deep sleep. DELTA waves. *Slow-wave sleep* (SWS). Most sleep disorders occur during stage 3 & 4 *non-rapid eye movement* (NREM) sleep. Growth hormone released.

Rapid Eye Mvmt: REM sleep. The mind appears awake on EEG, but the person is asleep. Eye movements and body paralysis. Mostly BETA waves.

Sleep Cycle: 90 min. Stages: 1-2-3-4-3-2-REM or 1-2-3-4-REM

Circadian Rhythm: 24 hours. *Melatonin* triggers sleepiness. *Cortisol* promotes wakefulness

Dreaming: Mostly during REM.

Activation-Synthesis Theory: Dreams result from brain activation during REM sleep. Activation in brainstem, synthesis in cortex.

Sleep Disorders: *Dyssomnias*: Difficult to fall asleep, stay asleep, or avoid sleep. Insomnia, narcolepsy, sleep apnea.
Parasomnias: Abnormal movements or behaviors during sleep. Night terrors, sleepwalking.

Alertness

Selective Attention: Allows one to pay attention to particular stimulus while determining if additional stimuli in the background require attention.

Divided Attention: Uses *automatic processing* to pay attention to multiple activities at one time.

Motivation

Motivation: The purpose, or driving force, behind our actions. Can be *extrinsic* or *intrinsic*.

Instincts: Innate, fixed patterns of behavior in response to stimuli.

Instinct Theory: People perform certain behaviors because of these evolutionarily programmed instincts.

Arousal: The state of being awake and reactive to stimuli.

Optimal Arousal Theory: Optimal performance requires optimal arousal. Arousal levels that are too ↑ or too ↓ will impede performance.

Drives: Internal states of tension that beget particular behaviors focused on goals. *Primary drives*: related to biological processes. *Secondary drives*: stem from learning.

Drive Reduction Theory: Motivation arises from the desire to eliminate drives, which create uncomfortable internal states.

Maslow's Hierarchy of Needs: Physiological, safety and security, love and belonging, self-esteem, and self-actualization. Higher needs only produce drives once lower needs are met.

Self-Actualization: Full realization of one's potential.

Self-Determination Theory: Emphasizes 3 universal needs: autonomy, competence, and relatedness.

Incentive Theory: Explains motivation as the desire to pursue rewards and avoid punishments.

Expectancy-Value Theory: The amount of motivation for a task is based on the expectation of success and the value of that success.

Opponent-Process Theory: Explains motivation for drug use: as drug use increases, the body counteracts its effects, leading to tolerance and uncomfortable withdrawal symptoms.

House Money Effect: After a prior gain, people become more open to assuming risk since the new money is not treated as one's own.

Gambler's Fallacy: If something happens more frequently than normal, it will happen less frequently in the future, or vice versa.

Prisoner's Dilemma: Two people act out of their own self-interest, but if they had cooperated, the result would have been even better.

Stress

Stress: The physiological and cognitive response to challenges or life changes.

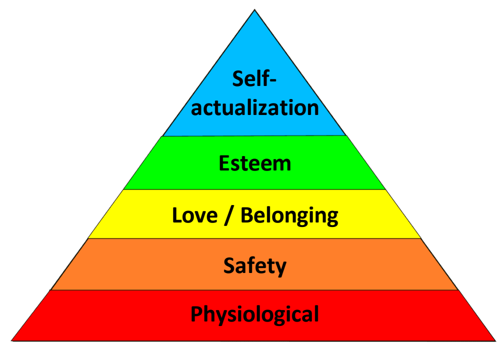
Stress Appraisal: *Primary Appraisal*: Classifying a potential stressor as irrelevant, benign-positive, or stressful. *Secondary Appraisal*: Evaluating if the organism can cope with the stress.

Stressors: Anything that leads to a stress response. Can lead to *distress* or *eustress*.

General Adaptation Syndrome: Specific stressors do not have specific responses, they all generate the same general physical stress response.

3 stages of stress: Alarm, resistance, exhaustion. These involve both the sympathetic nervous system and the endocrine system; release of ACTH leads to ↑cortisol.

Maslow's Hierarchy of Needs



Emotion

Emotion: A state of mind, or feeling, that is subjectively experienced based on circumstances, mood, and relationships

Three Components of Emotion: *Cognitive*: Subjective
Behavioral: Facial expressions and body language
Physiological: Changes in autonomic nervous system

7 Universal Emotions: Happiness, sadness, contempt, surprise, fear, disgust and anger

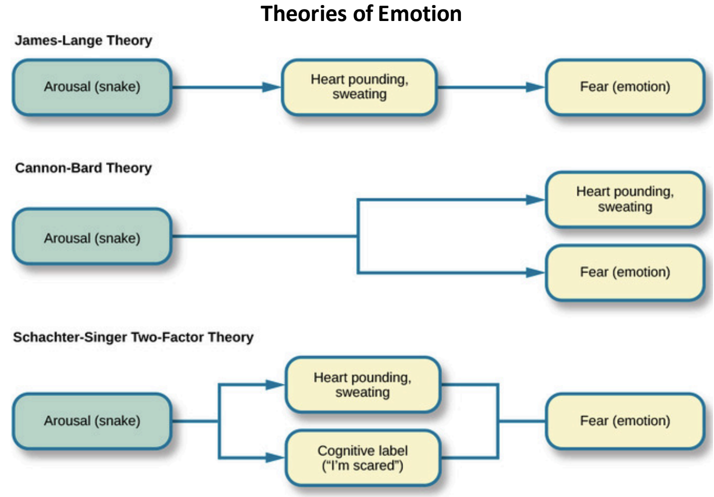
James-Lange Theory: Behavioral and physiological actions lead to emotions. Ex: Power posing.

Cannon-Bard Theory: Emotional and physiological responses to a stimulus occur simultaneously. They arise from separate and independent areas of the brain.

Schacter-Singer Theory: Two-factor theory of emotion. Physiological arousal and interpretation of context or "cognitive label" lead to emotion.

Limbic System: Concerned with instincts and mood. See appendix for full diagram.

Theories of Emotion



Self-Concept & Identity

Self-Concept: The sum of ways we describe ourselves.

Identities: Individual components of our *self-concept* related to the group to which we belong.

Self-Esteem: The closer our *actual self* is to our *ideal self* and our *ought self* (who others want us to be), the ↑ our self-esteem.

Self-Efficacy: The degree to which we see ourselves as being capable at a given skill or situation.

Learned Helplessness: A state of hopelessness that results from being unable to avoid repeated negative stimuli.

Locus of Control: *Internal*: We control our own success/failure
External: Outside factors have more control.

Formation of Identity

Freud: Psychosexual stages of personality development based on tensions caused by the *libido*. Failure at any stage leads to *fixation* which causes personality disorder.

0 → 1	**Oral**
1 → 3	**Anal**
3 → 6	**Phallic**
6 → puberty	**Latent**
Puberty →	**Genital**

Erikson: Stages stem from conflicts throughout life.

0 → 1	**1.** Trust vs. Mistrust
1 → 3	**2.** Autonomy vs. Shame
3 → 6	**3.** Initiative vs. Guilt
6 → 12	**4.** Industry vs. Inferiority
12 → 20	**5.** Identity vs. Role Confusion
20 → 40	**6.** Intimacy vs. Isolation
40 → 65	**7.** Generativity vs. Stagnation
65 → death	**8.** Integrity vs. Despair

Kohlberg: Stages based on moral dilemmas. 6 stages in 3 phases. Example: Mr. Heinz dilemma.

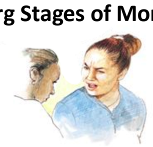
Vygotsky: *Zone of Proximal Development*: The skills that a child has not yet mastered and require a more knowledgeable other to accomplish.

Imitation & Role-Taking: Common ways children learn from others.

Reference Group: The group to which we compare ourselves.

Kohlberg Stages of Moral Development

Post-conventional



"Just because the law says to do it doesn't mean it is ethical!"

Conventional

"You need to drive slower because the law says so!"

Pre-conventional

"I must share this toy because if I don't, then I will get in trouble."

Personality

Psychoanalytic Perspective: Personality results from unconscious urges & desires. Freud, Jung, Adler, and Horney.

Freud's Theory: *Id*: Base urges of survival and reproduction.
Superego: The idealist and perfectionist.
Ego: Mediator between the two and the conscious mind. The ego uses *defense mechanisms* to ↓stress.

All three operate, at least in part, in the unconscious.

Jung: *Collective unconscious* links all humans together. Personality is influenced by archetypes.

Adler & Horney: Unconscious is motivated by social urges.

Humanistic Perspective: Emphasizes the internal feelings of healthy individuals as they strive for happiness and self-realization. Maslow's *hierarchy of needs* and Rogers's *unconditional positive regard* flow from the humanistic view of personality.

Type & Trait Theory: Personality can be described by identifiable traits that carry characteristic behaviors.

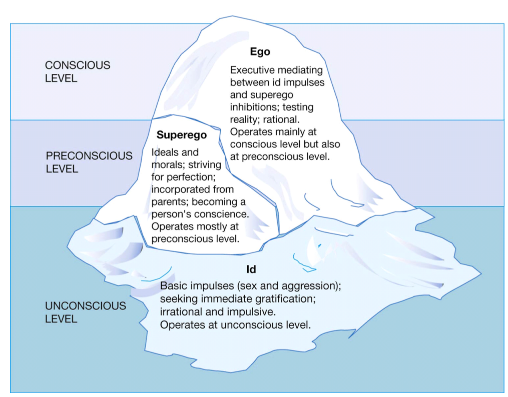
Type Theories: Ancient Greek *humors*, Sheldon's *somatotypes*, divisions into *Type A* and *Type B*, and *Myers-Briggs Type Inventory*.

Trait Theories: PEN: *Psychoticism* (nonconformity), *extraversion* (sociable), *neuroticism* (arousal in stressful situations).
Big Five: *Openness, conscientiousness, extraversion, agreeableness, and neuroticism*. OCEAN mnemonic.
3 Basic Traits: *Cardinal traits* (traits around which a person organizes their life), *central traits* (major characterizes of personality), *secondary traits* (more personal characteristics and limited in occurrence).

Social Cognitive Perspective: Individuals react with their environment in a cycle called *reciprocal determinism*. People mold their environments according to their personality, and those environments in turn shape their thoughts, feelings and behaviors.

Behaviorist Perspective: Our personality develops as a result of operant conditioning. E.g. it is reward and punishment based.

Biological Perspective: Behavior can be explained as a result of genetic expression.



Id **Superego** **Ego**

Types of Psych Disorders

Schizophrenia: Prototypical disorder with psychosis.
Positive Symptoms: Add something to behavior, cognition or affect. Such as delusions or hallucinations.
Negative Symptoms: The loss of something. Such as disturbances of affect and avolition.

Depressive Disorders: Include major depressive disorder and seasonal affective disorder.
Major Dep Disorder: At least 1 major depressive episode.
Persistent Dep Disorder: Dysthymia for at least 2 years that doesn't meet criteria for Major Depressive Disorder.
Seasonal Affective Disorder: Depression occurring in winter.

Bipolar and Related Disorders: Manic or hypomanic episodes.
Bipolar I: At least one manic episode.
Bipolar II: At least one hypomanic episode & at least one major depressive episode.
Cyclothymic Disorder: Hypomanic episodes with dysthymia.

Anxiety Disorders: Generalized anxiety disorder, phobias, social anxiety disorder, agoraphobia, and panic disorder.

Obsessive-Compulsive Disorder: *Obsessions*: Persistent, intrusive thoughts & impulses.
Compulsions: Repetitive tasks that relieve tension but cause impairment in a person's life.

Body Dysmorphic Disorder: Unrealistic negative evaluation of one's appearance.

PTSD: Intrusive symptoms such as flashbacks, nightmares. Avoidance symptoms, negative cognitive symptoms & arousal symptoms.

Dissociative Disorders: *Dissociative Amnesia*: Can't recall past experiences.
Dissociative Fugue: Assumption of a new identity.
Dissociative Identity Disorder: Multiple personalities.
Depersonalization / Derealization Disorder: Feeling detached from the mind and body, or environment.

Somatic Symptom & Related Disorders: Involve significant bodily symptoms.
Somatic Symptom Disorder: "Somatoform disorder". A somatic symptom causes disproportionate concern.
Illness Anxiety Disorder: Preoccupation with thoughts about having or coming down with illness.
Conversion Disorder: Associated with prior trauma, involves unexplained symptoms resulting in loss of body function.
Hypochondriasis: "Illness Anxiety Disorder". One strongly believes he or she has a serious illness despite few or no symptoms.

Personality Disorders: Patterns of inflexible, maladaptive behavior that cause distress or impaired function.
Cluster A: "weird" - Paranoid, schizotypal, schizoid.
Cluster B: "wild" - antisocial, borderline, histrionic, narcissistic.
Cluster C: "worried" – avoidant, dependent, OC.

Understanding Psych Disorders

Behaviorist Approach: Classical and operant conditioning shapes the disorder.

Biomedical Approach: Takes into account only physical and medical causes.

Biopsychosocial Approach: Considers relative contributions of biological, psychological, and social components.

Psychodynamic Approach: Related to Freud's psychoanalysis.

DSM-5: The *Diagnostic and Statistical Manual of Mental Disorders*, 5th edition. Categorizes mental disorders based on symptoms.

Biological Basis

Schizophrenia: Genetic factors, birth trauma, marijuana use, family history.

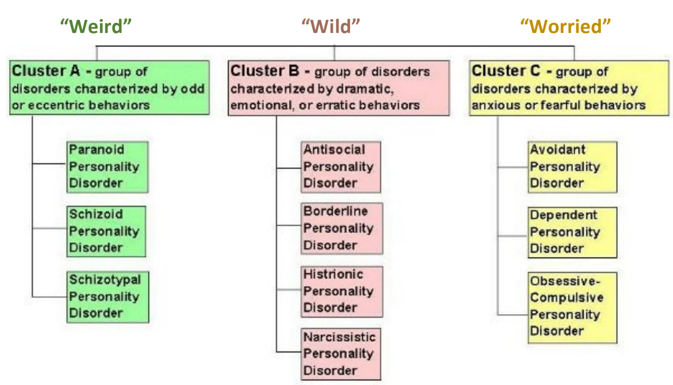
Depression: ↑glucocorticoids, ↓norepinephrine, serotonin and dopamine.

Bipolar Disorders: ↑norepinephrine and serotonin. Also heritable.

Alzheimer's: Genetic factors, brain atrophy, ↓acetylcholine, senile plaques of β-amyloid.

Parkinson's: Bradykinesia, resting tremor, pill-rolling tremor, masklike facies, cogwheel rigidity, and a shuffling gait. ↓dopamine

Personality Disorder Clusters



Group Psychology

Social Facilitation: Describes the tendency of people to perform at a different level when others are around.

Deindividuation: A loss of self-awareness in large groups.

Bystander Effect: When in a group, individuals are less likely to respond to a person in need.

Peer Pressure: The social influence placed on individuals by others they consider equals.

Social Loafing: An individual does not pull his or her weight in a group setting.

Polarization: The tendency toward making decisions in a group that are more extreme.

Groupthink: The tendency for groups to make decisions based on ideas and solutions that arise within the group without considering outside ideas.

Culture: The beliefs, ideas, behaviors, actions, and characteristics of a group or society.

Assimilation: The process by which an immigrant or minority takes up elements of mainstream culture. Assimilation is a specific type of socialization. To experience assimilation, a person must first have their own culture, then absorb elements of a new culture.

Multiculturalism: The encouragement of multiple cultures within a community to enhance diversity.

Subcultures: A group of people within a culture that distinguish themselves from the primary culture.

Attitudes & Behavior

Attitudes: Tendencies toward expression of positive or negative feelings or evaluations of something. Attitude has 3 components: *Affective*, *behavioral*, and *cognitive*.

Functional Attitudes Theory: States that there are four functional areas of attitudes: knowledge, ego expression, adaptability, and ego defense.

Learning Theory: States that attitudes are developed through forms of learning: direct contact, direct interaction, direct instruction, and conditioning.

Elaboration Likelihood Model: States that attitudes are formed and changed through different routes of information processing based on degree of elaboration: *central route processing, peripheral route processing*.

Social Cognitive Theory: States that attitudes are formed through watching others, personal factors, and the environment. People change their behavior or attitudes based on observation.

Socialization

Socialization: The process of internalizing the social norms and values expected in one's society.

Sanctions: *Positive*: A reward for a certain behavior.
Negative: A punishment for a certain behavior.

Formal Sanction: An official reward or punishment.
Informal Sanction: A sanction that is not enforced or punished by an authority but that occurs in everyday interactions with other people. Ex: Asking someone to lower their voice in a movie theater.

Norms: Determine the boundaries of acceptable behavior within a society.

Mores: Informal norms with major importance for society and, if broken, can result in severe sanctions. Ex: Drug abuse is not socially acceptable. "Right / Wrong"

Folkways: Informal norms that are less significant, yet they still shape our everyday behavior. Ex: Holding a door open for someone. "Right / Rude"

Taboos: Considered unacceptable by almost every culture (like cannibalism or incest).

Stigma: The extreme disapproval or dislike of a person or group based on perceived differences form the rest of society.

Deviance: Violation of norms, rules, or expectations in a society.

Differential Association Theory: Deviance can be learned through our interactions with others. People commit crimes, at least in part, because of their associations with other people.

Conformity: Changing beliefs or behaviors in order to fit into a group or society.

Compliance: When individuals change their behavior based on the requests of others.

Obedience: A change in behavior based on a command from someone seen as an authority figure.

Elements of Social Interaction

Status: A position in society used to classify individuals.

Ascribed Status: Involuntarily assigned to an individual based on race, gender, ethnicity, etc.

Achieved Status: Voluntarily earned by an individual.

Master Status: The status by which an individual is primarily identified.

Role: A set of beliefs, values, and norms that define the expectations of a certain status in a social situation.

Role Performance: Refers to carrying out behaviors of a given role.

Role Partner: Another individual who helps define a specific role within the relationship.

Role Set: A set of all roles that are associated with a status.

Role Conflict: Difficulty managing MULTIPLE roles.

Role Strain: Difficulty managing JUST ONE role.

Groups: 2 or more people with similar characteristics that share a sense of unity.

Peer Group: A self-selected group formed around shared interests.

Family Group: Group to which you are born, adopted or married.

Kinship: *Affinal Kinship*: Individuals that are related by choice. E. g. marriage.
Conanguineous Kinship: Related through blood.

In-Group: The group you are in.

Out-Group: Group you compete with or oppose.

Reference Group: Group you compare yourself to.

Primary Group: Those that contain strong emotional bonds.

Secondary Group: Often temporarily. Contain weaker bonds overall.

Gemeinschaft: Community

Gesellschaft: Society

Groupthink: Occurs when members begin to conform to one another's views and ignore outside perspectives.

Network: An observable pattern of social relationships between individuals or groups.

Organization: A group with identifiable membership that engages in certain action to achieve a common purpose.

Bureaucracy: A rational system of administration, discipline, and control. Max Weber gave it six defining characteristics.

Iron Law of Oligarchy: Democratic or bureaucratic systems naturally shift to being ruled by an elite group.

Sect: A religious group that arose from a split from a larger religion.

Self-Preservation and Interacting w/ Others

Basic Model of Expressing Emotions: States that there are universal emotions and expressions that can be understood across cultures.

Social Construction Model of Expressing Emotion: States that emotions are solely based on the situational context of social interactions.

Display Rules: Unspoken rules that govern the expression of emotions.

Cultural Syndrome: A shared set of beliefs, norms, values, and behaviors organized around a central theme.

Impression Management: Refers to the maintenance of a public image, which is accomplished through various strategies: Flattery, boasting, managing appearances, ingratiation, aligning actions, alter-casting.

Dramaturgical Approach: People create images of themselves in the same way that actors perform a role in front of an audience.
Front Stage: Where you are seen by an audience.
Back Stage: You are not in front of the audience.

Verbal Communication: Communicating through spoken, written, or signed words.

Nonverbal Communication: Communicating through means other than the use of words. Examples: Body language, prosody, gestures.

