Types of Metabolic Reactions

- Metabolism: sum total of all chemical reactions in cells
- Catabolic: involves the breakdown of larger molecules into smaller ones (food digestion)
- Anabolic: involves production of larger molecules from smaller reactants
- Metabolic Pathway: reactions linked together: A → B → C → D (initial substrate, intermediates, end-product)

- **Hydrolysis**: water reacts with molecules, breaking the bonds that link them together

$$A-B + H_2O \rightarrow A-OH + H-B$$

  - Splitting of a disaccharide into two monosaccharides → hydrolysis of sucrose:

$$\text{Sucrose} + H_2O \rightarrow \text{glucose} + \text{Fructose}$$

- **Condensation**: joining together of two or more molecules to form a larger one and water is generated as a product

$$A-OH + H-B \rightarrow A-B + H_2O$$

- **Phosphorylation**: addition of a phosphate group with a phosphate bond

$$A + P_i \rightarrow A-P \quad (P_i \rightarrow \text{inorganic phosphate})$$

  - ATP synthesis requires phosphorylation to ADP:

$$ADP + P_i \rightarrow ATP + H_2O$$ (→ water was produced, so the reaction is also condensation)

- **Dephosphorylation**: removal of a phosphate group

$$A-P \rightarrow A + P_i$$

- **Oxidation-reduction reaction**: any reaction of a substance with oxygen; reactions that remove electrons from an atom or molecule (oxidation), and then the electron must be accepted by another atom / molecule (reduction)

$A\cdot + B \rightleftharpoons AB\cdot$ (the · represents the electron)

- Oxidation of glucose to water and carbon dioxide:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

- Oxidative phosphorylation: electrons are fully removed from pairs of hydrogen atoms → causing it to become positively charged hydrogen ions (H^+)

$H_2 \rightarrow 2H^+ + 2e^-$ (oxidation), $2H^+ + 2e^- \rightarrow H_2$ (reduction)

- removal or addition of hydrogen atoms

$HA-BH \rightarrow A=B+2H$

Metabolic Reactions + Energy

- Exergonic reaction: releases energy (reactants → products + energy), always proceeds spontaneously (on its own w/out energy being put in) in the forward direction
- Endergonic reaction: requires energy, do not go forward spontaneously, only when energy is put into it, instead they spontaneously go in reverse
- Chemical equilibrium: reached when the energy levels of the reactant and product are equal
- Concentration: $\frac{\text{quantity of solute}}{\text{unit volume of solution}} \rightarrow \left(\frac{\text{mols}}{\text{liters}}\right)$, as the concentration of molecules increases, so does the energy of the solution
- Law of mass action: $aA + bB \rightleftharpoons cC + dD$ → a balanced equation, the equilibrium constant for this reaction can be measured as $K = \frac{[C]^c[D]^d}{[A]^a[B]^b}$
  - ↳ when $K=1$, the reactants and products contain equal energy → no net reaction; when $K>1$, it's an exergonic reaction (net to the right); when $K<1$, it's an endergonic reaction (net to the left)
  - ↳ an increase in the concentration of reactants pushes a reaction forward

- Activation energy: the difference between the energy in the transition state (high-energy intermediate conversion of reactants breaking down into products) and the energy of either the reactants or products
  - ↳ activation energy barrier: when the transition state has greater potential energy than either of the products or reactants

Reaction Rates

- Rate: how fast a chemical reaction consumes reactants and generates products
  - ↳ Factors affecting reaction rates
    - reactant + product concentration: if reactant's concentration increases relative to the products, the net rate will increase in the forward direction (+ vise versa)
    - Temperature: proportional relationship
    - Height of activation barrier: inversely proportional b/c the minimum energy required for a "successful" collision is reduced
- Enzymes in chemical reactions
  - ↳ enzymes: biomolecules (usually proteins) that act as catalysts → substances that increase reaction rates
  - ↳ To catalyze a reaction: enzyme bonds to a substrate (reactant molecule)

$$E + S \rightleftharpoons E \cdot S \rightleftharpoons P + E$$

(E·S → enzyme-substrate complex)

↑ Binding step ↑ catalytic step

- the enzyme is neither consumed nor altered, and can act on a new substrate
  - ↳ Substrate specificity: only if a substrate can fit into an enzyme's activation site, can the enzyme catalyze the reaction
  - ↳ Cofactors + Coenzymes

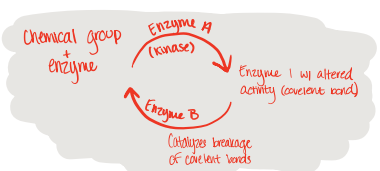
- Cofactors: nonprotein essential components of an enzyme → metal ions or vitamins
  - ↳ Coenzymes: vitamin-derived cofactors that participate in the reactions. Can dissociate from 1 enzyme and bind to another to participate in more than 1 reaction

↳ Factors affecting Enzyme-catalyzed reaction rates

1) Catalytic rate: how many product molecules it can generate in a set amount of time
   rate of an enzymatic reaction increases as the enzyme's catalytic rate increases
2) Substrate concentration: enzyme-catalyzed reaction rate increases as substrate concentration increases based on the law of mass action. Percent saturation → proportion of time that the active site is occupied
3) Enzyme Concentration: proportional to reaction rate
4) Affinity: measure of how tightly substrate molecules bind to an enzymes active site. Proportional to reaction rate

