Cell Biology: Thermodynamics, Metabolism, and Enzymes

AI-Generated Study Guide

(Based on lectures delivered by Dr. Ty C.M. Hoffman)

Quiz: Short-Answer Questions

Answer each question in 2-3 sentences.

1. **Biochemical Pathways:** Define a biochemical pathway and explain what makes it a "pathway" rather than a series of independent reactions.
2. **Potential vs. Kinetic Energy:** Differentiate between potential and kinetic energy, providing a biological example for each.
3. **First Law of Thermodynamics:** State the First Law of Thermodynamics and explain its implications for the total energy in the universe.
4. **Second Law of Thermodynamics & Entropy:** Define entropy and explain how the Second Law of Thermodynamics relates to energy transactions and the overall disorder of the universe.
5. **Delta G and Spontaneity:** Explain what a negative delta G value signifies for a process in terms of spontaneity and free energy.
6. **Endergonic vs. Exergonic Reactions:** Describe the difference between endergonic and exergonic reactions, noting how they relate to energy input/output and spontaneity.
7. **ATP as the "Energetic Middleman":** Explain why ATP is considered the "energetic middleman" or "energy currency" of the cell.
8. **Enzyme Function:** Describe the primary function of an enzyme in a biochemical reaction, referring to the concept of activation energy.
9. **Induced Fit:** Explain the concept of "induced fit" in enzyme-substrate interactions.
10. **Feedback Inhibition:** Define feedback inhibition in the context of biochemical pathways and explain why it is usually the first enzyme in a pathway that is regulated by this mechanism.

Quiz Answer Key

1. **Biochemical Pathways:** A biochemical pathway is a series of interconnected chemical reactions. What makes it a "pathway" is that the product of one reaction serves as the

reactant for the next reaction, daisy-chaining them together from a starting substance to a final product.
2. **Potential vs. Kinetic Energy:** Potential energy is stored energy that could be used but isn't currently, such as the chemical potential energy in food. Kinetic energy is the energy of motion, exemplified by a person falling from a diving board.
3. **First Law of Thermodynamics:** The First Law of Thermodynamics, also known as the Law of Conservation of Energy, states that energy cannot be created or destroyed. This means the total amount of energy in the universe remains constant, though it can be transferred or transformed.
4. **Second Law of Thermodynamics & Entropy:** Entropy is a measure of disorder or randomness. The Second Law of Thermodynamics states that in any energy transaction, the entropy of the universe increases, meaning the universe is continuously becoming more disordered.
5. **Delta G and Spontaneity:** A negative delta G (change in free energy) signifies a spontaneous process. This means the process will happen on its own because it represents a decrease in the system's free energy, leading to a more stable state.
6. **Endergonic vs. Exergonic Reactions:** Exergonic reactions release energy and have a negative delta G, making them spontaneous. Endergonic reactions require an input of energy and have a positive delta G, meaning they are non-spontaneous and must be forced to occur.
7. **ATP as the "Energetic Middleman":** ATP serves as the energetic middleman because cells cannot directly use the energy from fuel to perform processes. Instead, energy from fuel is used to build ATP molecules, which then store this energy and can be broken down to power various cellular activities.
8. **Enzyme Function:** Enzymes are biological catalysts that speed up biochemical reactions by lowering the activation energy required for the reaction to proceed. They do not get consumed or changed in the process.
9. **Induced Fit:** Induced fit describes the dynamic interaction between an enzyme and its substrate. Upon substrate binding, the enzyme undergoes a slight conformational change, molding itself more tightly around the substrate to achieve an even better fit and optimize catalytic activity.
10. **Feedback Inhibition:** Feedback inhibition is a regulatory mechanism where the end product of a biochemical pathway inhibits an enzyme earlier in the pathway, typically the first enzyme. This is done to prevent the unnecessary production of intermediates and conserve energy and resources when the end product is already abundant.

