STUDY GUIDE - *Ch. 9.2 - Glycolysis Harvests Chemical Energy by Oxidizing Glucose to Pyruvate* NAME: ________________
- *Ch. 9.3 - After Pyruvate is Oxidized, the Citric Acid (Krebs) Cycle Completes the Energy-Yielding Oxidation of Organic Molecules*

- **PHYSICALLY PRINT OUT this PDF and HANDWRITE (with a black or blue pen) your answers directly on this PDF.** *Typed or digitally-written work is **not** accepted. Do **not** answer questions on separate paper.*
- **Importantly, study guides are NOT GROUP PROJECTS!!!** *You, and you alone, are to answer the questions as you **read** your assigned textbook. You are **not** to share answers with other students. You are **not** to copy any answers from any other source, including the internet.*
- **Get in the habit of writing LEGIBLY, neatly, and in a medium-sized font.** *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.*
- **SCAN physical documents in color and with good resolution. Then, upload your final work as PDFs 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.*
- **READ FOR UNDERSTANDING and not merely to complete an assignment.** ***First***, *read a section quickly to get an overview of the topic covered. Then, read it a **second** time slowly, paraphrasing each paragraph **out loud** and analyzing every figure. Finally, read it a **third** 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.*

1. **The starting reactant of glycolysis, a six-carbon sugar called ________________________, is split into two __________ - carbon compounds, which are both oxidized to form two __________ - carbon compounds called ________________________.**

2. a. Read your text and study Figure 9.7. The biochemical pathway known as glycolysis can be thought of as having two stages. What are the **two stages of glycolysis** referred to as?

   1.

   2.

   b. What happens in the **first half of glycolysis** (stage 1)?

   c. Energy from how many ATPs are used in the first half of glycolysis?

   d. What two important events happens in the **second half of glycolysis** (stage 2)?

   1.

   2.

   e. How **many net molecules of ATP are produced during the breakdown of 1 glucose molecule by glycolysis**?

   f. How many **molecules of reduced NADH are produced during the breakdown of 1 glucose molecule by glycolysis**? *(Remember, each electron carrier carries two high-energy electrons).*

3. a. Read through each step of the glycolysis biochemical pathway outlined in **Figure 9.8**. **Where does glycolysis occur** in **all** cells (prokaryotic and eukaryotic)?

b. *Think:* What would be the overall results of the glycolysis of glucose molecules if you removed the dihydroxyacetone phosphate generated in step 4 as fast as it was produced? **WHY**? *(Check your answer by going to the Ch.9 **Figure Questions** for **Figure 9.8** in Appendix A of your textbook)*

c. During the redox reaction in glycolysis in step 6 in Figure 9.8, which one of the molecules acts as an oxidizing agent and thus gets reduced (gains electrons)?

d. During the redox reaction in glycolysis in step 6 in Figure 9.8, which molecule acts as the reducing agent as thus gets oxidized (loses electrons by the loss of H atoms)?

*(Check your answers to 3.c & d. by going to the Ch.9.2 **Concept Check Question #1** in Appendix A of your textbook)*

4. After analyzing steps 7 and 10 in Figure 9.8 when ATPs are made, and based on what you learned in Ch.9 Section 1, what is the **phosphorylation process used to make ATP in glycolysis**: oxidative phosphorylation, substrate-level phosphorylation or both? Describe **WHY**.

   Phosphorylation Process used to make ATP: ____

   Why:

5. *Think:* **Step 3** in in Figure 9.8 showing glycolysis is a **major point of regulation of glycolysis**! **The enzyme phosphofructokinase is allosterically regulated by ATP and related molecules**. Considering the overall purpose and result of glycolysis, would you expect ATP *(acting as an allosteric regulator not as a substrate of this enzyme)* to inhibit or stimulate activity of this enzyme? Why? *(Hint: When do you believe this enzyme needs to be active inside the cell - when ATP levels are high or when ATP levels are running low?)* *(Check your answer by going to Ch.9, Section 6, **Figure 9.19**)*

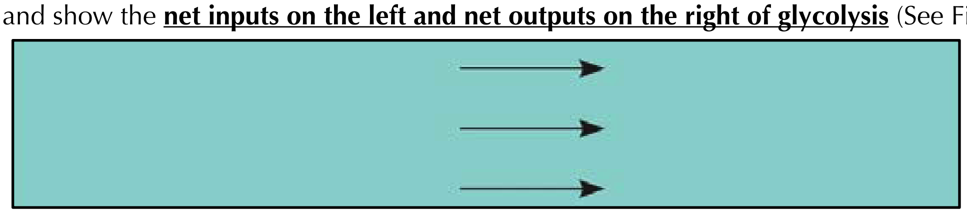
6. **Does glycolysis require O_2**?!