Animal Communication: Takes place not only between nonhuman animals, but between humans and other animals as well. Animals use body language, facial expressions, visual displays, scents, and vocalizations to communicate.

Max Weber's 6 Defining Characteristics of a Bureaucracy

1) It has a formal hierarchical structure.
2) It is managed via a set of defined, specific rules and regulations.
3) It is organized by functional specialty, with different workers performing different, specialized tasks.
4) The organization's focus is either "up-focused," that is, to serve shareholders, a board, or some other entity that empowers it, or "in-focused", that is, to serve itself through maximizing profit or maximizing market share.
5) It is purposefully impersonal.
6) Employment is based on technical qualifications like advanced degrees or training.

Social Behavior

Interpersonal Attraction: Is what makes people like each other. Influenced by physical attractiveness, similarity thoughts and physical traits, self-disclosure, reciprocity, and proximity.

Aggression: A physical, verbal, or nonverbal behavior with the intention to cause harm or increase social dominance.

Attachment: An emotional bond to another person. Usually refers to the bond between a child and caregiver.

Secure Attachment: Requires a consistent caregiver. Child shows a strong preference for the caregiver compared to strangers.

Avoidant Attachment: Occurs when a caregiver has little or no response to a distressed child. Child shows no preference for the caregiver compared to strangers.

Ambivalent Attachment: Occurs when a caregiver has an inconsistent response to a child's distress, sometimes responding appropriately, sometimes neglectful. Child will become distressed when caregiver leaves and is ambivalent when he or she returns.

Disorganized Attachment: Occurs when a caregiver is erratic or abusive; the child shows no clear pattern of behavior in response to the caregiver's absence or presence.

Social Support: The perception or reality that one is cared for by a social network.

Emotional Support: Listening to, affirming, and empathizing with someone's feelings.

Esteem Support: Affirms the qualities and skills of the person.

Material Support: Providing physical or monetary support.

Informational Support: Providing useful information to a person.

Network Support: Providing a sense to belonging to a person.

Foraging: Searching for and exploiting food resources.

Mating System: Describes the way in which a group is organized in terms of sexual behavior.

Monogamy: Exclusive mating relationships.

Polygamy: One member of a sex having multiple exclusive relationships with members of the opposite sex.
Polygyny: Male with multiple females.
Polyandry: Female with multiple males.

Promiscuity: No exclusivity.

Mate Choice: (Intersexual selection). The selection of a mate based on attraction and traits.

Altruism: A helping behavior in which the person's intent is to benefit someone else at some cost to him or herself.

Game Theory: Attempts to explain decision making between individuals as if they are participating in a game

Inclusive Fitness: A measure of an organism's success in the population based on how well it propagates ITS OWN genes. Inclusive fitness also includes the ability of those offspring to then support others.

Social Perception & Behavior

Social Perception: (Social cognition). The way by which we generate impressions about people in our social environment. It contains a *perceiver*, *target* and *situation*.

Social Capital: Non-financial social assets that promote social mobility beyond economic means. Examples include education, intellect, dress, or physical appearance.

Implicit Personality Theory: States that people make assumptions about how different types of people, their traits, and behavior are related.

Cognitive Biases: *Primacy effect*, *recency effect*, *reliance on central traits*, *halo effect*, *just-world hypothesis*, *self-serving bias*.

Attribution Theory: Focuses on the tendency for individuals to infer the causes of other people's behavior.

Dispositional: Internal. Causes of a behavior are internal.

Situational: External. Surroundings or context cause behavior.

Correspondent Inference Theory: Focuses on the intentionality of a person's behavior. When someone unexpectedly does something that either helps or hurts us, we form a dispositional attribution; we correlate the action to the person's personality.

Fundamental Attribution Error: The bias toward making dispositional attributions rather than situational attributions in regard to the actions of others.

Attribution Substitution: Occurs when individuals must make judgments that are complex but instead substitute a simpler solution or heuristic.

Actor-Observer Bias: Tendency to attribute your own actions to external causes and others' actions to dispositional causes.

Stereotypes, Prejudice, and Discrimination

Stereotypes: Cognitive. Occur when attitudes and impressions are made based on limited and superficial information.

Self-Fulfilling Prophecy: When stereotypes lead to expectations and those expectations create conditions that lead to confirmation of the stereotype.

Stereotype Threat: Concern or anxiety about confirming a negative stereotype about one's social group.

Prejudice: Affective. An irrational positive or negative attitude toward a person, group, or thing prior to an actual experience.

Ethnocentrism: Refers to the practice of making judgments about other cultures based on the values and beliefs of one's own culture.

Cultural Relativism: Refers to the recognition that social groups and cultures should be studied on their own terms.

Discrimination: Behavioral. When prejudicial attitudes cause individuals of a particular group to be treated differently from others.

Sociology: Theories & Institutions

Functionalism: Focuses on the function of each part of society. *Manifest Functions*: Deliberate actions that serve to help a given system. *Latent Functions*: Unexpected, unintended, or unrecognized positive consequences of manifest actions.

Conflict Theory: Based on the works of Karl Marx. Conflict Theory focuses on how power differentials are created and contribute to maintaining social order. It explains how groups compete for resources to attain power or superiority.

Conflict Sociology: The study of the way that distinct groups compete for resources.

Symbolic Interactionism: The study of the ways individuals interact through a shared understanding of words, gestures, and other symbols. The "meaning" of social symbols.

Micro Sociology: The study of expressions, symbolic gestures, and other small, individual components of a society.

Social Constructionism: Explores the ways in which individuals and groups make decisions to agree upon a given social reality. The "value" they place on certain social constructs. *Social constructivism* focuses on altering that constructed view.

Rational Choice Theory: States that individuals will make decisions that maximize benefit and minimize harm. *Expectancy Theory* applies rational choice theory within groups.

Feminist Theory: Explores the ways in which one gender can be subordinated.

Social Institutions: Well-established social structures that dictate certain patterns of behavior or relationships.

4 Tenets of Medicine: *Beneficence*, *nonmaleficence*, *respect for autonomy*, and *justice*.

Culture

Culture: Encompasses the lifestyle of a group of people.

Material Culture: Includes physical items one associates with a given group.

Symbolic Culture: Includes the ideas associated with a cultural group.

Cultural Lag: The idea that material culture changes more quickly than symbolic culture.

Language: Spoken or written symbols combined into a system.

Value: What a person deems important in life.

Belief: Something a person considers to be true.

Ritual: Formal ceremonial behavior usually includes symbolism.

Norms: Societal rules that define the boundaries of acceptable behavior.

Demographics

Demographics: Statistics of populations. Most common are *ageism*, *gender*, *race*, *ethnicity*, *sexual orientation*, and *immigration*.

Fertility Rate: Average number of children born to a woman during her lifetime in a population.

Birth & Mortality Rate: Usually measured as the number of births or deaths per 1000 people per year.

Migration: The movement of people from one location to another.

Ethnic Migrants: Ethnic groups emigrating to more industrialized countries tend to have ↑fertility and ↑mortality compared to the industrialized nation's population.

Demographic Transition: A model used to represent drops in birth and death rates as a result of industrialization.

Social Movements: Organized to either promote (*proactive*) or resist (*reactive*) social change.

Globalization: The process of integrating a global economy with free trade and tapping of foreign labor markets.

Urbanization: The process of dense areas of population creating a pull for migration.

Social Class

Social Stratification: The system by which society ranks categories of people into a hierarchy.

Functionalism: States that social stratification is necessary and results from the need for those with special intelligence, knowledge, and skills to be a part of the most important professions and occupations. A harmonious equilibrium.

Socioeconomic Status: *Ascribed Status*: Involuntary, derives from clearly identifiable characteristics such as age and gender. *Achieved Status*: Acquired through direct, individual efforts.

Social Class: A category of people with shared socioeconomic characteristics.

Prestige: Respect and importance tied to specific occupations or associations.

Power: The capacity to influence people.

Anomie: Lack of social norms, or the breakdown of social bonds between individuals and society.

Strain Theory: Focuses on how anomic conditions can lead to deviance, and in turn reinforce social stratification.

Social Capital: Benefits provided by social networks. Or, the investment people make in their society in return for rewards.

Meritocracy: Advancement up the social ladder is based on intellectual talent and achievement.

Social Mobility: Allows one to acquire higher-level employment opportunities by achieving required credentials and experience.

Poverty: In the USA, the poverty line is determined by the government's calculation of the minimum income required for the necessities of life.

Absolute: When one can't acquire basic life necessities.

Relative: When one is poor in comparison to a larger population. Ex: "Anyone who earns less than 60% of the median income is poor." It is relative to the population, not based a hard number value.

Relative Deprivation Theory: People seek to acquire something that others possess and which they believe they should have too. They are not necessarily poor, but they may perceive that they are lacking resources or money. It is all relative.

Social Reproduction: The passing on of social inequality, especially poverty, from one generation to the next.

Social Exclusion: A sense of powerlessness when individuals feel alienated from society.

Spatial Inequality: Social stratification across territories.

Globalization: Integrating one's economy to include foreign societies. Has led to increased poverty as production shifts to cheaper labor markets.

Epidemiology and Disparities

Incidence: The # of new cases of a disease per population at risk.

Prevalence: The # of cases of a disease per population.

Mortality: Deaths caused by a given disease.

Ethnic Migrants: Ethnic groups emigrating to more industrialized countries tend to have ↑fertility and ↑overall mortality compared to the industrialized nation's population.

Morbidity: The burden or degree of illness associated with a given disease.

Second Sickness: Refers to an exacerbation of health outcomes caused by social injustice.

Affordable Care Act: (ACA). Attempts to increase health insurance coverage rates and reducing the cost of health care.

Medicare: Covers people greater than 65 years old, those with end-stage renal disease, and those with ALS.

Medicaid: Covers patients in significant financial need.

Vectors and Scalars

Vectors: Physical quantities that have both magnitude and direction. Examples: displacement, velocity, acceleration, and force

Scalars Quantities without direction. Scalar quantities may be the magnitude of vectors, like speed, or may be dimensionless, like coefficients of friction

Vector Addition: Tip-to-tail method, or you can break the vector into its component parts and use Pythagorean theorem

Vector Subtraction: Change the direction of the subtracted vector and then do a tip-to-tail addition

Vector Multiplication: *By scalar*: Changes the magnitude and may reverse the direction.

Dot Product: $A \bullet B = |A||B| \cos(\theta)$, results in a scalar quantity

Cross Product: $A \times B = |A||B| \sin(\theta)$, results in a new vector. Direction of the new vector can be found using the *right-hand rule*

Mechanical Equilibrium

Free Body Diagrams: Representations of the forces acting on an object.

Translational Equilibrium: Occurs in the absence of any net forces acting on an object

Rotational Equilibrium: Occurs in the absence of any net torques acting on an object. The center of mass is the most commonly used pivot point.

Displacement and Velocity

Displacement: The vector representation of a change in position. Path independent

Distance: A scalar quantity that reflects the path traveled

Velocity: The vector representation of the change in DISPLACEMENT with respect to time

$$\text{Avg Velocity} = \frac{\text{Total displacement}}{\text{Total time}}$$

$$\text{Avg Speed} = \frac{\text{Total distance traveled}}{\text{Total time}}$$

Instantaneous Velocity: The change in displacement over time as the time approaches 0

Instantaneous Speed: The magnitude of the instantaneous velocity vector

Forces and Acceleration

Force: Any push or pull that has the potential to result in an acceleration

Gravity: The attractive force between two objects as a result of their masses

Friction: A force that opposes motion as a function of electrostatic interactions at the surfaces between two objects
Static Friction: Stationary object
Kinetic Friction: Sliding object
$f = u\,N$

Mass: A measure of the inertia of an object – its amount of material

Weight: The force experienced by a given mass due to the gravitational attraction to the Earth

Acceleration: The vector representation of the change in velocity over time.

Torque: A twisting force that causes rotation

$\tau = r\,F\sin(\theta)$ POS = counterclockwise
NEG = clockwise

Newton's Laws

First Law: An object will remain at rest or move with a constant velocity if there is no net force on the object
$F_{net} = m\,a = 0$ if at rest or constant velocity

Second Law: Any acceleration is the result a net force > 0
$F_{net} = m\,a$

Third Law: Any two objects interacting with one another experience equal and opposite forces as a result of their interaction
$F_{AB} = -F_{BA}$

Motion with Constant Acceleration

Linear Motion: Includes free fall and motion in which the velocity and acceleration vectors are parallel or antiparallel

<u>Kinematics Equations for Linear Motion</u>

$v_f = v_0 + a\,\Delta t$ $\Delta x = v_0\,\Delta t + \frac{1}{2}\,a\,(\Delta t)^2$

$v_f^2 = v_0^2 + 2\,a\,\Delta x$ $\Delta x = \bar{v}\,\Delta t$ (if a = 0)

Projectile Motion: Contains both an x- and y-component. Assuming negligible air resistance, the only force acting on the object is gravity. X velocity is constant throughout.

Inclined Planes: Force components:
Parallel to the ramp use sinθ. "Sin is sliding ↓ the slide".
Perpendicular to the ramp use cosθ.

Circular Motion: Best thought of as having radial and tangential dimensions. Centripetal force vector points radially inward, the instantaneous velocity vector points tangentially.

Centripetal force: $F_c = \frac{m\,v^2}{r}$

Energy

Structural Proteins: The property of a system that enables it to do something or make something happen, including the capacity to do work. SI units are joules (J). $J = \frac{kg \bullet m^2}{s^2}$

Kinetic Energy: Energy associated with the mvmt of objects. It depends on mass and speed squared. $KE = \frac{1}{2} m v^2$

Potential Energy: Energy stored within a system.

Gravitational Potential Energy: Related to the mass of an object and its height above a zero point. $U = m g h$

Elastic Potential Energy: Related to the spring constant and the degree of stretch or compression of a spring squared. $U = \frac{1}{2} k x^2$

Electrical Potential Energy: The energy between two charged particles.

Chemical Potential Energy: The energy stored in the bonds of compounds.

Conservative Forces: Path independent and do not dissipate the mechanical energy of a system. Examples: Gravity and electrostatic forces.

Nonconservative Forces: Path dependent and cause dissipation of mechanical energy from a system. Examples: Friction, air resistance, and viscous drag.

Work

Work: The process by which energy is transferred from one system to another. Can be expressed as the dot product of force and displacement: $W = F \; d = F \, d \cos(\theta)$

Power: The rate at which work is done or energy is transferred. SI unit is watt (W). $W = \frac{J}{s} = \frac{N \; m}{s} = \frac{Kg \; m^2}{s^3}$

Work-Energy Theorem: When net work is done on or by a system, the system's kinetic energy will change by the same amount. $W_{net} = \Delta K = K_f - K_i$

Mechanical Advantage

Mechanical Advantage: The factor by which a simple machine multiplies the input force to accomplish work. The input force necessary to accomplish the work is reduced and the distance through which the reduced input force must be applied is increased by the same factor.

MA of an Inclined Plane: $MA = \frac{\text{Length of incline}}{\text{Height of incline}}$

Simple Machines: Inclined plane, wedge, wheel and axle, lever, pulley, and screw.

Efficiency: The ratio of the machine's work output to work input when nonconservative forces are taken into account. $\text{Mechanical Advantage} = \frac{F_{out}}{F_{in}}$

0th Law of Thermodynamics

Thermal Equilibrium: When systems have the same average KE and thus the same temperature. No heat transfer.

Temperature: The average kinetic energy of the particles that make up a substance.

$°F = (\frac{9}{5}\,°C) + 32$

$°C = \frac{5}{9}\,(°F - 32)$

$K = °C + 273$

Thermal Expansion: Describes how a substance changes in length or volume as a function of the change in temperature.

$\Delta L = \alpha\, L\, \Delta T$

$\Delta V = \beta\, V\, \Delta T$

Systems

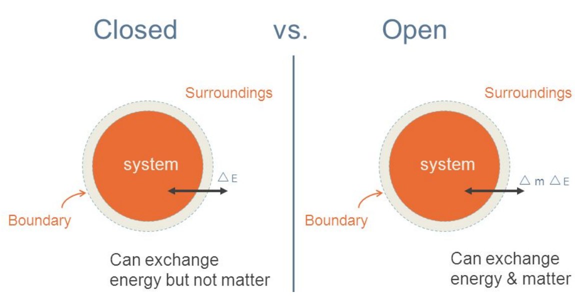
Isolated System: Do not exchange matter or energy with surroundings.

Closed System: Exchange energy but not matter with their surroundings.

Open System: Exchange both energy and matter with their surroundings.

State Functions: Pathway independent and are not themselves defined by a process. Include: Pressure, density, temp, volume, enthalpy, internal energy, Gibbs free energy, and entropy.

Process Functions: Describe the pathway from one equilibrium state to another. Include: work and heat.



Note: An isolated system does not exchange energy or matter with surroundings

1st Law of Thermodynamics

A statement of conservation of energy: The total energy in the universe can never decrease or increase. For an individual system: $\Delta U = Q - W$

ΔU = change in system's internal energy
Q = energy transferred into the system as heat
W = work done by the system

Heat: The process by which energy transfer between two objects at different temperatures that occurs until the two objects come into thermal equilibrium (reach the same temperature).

$q = m\, c\, \Delta T$

Specific Heat: The amount of energy necessary to raise one gram of a substance by 1° C or 1 K.

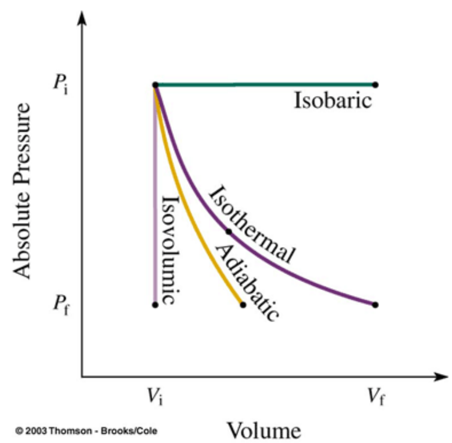
Specific heat of H_2O = $1\,\frac{\text{cal}}{\text{g}\bullet\text{K}} = 4.184\,\frac{\text{J}}{\text{g}\bullet\text{K}}$

Heat of Transformation: The energy required for a phase change of a substance (temperature does not change during the transformation).

$q = m\, L$ L = heat of transformation

Processes with Constant Variable:
Isobaric: Pressure is constant, $\Delta P = 0$
Isothermal: Temp is constant, $\Delta U = 0$
Adiabatic: No heat is exchanged, $Q = 0$
Isovolumetric (isochoric): Volume is constant, $\Delta V = 0$, so Work = 0

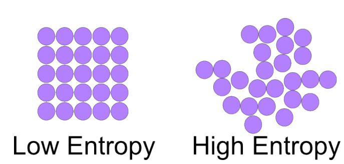
Work of a Gas: $W = -P\,\Delta V$



2nd Law of Thermodynamics

In a closed system, up to and including the universe, energy will spontaneously and irreversibly go from being localized to being spread out.

Entropy: A measure of how much energy has spread out or how spread out energy has become.



Characteristics of Fluids and Solids

Fluids: Substances that flow and conform to the shape of their containers, includes liquids and gases. They can exert perpendicular forces but not shear forces.

Solids: Do not flow. They maintain their shape regardless of their container

Density: Mass per unit volume of substance. $\rho = \frac{m}{V}$

Pressure: A measure of force per unit area; it is exerted by a fluid on the walls of its container and on objects placed in the fluid. Scalar quantity. The pressure exerted by a gas on its container will always be perpendicular to the container walls. $P = \frac{F}{A}$

Absolute Pressure: The sum of all pressures at a certain point within a fluid; it is equal to the pressure at the surface of the fluid plus the pressure due to the fluid itself. $P_{\text{total}} = P_0 + \rho g h$
In water, every additional 10m of depth adds ≈ 1 atm to P_{total}

Gauge Pressure: The difference between absolute pressure and atmospheric pressure. In liquids, gauge pressure is caused by the weight of the liquid above the point of measurement.
$P_{\text{guage}} = P - P_{\text{atm}} = (P_0 + \rho g z) - P_{\text{atm}}$

Hydrostatics

Pascal's Principle: A pressure applied to an incompressible fluid will be distributed undiminished throughout the entire volume of the fluid.
$P = \frac{F_1}{A_1} = \frac{F_2}{A_2}$

Hydraulic Machines: Operate based on the application of Pascal's principle to generate mechanical advantage.

