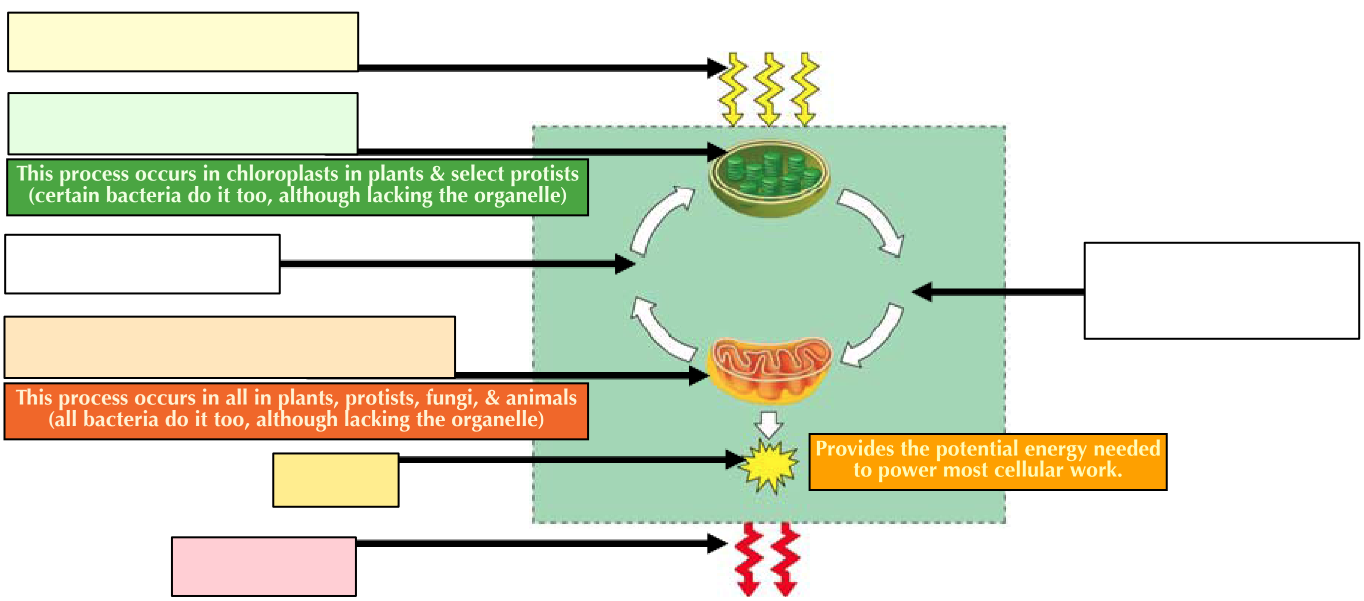
<u>STUDY GUIDE</u> - ***Ch. 9.1 - Catabolic Pathways Yield Energy by Oxidizing Organic Fuels*** **NAME: ____________________**

- **<u>PHYSICALLY PRINT OUT</u> this PDF and <u>HANDWRITE</u> (with a black or blue pen) your answers directly on this PDF.** *Typed or digitally-written work is **<u>not</u>** accepted. Do **<u>not</u>** answer questions on separate paper.*
- **Importantly, study guides are <u>NOT GROUP PROJECTS</u>!!!** *You, and you alone, are to answer the questions as you **<u>read</u>** your assigned textbook. You are **<u>not</u>** to share answers with other students. You are **<u>not</u>** to copy any answers from any other source, including the internet.*
- **Get in the habit of writing <u>LEGIBLY</u>, neatly, and in a <u>medium-sized font.</u>** *AP essay readers and I will skip grading anything that cannot be easily read so start perfecting your handwriting, and don't write so large you can't add all the relevant details and key elaborations in the space provided.*
- **<u>SCAN</u> physical documents in color and with good resolution. Then, upload your final work as <u>PDFs</u> to Archie.** *Avoid uploading dark, shaded, washed-out, sideways, or upside-down scans of homework. Keep completed physical study guides organized in your biology binder to use as future study and review tools.*
- **<u>READ FOR UNDERSTANDING</u> and not merely to complete an assignment.** ***<u>First</u>**, read a section quickly to get an overview of the topic covered. Then, read it a **<u>second</u>** time slowly, paraphrasing each paragraph **<u>out loud</u>** and analyzing every figure. Finally, read it a **<u>third</u>** time as you answer the study guide questions if assigned and start building your memory. Try to write answers out in your own words, when possible, and try to purposefully and accurately use all new terminology introduced.*

Chemical energy stored in high-energy molecules is used to build ATPs, the molecules that drive most cellular work.