   (As it turns out, glycolysis evolved in prokaryotes 3.5 billion years ago, eukaryotes later evolving from these prokaryotes, when **no** O_2 was yet available in Earth's atmosphere!)

7. a. **How many molecules of CO_2** *(containing carbons from the original glucose that entered the biochemical glycolysis pathway)* **are released during glycolysis**?

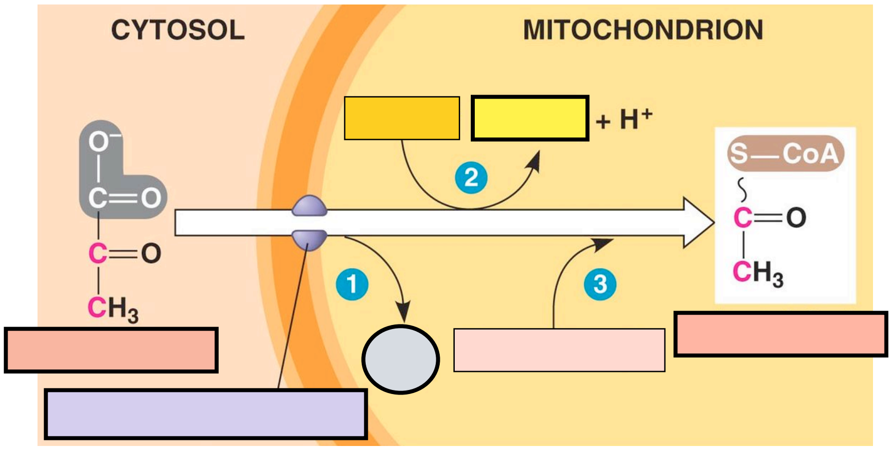
   b. Since atoms do not disappear during chemical reactions, **where are all the carbons from the original glucose found at the end of glycolysis**?

8. When analyzing the net gain of usable energy for the cell after glycolysis, it should be noted that, over 75% or **MOST of the energy in the original glucose is still present in the two molecules of pyruvate**. To review glycolysis then, fill in the chart below and show the **net inputs on the left and net outputs on the right of glycolysis** (See Figurer 9.7)



9. **Under which cellular condition** *(in aerobically respirating organisms)* **does pyruvate enter the citric acid cycle**, which is located inside the mitochondria in eukaryotes and in the cytoplasm in prokaryotes?

10. Pyruvate enters the mitochondria from the cytoplasm via active transport. In the **matrix of the mitochondria** in eukaryotes (or in the cytoplasm in prokaryotes), three reactions occur resulting in the conversion of pyruvate to acetyl CoA. Complete the missing parts of the chart below by studying Figure 9.9 and then read your text in order to explain the **three chemical reactions** that take place during the **Oxidation of Pyruvate** phase of cellular respiration.



1.

2.

3.

11. a. Based on what you learned in Figure 9.9, what happens to the **nonpolar CO_2 molecule** produced during the Oxidation of Pyruvate?

b. Where will reduced **NADH** be used later?

c. What happens to the **acetyl group** of the acetyl CoA produced?

12. Remember, the Oxidation of Pyruvate happens to each of the two pyruvate that form from the glycolysis of one glucose molecule. Now lets review the **net results of pyruvate oxidation per glucose molecule**.

a. Per glucose molecule, **how many CO_2 molecules are released** in the conversion of 2 pyruvates into Acetyl CoAs?

b. Per glucose molecule, **how many NADH are produced** in the conversion of 2 pyruvates into Acetyl CoAs?

c. Per glucose molecule, **how many $FADH_2$ are produced** in the conversion of 2 pyruvates into AcetylCoAs?

d. Per glucose molecule, **how many ATP are produced** in the conversion of 2 pyruvates into Acetyl CoAs?

13. What are the two **alternative names for the Citric Acid Cycle,** highlighting in Figure 9.10?

1. ________________________________ 2. ________________________________

14. Glycolysis started with one six-carbon glucose, which was split into two three-carbon pyruvates. Each pyruvate lost one carbon during the Oxidation of Pyruvate, four carbons from the original glucose remaining in two Acetyl CoA molecules. Now each of these two-carbon Acetyl portions of the Acetyl CoAs will each enter the biochemical pathways known as the Citric Acid (Krebs) Cycle to be **oxidized further**. **Review Figure 9.10 and Figure 9.11** to learn about the steps involved in the **CAC (Citric Acid or Krebs Cycle)**.

a. **How many times does the Citric Acid (Krebs) Cycle occur for each molecule of glucose** that started cellular respiration?