Archimedes' Principle: When an object is placed in a fluid, the fluid generates a *buoyant force* against the object that is equal to the weight of the fluid displaced by the object. $F_B = \rho V g$
Also, $m = \rho V$ and $F = P A$.

$$\frac{\text{Density}_{\text{object}}}{\text{Density}_{\text{displaced fluid}}} = \frac{\text{Weight}_{\text{object in air}}}{\text{Weight}_{\text{object in air}} - \text{Weight}_{\text{object in water}}}$$

If the max buoyant force is larger than the force of gravity on the object, the object will float. If the max buoyant force is smaller than the force of gravity on the object, the object will sink.

If $F_B > m_{\text{object}}\, g$, then the object floats.
If $F_B < m_{\text{object}}\, g$, then the object sinks.

Specific Gravity: Ratio of density of an object to density of water.
$\text{Specific gravity} = \frac{\rho_{\text{object}}}{\rho_{\text{water}}}$

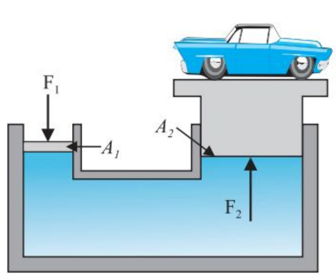
Cohesive vs. Adhesive: Fluids experience *cohesive* forces with other molecules of the same fluid and *adhesive* forces with other materials.

Surface Tension: Cohesive forces give rise to *surface tension*.

Hydraulic Lift:

$P = \frac{F_1}{A_1} = \frac{F_2}{A_2}$

$F_2 = F_1 (\frac{A_2}{A_1})$



Fluid Dynamics

Viscosity: A measure of a fluid's internal friction. *Viscous Drag* is a nonconservative force generated by viscosity.

Laminar Flow: Smooth and orderly.

Turbulent Flow: Rough and disorderly.

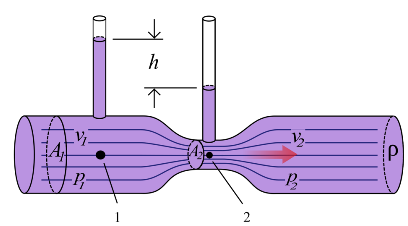
Poiseuille's Law: Determines the rate of laminar flow.
$Q = \frac{\pi r^4 \Delta P}{8 \eta L}$
The relationship between radius and pressure gradient is inverse exponential to the fourth power.

Flow Rate: $Q = \frac{Vol}{time} = A v$ $A =$ cross sectional area, $v =$ velocity

Continuity Equation: Fluids will flow more quickly through narrow passages and more slowly through wider ones.
$Q = v_1 A_1 = v_2 A_2$

Bernoulli's Equation: The sum of the *static pressure* and the *dynamic pressure* will be constant between any two points in a closed system.
$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$

Relationships: For a horizontal flow, there is an inverse relationship between pressure and speed, and in a closed system, there is a direct relationship between cross-sectional area and pressure exerted on the walls of the tube known as *Venturi Effect*.



Venturi Tube: The average height of the horizontal tube remains constant, so $\rho g h$ remains constant at points 1 and 2. As cross-sectional area decreases from point 1 to point 2, the linear speed must increase. As the dynamic pressure increases, the absolute pressure must decrease at point 2, causing the column of fluid sticking up from the Venturi tube be to be lower at point 2.

Fluids in Physiology

Circulatory System: The circulatory system behaves as a closed system with nonconstant flow. The nonconstant flow = our pulse.

$v = \frac{Q}{A} = \frac{\text{cardiac output}}{\text{cross-sectional area}}$ $Q = v A$

$\Delta P = Q \times R = \text{cardiac output} \times \text{resistance}$

$\Delta P = v A R$

Pressure is directly related to velocity, area, and resistance.
Area is inversely related to resistance and velocity.
Cross-sectional area↑ ⇒ Resistance↓ and/or velocity↓

Breathing: Inspiration and expiration create a pressure gradient not only for the respiration system, but for the circulatory system too.

Alveoli: Air at the alveoli has essentially zero speed.

Charges

Coulomb: The SI unit of charge

Protons & Electrons: Protons have a positive charge and electrons have a negative charge. Both protons and electrons possess the fundamental unit of charge ($e = 1.60 \times 10^{-19}$ C). Protons and electrons have different masses.

Attraction & Repulsion: Opposite charges exert *attractive* forces, and like charges exert *repulsive* forces

Conductors: Allow the free and uniform passage of electrons when charged

Insulators: Resist the movement of charge and will have localized areas of charge that do not distribute over the surface of the material

Coulomb's Law

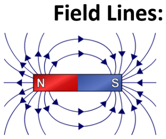
Coulomb's Law: Gives the magnitude of the electrostatic force vector between two charges. The force vector points along the line connecting the centers of the two charges.

$$F = k \frac{|q_1|\,|q_2|}{r^2}$$

Electric Field: Every charge generates an *electric field*, which can exert forces on other charges

$$E = \frac{\text{Force exerted on a test cahrge}}{\text{magnitude of that charge}} = \frac{F_e}{q} = \frac{k\,Q}{r^2}$$

Field Lines: Used to represent the electric field vectors for a charge. They show the activity of a *positive* test charge, which would move away from a positive charge and move toward a negative charge (north to south). The field is stronger where the field lines are closer together.



Special Cases in Electrostatics

Equipotential Lines: A line on which the potential at every point is the same.

Equipotential lines are always perpendicular to electrical field lines. Work will be done when a charge is moved from one equipotential line to another.

No work is done when a charge moves from a point on an equipotential line to another point on the same line.

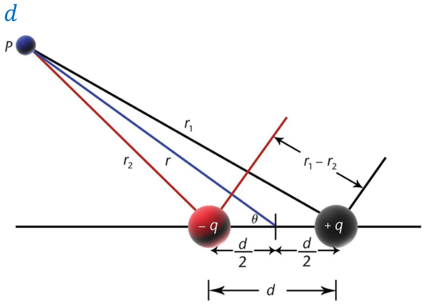
Electric Dipole: Generated by two charges of opposite sign separated by a fixed distance *d*. In an external electric field, an electric dipole will experience a *net torque* until it is aligned with the electric field vector. An electric field will not induce any translational motion in the dipole regardless of its orientation with respect to the electric field vector.

$$V = \frac{k\,q\,d}{r^2}\cos(\theta)$$

Net Torque: $\tau = p\,E\sin(\theta)$

Dipole Moment: The product of charge and separation distance

$p = q\,d$



Essential Equations for Test Day

$F_e = k\frac{\lvert q_1\rvert\,\lvert q_2\rvert}{r^2}$	$U = \frac{k\,Q\,q}{r}$
$E = \frac{k\,Q}{r^2}$	$V = \frac{k\,Q}{r}$

Electrical Potential Energy

Electrical potential energy is the amount of work required to bring the test charge from infinitely far away to a given position in the vicinity of a source charge.

Increases: Like charges move toward each other. Opp charges move apart
Decreases: Opp charges move toward each other. Like charges move apart

Electrical Potential Energy: $U = \frac{k\,Q\,q}{r}$

Electrical Potential

Electrical potential is the electrical potential energy per unit charge. Different points in the space of an electric field surrounding a source charge will have different electrical potential values.

Electrical Potential: From electrical potential energy

$V = \frac{U}{q}$ $\qquad$ $1\text{ volt} = 1\,\frac{\text{J}}{\text{C}}$

Voltage: Potential difference. The change in electrical potential that accompanies the mvmt of a test charge from one position to another.

$$\Delta V = V_b - V_a = \frac{W_{ab}}{q}$$

Test Charges: Will move spontaneously in whichever direction results in a decrease in their electrical potential energy.
POS Test Charges: High potential → Low potential
NEG Test Charges: Low potential → High potential

Magnetism

Magnetic Field: Created by magnets and moving charges.
SI unit is the tesla (T). $1\text{ T} = 10{,}000\text{ gauss}$
Straight Wire: $B = \frac{\mu_0 I}{2\pi r}$ $\qquad$ *Loop of Wire*: $B = \frac{\mu_0 I}{2r}$

Diamagnetic Materials: Possess NO unpaired electrons and are slightly REPELLED by a magnet

Paramagnetic Materials: Possess SOME unpaired electrons and become WEAKLY MAGNETIC in an external magnetic field

Ferromagnetic Materials: Possess SOME unpaired electrons and become STRONGLY MAGNETIC in an external magnetic field

Characteristics of Magnetic Fields: Current-carrying wires create magnetic fields that are concentric circles surrounding the wire. External magnetic fields exert forces on charges moving in any direction except parallel or antiparallel to the field.

Point charges may undergo uniform circular motion in a uniform magnetic field wherein the centripetal force is the magnetic force acting on the point charge. Determine direction using the *right-hand rule*.

Moving Point Charge: $F_B = q\,v\,B\sin(\theta)$
Current-Carrying Wire: $F_B = I\,L\,B\sin(\theta)$

Lorentz Force: Sum of the electrostatic and magnetic forces acting on a body

Charges

Current: The movement of charge that occurs between two points that have different electrical potentials. By convention, current is defined as the mvmt of positive charge from the high-potential end of a voltage source to the low-potential end. In reality, it is negatively-charged particles (electrons) that move in a circuit, from low potential to high potential
$I = \frac{Q}{\Delta t}$

Conductive Materials: *Metallic Conduction*: Relies on uniform mvmt of free electrons in metallic bonds
Electrolytic Conduction: Relies on the ion concentration of a solution
Insulators: Materials that do not conduct a current

Kirchhoff's Laws: Express conservation of charge and energy.

Junction Rule: The sum of currents directed into a point within a circuit equals the sum of the currents directed away from that point. $I_{\text{into } junction} = I_{\text{leaving junction}}$

Loop Rule: In a closed loop, the sum of voltage sources is always equal to the sum of voltage drops. $V_{\text{source}} = V_{\text{drop}}$

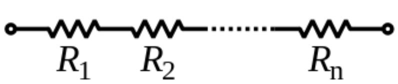
Resistance

Resistance: The opposition to the mvmt of electrons through a material.

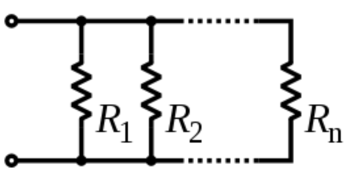
Resistors: Conductive materials with a moderate amount of resistance that slow down electrons without stopping them.
$R = \frac{\rho L}{A}$
$\rho = \text{resistivity}$, $L = \text{length of resistor}$, $A = \text{cross sectional area}$

Ohm's Law: For a given resistance, the magnitude of the current through a resistor is proportional to the voltage drop across the resistor. $V = I\,R$

Resistors in Series: Additive. Sum together to create the total resistance of a circuit.
Resistors in Parallel: ↓equivalent resistance of a circuit.



Resistors in Series: Total resistance is equal to the sum of all the individual resistors.
$R_s = R_1 + R_2 + R_3 + \cdots + R_n$



Resistors in Parallel: To get the total resistance, add the reciprocals of the resistances of each component and take the reciprocal of the sum. Total resistance will always be less than the value of the smallest resistance.
$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_n}$

Capacitance and Capacitors

Capacitors: Have the ability to store and discharge electrical potential energy.

Capacitance: In parallel plate capacitors, it is determined by the area of the plates and the distance between the plates.
$C = \frac{Q}{V}$
Capacitance based on parallel plate geometry: $C = \varepsilon_0 \left(\frac{A}{d}\right)$
Electric field in a capacitor: $E = \frac{V}{d}$
Potential energy of a capacitor: $U = \frac{1}{2}\,C\,V^2$

Series / Parallel: *Series*: ↓equivalent capacitance of a circuit
Parallel: Sum together to create a large equivalent capacitance

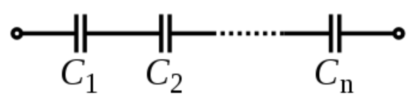
Dielectric Materials: Insulators placed between the plates of a capacitor that increase capacitance by a factor equal to the material's **dielectric constant, κ**

Meters

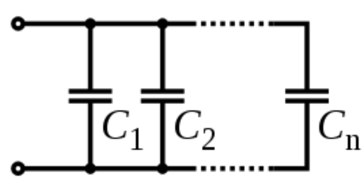
Ammeters: Inserted in SERIES in a circuit to measure current; they have negligible resistance

Voltmeters: Inserted in PARALLEL in a circuit to measure a voltage drop; they have *very large resistances*

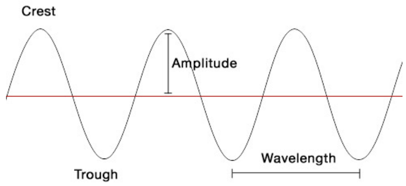
Ohmmeters: Inserted around a resistive element to measure resistance; they are self-powered and have negligible resistance



Capacitors in Series: The total capacitance of capacitors in series is equal to the reciprocal of the sum of the reciprocals of their individual capacitances. Total capacitance will always be less than the value of the smallest capacitor.
$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots + \frac{1}{C_n}$



Capacitors in Parallel: Total capacitance is equal to the sum of all the individual capacitances.
$C_p = C_1 + C_2 + C_3 + \cdots + C_n$



General Wave Characteristics

Transverse Waves: Have oscillations of wave particles *perpendicular* to the direction of wave propagation. LIGHT

Longitudinal Waves: Have oscillations of wave particles *parallel* to the direction of wave propagation. SOUND

$v = f\lambda$ v = wave speed f = frequency λ = wavelength

$v = \frac{B}{\rho}$ B = bulk modulus (increases from gas to liquid to solid) ρ = density

Displacement (x): Refers to how far a point is from the equilibrium position, expressed as a vector quantity.

Amplitude (A): The magnitude of its maximal displacement. The maximum point is called a *crest*. The minimum point is called a trough.

Wavelength (λ): The distance between two crests or two troughs.

Frequency (f): The number of cycles it makes per second. Expressed in Hz.

Angular Frequency (ω): Another way of expressing frequency and is expressed in radians per second. $\omega = 2\pi f = \frac{2\pi}{T}$

Period (T): The number of seconds it takes to complete a cycle. It is the inverse of frequency. $T = \frac{1}{f}$

Interference: Describes the ways in which waves interact in space to form a resultant wave.

Constructive Interference: Occurs when waves are exactly *in phase* with each other. The amplitude of the resultant wave is equal to the *sum of the amplitudes* of the two interfering waves.

Destructive Interference: Occurs when waves are exactly *out of phase* with each other. The amplitude of the resultant wave is equal to the *difference in amplitude* between the two interfering waves.

Partially Constructive / Destructive Interference: Occurs when two waves are not quite perfectly in or out of phase with each other. The displacement of the resultant wave is equal to the sum of the displacements of the two interfering waves.

Traveling Waves: Have continuously shifting points of maximum and minimum displacement.

Standing Waves: Produced by the constructive and destructive interference of two waves of the same frequency traveling in opposite directions in the same space.

Antinodes: Points of maximum oscillation.

Nodes: Points where there is no oscillation.

Resonance: The increase in amplitude that occurs when a periodic force is applied at the natural (resonant) frequency.

Damping: A decrease in amplitude caused by an applied or nonconservative force.

Sound

Sound: Produced by mechanical disturbance of a material that creates an oscillation of the molecules in the material.

Propagation: Sound propagates through all forms of matter but not through a vacuum. Fastest through solids, followed by liquids, and slowest through gases. Within a medium, as density increases, speed of sound decreases.

Pitch: Our perception of frequency.

Doppler Effect: A shift in the perceived frequency of a sound compared to the actual frequency of the emitted sound when the source of the sound and its detector are moving relative to one another.

The apparent frequency will be higher than the emitted frequency when the source and detector are moving toward each other.

The apparent frequency will be lower than the emitted frequency when the source and detector are moving away from each other.

The apparent frequency can be higher, lower, or equal to the emitted frequency when the two objects are moving in the same direction, depending on their relative speeds.

$f' = f\left(\frac{v \pm v_D}{v \mp v_s}\right)$ f' = percieved freq f = emitted freq

Use the Top sign for "toward", bottom sign for "away"

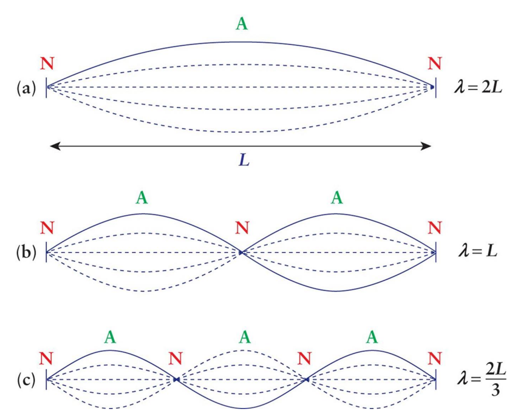
Intensity: Intensity is related to a wave's amplitude. Intensity decreases over distance and some energy is lost to attenuation from frictional forces.

$I = \frac{P}{A}$ P = power A = area

Strings and Open Pipes: Support standing waves and the length of the string or pipe is equal to some multiple of half-wavelengths. $L = \frac{n\lambda}{2}$ $(n = 1, 2, \ldots)$

Closed Pipes: Closed at one end. Support standing waves, and the length of the pipe is equal to some odd multiple of quarter-wavelengths. $L = \frac{n\lambda}{4}$ $(n = 1, 3, \ldots)$

Ultrasound: Uses high frequency sound waves to compare the relative densities of tissues in the body. *Doppler Ultrasound* is used to determine the flow of blood within the body.



1st, 2nd, and 3rd Harmonics of a String: N = node, A = antinode. As a shortcut, for strings attached at both ends, the number of antinodes present will tell you which harmonic it is

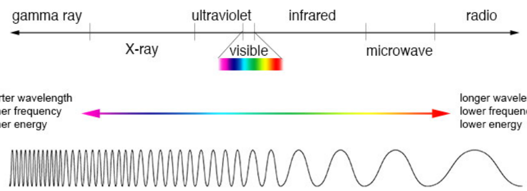
Electromagnetic Spectrum

Electromagnetic Waves: Transverse waves that consist of an oscillating electric field and an oscillating magnetic field. The two fields are perpendicular to each other and to the direction of propagation of the wave.

Electromagnetic Spectrum: The range of frequencies and wavelengths found in EM waves.

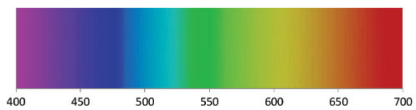
EM Spectrum: small λ ←→ high λ

high energy ←→ low energy



Note: Gamma, X-ray, and higher UV are ionizing. They can liberate electrons from nearby atoms and create free radicals.

Visible Spectrum:



Wavelength (nm)

Hydrogen Spectral Series: *Lyman*: Ultraviolet, n = 1
Balmer: Visible, n = 2
Paschen: Infrared, n = 3
Acrostic "Loves Beer Pong", then n = 1, n = 2, n = 3

Ryberg Formula: $h\,f = R\,(\frac{1}{n_{final}^2} - \frac{1}{n_{initial}^2})$

Diffraction

Diffraction: The bending and spreading out of light waves as they pass through a narrow slit. Diffraction may produce a large central light fringe surrounded by alternating light and dark fringes with the addition of a lens.

Interference: When waves interact with each other, the displacements add together in a process called *interference*.

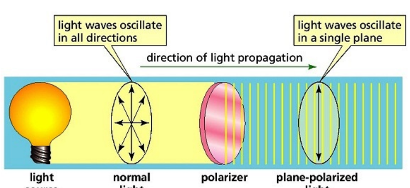
Young's Double-Slit Experiment: Shows the constructive and destructive interference of waves that occur as light passes through parallel slits, resulting in minima (dark fringes) and maxima (bright fringes) of intensity.