1. The energy (stored in organic molecules in our foods) that moves up the food chain in all terrestrial and most aquatic habitats **<u>ultimately</u>** comes from certain types of **<u>electromagnetic radiation</u>** *(the **<u>solar energy</u>** from the sun)*. Photosynthesis & cellular respiration are key ecological concepts involving **<u>energy flow</u>**. Label the figure below.



To summarize the figure above, energy ________________ into an ecosystem as ________________ and exists as ________________ . In contrast, the ________________ ________________ essential to life are ________________ . Photosynthesis generates ________________ (as a waste product) and (high-energy) ________________ ________________ used by mitochondria in eukaryotes for ________________ ________________ . Cellular Respiration, in turn, breaks down organic molecules (fuel), using ________________ and generating ________________ . The waste products of this type of (aerobic) respiration, ________________ ________________ and ________________ form the raw materials again needed for ________________________________ .

2. What do we call **<u>metabolic pathways that release energy stores in complex molecules</u>** by breaking them down?

3. a. Why do **organic compounds contain stored chemical (potential) energy**?

   b. If the goal is to **release the energy stored** in certain (high-energy) covalent bonds in these organic compounds, will the waste products that form when these complex organic molecules are broken down contain more or less energy than the complex organic molecules themselves? Fill in the sentence below with your answer.

   In an exergonic reaction, the products of the chemical reaction contain __________ stored energy (combined) than the (high-energy) starting reactants (combined).

   c. What happens to **the energy that is released from complex organic molecules**?

   1.

   2.

4. Energy is extracted from high-energy organic compounds and stored on ATP through fermentation (a form of partial anaerobic cellular respiration), anaerobic cellular respiration, and aerobic cellular respiration. How do these three processes differ?

   Fermentation:

   Aerobic Cellular Respiration:

   Anaerobic Cellular Respiration:

5. a. Though carbohydrates, fats, and proteins can all be catabolized and used as a fuel, what is **the molecule (a monosaccharide) that cells use most often as fuel**?

   b. Though high-energy compounds are broken down over many steps to release energy slowly, what is the overall **net BALANCED chemical reaction of aerobic cellular respiration starting with glucose**?

6. a. What is the **free energy change (ΔG) of breaking down 1 mol of glucose**?

   b. Is this a spontaneous exergonic or a non-spontaneous endergonic reaction?

   c. **FYI:** Just releasing energy from glucose through cellular respiration (an **exergonic process**) isn't going to result in work being done, however. **That energy released has to be used to produce ATP from ADP and phosphate (and endergonic process) that results in the energy being stored on ATP.** Then, ATP carries the stored energy to the locations within the cell that need energy to perform mechanical, transport, or chemical work, releasing the energy again when ATP is hydrolyzed eventually into ADP and phosphate again (another **exergonic process**).

7. **In cellular respiration, electrons are transferred during chemical reactions in a way that releases the energy stored in these high-energy electrons obtained from organic molecules.** These reactions that involve the transfer of electrons are known as oxidation-reduction reactions or **redox reactions**.

   a. What is **oxidation**?

b. What is **reduction**?

c. Indicate with arrows on the generic redox reaction below what is being oxidized and that is being reduced.

$$Xe^{-} + Y \rightarrow X + Ye^{-}$$

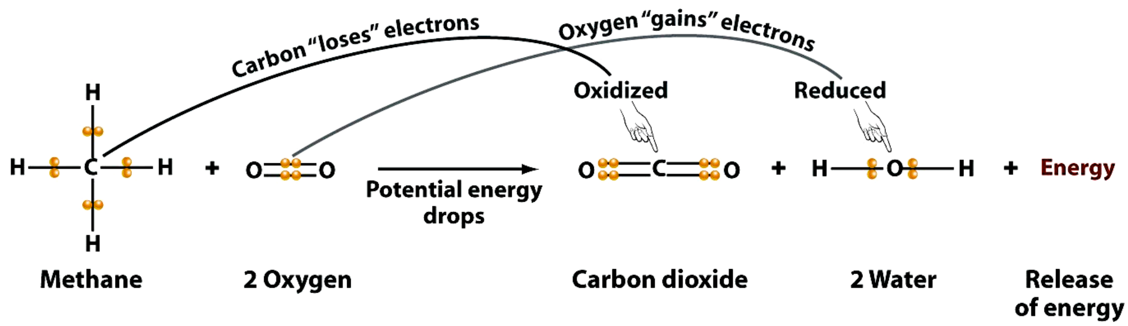
d. What is a **Reducing Agent**?

