Biochemistry

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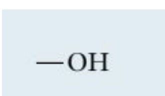
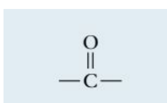
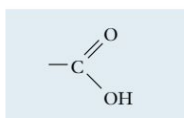
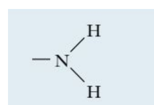
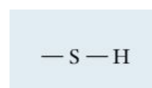
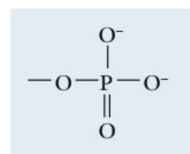
1.1 - Chemistry in Living Systems

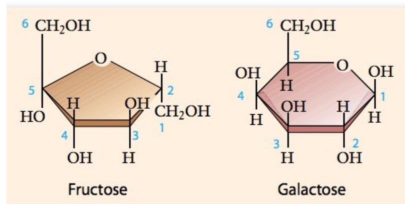
- Isotopes: same number of protons, different # neutrons
    - Radioisotopes: unstable, nuclei randomly break. Half-life is constant, used in radiometric dating
- Further from nucleus, more potential energy
- Intramolecular forces hold atoms together. Inter is in between molecules
- Nonpolar - 0.5 - polar - 1.7 - ionic
- Miscible liquids dissolve in each other
- Immiscible liquids don't

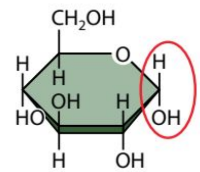
					
Hydroxyl **OH** *polar* *Carbs, proteins, nucleic acids, lipids*	**Carbonyl** **C = O** *polar* *Carbs, nucleic acid*	**Carboxyl** **COOH** *polar* *Proteins, lipids*	**Amino** **NH_2** *polar* *Proteins, nucleic acids*	**Sulfhydryl** **SH** *~polar* *proteins*	**Phosphate** **PO_4** *polar, charged* *Nucleic acids*

1.2 - Biologically Important Molecules

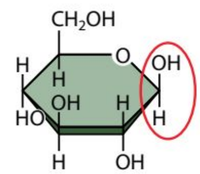
- Carbon can form long chains and rings
- Macromolecules are usually made of monomers (polymer)

Carbohydrates





alpha glucose



beta glucose

- C, H and O in 1:2:1 ratio
- Often polar
- Monosaccharides
    - Simple sugars, made of one monomer
    - $C_6H_{12}O_6$
        - Glucose, fructose (fruit), galactose (milk)
- Disaccharides
    - 2 monos joined with glycosidic linkage (-O-)
    - Sucrose (glucose + fructose)
    - Lactose (glucose + galactose)
    - Forms through condensation/dehydration
        - 2 OH groups → leaves -O-, takes out H_2O
- Polysaccharides
    - Glycogen: glucose stored in animals. Easily broken down
    - Starch: glucose in plants. Fewer branching chains than glycogen → harder to break down
    - Cellulose: structural support in plants. Humans lack cellulose-breaking enzymes

Lipids

- C, H, and less oxygen
    - Hydrophobic cause it's mainly C-H bonds
- Long term energy for when carbs are used up
    - Energy stored in C-H bonds (lil harder to access)
- Insulation (less heat loss)
- Protects organs (cushion)
- Cell membrane
- Water-repellent coat
- Fatty acids: long hydrocarbon chain w/ carboxyl group (COOH)
    - Saturated: no double bonds → linear → solid at room temp. Heart disease.

        - Unsaturated: double bond(s) → bent → liquid at room temp. Reduce heart disease.
- Triglyceride: 3 fatty acids + glycerol
    - 3-C chain w/ OH group bonds with the OH (in COOH) from the fatty acids
        - Dehydration synthesis (produce H_2O)
        - Ester linkage (-O-)
    - Most fats me eat, and also how we store fat
- Phospholipids: glycerol + 2 fatty acids + phosphate (-R)
- Wax: long fatty acids + alcohol (R-OH) / C rings
    - Solid at room temp
    - Produced by plants and animals
- Steroids: 4 hydrocarbon rings w/ functional groups
    - Cholesterol (makes membrane more rigid when hot)
    - Hormones (testosterone, estrogen, adrenaline)
    - Inflammation treatment
    - Vitamin D

Proteins

- Chain of amino acids (polypeptides)
    - Joined by peptide bonds (OH from COOH + H from NH_2)
- **AMINO ACID**S: C in the middle + amino group (NH_2), carboxyl (COOH), -R, H
    - R group gives unique properties
- Categorized based on function:
    - Catalyst
    - Structural support
    - Transportation
    - Enabling movement
    - Regulate cell processes
    - Defend from disease (antibodies)