Polarization

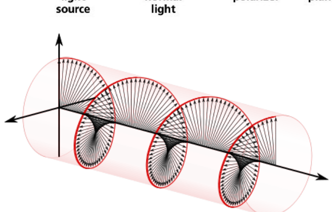
Plane-Polarized Light: A polarizing filter only lets light through if the E field of the wave aligns with the openings in the filter. The E fields of the exiting light oscillate along the same axis.

Circular Polarized Light: All of the light rays have electric fields with equal intensity but *constantly rotating direction*. Circularly polarized light is created by exposing unpolarized light to special pigments or filters.

Plane-Polarized Light



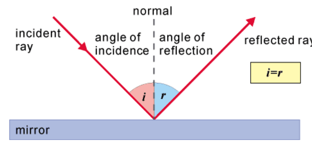
Circular-Polarized Light



Geometric Optics

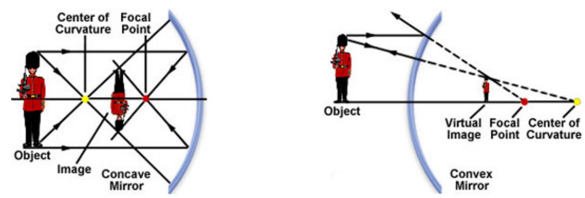
Reflection: Rebounding of incident light waves at a medium's boundary

Law of Reflection: $\theta_1 = \theta_2$



Spherical Mirrors:

Mirror	Image Produced	Position	Cause
Concave	Real	Inverted	Object's position is greater than the focal length
	Virtual	Upright	Object's position is less than the focal length
Convex	Virtual	Upright & smaller	
Plane	Virtual	Upright & same size	Can think of these as spherical mirrors with infinite radii of curvature



Refraction: The bending of light as it passes from one medium to another. The speed of light changes depending on index of refraction of the medium. This speed change causes refraction. The amount of refraction depends on the wavelengths involved.

Index of refraction: $n = \frac{c}{v}$

c = speed of light in vacuum v = speed of light in the medium

Dispersion: When various wavelengths of light separate from each other.

Snell's Law: The law of refraction. There is an inverse relationship between the index of refraction and the sine of the angle of refraction (measured from the normal)

$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$

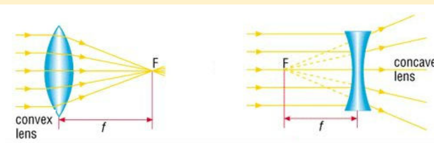
Total Internal Reflection: When light cannot be refracted out of a medium and is instead reflected back inside the medium. Occurs when light moves from a medium with a HIGHER index of refraction to a medium with a LOWER index of refraction with a high incident θ.

Critical Angle: The minimum incident angle at which total reflection occurs.

$\theta_c = \sin^{-1}(\frac{n_2}{n_1})$

Lenses: Refract light to form images of objects. Thin symmetrical lenses have focal points on each side.

Lens	Image Produced	Position	System
Convex	Real	Inverted	Converging system
	Virtual	Upright	Converging system
Concave	Virtual	Upright	Diverging system



F = focus f = focal length $f = \frac{1}{2}r$

Lensmaker's Equation: Lenses with non-negligible thickness require the lensmaker's eq.

$\frac{1}{f} = (n-1)(\frac{1}{r_1} - \frac{1}{r_2})$

The Photoelectric Effect

The ejection of an electron from the surface of a metal in response to light

Energy of a photon of light: $E = h\,f$

To calculate λ from f use: $c = f\,\lambda$ $\quad c = \text{speed of light} = 3 \times 10^8 \frac{\text{m}}{\text{s}}$

Maximum kinetic energy in the photoelectric effect: $K_{\text{max}} = h\,f - W$

Threshold Frequency: The minimum light *frequency* necessary to eject an electron from a given metal.

Work Function: The minimum *energy* necessary to eject an electron from a given metal.

$W = h\,f_{\text{T}}$ $\quad h = \text{Planck's constant} = 6.626 \times 10^{-34}\ \text{J s}$

Absorption and Emission of Light

Bohr Model: States that electron energy levels are stable and discrete, corresponding to specific orbits.

Absorption: An electron can jump from a lower-energy to a higher-energy orbit by absorbing a photon of light of the same frequency as the energy difference between the orbits.

Emission: When an electron falls from a higher-energy to a lower-energy orbit, it emits a photon of light of the same frequency as the energy difference between the orbits.

Absorption Spectra: May be impacted by small changes in molecular structure.

Fluorescence: Occurs when a species absorbs high-frequency light and then returns to its ground state in multiple steps. Each step has less energy than the absorbed light and is within the visible range of the electromagnetic spectrum.

Nuclear Binding Energy and Mass Defect

Nuclear Binding Energy: Is the amount of energy that is released when nucleons (protons and neutrons) bind together.

4 Fundamental Forces of Nature: Strong and weak nuclear force, electrostatic forces, gravitation.

Mass Defect: The difference between the mass of the unbonded nucleons and the mass of the bonded nucleons within the nucleus. The unbonded constituents have more energy and, therefore, more mass than the bonded constituents. The mass defect is the amount of mass converted to energy during nuclear fusion.

Nuclear Reactions

Fusion: Occurs when small nuclei combine into larger nuclei.

Fission: Occurs when a large nucleus splits into smaller nuclei.

Energy is released in both fusion and fission because the nuclei formed in both processes are more stable than the starting nuclei.

Radioactive Decay: The loss of small particles from the nucleus.

Mass → Charge → $^{4}_{+2}\alpha \qquad ^{0}_{-1}\beta^{-} \qquad ^{0}_{+1}\beta^{+} \qquad ^{0}_{0}\gamma$

Alpha (α) Decay: The emission of an alpha particle (α, $^{4}_{2}\alpha$, $^{4}_{2}\text{He}$), which is a helium nucleus.

$^{A}_{Z}\text{X} \rightarrow {}^{A-4}_{Z-2}\text{Y} + {}^{4}_{+2}\alpha$

Beta-negative (β^-) Decay: The decay of a neutron into a proton, with emission of an electron (e^-, β^-) and an antineutrino ($\bar{\nu}$).

$^{A}_{Z}\text{X} \rightarrow {}^{A}_{Z+1}\text{Y} + {}^{0}_{-1}\beta^{-}$

Beta-positive (β^+) Decay: "*Positron emission*", the decay of a proton into a neutron, with emission of a positron (e^+, β^+) and a neutrino (ν).

$^{A}_{Z}\text{X} \rightarrow {}^{A}_{Z-1}\text{Y} + {}^{0}_{+1}\beta^{+}$

Gamma (γ) Decay: The emission of a gamma ray, made up of photons, which converts a high-energy nucleus into a more stable nucleus.

$^{A}_{Z}\text{X}^{*} \rightarrow {}^{A}_{Z}\text{X} + {}^{0}_{0}\gamma$

Electron Capture: Is the absorption of an electron from the inner shell that combines with a proton in the nucleus to form a neutron.

$^{A}_{Z}\text{X} + \text{e}^{-} \rightarrow {}^{A}_{Z-1}\text{Y}$

Half-Life: The amount of time required for half of a sample of radioactive nuclei to decay. Or, the time it takes to reduce the radioactivity of a substance by half.

Exponential Decay: The rate at which radioactive nuclei decay is proportional to the number of nuclei that remain.

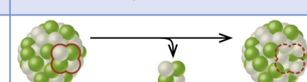
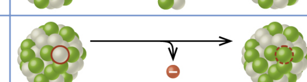
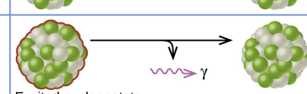
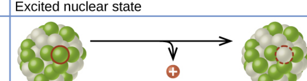
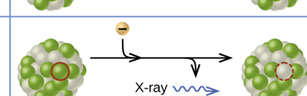
$n = n_0\, e^{-\lambda t}$

$n = \#\text{ of undecayed nuclei}$

$n_0 = \#\text{ of undecayed nuclei at } t = 0$

$\lambda = \text{known decay constant}$

Note: If the problem just says "beta", they mean "beta negative". Beta-negative is the default.

Type	Nuclear equation	Representation	Change in mass/atomic numbers
Alpha decay	$^{A}_{Z}\text{X} \quad {}^{4}_{2}\text{He} + {}^{A-4}_{Z-2}\text{Y}$		A: decrease by 4 Z: decrease by 2
Beta decay	$^{A}_{Z}\text{X} \quad {}^{0}_{-1}\text{e} + {}_{Z+1}^{A}\text{Y}$		A: unchanged Z: increase by 1
Gamma decay	$^{A}_{Z}\text{X} \quad {}^{0}_{0}\gamma + {}^{A}_{Z}\text{Y}$		A: unchanged Z: unchanged
Positron emission	$^{A}_{Z}\text{X} \quad {}^{0}_{+1}\text{e} + {}_{Y-1}^{A}\text{Y}$		A: unchanged Z: decrease by 1
Electron capture	$^{A}_{Z}\text{X} \quad {}^{0}_{-1}\text{e} + {}_{Y-1}^{A}\text{Y}$		A: unchanged Z: decrease by 1

Arithmetic and Sig Figs

Scientific Notation: Improves the ease of calculation. It is usually helpful to convert a number to scientific notation

$(3 \times 10^3) - (9 \times 10^2) = (3 \times 10^3) - (0.9 \times 10^3) = 2.1 \times 10^3$

$(1.5 \times 10^3)(3 \times 10^2) = 4.5 \times 10^5$ - Add exponents

$\frac{8 \times 10^{-2}}{2 \times 10^3} = 4 \times 10^{-5}$ - Subtract exponents

$(2 \times 10^{-2})^3 = 8 \times 10^{-6}$ - Multiply exponents

$\sqrt{9 \times 10^8} = (9 \times 10^8)^{1/2} = 3 \times 10^4$ - Divide the exponent by 2

LARS mnemonic when moving the decimal within scientific notation.
Left $\Rightarrow$ Add, Right $\Rightarrow$ Subtract

$481.2 \times 10^7 = 4.812 \times 10^9$ - Left Add
$0.00314 \times 10^{-3} = 3.13 \times 10^{-6}$ - Right Subtract

Significant Figures: Include all nonzero digits and any trailing zeroes in a number with a decimal point.

Estimation: *Multiplication*: If one number is rounded up, the other should be rounded down in proportion.

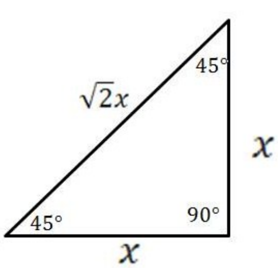
Division: If one number is rounded up, the other should also be rounded up in proportion.

Trigonometry

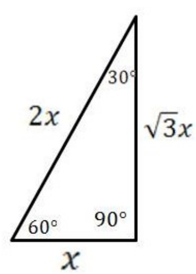
SOH CAH TOA: $\sin(\emptyset) = \frac{O}{H}$ $\cos(\emptyset) = \frac{A}{H}$ $\tan(\emptyset) = \frac{O}{A} = \frac{\sin(\emptyset)}{\cos(\emptyset)}$

Common Values:

θ	cos(θ)	sin(θ)	tan(θ)
0°	1	0	0
30°	$\frac{\sqrt{3}}{2}$	$\frac{1}{2}$	$\frac{\sqrt{3}}{3}$
45°	$\frac{\sqrt{2}}{2}$	$\frac{\sqrt{2}}{2}$	1
60°	$\frac{1}{2}$	$\frac{\sqrt{3}}{2}$	$\sqrt{3}$
90°	0	1	undefined
180°	-1	0	0



45-45-90 triangle



30-60-90 triangle

Exponents, Log and Ln

Estimating Square Roots: To calculate the square root of any number less than 400, you can approximate its value by determining which two perfect squares it falls between. $\sqrt{180}$ is between 13 and 14.

$\sqrt{180} = \sqrt{4} \times \sqrt{9} \times \sqrt{5} = 2 \times 3 \times \sqrt{5} = 6\sqrt{5}$
$\sqrt{5} \approx 2.2$ so $6\sqrt{5} \approx 13.2$.

Common Squares:

$1^2 = 1$	$6^2 = 36$	$11^2 = 121$	$16^2 = 256$
$2^2 = 4$	$7^2 = 49$	$12^2 = 144$	$17^2 = 289$
$3^2 = 9$	$8^2 = 64$	$13^2 = 169$	$18^2 = 324$
$4^2 = 16$	$9^2 = 81$	$14^2 = 196$	$19^2 = 361$
$5^2 = 25$	$10^2 = 100$	$15^2 = 225$	$20^2 = 400$

Log and Ln: $\mathbf{\log(B) = A}$, $\mathbf{10^A = B}$ $\mathbf{\ln(B) = A}$, $\mathbf{e^A = B}$ $\mathbf{e = 2.7}$

$\log_A(1) = 0$ $\log_A(\text{greater than } 1) = \text{Positive}$

$\log_A(A) = 1$ $\log_A(\text{less than } 1) = \text{Negative}$

$\log(A \times B) = \log(A) + \log(B)$

$\log\left(\frac{A}{B}\right) = \log(A) - \log(B)$

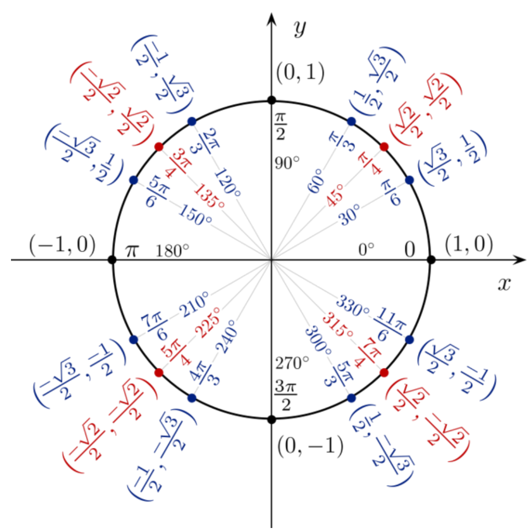
$\log(A^B) = B \log(A)$

$\log\left(\frac{1}{A}\right) = -\log(A)$

Estimating Log: $\log(n \times 10^m) = \log(n) + \log(10^m) = \log(n) + m$

$\log(n \times 10^m) \approx m + 0.n$

The Unit Circle



$x = \cos(\theta)$ $y = \sin(\theta)$

$\tan(\theta) = \frac{y}{x} = \frac{\sin(\theta)}{\cos(\theta)}$

The Scientific Method

Initial steps: Focus on formulating a hypothesis.
Intermediate steps: Focus on testing that hypothesis.
Final steps: Provide results for further testing of the hypothesis.

FINER Method: Assesses the value of a research question on the basis of whether or not it is feasible, interesting, novel, ethical, and relevant.

Ethics

Medical Ethics: 4 tenets: *beneficence*, *nonmaleficence*, respect for patient *autonomy*, and *justice*

Research Ethics: *Respect for persons*, *justice*, *beneficence*. Must have *equipoise* – a lack of knowledge about which arm of research study is better for the subject

Research in the Real World

Populations: All of the individuals who share a set of characteristics. Population data are called *parameters*.

Samples: A subset of a population that are used to estimate population data. Sample data are called *statistics*.

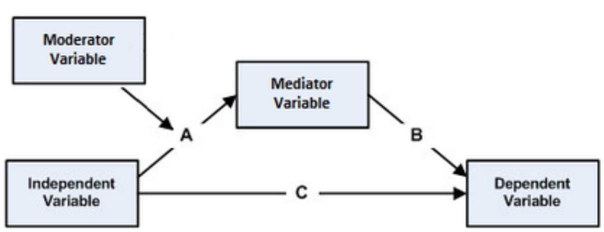
Internal Validity: If the outcome of the research is that the DV has been affected as a result of manipulating the IV. Any confounding variables have been controlled for.

External Validity: Refers to the ability of a study to be *generalized* to the population that it describes.

Within-Subject Design: Controls for individual variations in a measurement by comparing the scores of a subject in one condition to the scores of the same subject in other conditions. So the subject serves as its own control.

Statistical Significance: Refers to the low likelihood of the experimental findings being due to chance.

Clinical Significance: Refers to the usefulness or importance of experimental findings to patient care or patient outcomes.



Basic Science Research

Occurs in the lab, not in human subjects. Basic science research is often the best type for demonstrating causality because the experimenter has the highest degree of control over the experimental conditions.

Variables: *Independent Variable*: Manipulated
Dependent Variable: Observe for change.

Controls: *Positive Controls*: Ensure that a change in the dependent variable occurs when expected.
Negative Controls: Ensure that no change in the dependent variable occurs when none is expected.

Accuracy (Validity): The quality of approximating the true value.

Precision (Reliability): The quality of being consistent in approximations.

Human Subject Research

Human subjects research is subject to ethical constraints that are generally absent in basic science research. Causal conclusions are harder to determine because circumstances are harder to control. Much of human subject research is *observational*.

Cohort Studies: Record exposures throughout time and then assess the rate of a certain outcome.

Cross-sectional Studies: Assess both exposure and outcome at the same point in time.

Case-Control Studies: Assess outcome status and then assess for exposure history.

Hill's Criteria: Used to determine if causality can be supported. The criteria include *temporality* (necessary for causality), *strength*, *dose-response*, *relationships*, *consistency*, *plausibility* etc.

Bias: *Selection Bias*: The sample differs from the population.

Detection Bias: Arises from educated professionals using their knowledge in an inconsistent way by searching for an outcome disproportionately in certain populations.

Hawthorne Effect: Behavior of subjects is altered simply by knowing that they are being studied.

Social Desirability Bias: A type of response bias that is the tendency of survey respondents to answer questions in a manner that will be viewed favorably by others.

Placebo Effect: Results are influenced by the fact that the subjects are aware they are or are not in the control group.

Confounding Variable: An extraneous variable that relates to BOTH the dependent and independent variables.

Mediating Variable: The means by which the IV affects the DV. It is the "middleman" between the IV and DV.

Moderating Variable: Influences the already established relationship between the IV and DV. Moderators affect the strength of the relationship between the two variables.

Measures of Central Tendency

Provide a single value representation for the middle of the data set.

Mean: The average.

Median: The value that lies in the middle of the data set. Tends to be least susceptible to outliers, but may not be useful for data sets with large ranges.

Mode: The data point that appears most often.

Probability

Independent Events: The probability of independent events does not change based on the outcomes of other events.

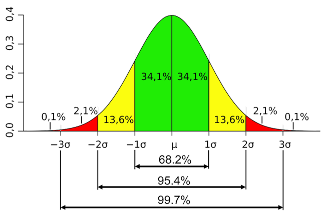
Dependent Events: The probability of a dependent event changes depending on the outcomes of other events.

Terminology: *Mutually Exclusive:* Cannot occur simultaneously.

When a set of outcomes is *exhaustive*, there are no other possible outcomes.

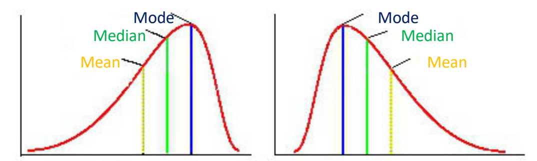
Distributions

Normal Distribution: Symmetrical and the mean, median, and mode are equal.



Standard Distribution: A normal distribution with a mean of 0 and a standard deviation of 1. It is used for most calculations.

Skewed Distribution: Have differences in their mean, median, and mode. Skew direction is the direction of the *tail*.



LEFT skewed (negative skewedness) RIGHT Skewed (positive skewedness)

Bimodal Distribution: Multiple peaks, although not necessarily multiple modes.

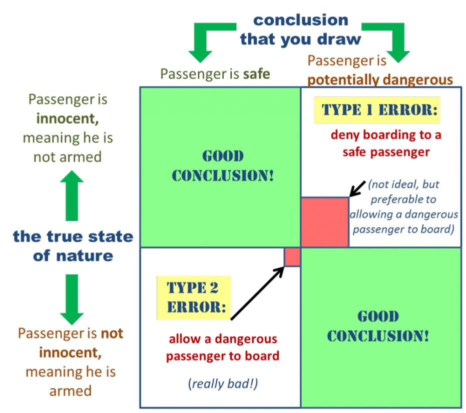
Statistical Testing

Hypothesis Tests: Use a known distribution to determine whether the null hypothesis can be rejected.

p-value: Whether or not a finding is statistically significant is determined by the comparison of a *p-value* to the selected *significance level* (α). A significance level of 0.05 is commonly used.