e. What is an **Oxidizing Agent**?

f. In the generic redox reaction of 7.c. above, ______ is the reducing agent in this reaction, and ______ is the oxidizing agent, ______ being oxidized and ______ being reduced.

8. Note that not all redox reactions involve the complete transfer of electrons from one atom (or compound) to another atom (or compound). Sometimes the **degree of electron sharing in covalent bonds of molecules change**, an atom (like hydrogen or carbon) loosing electron density compared to what it had before. Such changes can be seen when a **hydrogen** that was bonded to a **carbon** (and was **sharing a bonding valence electron equally, the electron having a certain amount of potential energy because of its position within the hydrogen's electron cloud**) bonds instead with much more electronegative atoms like **oxygen**. In such a chemical reaction, the hydrogen partially loses the bonding valence electron, which now is **shared unequally with and pulled much more closely to the nucleus of oxygen**, ***losing potential energy***, though the hydrogen may still not have fully and permanently lost access to this electron, which occasionally still spends time in the hydrogen's electron cloud.

   Analyze Figure 9.2 showing one such scenario in which the hydrogens and carbon in methane becomes partially oxidized when methane react with oxygen to form carbon dioxide and water. Now it's your turn to explain clearly **why energy is released to the surrounding environment when methane undergoes a combustion reaction with oxygen to form carbon dioxide and water** *(when the partially-reduced hydrogen and carbon in methane become partially oxidized by no longer being covalently bonded to carbon or hydrogen, but instead becoming covalently bonded to oxygen)*? Note that though cellular respiration, which starts with a high-energy organic molecule like glucose, is not identical to a combustion reaction in how the chemistry occurs, the **net equation** for cellular respiration, which you wrote out in equation 5.b. is similar to a combustion reaction in that a high-energy organic glucose reacts with oxygen leading to the eventual formation of carbon dioxide and water.



9. a. Using arrows, indicate what is being **oxidized** and what is being **reduced** in (aerobic) **cellular respiration**.

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{Cellular respiration}} 6CO_2 + 6H_2O$$

b. **FYI: The potential energy released from (high-energy) electrons in C-H bonds** is the energy that will be extracted from organic molecules during cellular respiration in order to be **stored on ATP**, and later used for performing cellular **work**!!!

So, in general, we see fuels with multiple C-H bonds oxidized into products with multiple __________ bonds.

10. If the catabolism of glucose is an exergonic, spontaneous reaction, why does glucose not react instantly with the O_2 in our bodies to form carbon dioxide and water, and release its stored energy?

11. a. Why is the **energy in glucose not released in one chemical step during cellular respiration** as occurs in a combustion reaction?

b. To **increase the efficiency of energy harvesting** (transferring the released energy from glucose's electrons onto ATP) and prevent damage to other molecules's covalent bonds if too much energy is released from glucose in one step, what does the cell do instead of releasing all of glucose's energy in one chemical step?

12. As you are learning, in cellular respiration, electrons are not transferred directly from glucose to oxygen. An electron, often coupled with a proton to form a hydrogen atom, first passes to a type of coenzyme called an **electron carrier**. *Following the movement of hydrogen allows you to follow the flow of electrons through the cellular respiration process.* Please, answer the following questions regarding the electron carrier NAD+.

a. What is the **role** of **NAD^+** during cellular respiration?

b. What is the name of the **enzymes that remove pairs of hydrogen atoms (2 electrons and 2 protons) from organic molecules, oxidizing them and reducing electron carrier molecules such as NAD^+ and FAD** *(FAD being a coenzyme you will encounter later in the chapter*?

c. Which the help of the enzyme identified above, how does **NAD^+ act as an oxidizing agent**?

d. What is the **reduced form of NAD^+**?

e. Is a lot or a little potential energy lost from an electron when electrons are transferred from an organic fuel to NAD^+?