Levels of Organization

- Primary
    - Linear
- Secondary
    - Hydrogen bonding makes alpha helix / beta pleated (bent) sheet
- Tertiary
    - Structures fold together based on hydrophobic/philic interactions (polypeptide)

- Quaternary
  - Polypeptides join to make more than one chain (protein?)
- **DENATURATION**: extreme heat/cold or exposure to some chemicals → protein unfolds
  - Bonding between R groups are disturbed (intermolecular bonds break)
  - Once protein loses its normal 3D shape, it can't perform its normal function

Nucleic Acids

- **DNA**: deoxyribonucleic acid (generic info of cell)
- **RNA**: ribonucleic acid. Assists in decoding DNA info → amino acid sequence → protein
- Nucleotide monomers:
  - Phosphate – 5-C sugar – nitrogenous base

Carbohydrates

Type	Structure	Examples	Some Functions
Monosaccharide	• Contains a single three- to seven-carbon atom-based structure	Glucose, fructose, galactose	• Glucose is used as a primary energy source
Disaccharide	• Contains two monosaccharides joined by a glycosidic linkage	Sucrose, lactose, maltose	• Sucrose and lactose are dietary sugars that are used for energy
Polysaccharide	• Contains many monosaccharides joined by glycosidic linkages	Starch, glycogen, cellulose	• Glycogen is a form of storing glucose in animals • Cellulose provides structural support in plants

Lipids

Type	Structure	Examples	Some Functions
Triglyceride	• Contains three fatty acids joined to glycerol by ester linkages	Lard, butter, vegetable oils	• Provides long-term energy storage • Acts to cushion organs and insulate from heat loss
Phospholipid	• Contains two fatty acids and a phosphate group joined to glycerol	Phosphatidylcholine	• Forms the main structure of cell membranes
Steroid	• Contains four carbon-based rings attached to one another	Cholesterol, testosterone, estrogen	• Cholesterol is part of cell membranes • Testosterone and estrogen are sex hormones
Wax	• Contains long carbon-based chains	Earwax, beeswax, spermaceti	• A variety of functions, including protection

Protein

Type	Structure	Examples	Some Functions
Catalyst	• Contains amino acid monomers joined by peptide bonds • All have primary, secondary, tertiary structure	Amylase, sucrase	• Speeds up chemical reactions
Transport		Hemoglobin, ion channel proteins	• Transports specific substances
Structural		Collagen, keratin	• Provides structure
Movement		Myosin, actin	• Enables movement
Regulatory		Hormones, neurotransmitters	• Carries cellular messages
Defence		Antibodies	• Fights infection

Nucleic Acids

Type	Structure	Some Functions
DNA	• Contains deoxyribonucleotide monomers (A, G, T, C)	Stores genetic information of an organism
RNA	• Contains ribonucleotide monomers (A, U, G, C)	Participates in protein synthesis

1.3 - Reactions

Neutralization

- Acid makes H^+ in water
- Bases produce OH^- in water
    - accepts/react with H^+
- Normal pH range is 7.35 - 7.45
- Alkalosis: blood is basic (over 7.5)
    - Symptoms:
        - Dizzy
        - Agitated
    - Causes:
        - Breath too quick at high altitudes
        - Too many antacids
- Acidosis: blood is acidic
    - Causes:
        - Kidney disease or severe vomiting
- **BUFFER**: minimize changes in/maintains pH
    - Donates H^+ when solution is basic, accepts when acidic

Redox (Oxidation-Reduction)

- **OXIDATION**: loss of electrons
- **REDUCTION**: gain of electrons
- Examples: cellular respiration and combustion
    - Propane is oxidized → releases energy
    - Sugar is oxidized $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + ATP$

Condensation and Hydrolysis

- This reaction is involved in synthesis of: carbs, lipids, proteins and nucleic acids (all)
- **CONDENSATION**: molecule + molecule, bonded by removing H from first and OH from other. Produces water + one larger molecule
- **HYDROLYSIS**: add water to break bonds (reverse condensation, restoring original molecule)

Catalyzation of Reactions

- **ACTIVATION ENERGY**: energy needed to initiate reaction
    - Large activation energy = slower reaction (need more time to reach)
- **CATALYSTS**: speed up reactions but aren't used up
    - Enzymes are proteins that act as catalysts
    - Most reactions in living things need enzymes