Confidence Intervals: Are a range of values about a sample mean that are used to estimate the population mean. A wider interval is associated with a higher *confidence level* (95% is common).

Hypothesis Testing Chart with Type 1 and Type 2 Errors



Measures of Distribution

Range: Difference between largest and smallest value.

Interquartile Range: The difference between the value of the *third quartile* and *first quartile*. Can be used to determine outliers.

Standard Deviation (σ): A measurement of variability about the mean. Can be used to determine outliers.

Outliers: In general, any value that lies more than 3 standard deviations from the mean.

Charts, Graphs, and Tables

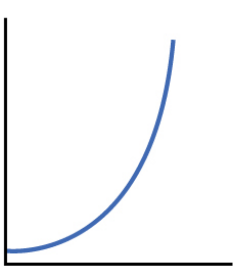
Pie and Bar Charts: Used to compare categorical data.

Histograms and Box Plots: Used to compare numerical data.

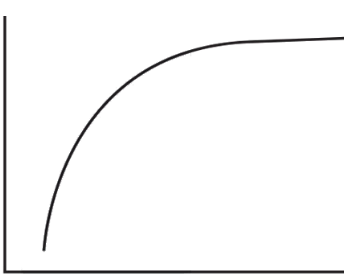
Linear, Semilog, and Log-log Plots: Can be distinguished by the axes.

Slope: $\frac{\text{rise}}{\text{run}}$

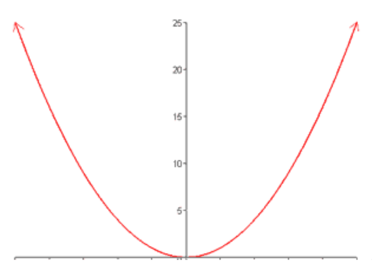
Exponential Relationship



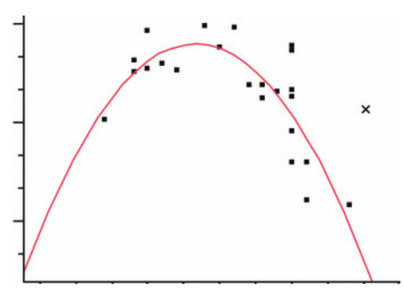
Logarithmic Relationship



Quadratic Relationship

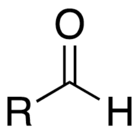


Curvilinear Relationship

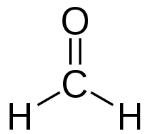


Organic Chemistry Common Names

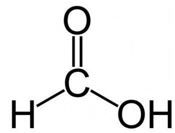
Formyl Group



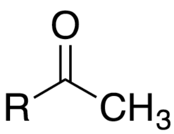
Formaldehyde



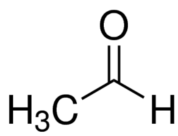
Formic Acid



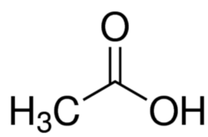
Acetyl Group



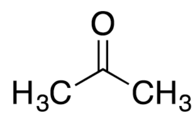
Acetaldehyde



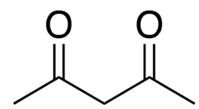
Acetic Acid



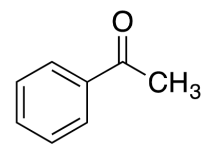
Acetone



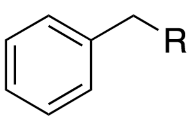
Acetylacetone



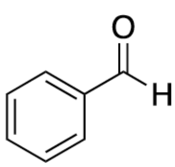
Acetophenone



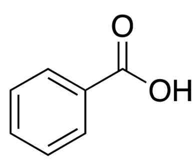
Benzyl Group



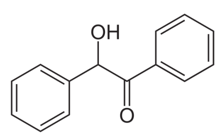
Benzaldehyde



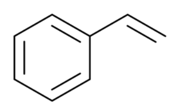
Benzoic Acid



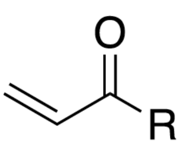
Benzoin



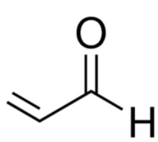
Styrene



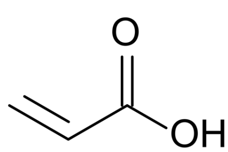
Acryl Group



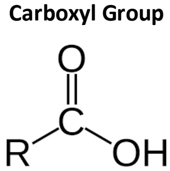
Acrolein



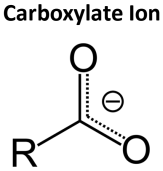
Acrylic Acid



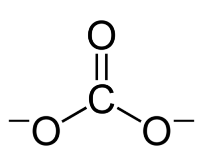
Carboxyl Group



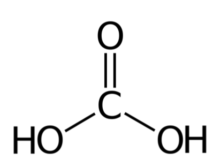
Carboxylate Ion



Carbonate Ion

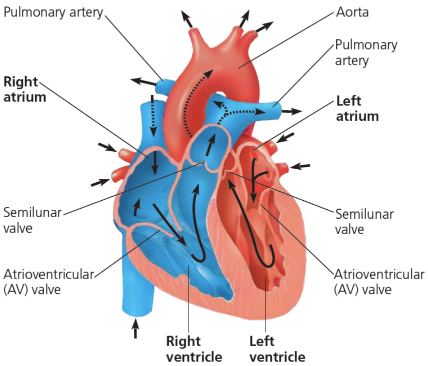


Carbonic Acid

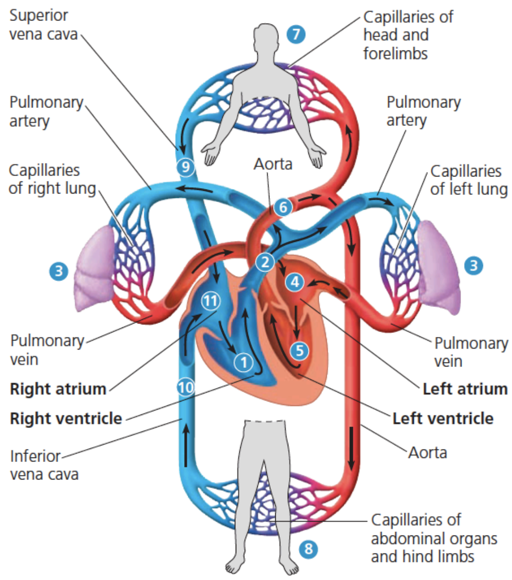


The Heart and Oxygen Transport

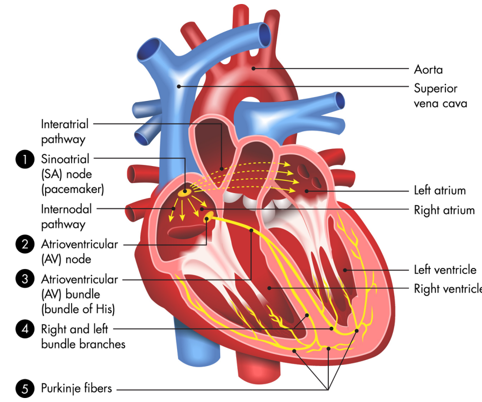
Anatomy of the Heart



Blood Flow Through the Heart



Electrical Conduction Through the Heart



Hemoglobin

Found in blood. It has four polypeptide chains (tetramer), each combined with an iron-containing heme group. Most oxygen transport takes place through the use of hemoglobin. A small amount of oxygen will still dissolve in the plasma and be transported on its own.

Each RBC contains 2.7×10^8 hemoglobin molecules.

Cooperative Binding: When an O_2 binds to one of the four binding sites, it becomes more likely that the remaining sites will bind to O_2.

CO_2 and H^+ Inhibition: Allosterically inhibits Hemoglobin. That means CO_2 and H^+ will trigger the heme group to release its O_2.

The process starts when CO_2 enters the RBC where carbonic anhydrase resides (the enzyme for the bicarbonate buffer). The CO_2 combines with H_2O to make H_2CO_3 which dissociates into H^+ and HCO_3^-. The H^+ allosterically inhibits hemoglobin, e.g. changes the shape of hemoglobin, so it can't hold onto the O_2. Since CO_2 initiates this process, the result is O_2 is released near lots of CO_2, which is where respiration is happening and O_2 is needed.

$\downarrow$pH $\Rightarrow$ $\downarrow$heme affinity for O_2, curve shifts RIGHT (Bohr shift).

2,3-BPG Inhibition: Another allosteric regulator. It places itself in the center of the tetramer and causes α and β subunits to release their O_2. Note, fetal hemoglobin has α and γ (gamma) subunits. γ subunits do not respond to 2,3-BPG, so HbF ends up with more O_2 than HbA. 2,3-BPG causes a RIGHT shift on the dissociation curve, like CO_2 and H^+.

$\uparrow$2,3-BPG means your body needs more oxygen.

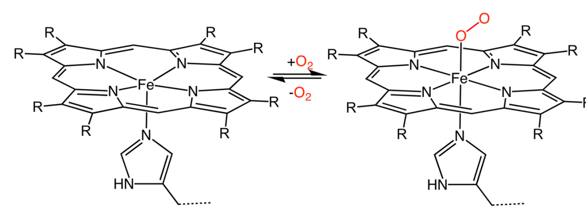
CO_2 Transport: After delivering O_2 to a muscle, the CO_2 that triggered the release of O_2 will remain in the hemoglobin. The RBC then travels back to the lung, bringing the CO_2 with it.

Fetal Hemoglobin: HbF has a higher affinity for O_2 compared to adult hemoglobin (HbA). This is because its tetramer contains γ subunits, which don't respond to 2,3-BPG. HbF dissociation curve has a LEFT shift, as if 2,3-BPG levels are low.

p50: Oxygen pressure when 50% of hemoglobin has an O_2 bound. P50 is LOWER for HbF due to the high affinity HbF has for oxygen.

Sickle Cell Anemia: A disease that affects hemoglobin. Caused when Val replaces Glu. Hemoglobin aggregates into insoluble fibers. ~~Glu~~ $\Rightarrow$ Val

Hypoxia: Oxygen deprivation.



Binding of Oxygen to a Heme Prosthetic Group
Without O_2, the Fe atom sits below the plane. When O_2 binds, the electrons in the Fe atom rearrange so it fits in the hole and becomes level with the plane; also pulls His up towards the plane.

Myoglobin

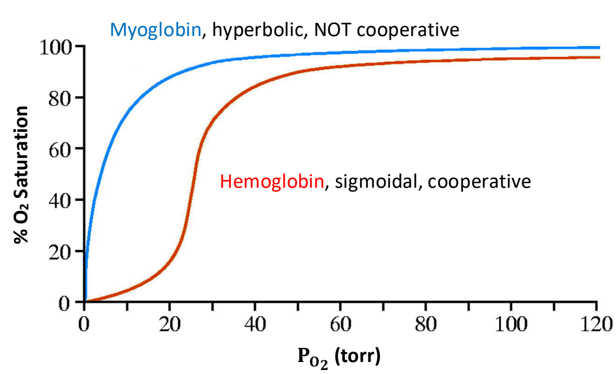
Found in muscle tissue, it stores and releases oxygen. It is a monomer and contains only 1 heme group. Myoglobin is NOT pH sensitive.

O_2 Affinity: Myoglobin has a much HIGHER oxygen affinity than hemoglobin. This means it can bind more securely to the oxygen.

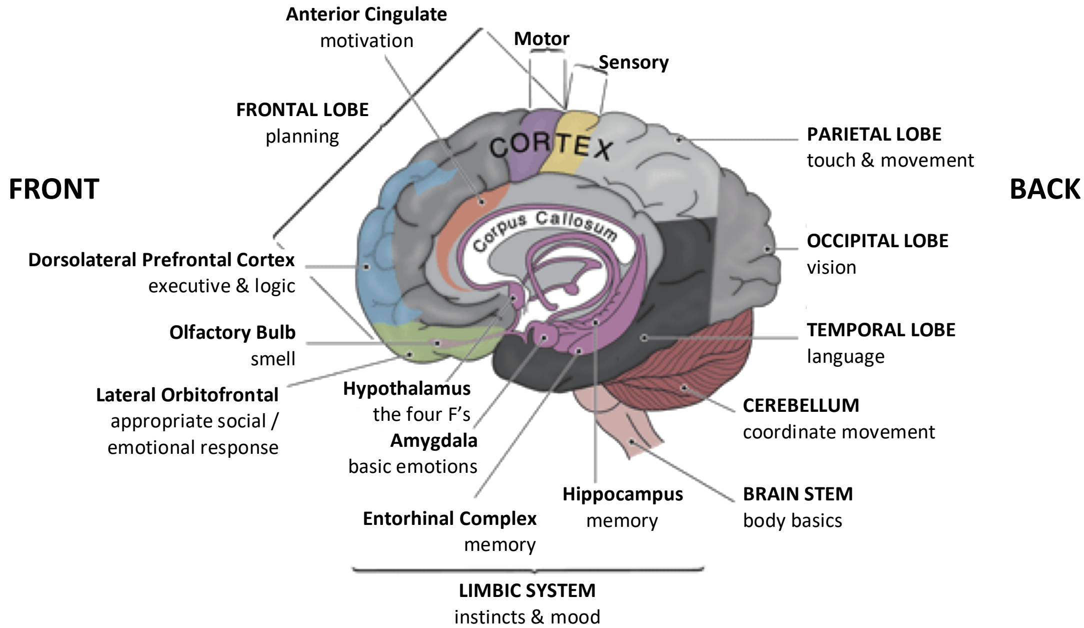
Heme Group: Myoglobin has only 1 heme group. This is why it cannot exhibit cooperative binding and it has a hyperbolic curve.

2,3-BPG: 2,3-BPG has NO AFFECT on myoglobin.

Hemoglobin and Myoglobin Dissociation Curves



The Brain



Cerebrum

Higher brain function such as though and action.

Cerebral Cortex: Layer of grey matter on the outside of the Cerebrum. *Primary Cortex*: Basic motor and sensory functions. *Associative Cortex*: Associates different types of information to do more complex processing and functions.

Prefrontal Cortex: Located at the front of the brain, behind the forehead. It is part of the Cerebral Cortex. Associated with "cerebral" activities. Ex: If your instinct is to attack someone, your prefrontal cortex will think about it and tell you to walk away.

Frontal Lobe: Reasoning, planning, speech production (Broca's Area), movement, emotions, and problem solving.

Temporal Lobe: Perception of auditory stimuli, memory, and language comprehension (Wernicke's Area).

Parietal Lobe: Movement, orientation, proprioception, recognition and perception of stimuli.

Occipital Lobe: Visual processing.

Hemispheres and Functions:

Left: Language, logic, math and science, analytic thought, written, right-hand control.

Right: Creativity, 3-D forms, imagination, intuition, art & music, left-hand control.

Hemispheres and Emotion:

Left: Positive emotions, more sociable, joyful, enthusiastic.

Right: Negative emotions, socially isolated, fearful, avoidant, depressed.

Cerebellum

Motor control. Regulation and coordination of movement, posture, and balance. The cerebellum does not initiate mvmt, it helps control and smooth out the mvmt.

Movement Control: The cerebellum receives a motor plan from the Cerebrum and compares it to position sense information from Somatosensory Neurons. It then determines if corrections are necessary. If needed, the cerebellum will tell the cerebrum to adjust the mvmt.

Speech Control: Cerebellum coordinates the mouth muscles that produce speech.

Damage: Damage to the cerebellum produces disorders in fine movement, equilibrium, posture, and motor learning. The damage could also impair speech enunciation or eye movement.

Limbic System

Sits on top of the brain stem.

Hypothalamus: "Below the thalamus". Regulates the autonomic nervous system via the endocrine system. The four Fs.

Amygdala: Aggression center. Fear and anxiety. Stimulation causes more fear & anxiety. Damage causes mellow mood, and less fear; hypersexualtiy, disinhibition. *Kluver-Busy Syndrome* is the destruction of the amygdala.

Thalamus: Sensory relay station.

Hippocampus: Converts STM → LTM. If damaged, new memories fail to form.

Brain Stem

Connects all parts of the nervous system together, including cranial nerves.

Pons: Regulates waking and relaxing.

Reticular Formation: Alertness and motivation. Controls autonomic functions such as circulation, respiration and digestion. Also plays a role in higher cognition functions.

Medulla: Regulates the autonomic activity of the heart and lungs.

Long Tracts: Collections of axons connecting the cerebrum to the spinal cord, passing through the brainstem. Upper motor neurons signaling down and somatosensory long tracts signaling up.

Endocrine Organs and Hormones

Hypothalamus

"Below the thalamus". Regulates the autonomic nervous system via the endocrine system. The four F's.

GnRH: Gonadotropin-Releasing Hormone. Stimulates the release of **FSH** and **LH**.

GHRH: Growth Hormone-Releasing Hormone. Stimulates the release of **GH**.

TRH: Thyrotropin-Releasing Hormone. Stimulates the release of **TSH**.

CRH: Corticotropin-Releasing Hormone. Stimulates pituitary synthesis of **ACTH**.

PIF or Dopamine: A catecholamine. As a neurotransmitter, most rewards will increase the level of dopamine.

ADH and Oxytocin: Produced in the hypothalamus; released from the posterior pituitary.

Pancreas

A large gland behind the stomach. It secretes digestive enzymes into the duodenum. Embedded in the pancreas are the islets of Langerhans which secrete insulin and glucagon into the blood.

Insulin: Peptide hormone secreted by β-islet cells. Its function is to help glucose enter the cells. ↑Glucose triggers insulin secretion. Inhibited by **norepinephrine**.

Glucagon: Peptide hormone secreted by α-islet cells. Its function is to help glucose enter the blood stream. ↓Glucose triggers glucagon secretion.

Somatostatin: (GHIH) Growth Hormone-Inhibiting Hormone. A peptide hormone secreted by δ-islet (delta) cells. Inhibits **GH** and also leads to ↓**insulin** and ↓**glucagon**.

Gonads

A gland that produces gametes (sex cells) and sex hormones. In males, the gonads are testicles, in females they are ovaries.

Testosterone: Produced by the testes in me and ovaries in women with a small amount produced by the Adrenal Cortex. In males, it is the primary sex hormone and an anabolic steroid.

Estrogen: Produced by the ovaries. It is the primary female sex hormone and leads to the development of secondary sexual characteristics. Estrogen also regulates the menstrual cycle. ↓milk production.

Progesterone: Produced by the ovaries. Prepares the endometrium for potential pregnancy following ovulation. ↓milk production

Pineal Gland

Located in the epithalamus, tucked into a groove between the two thalamus halves.

Melatonin: Regulates sleep / wakefulness and controls the circadian rhythm.

Adrenal Cortex

Sits along the perimeter of the adrenal gland (top of kidney). Mediates stress response.

Glucocorticoids: *Cortisol* is released during stress.
↑Glucose in blood through gluconeogenesis
↓Immune system
↓Protein synthesis
Cortisone is similar to Cortisol.
↓Immune response so ↓inflammation and ↓allergic response

Mineralcorticoids: *Aldosterone* causes ↑Na^+ in blood which ↑BP. It is regulated by K^+ and angiotensin II which is derived from angiotensin I.

Androgens: Converted to Testosterone and Estrogen in the gonads.

Anterior Pituitary

Anterior lobe of the pituitary gland. It regulates several physiological processes including stress, growth, reproduction, and lactation.

FSH: Follicle-Stimulating Hormone. A gonadotropin. In males it promotes spermatogenesis. In females it stimulates growth of ovarian follicles.

LH: Luteinizing Hormone. A gonadotropin that induces ovulation.

ACTH: Adrenocorticotropic Hormone. Stimulates the production and release of **cortisol**.

TSH: Thyroid-Stimulating Hormone. Stimulates the Thyroid to produce **Thyroxine** (T_4) and **Triiodothyronine** (T_3), which stimulates metabolism.

Prolactin: Stimulates milk production.

Endorphins: ↓Pain

Growth Hormone: Also known as **somatotropin**. Stimulates growth and cell reproduction.

