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**Unit 3 Review Packet: Cell Energy**

AP Biology, adapted from Mrs. Krouse – thank you!

**Topic #1: Cell Respiration**

1. Scientists consider glycolysis to be an ancient process. In other words, scientists claim that glycolysis was found in the common ancestor of all living things. What types of organisms use glycolysis today, and how does this provide support for their claim?

*All organisms, even* ***prokaryotes****, use glycolysis. In addition, glycolysis takes place in the cytosol. This means that there are no membrane-bound organelles needed. Similarly, glycolysis happens in both aerobic and anaerobic organisms. This provides evidence that all organisms on earth share a common ancestor that was capable of glycolysis.*

2. What are the reactants (starting molecules) and products (ending molecules) of glycolysis?

*Reactants:* ***C6H12O6****, 2 ADP, and 2 NAD+*

*Products:* ***2 pyruvate (C3H4O3),*** *2 ATP, and 2 NADH (electron carrier)*

3. Describe the amount and type of ATP production during **glycolysis**. (Note: The type of ATP production refers to substrate-level phosphorylation vs. oxidative phosphorylation.)

*In glycolysis, 2 net ATPs are made (4 are made total, but 2 are used, so only 2 ATP are made and actually available for use in the cell). The type of ATP production is substrate-level phosphorylation. Substrate-level phosphorylation is when a phosphate group is transferred from one molecule (a substrate) directly onto ADP (to form the product ATP).*

4. What are the reactants (starting molecules) and products (ending molecules) of the **intermediate step** between glycolysis and the Krebs / citric acid cycle in which pyruvate is converted to Acetyl CoA?

*Reactants:* ***2 pyruvate (C3H4O3)****, coenzyme A (CoA), 2 NAD+*

*Products:* ***2 acetyl-CoA****, 2 NADH, 2 CO2*

*\*Pyruvate is a 3 carbon molecule and acetyl (which later gets joined with coenzyme A to make acetyl-CoA) is a 2 carbon sugar. Hence for each pyruvate that is converted into acetyl, one CO2 is lost.*

5. What are the reactants (starting molecules) and products (ending molecules) of the **Krebs / citric acid cycle**?

*Reactants:* ***2 acetyl-CoA****, 6 NAD+ (3 for each cycle of acetyl-CoA), 2 FAD, 2 ADP*

*Products:* ***4 CO2,*** *6 NADH, 2 FADH2, 2 ATP*

*\*For every single glucose molecule sent into glycolysis, 2 acetyl-CoAs are made. That means for each glucose going into glycolysis, the Krebs Cycle happens twice. For each acetyl-CoA molecule that enters the cycle, 3 NADH, 1 FADH2, 1 CO2, and 1 ATP are made. To get the total from the one glucose molecule, we double all of the products since we have to account for* ***both*** *acetyl-CoAs.*

6. After the Krebs cycle, how is most of the energy from the original glucose molecule stored?

*Most of the energy from the original glucose molecule is stored* ***in the electron carriers NADH and FADH2.*** *This energy is later used to power the electron transport chain.*

1. How are high-energy electrons from NADH and FADH2 used during the electron transport chain?

*Electrons are transported from the carriers to the electron transport chain proteins. The energy they provide the proteins allows the proteins to actively pump H+ against their concentration gradient (from low to high) into the intermembrane space.*

1. How is oxygen gas (O2) used during the electron transport chain?

*Oxygen is the final electron acceptor in the Electron Transport Chain. After the electrons from NADH and FADH2 travel through the whole electron transport chain, they are picked up by Oxygen (along with some H+) and water is formed. Without oxygen to pick them up, the electrons would stop moving down through the chain and ATP would cease to be made. This is what suffocation does to our cells/mitochondria.*

1. Why are there folds (aka cristae) in the inner mitochondrial membrane?

*The folds increase the surface area of the inner membrane which allows from more Electron Transport Chain complexes, which allows for more ATP production. The inner membrane has about 5x the surface area of the outer membrane.*

1. Define “proton motive force.” How is this used during the electron transport chain?

*During the electron transport chain, H+ builds up in the intermembrane space. This makes the intermembrane space an area of high concentration of H+. Relatively speaking, the matrix (inside the inner membrane) has a lower concentration of H+. This means that the H+ “want” to flow down its concentration gradient into the matrix (from high to low concentration). This gradient that has been created is called the H+ or proton gradient. We call the “desire” of H+ to move back down is gradient (from high to low) the* ***“proton motive force.”*** *The only way for it to travel from high to low concentration in the matrix is through the enzyme ATP synthase. As H+ move back down the concentration gradient through ATP synthase, ATP is produced. The proton motive force acts like water turning a water wheel (of an old factory) to generate power. As H+ flow through ATP synthase, ATP is generated to power the cell.*

1. How is oxidative phosphorylation / chemiosmosis (the type of ATP production that occurs in the electron transport chain) different from substrate-level phosphorylation? Is there more or less ATP made during oxidative phosphorylation than substrate-level phosphorylation?