Enzymes

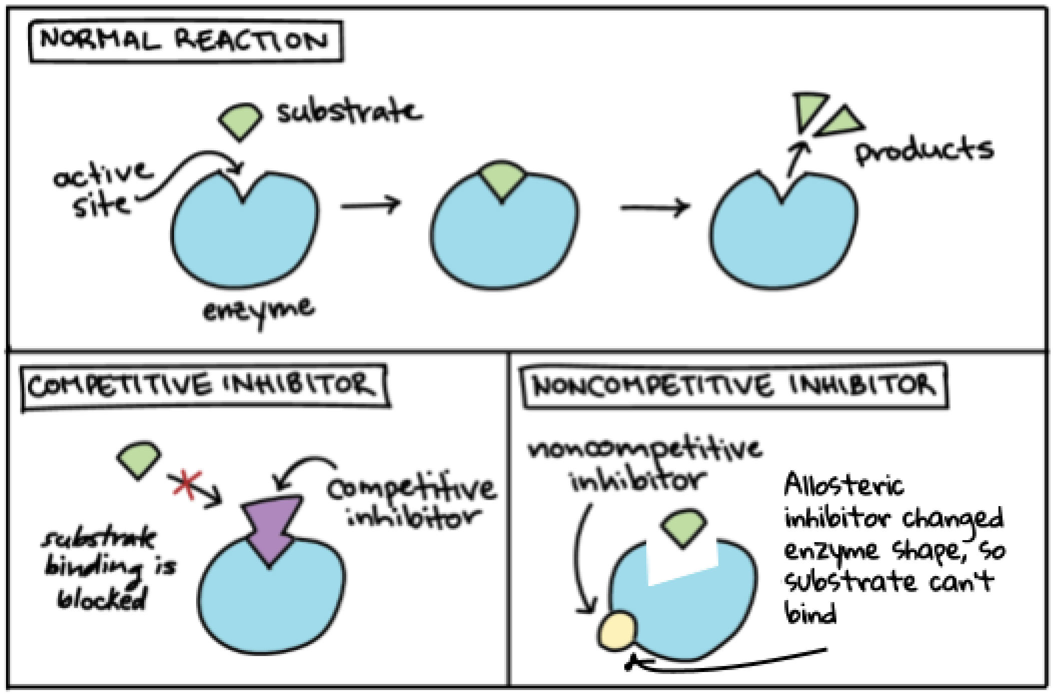
- Long amino acid chains folded into 3D structure
- Have pockets or indentations that *substrates* fit into
    - Pockets are called **ACTIVE SITES**
        - reaction/change in substrate happens here
    - **SUBSTRATES**: reactant that enzyme works on. It binds to enzyme's active site
        - To make this happen, the active site has to change a bit to accommodate the substrate (induced fit)
        - Once they bind, an enzyme-substrate complex is made
    - H bonds form between enzyme and substrate
- Enzyme speeds up reaction by changing the substrate and/or its environment
- Catalytic cycle:
    - Enzyme takes substrate, catalyzes (create/break bonds, etc), releases, repeat
- Sometimes, other molecules (vitamins/ions) are needed for the catalyzation
    - Called **COENZYMES**
    - **COFACTORS** are metal ions that are coenzymes

Things that Affect Enzyme Activity

- Change in condition alters its 3D shape
    - Usually b/c of change in temp. or pH
- Enzyme-substrate complex will take longer to form if there's less substrate (low conc.)
- Regulators:
    - **INHIBITORS**: interacts w/ enzyme to reduce its activity
        - interferes with it's interaction w/ substrate
        - Competitive inhibitor: competes with substrate for active site
        - Noncompetitive inhibitor: binds to allosteric site → changes shape of enzyme, reducing its ability to interact with substrates at active site
    - **ACTIVATORS**: bind to *allosteric site* to increase enzyme activity
        - **ALLOSTERIC SITE**: pocket regulators can bond to (not active site)

Feedback Inhibition

- Product of last reaction in pathway is a noncompetitive inhibitor of the enzyme that catalyzes one of the first reactions in pathway. This is to prevent overproduction.