Posterior Pituitary

Posterior lobe of the pituitary gland.

ADH: (Vasopressin) Antidiuretic Hormone. A peptide hormone synthesized in the hypothalamus and released by the posterior pituitary. It regulates the tonicity of body fluids. ADH is released in response to hypertonicity and causes the kidneys to reabsorb H_2O. Results in concentrated urine and reduced urine volume. Can also ↑BP.

Oxytocin: A peptide hormone synthesized in the hypothalamus and released by the posterior pituitary. During childbirth, it increases uterine contractions and is released in response to cervix stretching. Also increases milk production and certain bonding behaviors.

Thyroid Gland

In the neck and below the Adam's Apple. Secretes thyroid hormones that regulate metabolism. Also helps regulate calcium homeostasis.

T_4 & T_3: Thyroxine (T_4) and Triiodothyronine (T_3). T4 is a precursor to T_3. Regulates metabolism. Created from Iodine and Tyrosine.

Calcitonin: Builds bone.
↑Ca^{2+} in bone
↓Ca^{2+} in blood
↓Ca^{2+} absorption in gut
↑Ca^{2+} excretion from kidneys

Parathyroid Glands

A collection of 4 parathyroid glands located on the back of the thyroid. Primary function is to maintain the body's Ca^{2+} and K^+ levels so that the nervous and muscular systems can function properly.

PTH: Parathyroid Hormone. Bone breakdown.
↓Ca^{2+} in bone
↑Ca^{2+} in blood
↑Ca^{2+} absorption in gut
↓Ca^{2+} excretion from kidneys
Activates Vitamin D (**Calcitriol**)

Adrenal Medulla

Sits on top of the kidney. Adrenal Medulla is located at the center of the adrenal gland, surrounded by the adrenal cortex. It converts tyrosine into catecholamines.

Epinephrine: ↑HR and ↑BP. Primarily a hormone. Also an anti-histamine.

Norepinephrine: ↑HR and ↑BP. A hormone and a neurotransmitter; inhibits insulin.

Dopamine: The adrenal medulla secretes a small amount of dopamine.

Lab Techniques

Gel Electrophoresis

Separates macromolecules (proteins, DNA, or RNA). For proteins and small molecules the gel is **polyacrylamide**. For larger molecules (>500 bp), the gel is **agarose**. Negatively charged molecules travel toward the anode at the bottom. Large molecules will move SLOWER. Coomassie Blue stain can be used for visualization.

Native-PAGE: A polyacrylamide gel electrophoresis method for proteins using NON-DENATURING conditions. Proteins keep their native charge and structure so they are separated based on charge and size.

SDS-PAGE: A polyacrylamide gel electrophoresis method for proteins using DENATURING conditions. Sodium Dodecyl Sulfate denatures the proteins and gives the proteins a uniform charge. This allows them to be separated solely on mass, thus, you can estimate the protein's molecular mass.

Reducing SDS-PAGE: Exactly the same as SDS-PAGE, but with the addition of a reducing agent, β-mercaptoethanol, which will reduce the disulfide bridges and result in a completely denatured protein.

Isoelectric Focusing: A gel electrophoresis method that separates proteins on the basis of their relative contents of acidic and basic residues. The gel has a pH gradient and the proteins will migrate through the gel until they reach the pH that matches their isoelectric point. At the pI, the protein has a neutral charge, so it will no longer be attracted to the anode and it will stop migrating.

Southern Blotting: Detection of a specific DNA sequence in a sample.

Northern Blotting: Detection of a specific RNA sequence in a sample.

Western Blotting: Detection of a specific PROTEIN in a sample.

S	D
N o W	R o P

Chromatography

Separates two or more molecules from a mixture.

Stationary Phase: Typically polar. Polar molecules elute slower.

Mobile Phase: Typically nonpolar. Nonpolar molecules elute faster.

Liquid Chromatography: Silica is used as the stationary phase while toluene or another nonpolar liquid is used as the mobile phase.

High-Performance Liquid Chromatography: HPLC is a type of liquid chromatography that uses high pressure to pass the solvent phase through a more finely-ground stationary phase which increases the interactions between the moelcuels and the stationary phase. This gives HPLC higher resolving power.

Gas Chromatography: Vaporizes the liquid before separation. Molecules are separated based on polarity and boiling point. The stationary phase is a thin layer of material applied to the inside of the column. Typically the polarity of the stationary phase matches that of the solute. The mobile phase is an inert gas.

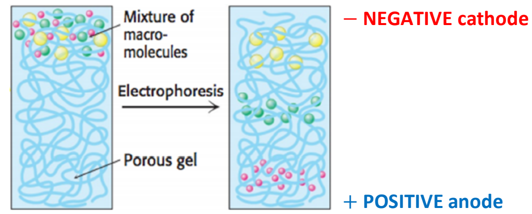
Gel-Filtration Chromatography: (Size-exclusion) Separates molecules by size rather than polarity. Smaller molecules enter the porous gel beads allowing them to elute later. Larger molecules will elute faster because they do not fit in the pores and will not be slowed down.

Ion Exchange Chromatography: Separates proteins by their net charge. The column is filled with charged beads, either POS or NEG.
Cation Exchange: NEG beads used, NEG proteins elute 1st.
Anion Exchange: POS beads used, POS proteins elute 1st.

Affinity Chromatography: Separates proteins based on their affinity for a specific ligand. Beads are bound to a specific ligand and proteins with a high affinity for that ligand will bind to the beads. Proteins with a low affinity for the ligand will elute first.

Thin-Layer Chromatography: Sheet coated in polar silica gel. Molecules are spotted on the bottom of the sheet. Sheet is placed in a nonpolar liquid. Mobile phase travels up the plate using capillary action. Nonpolar molecules have the highest R_f value.

Gel electrophoresis



Sanger DNA Sequencing

Chain termination method. Uses dideoxy nucleotides. The ddNTP lacks a hydroxyl group on the 3' carbon of the sugar ring. With the 3' hydroxyl group missing, no more nucleotides can be added to the chain. The chain ends with the ddNTP, which is marked with a particular color of dye depending on the base that it carries.

After mixing all components, it is virtually guaranteed that a ddNTP has incorporated at every single position of the target DNA strand. The strands are run through gel electrophoresis to separate them based on length. The colored dye is read and is used to establish the DNA sequence.

Polymerase Chain Reaction

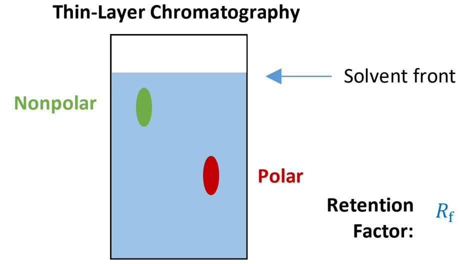
Used to make many copies of a specific DNA region *in vitro*. The key ingredients of PCR are *Taq polymerase*, primers, template DNA, and nucleotides (DNA building blocks). The ingredients are assembled in a tube, along with cofactors needed by the enzyme, and are put through repeated cycles of heating and cooling that allow DNA to be synthesized.

Primer: Must have high GC content and either a G or C at each end. Example: 5'-GCATAGAAGCATTCCGC-3'

Taq Polymerase: The DNA polymerase typically used in PCR. Named after the heat-tolerant bacterium from which it is isolated (**T**hermos **aq**uaticus). Very heat-stable and most active around 70°C.

Steps:
1. Denaturationg (96°C)
2. Annealing (55 - 65°C)
3. Extension (72°C)
4. Cycle is repeated until you have enough DNA

Thin-Layer Chromatography



Retention Factor: $R_f = \frac{\text{distance spot moved}}{\text{distance solvent front moved}}$

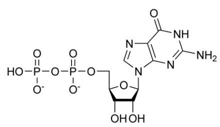
DNA and RNA

DNA Structure: A polymer made up of monomers called *nucleotides*. Long strands form a double helix which runs antiparallel.

Charge: DNA is negatively charged due to its phosphate backbone.

Nucleotides: Each nucleotide has three parts:

- **5-carbon sugar,** (DNA uses *deoxyribose*)
- **Nitrogen-rich base**
- **Phosphate Group**
- **Note:** A *nucleoside* lacks the phosphate group



Example of a Nucleotide: Guanosine diphosphate (GDP)

Nucleotide Pairs:

- **Adenine – Thymine** 2 H-bonds
- **Guanine – Cytosine** 3 H-bonds, stronger
- **Note:** RNA has U instead of T

Structural Bonds: DNA backbone is held together via *phosphodiester bonds* that form between the sugar and the phosphate groups. *Hydrogen bonds* hold the nucleotide bases together inside the double helix.

Pyrimidines
1 ring: A pyrimidine ring

Purines
2 rings: A pyrimidine ring fused to an imidazole ring

(DNA only) (RNA only)

Pairing: purine + pyrimidine = uniform width
purine + purine = too wide
pyrimidine + pyrimidine = too narrow

DNA Double Helix Width: DNA double helix has a diameter of 20 angstroms.

RNA: Also a polymer of nucleotides, but differs from DNA in three major respects:

1. RNA is usually *single stranded*.
2. The sugar in RNA is ribose, which is more reactive than deoxyribose.
3. The nitrogenous base is Uracil (U), not thymine (T).

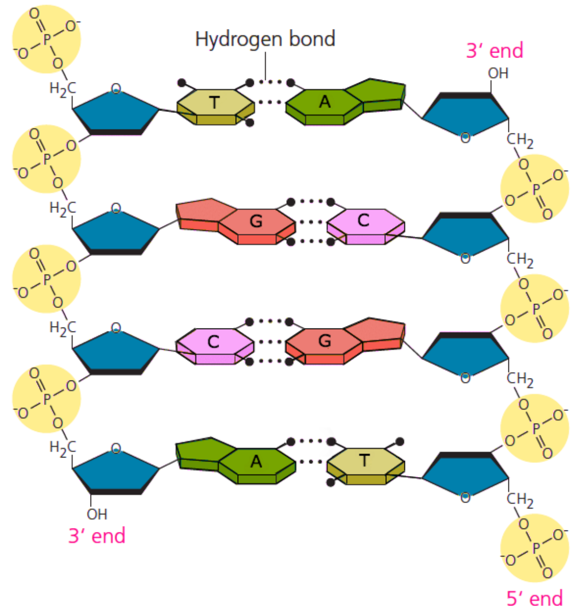
mRNA: Messenger. Encodes AA sequence.
tRNA: Transfer. Brings AA to ribosomes during translation.
rRNA: Ribosomal. Form ribosomes.
snRNA: Small nuclear. Form spliceosomes that remove introns.

DNA vs. RNA

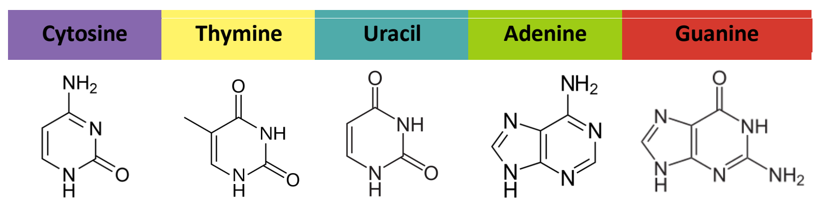
Proofreading: DNA replication has proofreading while RNA transcription does not. This makes DNA replication more accurate than RNA transcription.

Stability: RNA is less stable than DNA because it contains the sugar ribose compared to DNA's deoxyribose. As a result, mRNA degrades rapidly in the cytoplasm.

DNA Structure

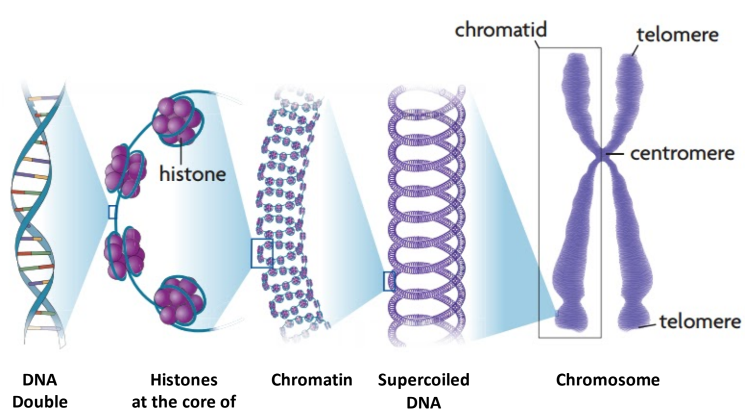


Nitrogenous Bases

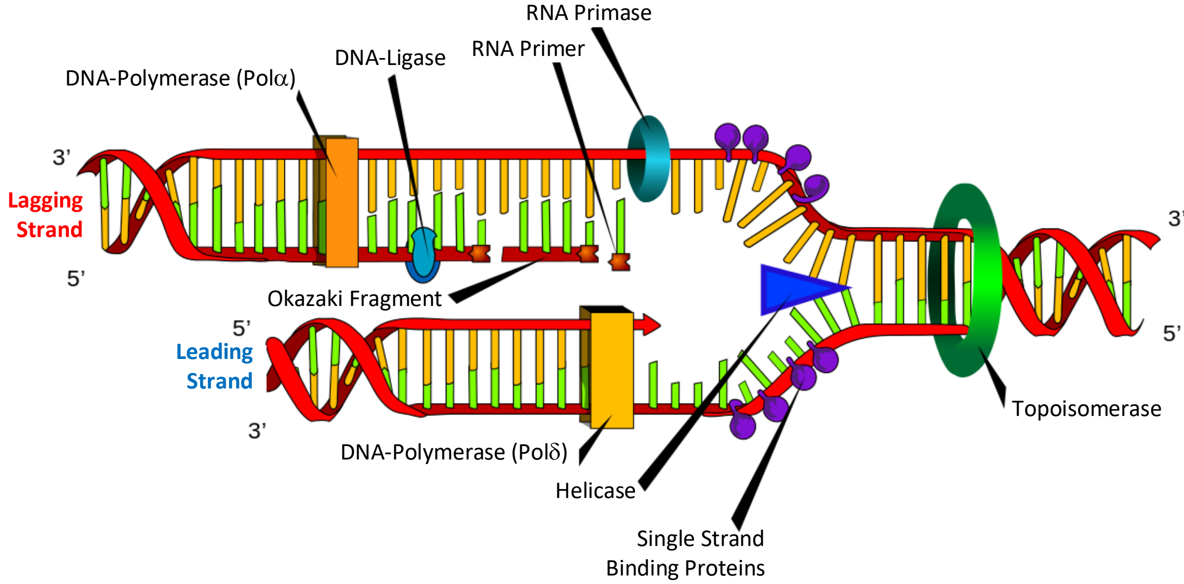


Levels of DNA Packaging

- Strands of DNA wrap around a **histone protein** forming **nucleosomes**
- Nucleosomes coil together forming **chromatin**
- Chromatin loops and coils together forming **supercoils**
- Supercoils bunch together forming **chromosomes**



DNA Replication



Topoisomerase: Unwinds the DNA double helix.

Helicase: Breaks the hydrogen bonds between the nitrogenous bases in order to separate the DNA strands.

Single Strand Binding Protein: (SSB). Binds to ssDNA and prevents annealing of ssDNA into double-stranded DNA.

DNA Primase: Catalyzes the synthesis of the RNA primer.

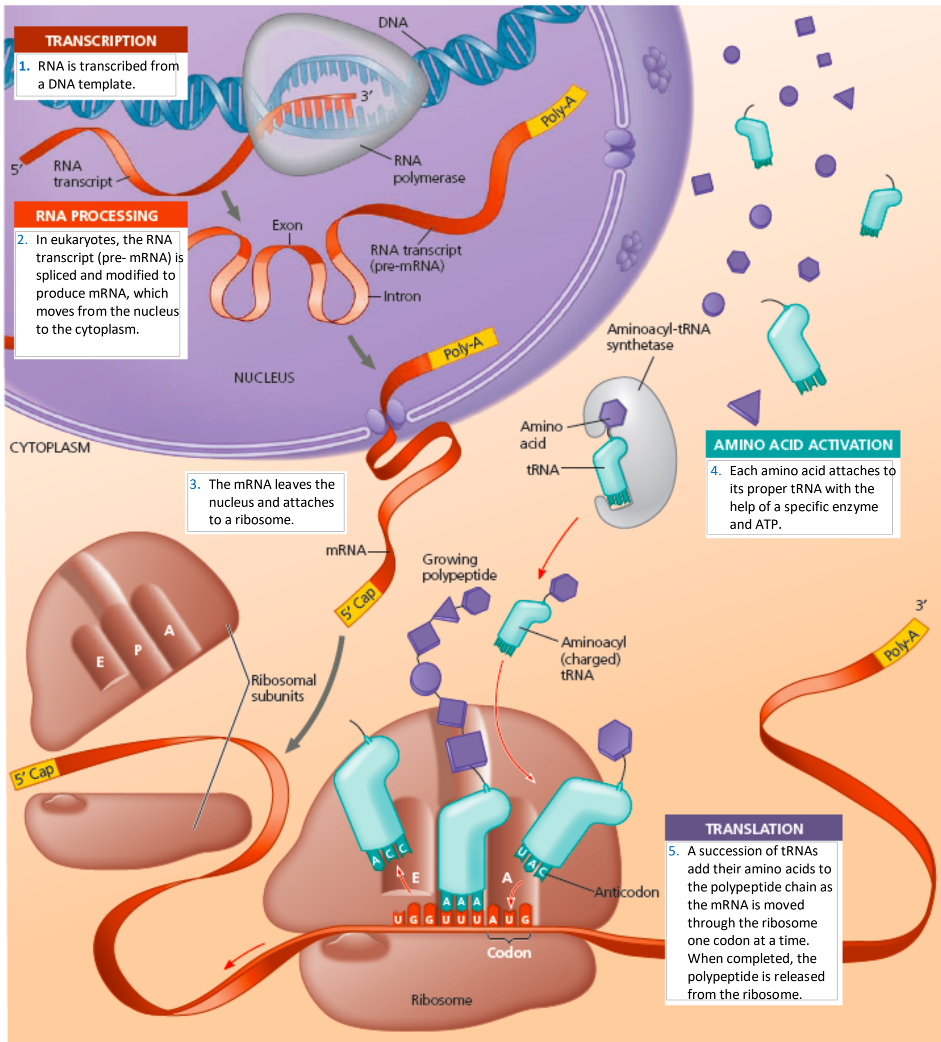
RNA Primers: Short RNA nucleotide sequences that are complementary to the ssDNA. They allow DNA replication to start.

DNA Polymerase: Adds nucleotides to the growing strand. It reads the template 3' $\rightarrow$ 5' and synthesize the new strand 5' $\rightarrow$ 3'. DNA Polymerase also removes the RNA primer at the end of the strand. There are many varieties of DNA polymerase. Eukaryotes use Pol α, β, δ, ε etc. Prokaryotes use Pol I, II, III, IV, V.

Okazaki Fragment: Short, newly synthesized DNA fragments that are formed on the lagging template strand during DNA replication.