13. a. What are and where do you find (in eukaryotes and prokaryotes) **electron transport chains**?

b. The high-energy electrons extracted from glucose (and other organic molecules), which store potential energy on NADH (or $FADH_2$), will eventually be discarded by reducing oxygen, but only once the energy from the electrons has been extracted so it can be used to make ATP. Electrons from electron carriers like NADH (and $FADH_2$) are, therefore, **not** passed directly to oxygen as doing so would instead cause the energy in the high-energy electrons extracted from organic molecules and stored on NADH (and $FADH_2$) to be released (as thermal energy) in one explosive step when they bond to oxygen and loose their potential energy all at once, the energy, thus, being lost, wasted instead of used to make ATP. Read your textbook and review Figure 9.4. Then, describe how **electron transport chains** involve a series of redox reactions and alter *the way* energy is released from electrons as they move from electron carriers like NADH (and $FADH_2$) to oxygen atoms?

14. Show the normal, downhill **route most electrons follow in (aerobic) cellular respiration.**

Glucose → ______________________________ → ______________________________ → **Oxygen**

15. What are the **three stages of aerobic cellular respiration**?

1. ______________________________

2. ______________________________ **&** ______________________________

3. ______________________________ **=** ______________________________ **&**

____

16. a. Which stages of aerobic cellular respiration are catabolic, involving the oxidation of glucose and other organic molecules (or their intermediates)?

b. Where does **glycolysis** take place in prokaryotes **and** eukaryotes?

Prokaryotes =

Eukaryotes =

c. What happens during **glycolysis**?

d. What **happens next to pyruvate** that form from breaking down glucose during glycolysis?

e. What **happens to the acetyl from Acetyl CoA once it enters the citric acid cycle** (also known as the Krebs Cycle)?

f. Where does the **citric acid cycle** occur in prokaryotes?

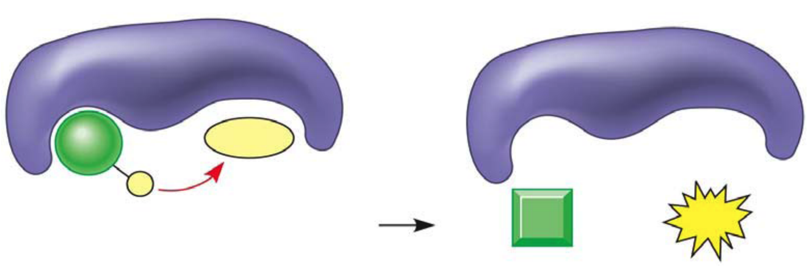
g. Where does the **citric acid cycle** occur in eukaryotes?

h. **During glycolysis, pyruvate oxidation, and the citric acid (Krebs) cycle, high-energy electrons from the intermediates of glucose catabolism are transferred to electron carriers NAD^+ and FAD, reducing them into NADH and FAH_2.** What happens to the (high-energy) **electrons** passed on from these electron carriers to the the **electron transport chain** stage of cellular respiration?