2.1 - Structures and Functions of Eukaryotic Cells

- Components of Euk cells
  - Nucleus with a membrane, containing DNA
  - Cell membrane made of phospholipid bilayer
    - Proteins and lumen b/w layers
  - Cytoplasm, containing organelles, cytosol, molecules

find plant and animal cell diagrams and memorize (pg. 59)

Nucleus

- Contains DNA which stores and replicated genetic info
  - Chromosomes only visible during replication. Otherwise, condensed chromatin
- **Nucleoplasm**: thick fluid that fills nucleus
- **Nuclear matrix**: network of protein fibres that provide internal structure + support
- **Nucleolus**: contains RNA, protein, chromatin
- **Nuclear envelope**: double membrane w/ 2 phospholipid layers
- **Lumen**: space b/w any 2 phospho bilayers
- **Nuclear pore complexes**: proteins that form openings in nuclear envelope. Small particles pass freely while macros are regulated

nucleus diagram pg. 60

The Endoplasmic Reticulum

- Connects to the nucleus
- **ROUGH ER**: ribosomes assemble proteins here (intended for membrane formation or export out of cell)
  - **RIBOSOME**: RNA and proteins responsible for synthesis of polypeptides
- **SMOOTH ER**: synthesizes and metabolizes lipid-based molecules

Peroxisomes

- Budding off ER: manufactures cholesterol and bile acids
- From ER: contains oxidase (catalyzes redox reactions)

Endomembrane System

- Composed of:
    - Nuclear envelope, ER, Golgi apparatus, vesicles
- Transports and processes products
    - Proteins synthesized and modified
- Golgi apparatus:
    - Sorts, packages, distributes lipids
    - Manufactures macros (ex. carbs)
    - Produces lysosomes in animals cells and pectin in plant cells
        - Lysosomes: vesicles bound to membrane containing enzymes
        - Cis face: where vesicles merge with G.B
        - Trans face: vesicles leave
- **VESICLES**: transport and store
- **VACUOLES**: large central vesicle in plant cells
    - store water, ions, sugars, amino acids, macro
    - Control turgor pressure (determined by amount of water) → want rigidity

Chloroplasts

- Through redox reactions: absorb light to convert CO_2 + water → energy-rich molecules
- Filled with grana, which is surrounded by a thick liquid called stroma
    - Granum: a stack of thylakoids
    - Thylakoids: system of flattened disks that have chlorophyll in membrane
- Has its own DNA that codes for specific proteins

Mitochondria

- Break down energy-rich molecules and converts the energy stored into usable energy
- Has its own DNA that codes for specific proteins
- Cristae: folds in inner membrane
- Matrix: fluid-filled space inside

Cell wall and Cytoskeleton

- Provides protection and support
- Made of polysaccharides
- **CYTOSKELETON**: network of protein fibres extending throughout cytosol
    - Vesicles + organelles move along fibres

microtubules	thick	hollow	Cell shape, division, movement
Intermediate filaments	medium	Coiled cables	Cell shape, anchor
microfilaments	thin	2 strands wound together	Cell shape, division, muscle contraction

Cilia and Flagella

- Appendages that develop outside eukaryotes
- Made of microtubules

Cell Membrane

- Made of lipids, proteins, and carbs
- Separates cell from environment
- Fluid mosaic model:
    - Semi-fluid bilayer with proteins in/on bilayer
    - 2 layers slide across each other, and phospholipids exchange places frequently
- Factors affecting fluidity
    - Temperature (fluid and porous), double bonds in fatty acid tails (tightly packed), length of fatty acid tail (longer = stronger inter forces), cholesterol (controls fluidity, makes less permeable)
- Peripheral and integral proteins:
    - Transport, catalyst, cell recognition, send and receive signals

Transport across membrane

- Passive transport/diffusion down concentration gradient
    - Rate affected by: size, charge, polarity, temp, pressure
- **ISOTONIC**: 2 solutions have equal concentration
- **HYPERTONIC**: solution with higher concentration (less water)
- **HYPOTONIC**: solution with lower concentration

Facilitated Diffusion

- Channel proteins:
    - Highly specific, hollow cylinders
    - Shape and size determines what can pass through

- Carrier proteins:
    - Bind to specific molecules and carry across
    - Can transfer larger molecules
    - Slower rate of diffusion

Active Transport

- Against concentration gradient
    - Requires ATP
        - Direct use is primary AT (sodium-potassium pump)
        - indirect is secondary (electrochemical gradient made from pumped ions)

Membrane-Assisted Transport

- Transports large macros through vesicles
- **Endocytosis**: moving material into cell
    - Phagocytosis: cell engulfs large particle and liquid around it
    - Pinocytosis: engulfs liquid and small particles dissolved in it
    - Receptor-mediated: receptor (proteins) on membrane binds to molecules outside cell. Then membrane folds inward, making vesicle.
- **Exocytosis**: moving materials out of cell