Essay Format Questions

1. Discuss the interplay between the First and Second Laws of Thermodynamics in biological systems. How do organisms maintain order and perform work while adhering to the principle of increasing universal entropy? Use specific examples discussed in the lecture.

2. Explain the concept of free energy (G) and change in free energy (ΔG). How do these concepts determine whether a reaction is spontaneous, endergonic, exergonic, catabolic, or anabolic? Provide a detailed explanation of how these terms are interconnected and used to describe a single process.
3. Describe the structure of ATP and explain its role as the primary energy currency of the cell. Detail the cycle of ATP hydrolysis and synthesis, outlining the types of reactions (endergonic/exergonic) that drive each part of the cycle within a living cell.
4. Elaborate on the mechanism of enzyme action, focusing on how enzymes reduce activation energy and the factors that influence their activity. Discuss the importance of enzyme specificity and how environmental factors like temperature and pH affect enzyme function, providing examples from the lecture.
5. Explain the various methods of enzyme regulation, including competitive inhibition, non-competitive inhibition (allosteric regulation), and feedback inhibition. Discuss the biological advantages of these regulatory mechanisms for controlling metabolic pathways within a cell.

Glossary of Key Terms

- **Activation Energy (Ea):** The amount of energy that must be supplied to a chemical system to initiate a reaction. Enzymes lower this energy barrier.
- **Active Site:** The specific region on an enzyme where the substrate binds and catalysis occurs.
- **Adenosine Diphosphate (ADP):** A nucleotide with two phosphate groups; a lower energy form that can be phosphorylated to ATP.
- **Adenosine Monophosphate (AMP):** A nucleotide with one phosphate group; an even lower energy form than ADP.
- **Adenosine Triphosphate (ATP):** The primary energy currency of the cell, a nucleotide with three phosphate groups, storing potential energy in its bonds.
- **Allosteric Regulation:** The regulation of an enzyme's activity by the binding of a molecule to a site other than the active site, inducing a conformational change that either activates or inhibits the enzyme.
- **Anabolic Reaction (Anabolism):** A metabolic pathway that synthesizes larger, more complex molecules from smaller ones, typically requiring energy input (endergonic).
- **Biochemical Pathway:** A series of interconnected chemical reactions where the product of one reaction becomes the reactant for the next.
- **Catabolic Reaction (Catabolism):** A metabolic pathway that breaks down larger, complex molecules into smaller ones, typically releasing energy (exergonic).
- **Catalyst:** A substance that speeds up the rate of a chemical reaction without being consumed or permanently altered in the process. Enzymes are biological catalysts.
- **Change in Free Energy (ΔG):** The difference in free energy between the products and reactants of a reaction ($G_{final} - G_{initial}$). It determines the spontaneity of a reaction.

- **Closed System (Thermodynamic):** A system that can exchange energy with its surroundings but not matter.
- **Competitive Inhibition:** A type of enzyme inhibition where an inhibitor molecule structurally similar to the substrate binds reversibly to the enzyme's active site, competing with the substrate.
- **Conformational Change:** A change in the three-dimensional shape of a protein, often induced by the binding of a ligand, which can alter its function.
- **Conservation of Energy:** See First Law of Thermodynamics.
- **Coupled Reactions:** The pairing of an exergonic (energy-releasing) reaction with an endergonic (energy-requiring) reaction, such that the energy released from the exergonic reaction drives the endergonic one.
- **Dehydration Reaction:** A chemical reaction that involves the loss of a water molecule from the reacting molecule or ion.
- **Dephosphorylation:** The removal of a phosphate group from a molecule, often releasing energy (e.g., ATP to ADP).
- **Disaccharide:** A carbohydrate (sugar) composed of two monosaccharides linked by a glycosidic linkage.
- **Disorder:** See Entropy.
- **Endergonic Reaction:** A chemical reaction that requires a net input of free energy and is non-spontaneous (ΔG > 0).
- **Energy:** The capacity to do work.
- **Enzyme:** A protein that acts as a biological catalyst, speeding up specific biochemical reactions.
- **Enzyme-Substrate Complex:** A temporary molecule formed when an enzyme binds to its substrate(s) at the active site.
- **Entropy:** A measure of the disorder or randomness of a system.
- **Exergonic Reaction:** A chemical reaction that releases free energy and is spontaneous (ΔG < 0).
- **Feedback Inhibition:** A type of regulation where the end product of a metabolic pathway inhibits an enzyme earlier in the pathway, often allosterically.
- **First Law of Thermodynamics:** States that energy cannot be created or destroyed, only transferred or transformed. Also known as the Law of Conservation of Energy.
- **Free Energy (G):** Also known as Gibbs free energy, it is the portion of a system's energy that can perform work when temperature and pressure are uniform throughout the system.
- **Glycosidic Linkage:** A covalent bond that joins a carbohydrate (sugar) molecule to another group, especially another carbohydrate.
- **Gradient:** A difference in concentration, pressure, or electrical potential between two regions, representing a form of potential energy.
- **Hydrolysis Reaction:** A chemical reaction in which water is used to break down a compound.
- **Induced Fit:** A model of enzyme-substrate interaction where the binding of the substrate induces a conformational change in the enzyme, creating a more precise fit.