b. **While a two-carbon Acetyl group enters the Citric Acid Cycle**, the first step involving the reaction of the Acetyl CoA with four-carbon Oxaloacetate to form a six-carbon Citrate, **how many carbons will leave this biochemical pathways as waste products in the form of CO_2** as oxidation occurs and a citrate is eventually decomposed back into a molecule of oxaloacetate?

c. Some energy from the organic intermediates of the Citric Acid Cycle will be released and stored on a molecule of GTP, which is used to make a molecule of ATP from ADP. **How many molecules of ATP (or GTP) are made during one Citric Acid (Krebs) Cycle**?

d. **How many molecules of ATP (or GTP) are made in the Citric Acid (Krebs) Cycle then per glucose** that starts cellular respiration?

e. After analyzing steps 5 in Figure 9.11, when ATP is made and based on what you learned in Ch.9 Section 1, what is the **phosphorylation process used to make ATP in glycolysis**: oxidative phosphorylation, substrate-level phosphorylation? Describe **WHY**?

f. While some of the energy from the organic, carbon-based Acetyl group that entered the Citric Acid (Krebs) Cycle ends up on one molecule of ATP (or GTP) as oxidation occurs, **to which two molecules is the majority of the chemical energy transferred during the Citric Acid (Krebs) Cycle**?

1.

2.

15. **Most of the energy released by the the citric acid cycle's redox reactions is conserved in the high-energy electrons transferred to the two types of electron carriers during the Citric Acid (Krebs) Cycle.**

a. What is **reduced form the the electron carrier NAD^+**?

b. How many electrons and/or protons does oxidized NAD^+ accept?

c. What is the **reduced form of the electron electron carrier FAD**?

d. How many electrons and/or protons does oxidized FAD accept?

16. Let's summarize the results of the Citric Acid Cycle. As seen in Figure 9.10, **per turn of the Citric Acid Cycle**…

a. How many **CO_2s** are formed?

b. How many **NADHs** are formed?

c. How many **$FADH_2$** are formed?

d. How many **ATPs** are formed?

17. Let's review all steps that take place ***after*** pyruvate forms from glycolysis of glucose. Return to Figure 9.10 as needed. **Per Pyruvate Oxidation and turn of the Citric Acid Cycle**…

a. How many total **carbons are lost as CO_2** as pyruvate is fully oxidized?

b. How many **NADHs are reduced** as pyruvate is fully oxidized?

c. How many **$FADH_2$s are reduced** as pyruvate is fully oxidized?

d. How many **ATPs (or GTPs)** are formed as pyruvate is fully oxidized?

18. Note that figure 9.10, only shows the breakdown of one pyruvate molecule, although **two pyruvates are formed from a single glucose after glycolysis**.

a. Per glucose molecule oxidized, how many **CO_2 are released** in Pyruvate Oxidation and the Citric Acid Cycle?

b. Per glucose molecule oxidized, how many **NADH form** in Pyruvate Oxidation and the Citric Acid Cycle?

c. Per glucose molecule oxidized, how many **$FADH_2$ form** in Pyruvate Oxidation and the Citric Acid Cycle?

d. Per glucose molecule oxidized, how many **ATP (or GTP) form** in Pyruvate Oxidation and the Citric Acid Cycle?

19. **Almost all the enzymes that perform Pyruvate Oxidation and the Citric Acid Cycle in eukaryotes are located in the Mitochondrial Matrix, the very inner volume of space surrounded by the inner mitochondrial membrane.** Without a mitochondria, these enzymes are found in the cytoplasm in prokaryotes. Why is the Citric Acid (Krebs) Cycle called a cycle? *What is **the first product of the cycle** and **what must always regenerated** through the series of biochemical reactions that make up the citric acid pathway or cycle?*

20. **By the end of the citric acid cycle**, what has happened to the **six-carbons found in the original glucose fuel molecule**?

21. To summarize Ch.9.2 & 9.3, **after the citric acid cycle finishes, where is the energy, originally in glucose, now stored**:

1. ______________________ *(Hint: These molecules were made in Glycolysis & the Citric Acid [Krebs] Cycle)*

2. ______________________ *(Hint: These molecules were reduced with high-energy electrons in Glycolysis, Pyruvate Oxidation, and the Citric Acid (Krebs) Cycle)*

3. ______________________ *(Hint: These molecules were reduced with high-energy electrons in the Citric Acid (Krebs) Cycle)*

22. Where will the **high-energy electrons originally from glucose** and now **stored on reduced NADH and $FADH_2$ electron carriers be moved to** - following Glycolysis, Pyruvate Oxidation, and the Citric Acid (Krebs) Cycle - so that their potential energy can be extracted and used to phosphorylate ADPs into an additional 26 to 28 ATPs (on top of the 4 ATPs produced directly in Glycolysis and the Citric Acid (Krebs) Cycles)?