Some vOcAb

- **Cytology:** study of cellular functions

Metabolic Processes

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Chapter 3: Energy and Cellular Respiration

3.1 - Metabolism and Energy

- **Metabolism**: sum of all anabolic and catabolic processes
- **Metabolic pathways:** product of one reaction is reactant of the next. Enzyme involved.
- **Catabolic:** breakdown of complex substances, releasing energy
- **Anabolic:** build up complex substances, using energy
- **Bond energy**: energy required to form/break bond
    - free/unbonded atoms have more energy (released when bonding)

Thermodynamics

- Study of energy changes
- First law: energy cannot be created or destroyed, only converted
- Second law: entropy (randomness in universe) increases with any change
    - Only applies to closed systems. Bio is open systems, using energy to reduce entropy (transfer to surroundings)
- Free energy is enthalpy minus temperature x entropy
    - $G = H - TS$ (constant temp. pressure and volume)
- **Exergonic:** releases energy
- **Endergonic**: requires energy

Adenosine Triphosphate

- Primary source of free energy
- When energy is needed, enzyme breaks down ATP, removing inorganic phosphate, producing ADP and energy (54 kJ/mol)
- **Phosphorylation**: attaching a phosphate group
- Recycling ATP:
    - Exergonic reaction → released energy synthesizes ATP (ADP + P_i) → endergonic uses energy from the breakdown of ATP back to ADP etc.

Electron Carriers

- Compounds that pick up electrons from energy-rich compounds and donate them to low-energy ones
  - NAD+ reduces to NADH
  - FAD reduces to $FADH_2$
  - Reduced (OIL RIG, reduce is gain) has more energy b/c electrons carry energy

double check the "things you should know" section on cellular resp Day 2

3.2 - Aerobic Respiration

- 4 pathways:
  1) glycolysis, 10 steps in cytoplasm
  2) Pyruvate Oxidation, 1 step in mitochondria
  3) Krebs cycle, 8 steps in mitochondria
  4) ETC, in mitochondria cristae (inner membrane)
- cellular respiration includes catabolic pathways
  - Turning energy-rich compounds into ATP
- **Substrate level phosphorylation:** when a compound that contains phosphate transfers the phosphate to ADP, making ATP
- Glycolysis
  - Glucose (6-C) → 2 x 3-C → pyruvate molecule (also 3-C)
  - 2 pyruvates produced per glucose
  - In the process: 2 NAD^+ → 2 NADH, net productions of 2 ATP
- Pyruvate oxidation
  - When oxygen is available, pyruvate enters mitochondria
  - CO_2 released
  - Oxidation paired with reduction of NADH
  - Product is a 2-C molecule, acetyl-CoA
- Krebs Cycle
  - Acetyl is separated from CoA
  - Acetyl bonds with oxaloacetate (4 C) → citrate (6 C)
  - 2 CO_2, 2 NADH, 1 ATP, 1 $FADH_2$, and then one more NADH produced
- Oxidative phosphorylation (loss of electrons and addition of phosphate group)
  - NADH and $FADH_2$ let go of Hs and gives e^-s to ETC

        - e- provide energy to pump H+ into intermembrane
        - O_2 waits at final protein to accept electrons, then attracts H+ → H_2O
        - H+ concentration b/w membranes powers ATP synthase, jamming ADP + P_i

Glycolysis

- Starts with glucose
- + 1 ATP to make it unstable
- + another ATP to make it even more unstable
- breaks into 2 three-carbon molecules (DHAP and G3P)
- converted to G3P (isomer)
    - From this point on, everything is DOUBLED cause 2 G3Ps
- G3P is oxidized
    - Electrons lost reduce NAD+ to NADH (redox), which releases energy
        - Energy used to add phosphate group
- G3Ps transfer phosphate groups to 2 ADPs, making them ATP (substrate level phosphorylation)

$$\text{Glucose} + 2P_i + 2\ NAD^+ + 2\ ADP \rightarrow 2\ NADH + 2\ ATP + 2\ \text{pyruvate}$$

Pyruvate oxidation *remember, oxid. Means losing electrons*

- Pyruvates enter mitochondria (2 per glucose)
- carboxyl group removed as CO2 (now its a 2 C molecule)
- pyruvate loses 2 electrons, making NAD+ into NAD-
    - Negative charge attracts an H+ from environment, making NADH
- pyruvate has now become acetyl
- CoA is added

$$2\ (\text{pyruvate} + \text{CoA}) \rightarrow 2\ (CO_2 + NADH + \text{acetyl-CoA})$$