- **Inorganic Phosphate (Pi):** A phosphate group not associated with a carbon skeleton, often released during ATP hydrolysis.
- **Intermediate:** A substance formed in a biochemical pathway as a product of one reaction and a reactant for the next, but not the final product.
- **Isolated System (Thermodynamic):** A theoretical system that cannot exchange either matter or energy with its surroundings.
- **Kinetic Energy:** The energy of motion.
- **Law of Conservation of Energy:** See First Law of Thermodynamics.
- **Ligand:** A molecule that binds to another, typically larger, molecule.
- **Monosaccharide:** The simplest form of carbohydrate; a single sugar unit.
- **Non-Competitive Inhibition:** A type of enzyme inhibition where an inhibitor binds to an allosteric site on the enzyme (not the active site), changing the shape of the active site and reducing its ability to bind to the substrate.
- **Nucleotide:** A monomer of nucleic acids, consisting of a pentose sugar, a nitrogenous base, and one or more phosphate groups.
- **Nucleoside:** A molecule consisting of a pentose sugar and a nitrogenous base, without a phosphate group.
- **Open System (Thermodynamic):** A system that can exchange both matter and energy with its surroundings (e.g., living organisms).
- **Optimum Temperature/pH:** The temperature or pH at which an enzyme exhibits its maximum activity, reflecting its ideal shape and function.
- **Phosphorylation:** The addition of a phosphate group to a molecule, often increasing its energy content (e.g., ADP to ATP).
- **Potential Energy:** Stored energy; energy that matter possesses because of its location or structure.
- **Product:** The substance(s) formed as a result of a chemical reaction.
- **Progress of the Reaction:** A measure of how far a reaction has proceeded from reactants to products, often depicted on the x-axis of energy diagrams.
- **Reactant:** A starting material in a chemical reaction that undergoes change.
- **Second Law of Thermodynamics:** States that every energy transfer or transformation increases the entropy (disorder) of the universe; also implies that no energy transaction is 100% efficient, with some energy lost as unusable heat.
- **Spontaneous Process:** A process that can occur without an input of external energy; characterized by a negative ΔG.
- **Substrate:** The reactant in an enzyme-catalyzed reaction that binds to the enzyme's active site.
- **System (Thermodynamic):** The part of the universe that is being studied; anything one chooses to define for observation.
- **Thermodynamics:** The study of energy transformations and heat flow.
- **Transformation (Energy):** The change of energy from one form to another (e.g., chemical to heat).
- **Transition State:** A very unstable, high-energy intermediate state in a chemical reaction where bonds are breaking and forming.
- **Transference (Energy):** The movement of energy from one object or system to another.

- **Transport Work:** The energy-requiring movement of substances across membranes or within the cell, often powered by ATP (e.g., active transport, motor proteins).