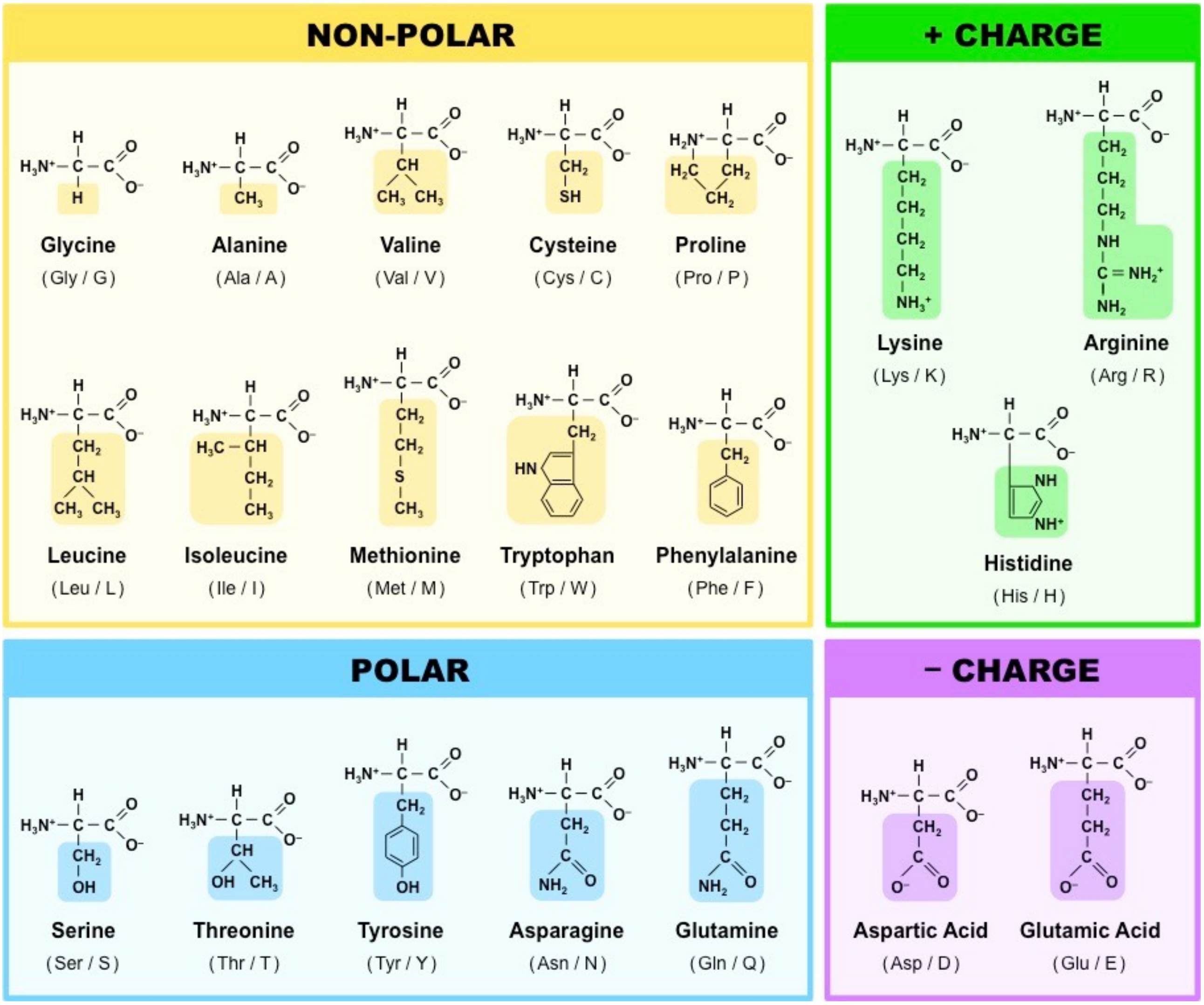
DNA Ligase: Joins DNA strands together by catalyzing the formation of phosphodiester bonds.

The Central Dogma



DNA	5′	ATGGGGCTCAGCGAC	3′	**Sense strand**
	3′	TACCCCGAGTCGCTG	5′	**Antisense strand**
Transcription		↓		
mRNA	5′	AUGGGGCUCAGCGAC	3′	**mRNA** with codons
		UACCCCGAGUCGCUG		**tRNA** with anti-codons
Translation		↓		
Protein		Met Gly Leu Ser Asp		**Peptide**

Amino Acids



Hydrophobic

Glycine, Gly, G

Alanine, Ala, A

Valine, Val, V

Leucine, Leu, L

Isoleucine, Ile, I

Methionine, Met, M

Proline, Pro, P

Phenylalanine, Phe, F

Tryptophan, Trp, W

Polar Neutral

Serine, Ser, S

Threonine, Thr, T

Tyrosine, Tyr, Y

Cysteine, Cys, C

Asparagine, Asn, N

Glutamine, Gln, Q

Basic, ⊕, Hydrophilic

Lysine, Lys, K

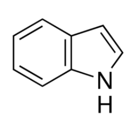
Arginine, Arg, R

Histidine, His, H

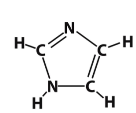
Acidic, ⊖

Aspartic Acid, Asp, D

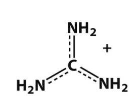
Glutamic Acid, Glu, E



Indole Group
(Tryptophan)



Imidazole Group
(Histidine)



Guanidinium Group
(Arginine)

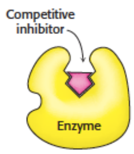
Enzyme Inhibition

V_{max}: The maximum rate of the reaction

K_m: The amount of substrate needed for the enzyme to work half as fast as it is capable of.
↑K_m = ↓enzyme-substrate affinity ↓K_m = ↑ enzyme-substrate affinity

Competitive Inhibition

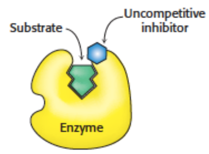
V_{max} no change
↑K_M



A competitive inhibitor binds at the active site and thus prevents the substrate from binding.

Uncompetitive Inhibition

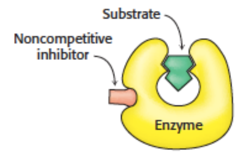
↓V_{max}
↓K_M



An uncompetitive inhibitor binds only to the enzyme–substrate complex.

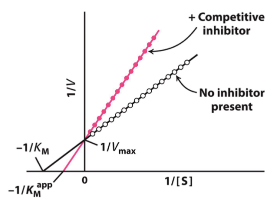
Noncompetitive Inhibition

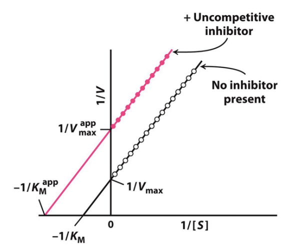
↓V_{max}
K_M no change

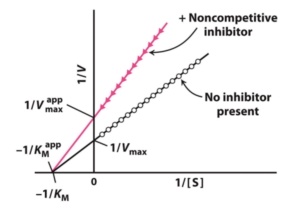


A noncompetitive inhibitor binds at the allosteric site, away from the active site. It does NOT prevent the substrate from binding to the active site.

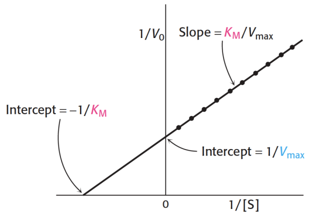
Lineweaver-Burk Plots





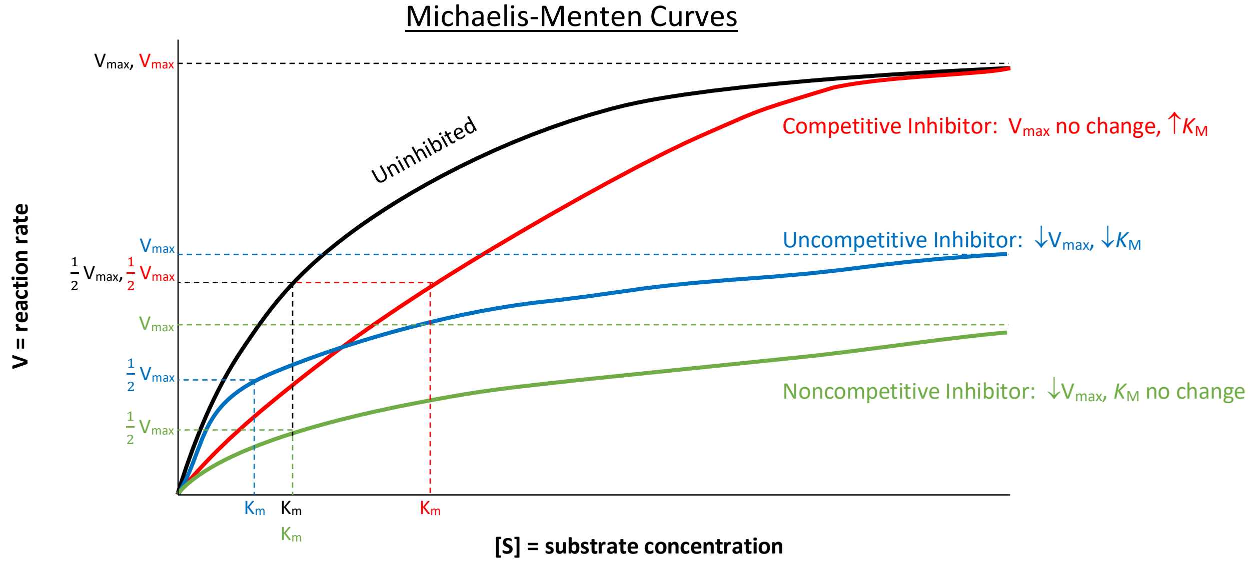


Lineweaver-Burk Plots

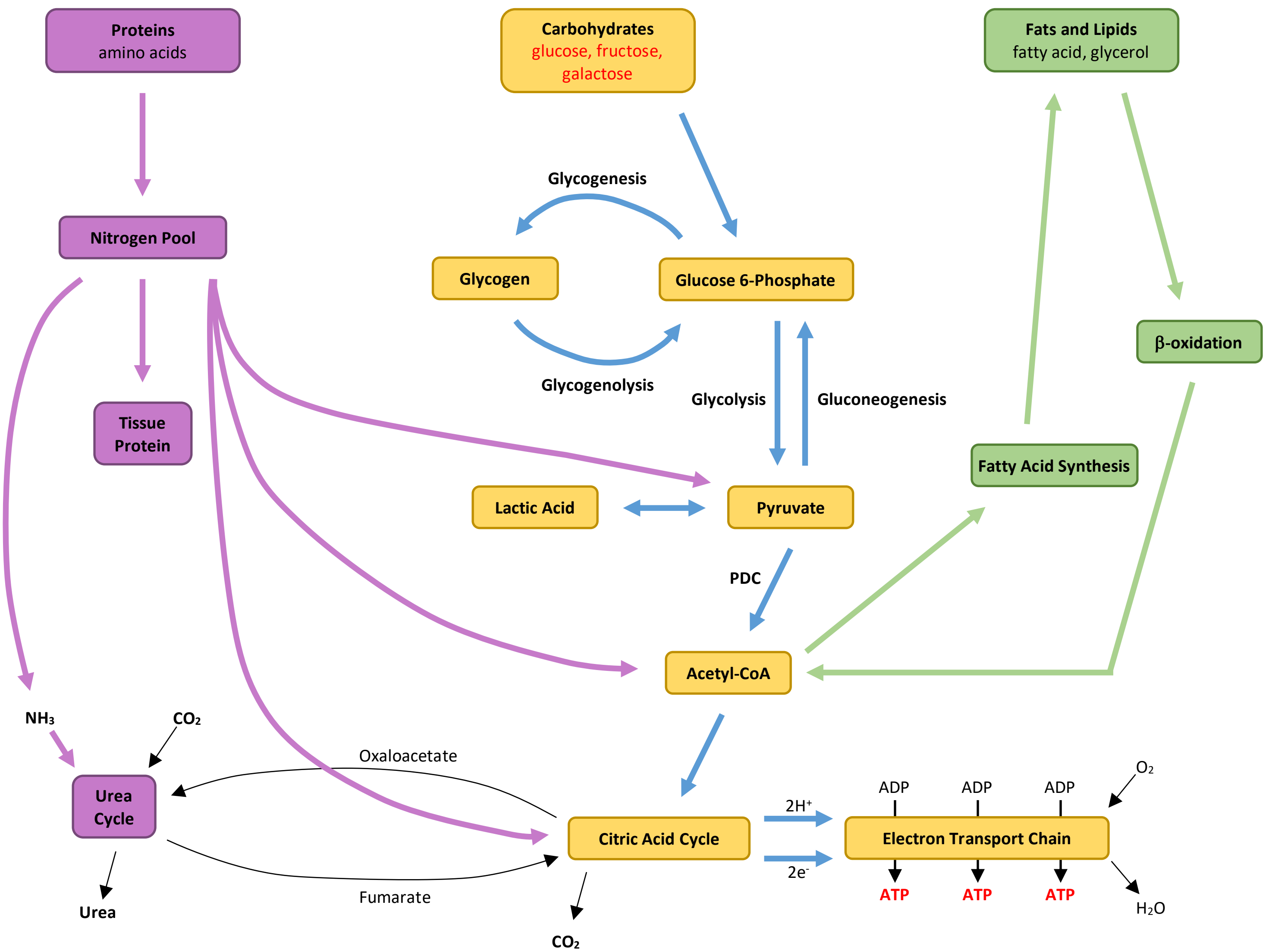


- A double-reciprocal plot of $\frac{1}{V}$ vs. $\frac{1}{[S]}$ $\text{slope} = \frac{K_m}{V_{max}}$
- Left side of the graph is theoretical because you can't have negative substrate or velocity higher than V_{max}
- V_{max} and K_m can be more precisely calculated using Lineweaver-Burk because you are extrapolating out theoretical values.
- Michaelis-Menton curves show observed values only, not theoretical values. This makes calculations using Michaelis-Menton less accurate than Lineweaver-Burk.
- Lineweaver-Burk allows the different types of inhibition to be visualized more clearly.

Michaelis-Menten Curves



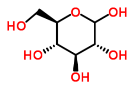
Metabolism Overview



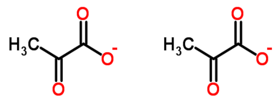
Glycolysis

Occurs in cytoplasm

Glucose has 6 carbons



Pyruvate has 3 carbons and Glycolysis produces two Pyruvates



STEPS

Glucose

1 — **Hexokinase**
Induced fit
Regulated by G 6-P feedback
ATP → ADP

Glucose 6-phosphate

2 — Phosphoglucose isomerase

Fructose 6-phosphate

3 — **Phosphofructokinase (PFK)**
Committed step
Regulated by ATP/AMP ratio and fructose 2,6-bisP
ATP → ADP

Fructose 1,6-bisphosphate

4 — Aldolase

Dihydroxyacetone phosphate ⇄ **Glyceraldehyde 3-phosphate**

5 — Triose phosphate isomerase

6 — Glyceraldehyde 3-phosphate dehydrogenase
Pi, NAD^+ → NADH

1,3-Bisphosphoglycerate

7 — Phosphoglycerate kinase
ADP → ATP

3-Phosphoglycerate

8 — Phosphoglycerate mutase

2-Phosphoglycerate

9 — Enolase
→ H_2O

Phosphoenolpyruvate (PEP)

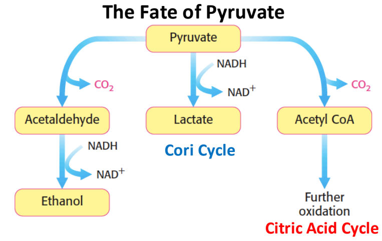
10 — **Pyruvate Kinase**
Regulated by covalent modification.
Phosphorylated = inactive
↑Alanine = inactive
ADP → ATP

Pyruvate

Note: **PEP is high energy** because the phosphoryl group traps PEP in its enol form. When the phosphoryl group is donated to ADP, making ATP, the enol converts to a more stable ketone (pyruvate), which releases a lot of energy.

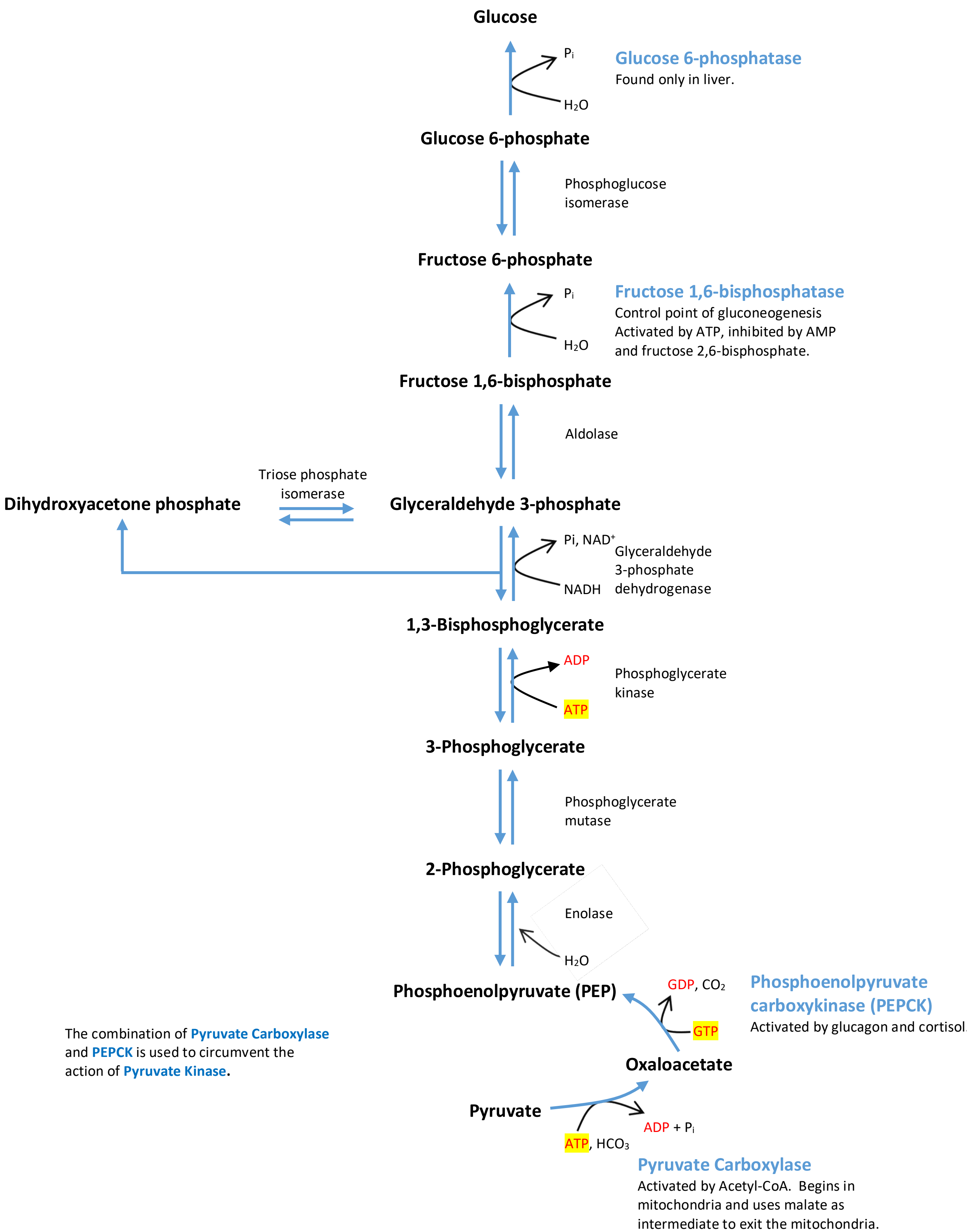
Reactants	Products
1 Glucose	2 Pyruvate
2 ATP	2 ADP
4 ADP	4 ATP (2 net gain)
2 Pi	2 NADH
2 NAD^+	2 H^+
	2 H_2O