Krebs Cycle

- Cyclic pathway, with oxaloacetate as the receiver of acetyl-CoA
- CoA gets ripped off from acetyl, which proceeds to react with oxaloacetate to produce citrate
- COO- is ripped off, leaves as CO2
- Coupled reaction is oxidation, resulting in reduction of NAD+ to NADH
- Production of CO_2 and NADH happens again
- Add CoA back
- Phosphate group replaces CoA on the compound
- The compound transfers the phosphate group to a GDP, making it a GTP
- GTP retransfers the phosphate group to an ADP, making ATP

- Another oxidation, this time reducing FAD to $FADH_2$
- Oxidize one last time, reducing NADH and returning the compound to oxaloacetate

2 (acetyl-CoA + oxaloacetate) → 2 ($2CO_2$ + 2 NADH + ATP + $FADH_2$ + NADH + oxaloacetate)

Recap of Yield

- 4 ATP (glycolysis - 2, krebs - 2)
- 10 NADH (glycolysis - 2, pyruvate oxid - 2, krebs - 6)
- 2 $FADH_2$ (krebs)
- Exception: 2 NADH from glycolysis can't pass thru mitochondrial membrane. Transfer electrons to FAD, which makes less ATP (that's why prokaryotes yield 2 more than euks)

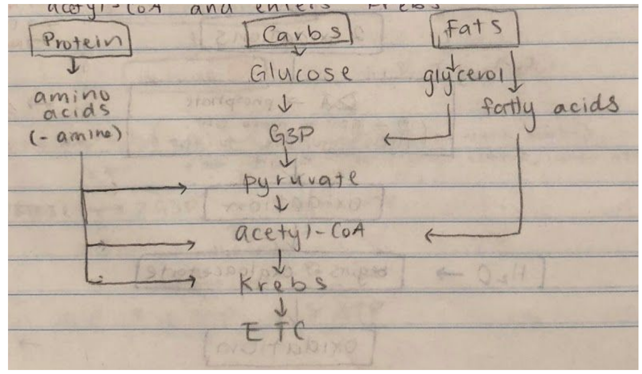
Oxidative phosphorylation (ETC and Chemiosmosis)

- Generally: oxidation of NADH and $FADH_2$ by ETC, e^- energy used to synthesize ATP
- **Electron transport chain:** series of electron carriers and proteins in inner membrane
- Oxidation means loss of electrons, which are taken off carriers and put into proteins
- At the NADH dehydrogenase (1st protein), carrier is oxidized and become NAD+ again, giving 2 e- to enter the transport chain
- Electron goes thru bc_1 complex and cytochrome oxidase complex, pumping out H+ each time
    - Active transport b/c moving H+ against concentration gradient
    - Energy comes from the e-
- At the end of the chain, oxygen if the final acceptor cause it's more electronegative (attracts e-) than other things in chain
    - This makes oxygen negative, so H+ is attracted, producing H_2O
- $FADH_2$ is the same thing but misses first protein → only pumps 2 H+
- When a certain pH is reached (amount of H+), ATP synthase is activated
- Energy from the concentration gradient is used to jam phosphate group and ADP → ATP

Experimental Yield

- Lower b/c:
    - Some H+ leak through membrane into matrix without passing thru ATP synthase
    - Some energy from H+ gradient is used to transport pyruvate into mitochondria
    - Some energy is used to transport ATP out of mitochondria

Interconnections of Metabolic Pathways



- Carbs: can be broken down and converted to glucose
- Proteins: when amino group is removed, the remainder is usually an intermediate
- Fats:
    - glycerol can be converted into G3P
    - fatty acids are taken into mitochondria, and cut up into 2-C → acetyl-CoA

Feedback Control

- In glycolysis, phosphofructokinase is main control point
    - Has allosteric binding site for ATP. Excess ATP will bind to and prevent G3P prod.

3.3 - Anaerobic Respiration

- **Anaerobic respiration:** inorganic molecule (that's not oxygen) is final acceptor

Fermentation

- Transfers electrons from NADH to an acceptor (reoxidize)
- Only produces the amount of ATP made in glycolysis

Lactate Fermentation

- NADH transfers H to pyruvate, forming lactate
- Can be reoxidized back to pyruvate when strenuous exercise stops
- Occurs in animal cells

Ethanol Fermentation

- CO_2 is removed from pyruvate, forming acetaldehyde
- NADH passes H to acetaldehyde, forming ethanol
- Carried out by yeast, breads, wine, beer, liquor, etc.