↳ Regulation of enzyme activity

- Allosteric Regulation: binding of a modulator (effector molecule) at the regulatory site on the enzyme → either activates or inhibits the reaction rates (reversible)
- Covelent Regulation: enzymes activating/inhibiting other enzymes
- Feedback inhibitation: enzymes activity is regulated by the enzymes end-product → no more recycling, so less is produced
- Feedforward Activation: speeds up reactions



ATP: Energy Exchange

- Cells harnesses energy that's released in exergonic reactions to synthesize ATP from ADP and a phosphate: $ADP + P + energy \rightarrow ATP (+ H_2O)$

↳ ATP synthesis occurs in two basic processes:

- Substrate-level phosphorylation: phosphate group is transferred from a metabolic intermediate (X) to ADP $X-P + ADP \rightarrow X + ATP$
- Oxidative Phosphorylation: ADP binds with a free inorganic phosphate. Requires e^- transport system in the mitochondria and oxygen $ADP + P \rightarrow ATP$

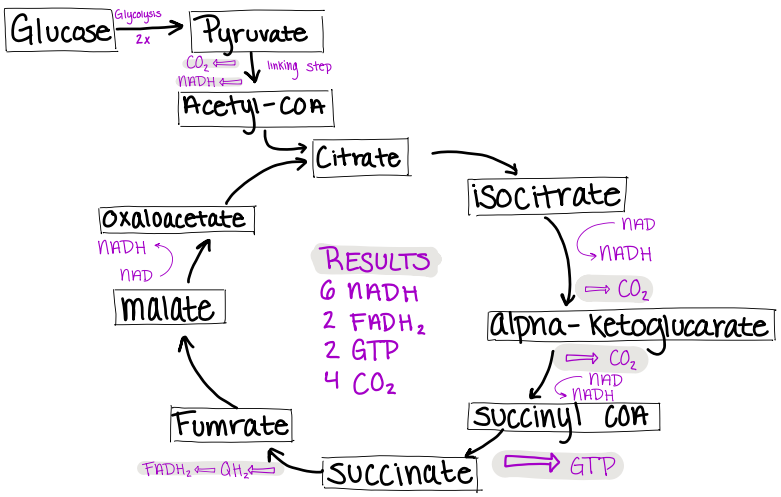
• When cells need energy, ATP is broken down through hydrolysis: $ATP + H_2O \rightarrow ADP + P_i + energy$

Glucose Oxidation

• **Glycolysis**: takes place in the cytosol
- each glucose molecule (6 carbons) breaks down into two molecules of pyruvate, 2 ATP molecules, and 2 molecules of NADH

$Glucose + 2NAD^+ + 2ADP + 2P_i \rightarrow 2\,pyruvate + 2NADH + 2H^+ + 2ATP$

• **The Krebs Cycle**: occurs in the mitochondrial matrix
- Pyruvate from glycolosis enters the mitochondrial matrix, is converted to acetyl CoA → the **linking step** to the Krebs cycle

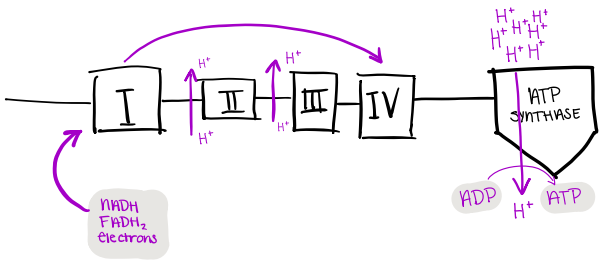


• **Oxidative Phosphorylation**: in the inner mitochondrial membrane
- involves 2 simotaneous processes
  1) $NADH + H^+$ and $FADH_2$ release electrons into the e^- transport chain
  2) Released e^- move through the chain by oxidation-reduction reactions that

release energy → used to move hydrogen ions across inner mitochondrial membrane to create a concentration gradient that stores the released energy

3) Stored energy is released when ions flow through ATP synthase → ATP is produced

4) released electrons and protons form water as an end-product



- Cori Cycle: Glucose Catabolism without oxygen
  - lactate dehydrogenase (LDH enzyme) can convert Pyruvate to lactate → allows for an alternative pathway for glycolysis and ATP synthesis

$$\text{pyruvate} + \text{NADH} + H^+ \xrightarrow{\text{LDH}} \text{lactate} + \text{NAD}^+$$

Energy Storage

- Glycogenesis: storage of abundant glucose as glycogen
- Glycogenolysis: glucose being replenished by breakdown of glycogen
- Gluconeogenesis: process of synthesizing new glucose molecules from noncarbohydrates:
  - glycerol (breaking down of triglycerides), lactate, amino acids (breakdown of proteins). Occurs mainly in the liver
- Fat metabolism
  - adipose tissue: contains fat cells, main storage depot for fats
  - Lipolysis: fat breakdown → seperation of fatty acids from the glycerol, glycerol enters glycolysis pathway then goes to the krebs cycle
    - ↳ fatty acids are catabolized to acetyl CoA through beta oxidation

- Ketones: when triglycerides are broken down for energy at a higher rate than needed. B/c they are acids, it can alter the acid-base balance → state of Ketoacidosis

- Protein Metabolism
  - Proteolysis: Proteins broken down into amino acid → amino acids are deaminated (an amino group ($-NH_2$) is removed, and amonia (NH_3) is produced
- Essentail nutrient: any biomolecule necessary for bodily functions that can't be synthesized in cells → have to be obtained from dietary sources