The Fate of Pyruvate

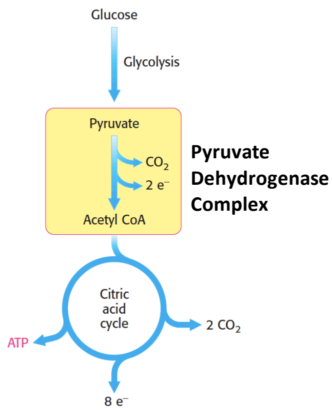


Gluconeogenesis

Takes place mainly in the liver and, to a lesser extent, in the kidneys



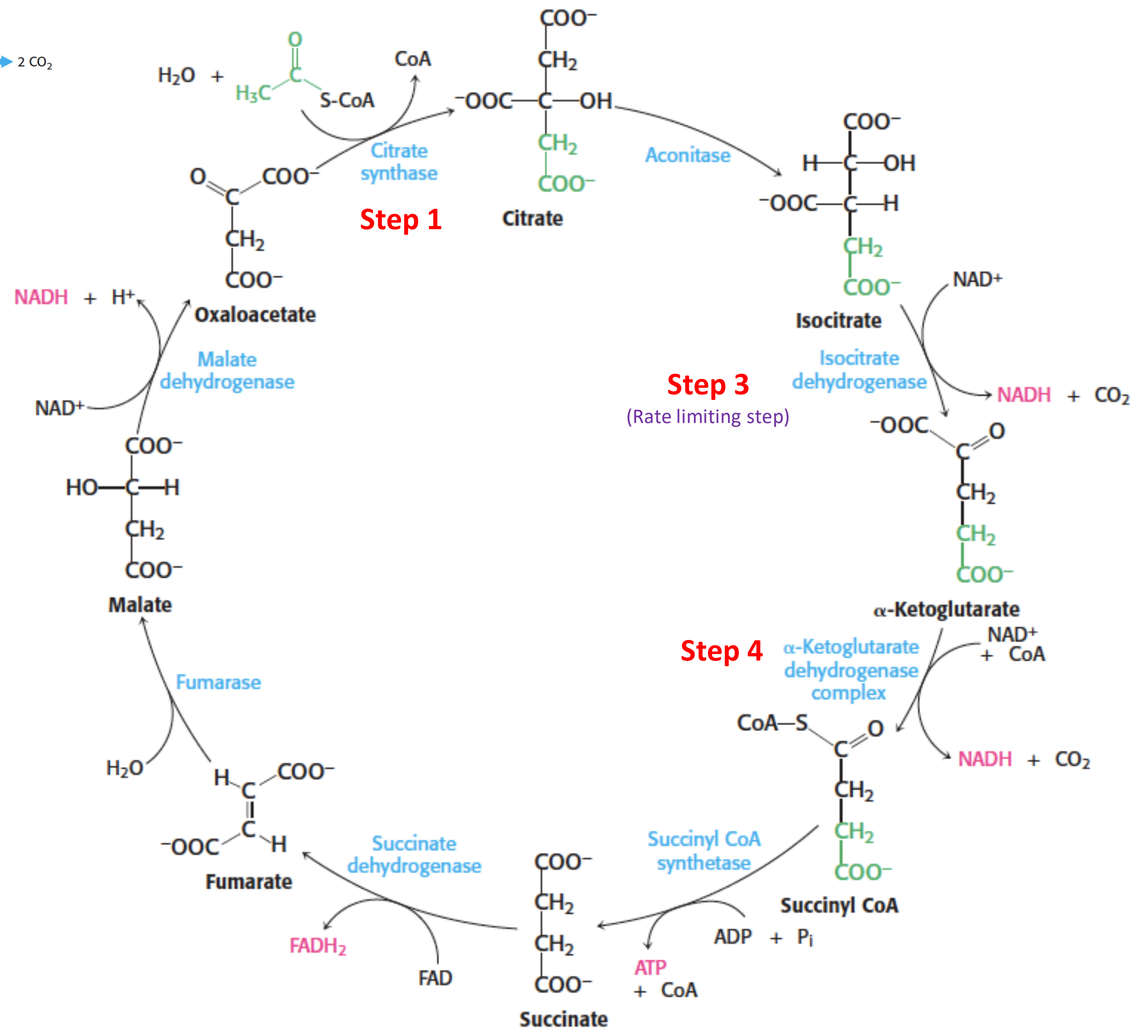
The combination of **Pyruvate Carboxylase** and **PEPCK** is used to circumvent the action of **Pyruvate Kinase**.



Citric Acid Cycle

Eukaryotes: CAC occurs in mitochondrial matrix

Prokaryotes: CAC occurs in cytoplasm



Reactants	Products
1 Acetyl CoA	2 CO_2
3 NAD^+	3 NADH
1 ADP	1 $FADH_2$
1 P_i	3 H^+
1 FAD	1 ATP
3 H_2O	

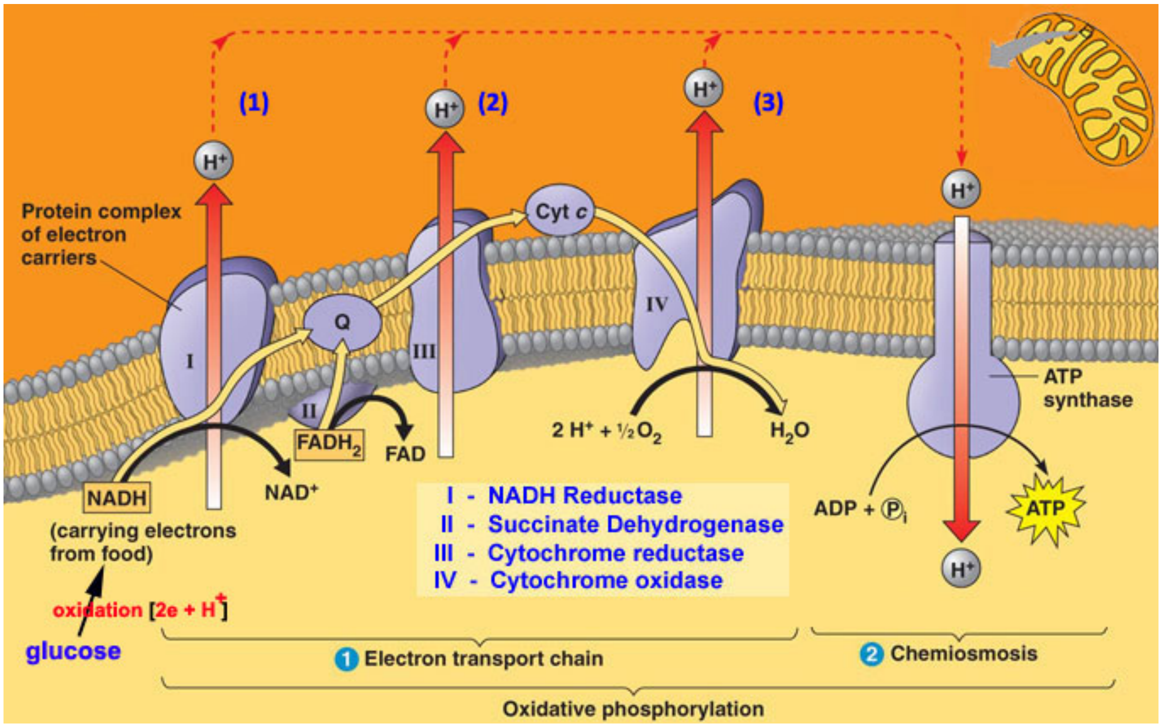
Step	Regulatory Enzyme	Inhibitors / Activators
1	Citrate Synthase	Inhibitors: ATP, NADH, Citrate, Succinyl-CoA Activator: ADP
3	Isocitrate dehydrogenase (Rate limiting enzyme)	Inhibitors: ATP and NADH Activators: ADP and NAD^+
4	α-Ketoglutarate dehydrogenase complex	Inhibitors: Succinyl-CoA, NADH, ATP Activator: ADP

Oxidative Phosphorylation

(ETC and Chemiosmosis)

Eukaryotes: ETC occurs in mitochondria

Prokaryotes: ETC occurs in the cell membrane



Total Energy Produced from One Glucose

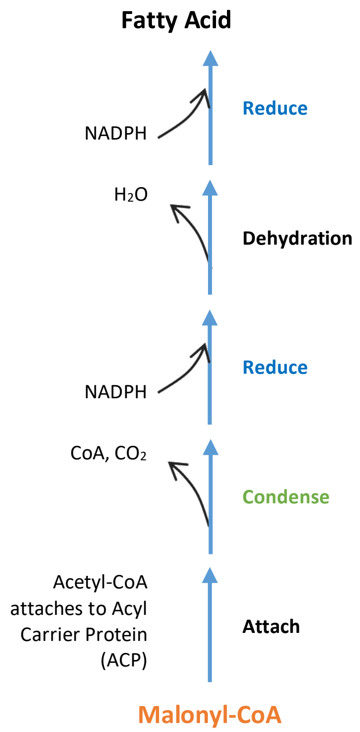
Glycolysis:	2 NADH and 2 ATP	2 NADH + 2 ATP = 7 ATP
Pyruvate Dehydrogenase Complex:	1 pyruvate makes 1 NADH. Glucose forms 2 pyruvates, so PDC generates a total of 2 NADH per molecule of glucose.	2 NADH = 5 ATP
Citric Acid Cycle:	One Acetyl-CoA leads to 3 NADH, 1 $FADH_2$, and 1 GTP. Glycolysis forms two pyruvates, so two Acetyl-CoA molecules exit the PDH complex. A total of 6 NADH, 2 $FADH_2$, and 2 GTP per molecule of glucose.	6 NADH + 2 $FADH_2$ + 2 GTP = 20 ATP

1 Glucose = 32 ATP

Each **NADH** $\Rightarrow$ **2.5 ATP**; 10 NADH form 25 ATP
Each **$FADH_2$** $\Rightarrow$ **1.5 ATP**; 2 $FADH_2$ form 3 ATP

Fatty Acid Synthesis

Occurs in the cell's cytoplasm

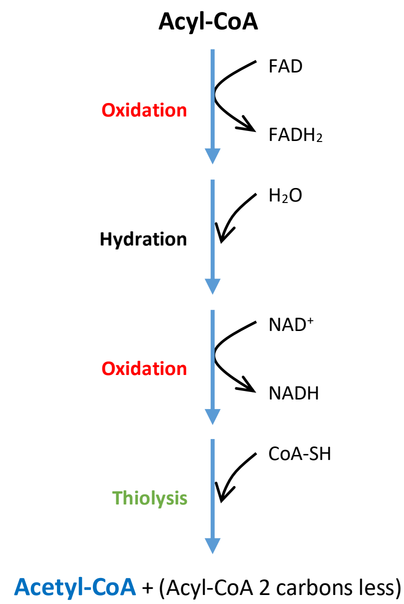


Initiation of Fatty Acid Synthesis

1. Fatty acid synthesis begins with the transfer of Acetyl-CoA from the mitochondria to the cytosol.
2. Activation of Acetyl-CoA through the synthesis of Malonyl-CoA. Enzyme is Acetyl-CoA Carboxylase (regulatory enzyme for fatty acid synthesis).
3. Malonyl-CoA elongation using ACR DR.

β-Oxidation

Occurs in the mitochondrial matrix



<u>β-Oxidation Energy Products</u>

Example: C_{16} Fatty Acid

(C_2) Acetyl-CoA = 8

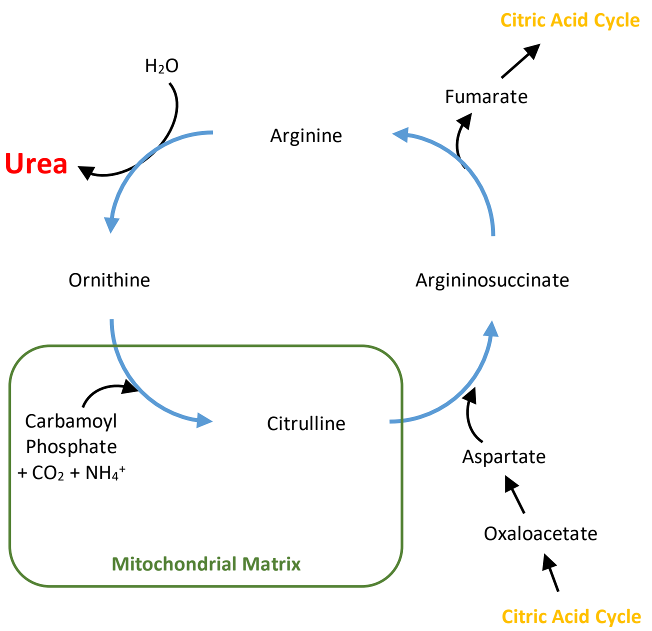
 # Rounds of β-Oxidation = 7

NADH: 7

$FADH_2$: 7

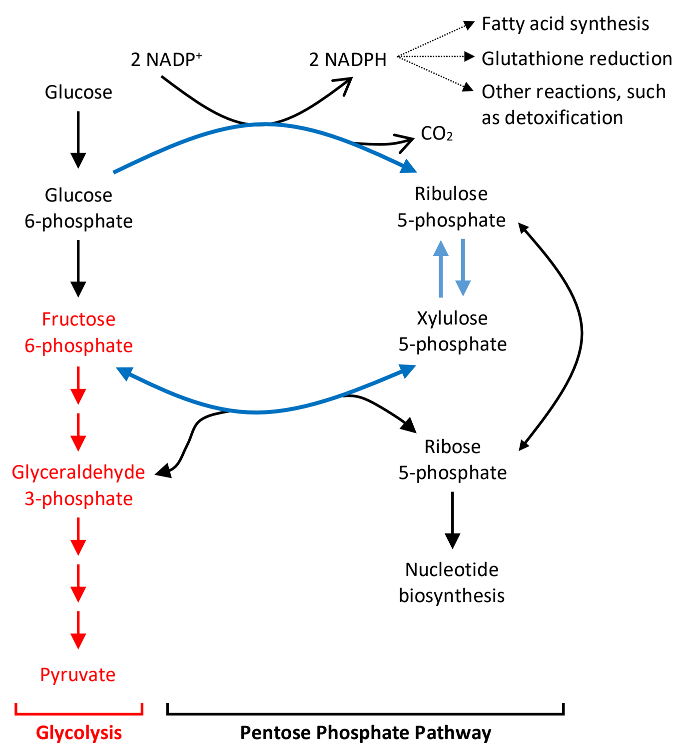
Urea Cycle

Occurs in the cytosol and mitochondrial matrix of liver.



Pentose Phosphate Pathway

and its link to glycolysis. Occurs in cytosol.



Kinematics

$v_f = v_0 + a\,\Delta t$

$v_f^2 = v_0^2 + 2\,a\,\Delta x$

$\Delta x = v_0\,\Delta t + \frac{1}{2}\,a\,(\Delta t)^2$

$a_c = \frac{v^2}{r}$

$F_c = \frac{m\,v^2}{r}$

$v_x = V_0 \cos(\theta)$

$v_y = V_0 \sin(\theta)$

Mechanics

$F = m\,a$

$F_{\text{a on b}} = -F_{\text{b on a}}$

$F_{\text{friction}} = \mu\,F_{\text{normal}}$

$F_g = \frac{G\,M_1\,m_2}{r^2}$

$F_g = m\,g$

$\tau = r\,F \sin(\theta)$

$W = F\,d \cos(\theta)$

$P = \frac{W}{t} = F\,v \cos(\theta)$

$KE = \frac{1}{2}\,m\,v^2$

$U = \frac{1}{2}\,k\,x^2$

$U = m\,g\,h$

$U = -\frac{G\,M_1\,m_2}{r^2}$

Inclined Plane

$F_{\text{incline}} = m\,g \sin(\theta)$

$F_N = m\,g \cos(\theta)$

$F_{\text{fric}} = \mu\,m\,g \cos(\theta)$

Thermochemistry

$\Delta U = Q - W$

$\Delta U = \frac{3}{2}\,n\,R\,T$

$W = P\,\Delta V$

$Q = m\,c\,\Delta T$

$Q = m\,H_L$

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

$\Delta H_{\text{rxn}} = \Delta H_{\text{prod}} - \Delta H_{\text{react}}$

Gases

$P\,V = n\,R\,T$

Boyle: $P\,V = k$

Gay-Lussac: $\frac{P}{T} = k$

Charles: $\frac{V}{T} = k$

Avogadro: $\frac{n}{V} = k$

$\frac{R_1}{R_2} = \sqrt{\frac{m_2}{m_1}}$

Solutions

$\text{pH} = \text{pK}_a + \log\frac{[\text{A}^-]}{[\text{HA}]}$

$M = \frac{\text{mol}}{\text{L}}$

$m = \frac{mol}{kg}$

$N = M \times (\#\text{ of H}^+)$

$\text{pH} = -log\,[\text{H}^+]$

$M_1\,V_2 = M_2\,V_2$

$\pi = i\,M\,R\,T$

$\Delta T_f = i\,k_f\,m$

$\Delta T_b = i\,k_b\,m$

$X_A = \frac{mol_A}{\text{mol}_{\text{total}}}$

Waves

$v = \lambda\,f$

$T = \frac{1}{f}$

Light

$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$

$n = \frac{c}{v}$

$E = \frac{h\,c}{\lambda} = h\,f$

$\text{h} \times \text{c} \approx 2.0 \times 10^{-25}\ \text{J}\bullet\text{m}$

$M = \frac{d_i}{d_o}$

$f = \frac{1}{2}\,r$

$P = \frac{1}{f}$

$\frac{1}{f} = \frac{1}{d_i} + \frac{1}{d_o}$

$h\,f = R\,\left(\frac{1}{n_{final}^2} - \frac{1}{n_{initial}^2}\right)$

Sound

$d\beta = 10 \log\left(\frac{I}{I_o}\right)$

$\lambda = \frac{2\,L}{n}\quad (n = 1, 2, \ldots)$

$\lambda = \frac{4\,L}{n}\quad (n = 1, 3, \ldots)$

$f_{\text{beat}} = |f_1 - f_2|$

$f = f_e\,\frac{[\pm v_d]}{[v \pm v_s]}$

Fluids

$\rho = \frac{m}{V}$

$P = \frac{F}{A}$

$P = P_{\text{atm}} + \rho\,g\,h$

$F_b = \rho V\,g = m\,g$

$Q = A\,v$

$P + \rho\,g\,h + \frac{1}{2}\,\rho\,v^2 = \text{constant}$

Electricity & Magnetism

$F = k\,\frac{|q_1|\,|q_2|}{r^2} = q\,E$

$E = \frac{k\,Q}{r^2}$

$V = \frac{k\,Q}{r}$

$U_{elect} = \frac{k\,q_1\,q_2}{r} = q\,V$

$F = q\,v\,B \sin(\theta)$

$F = i\,L\,B \sin(\theta)$

$V = I\,R$

$E_{cap} = \frac{Q}{\varepsilon_0 A} = \frac{\Delta V}{d}$

$Q = C\,\Delta V$

$C = \frac{\varepsilon_0 A}{d}$

$U_{cap} = \frac{1}{2}\,C\,\Delta V^2$

$E_{\text{cell}} = E_{\text{cath}} - E_{\text{an}}$

$R = \frac{\rho\,L}{A}$

$V_{\text{rms}} = \frac{V_{\text{max}}}{\sqrt{2}}$

$I_{\text{rms}} = \frac{I_{\text{max}}}{\sqrt{2}}$

Resisters in Series

$R_{\text{tot}} = R_1 + R_2 + \cdots$

Resisters in Parallel

$\frac{1}{R_{\text{tot}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$

Capacitors in Series

$\frac{1}{C_{\text{tot}}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots$

Capacitors in Parallel

$C_{\text{tot}} = C_1 + C_2 + \cdots$

Constants & Units

Avogadro's Number: 6.022×10^{23}

Gas Constant: $R = 8.314\ \frac{\text{J}}{\text{mol K}}$

$R = 0.08021\ \frac{\text{L atm}}{\text{mol K}}$

Planck's Constant: $h = 6.626 \times 10^{-34}\ \frac{\text{kg m}^2}{\text{s}}$

Density of Water: $1\ \frac{\text{g}}{\text{cm}^3} = \frac{1\ \text{kg}}{\text{L}} = \frac{1000\ \text{kg}}{\text{m}^3}$

Wavelengths: red = 700 nm
violet = 400 nm

Speed of Light: $c = 3.0 \times 10^8\ \frac{\text{m}}{\text{s}}$

Speed of Sound: $v_{\text{sound}} = 343\ \frac{\text{m}}{\text{s}}$

Faraday's Constant: $1\ \text{mol e}^- = 96{,}000\ \text{C}$

Newton: $\text{N} = \frac{\text{kg m}}{\text{s}^2}$

Joule: $\text{J} = \frac{\text{kg m}^2}{\text{s}^2} = \text{N m}$

Pascal: $\text{Pa} = \frac{\text{N}}{\text{m}^2}$

Volt: $\frac{\text{J}}{\text{C}}$ **Amp:** $\frac{\text{C}}{\text{sec}}$ **Watt:** $\frac{\text{J}}{\text{sec}} = \text{V A}$

Ohm: $\frac{\text{V}}{\text{A}}$ **Farad:** $\frac{\text{C}}{\text{V}}$