*Chemiosmosis / oxidative phosphorylation is the process of H+ flowing through ATP synthase to produce ATP. In oxidative phosphorylation, as H+ ions flow through ATP synthase, the protein turns, and this turning motion causes ADP and Pi to “squish” together and create ATP. This is using the energy from H+ flow to “mass produce” ATP from ADP and single Phosphates. This differs from substrate-level phosphorylation where a phosphate is directly transferred from one molecule to ADP to make ATP. 32-34 ATP molecules can be created during this process (per original glucose molecule), which much more than substrate-level phosphorylation is capable of.*

1. How is aerobic respiration different from anaerobic respiration (aka fermentation)? Which steps of aerobic respiration (i.e. glycolysis, the conversion of pyruvate to acetyl CoA, the Krebs cycle, or the electron transport chain) occur during anaerobic respiration?

*Aerobic respiration occurs when oxygen is present. Anaerobic respiration is the breakdown of glucose to make some ATP in the* ***absence of oxygen****. Without oxygen, most cellular respiration stops, but fermentation provides a mechanism by which some cells can continue to oxidize (break down) glucose and generate ATP. In anaerobic respiration (aka fermentation) only glycolysis is performed. Since the Krebs Cycle and the ETC don’t occur, the amount of ATP produced in anaerobic respiration is significantly less than in aerobic respiration.*

1. Why does NAD+ need to be regenerated from NADH for glycolysis to continue? How is this accomplished in **lactic acid fermentation vs. alcoholic fermentation**?

*NAD+ is used to oxidize glucose (NAD+ breaks apart glucose by taking some of its electrons and H+). Without NAD+ to oxidize glucose, no more ATP can be generated. Under aerobic conditions (i.e. oxygen is present), NADH transfers its electrons to the electron transfer chain, recycling NAD+. Under anaerobic conditions (i.e. oxygen is NOT present), pyruvate then accepts electrons from NADH, oxidizing it back to NAD+. The NAD+ is then available to oxidize more glucose.*

*Lactic acid fermentation is different from alcoholic fermentation in what* ***form*** *of pyruvate actually accepts the electrons from NADH to turn it back into NAD+. In* ***lactic acid fermentation, pyruvate itself actually accepts the electrons and H+, forming lactic acid****. In* ***alcoholic fermentation****, pyruvate first breaks down into CO2 and acetaldehyde. CO2 is released as a waste (bubbles in bread), and* ***acetaldehyde is the molecule that accepts the electrons and H+, forming ethanol (a type of alcohol).***

1. In what types of organisms/cells does each type of fermentation occur?

*Alcoholic Fermentation = yeast and some bacteria (hence yeast is used to ferment wines, and also to make breads rise with its CO2 bubbles)*

*Lactic Acid Fermentation = animal muscle cells and some bacteria (used in yogurt)*

**Topic #2: Photosynthesis (The Light Reactions and Calvin Cycle)**

1. What pigments are found in the thylakoid membranes? What is their role in the light reactions of photosynthesis?

*Chlorophyll along with the accessory pigments (like carotenoids) are found in the thylakoid membranes. The pigments absorbs the sun’s energy and use that to energize the electrons that go down the electron transport chain. Chlorophyll absorbs most colors of light except green. Carotenoids are orange and so they absorb all colors of light except orange. Carotenoids and other colored pigments are called “accessory pigments” because they help absorb the colors of light that chlorophyll cannot.*

1. What colors of light are most ABSORBED by chlorophyll a? What color of light is most REFLECTED by chlorophyll a?

*Chlorophyll best absorbs red and blue/violet lights and most reflect the green color – that is why chlorophyll appears green.*

1. What happens to water during the light reactions of photosynthesis?

*Water is split using the sun’s energy into Oxygen (waste product), Hydrogen ions (proton gradient) and electrons (used in the electron transport chain to create proton gradient). The electrons are used to replace the electrons lost by the chlorophyll in Photosystem II to the electron transport chain.*

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1. What is the goal of cyclic electron flow?

***The goal of cyclic electron flow is to be able to create more ATP without creating NADPH, because the Calvin Cycle requires more ATP than it does NADPH.*** *Cyclic electron flow (CEF) happens when the electrons energized in PHOTOSYSTEM 1 are sent backwards to the H+ pumping proteins in the electron chain before it. The electrons then flow back down the chain to Photosystem I again, which sends it back again. That way, no H2O is used and turned into O2 to replace the electrons from the photosystem (like in PS2), AND ATP can be made without producing unnecessary NADPH.*

1. What role do the electron transport chains in the thylakoid membrane play in the creation of a proton motive force? How is the proton motive force used?