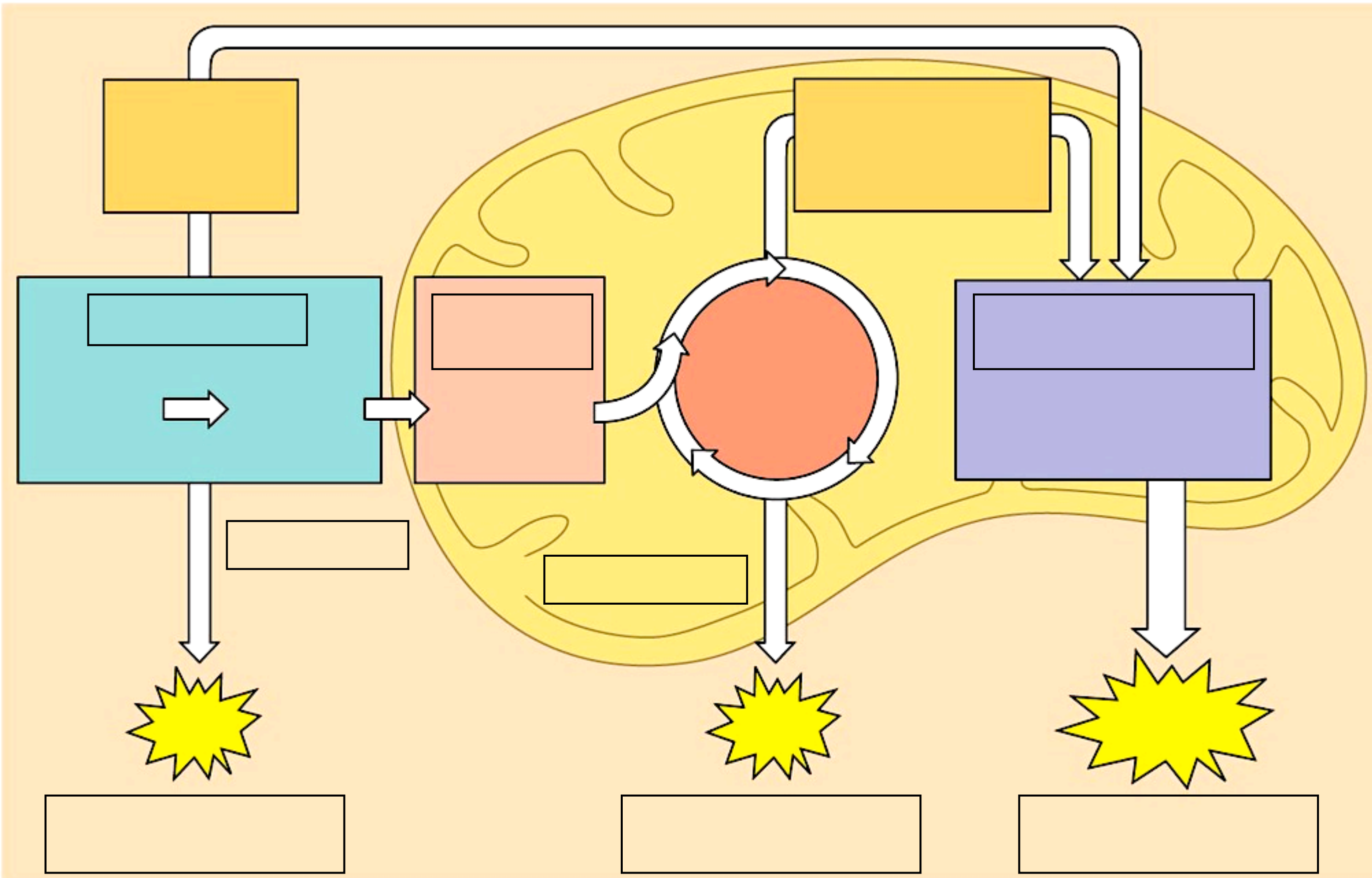
i. What happens to the **potential energy that was stored in the (high-energy) electrons** that are put into the electron transport chain?

17\. a. In order **to make ATP, a molecule of ADP must be phosphorylated into ATP**. **90% of the ATP** made during aerobic cellular respiration occurs through **oxidative phosphorylation**, which occurs with the help of the **electron transport chain** and another enzyme in the inner mitochondrial member (or plasma membrane in prokaryotes) known as **ATP Synthase**. Oxidative phosphorylation involves an **inorganic** phosphate (a PO^{-3}_4 polyatomic ion and solute, which is not covalently bonded to a carbon-based molecule) getting added to the organic Adenosine Diphosphate or ADP molecule. The other **10% of ATP is made during glycolysis and the citric acid (Krebs) cycle by substrate-level phosphorylation**. How is substrate level phosphorylation different?

b. Label the figure below, showing the direct transfer of an **ORGANIC** phosphate from a substrate, a carbon-based intermediate of the glycolysis and citric acid cycle biochemical pathways, to ADP to form ATP as occurs during **substrate-level phosphorylation**.



18. Understanding the overall "map" of how cellular respiration will make the details easier to learn. Before continuing to read your textbook, **memorize Figure 9.5., which shows a model of respiration.** When you feel you have learned it, try to label the missing information in the figure below from memory as a self-quiz. *This is a must know!*



19. a. How much chemical free energy is **stored in the bonds of a mole of glucose molecules**? *Always include proper units with any number reported!*

b. For **each molecule** of glucose degraded through cellular respiration, **how many molecules of ATP can be made**?

b. **How much energy does a mole of ATP store**? *Always include proper units with any number reported!*