*The electron transport chain uses the energy from the moving electrons to pump the H+ into the lumen (thylakoid space). This creates a proton gradient thus creating the proton motive force. This force is then used to allow H+ to flow though ATP synthase from high concentration in the lumen to the lower concentration in the stroma. This movement allows ADP+P to come together to form ATP with the help of the ATP synthase enzyme.*

1. What is the main goal of the Calvin cycle?

*The main goal of the Calvin Cycle is to combine CO2 with other carbon molecules using the energy of ATP and NADPH. This carbon fixation leads to the formation of a 3-carbon sugar named PGAL/G3P. When two of those molecules are combined, they form glucose (C6H12O6).*

1. Describe the relationship between the light reactions and the Calvin cycle.

*Building glucose is an anabolic reaction that takes energy (endergonic). The light reactions produce ATP and NADPH, high energy molecules that are needed to power the Calvin Cycle.*

1. What are the reactants and products of the Calvin cycle?

*Reactants:* ***CO2,*** *ATP, NADPH*

*Products:* ***PGAL*** */ G3P, ADP, NADP+*

1. Where in the chloroplast does the Calvin cycle occur?

*In the stroma, the liquid between the chloroplasts membranes and the thylakoids.*

**Topic #3: Exceptions to Normal Photosynthesis and Comparing Photosynthesis and Cellular Respiration**

1. What occurs during photorespiration? Why is this an issue for plants?

*The enzyme Rubsico (used in the Calvin Cycle) can bind to both O2 and CO2, thus oxygen acts as a competitive inhibitor, making the Calvin Cycle less efficient. When oxygen binds to Rubsico, it is called photorespiration. This is an issue because if Rubsico is bound to oxygen, it cannot fix CO2 to RuBP.*

1. How do C4 plants minimize photorespiration?

*C4 plants have the beginning step of the Calvin cycle (the one that uses Rubisco) take place in the bundle sheath cells instead of the mesophyll cells. This allows the Rubisco enzyme to only be exposed to carbon dioxide and not to the oxygen gas produced in the light reactions. This* ***spatial separation*** *(doing the processes in different places) decreases photorespiration.*

1. How do CAM plants minimize photorespiration? Why do CAM plants keep their stomata closed during the daytime?

*CAM plants take in Carbon Dioixde during the night and transform it into Malic Acid and store this molecule in their vacuole.* ***During the daytime they close their stomata to reduce water loss*** *since they usually inhabit deserts and take the Malic acid that is stored out of the vacuoles and transform it back into carbon dioxide to be used to photosynthesize during the day. Otherwise, if the stomata were closed during the day and there was no back-up storage of CO2, CO2 would be used up quickly and photorespiration would happen more frequently as the day went on. This* ***temporal separation*** *(stocking up on CO2 during the nighttime when the stomata are open, then using it all during the day) minimizes photorespiration because even though O2 will build up as a waste of the light reactions during the day when the stomata are closed, there is so much CO2 stored in the vacuole that the cell floods the chloroplast with CO2, overpowering the amount of O2 present and making it less likely for Rubisco to bind to O2.*

1. Why are photosynthesis and cellular respiration often thought of as a cycle? Write out the full, balanced chemical equation for each process and compare them.

*The products of photosynthesis are the reactants of cellular respiration and the products of cellular respiration are the reactants of photosynthesis. They are basically the same reaction, but run in opposite directions.*

*\*This is only true for AEROBIC cellular respiration.*

*\*The other difference is the type of energy – light energy is a reactant for photosynthesis, but energy in the form of ATP is the product of Cellular Respiration*

1. What types of organisms have chloroplasts? What types of organisms have mitochondria?

*Only autotrophs (specifically photoautotrophs) have chloroplasts. On the other hand, ALL eukaryotic organisms (autotrophs AND heterotrophs) have mitochondria. Remember, mitochondria and cellular respiration make the energy needed to keep your cells functioning. ALL cells need energy.*

1. Compare / contrast the electron transport chain in the mitochondrion vs. chloroplast in terms of the electron carriers used to “drop off” electrons, the direction of H+ pumping, the creation of an electrochemical gradient, the synthesis of ATP, the final electron acceptor, etc. How are they similar? How are they different?

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| --- | --- | --- |
|  | **Mitochondria (final step)** | **Chloroplast (first step)** |
| **Electrons Carriers used** | **NADH and FADH2** donate electrons to **beginning** of the ETC | **NADPH** is created at the **end** of the ETC (it is the final electron acceptor) and then used for the Calvin Cycle. *(The thing that donates the electrons at the beginning is Chlorophyll / H2O.)* |
| **Direction of H+** | Gets pumped from Matrix OUT to the intermembrane space | Gets pumped from the stroma INTO the thylakoid space/lumen. |
| **Gradient Creation** | Gradient created in the intermembrane space by the energy from the electrons | Gradient created in the lumen by the energy from the electrons |
| **Synthesis of ATP** | By the proton-motive force through ATP synthase | By the proton-motive force through ATP synthase |
| **Final Electron Acceptor** | Oxygen to form water | NADP+ to form NADPH |