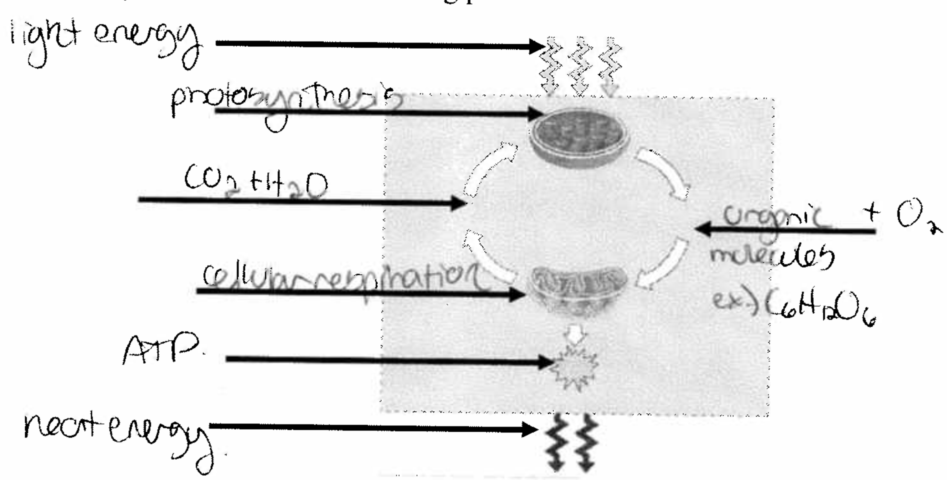
Name key Period ______

Chapter 9: Cellular Respiration: Harvesting Chemical Energy

Overview: Before getting involved with the details of cellular respiration and photosynthesis, take a second to look at the big picture. Photosynthesis and cellular respiration are key ecological concepts involved with energy flow. Use Figure 9.2 to label the missing parts below.



Concept 9.1 Catabolic pathways yield energy by oxidizing organic fuels

1. Explain the difference between fermentation and cellular respiration.

   - O_2 is used as a reactant in cellular respiration, but not fermentation
   - sugars are completely broken down in cellular respiration, but not fermentation.

2. Give the formula (with names) for the catabolic degradation of glucose by cellular respiration.

   $6O_2 + C_6H_{12}O_6 \Rightarrow 6CO_2 + 6H_2O + \text{Energy}$ (glucose) energy is used to make ATP, some released as heat.

3. Both cellular respiration and photosynthesis are *redox reactions*. In redox, reactions pay attention to the flow of electrons. What is the difference between oxidation and reduction?

   LEO the lion says GER — in oxidation, electrons are lost; in reduction, electrons are gained.

4. The following is a generalized formula for a redox reaction:

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

   reduced (GER); oxidized (LEO)

   Draw an arrow showing which part of the reaction is oxidized and which part is reduced.

   Xe^- is the reducing agent in this reaction, and Y is the oxidizing agent.

5. When compounds lose electrons, they require energy; when compounds gain electrons, they release energy.

6. In cellular respiration, electrons are not transferred directly from glucose to oxygen. Each electron is coupled with a proton to form a hydrogen atom. Following the movement of hydrogens allows you to follow the flow of electrons. The hydrogens are held in the cell temporarily by what electron carrier?

NAD^+ (nicotinamide adenine dinucleotide ... derivative of the vitamin niacin)

What is a coenzyme? (If you have forgotten, look back to a few pages in Chapter 8.)

a non-protein biological molecule required for the proper functioning of an enzyme. In this case, NAD^+ is a coenzyme for dehydrogenase.

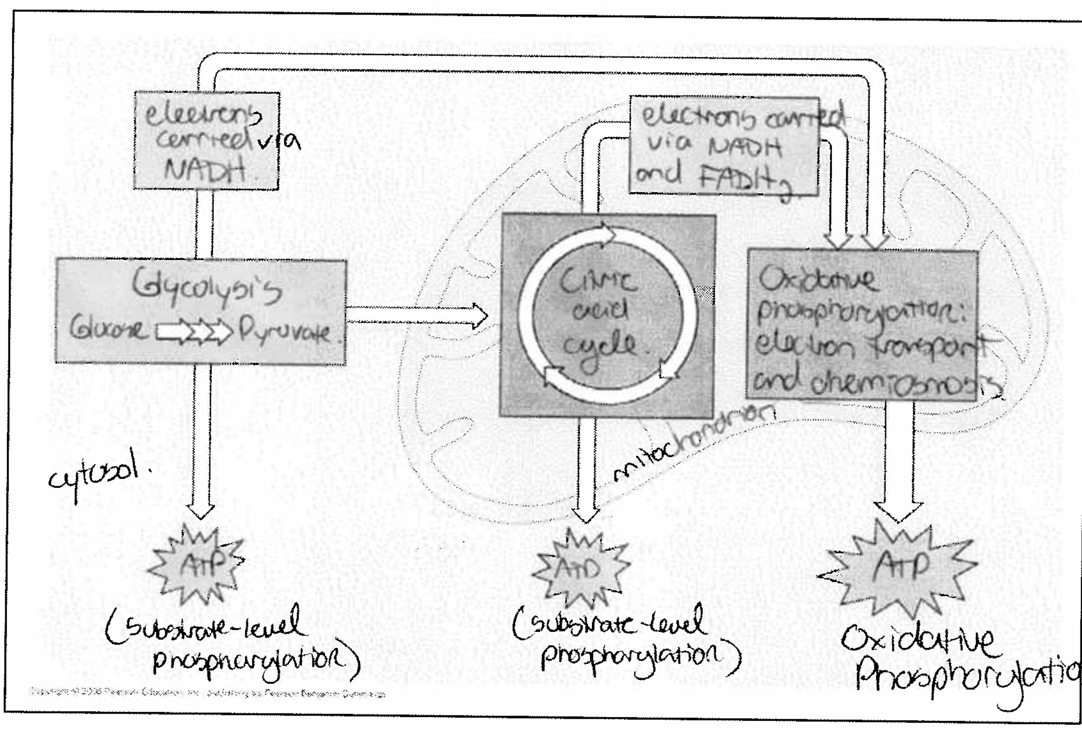
7. What is the function of the *electron transport chain* in cellular respiration?

- a sequence of electron carrier molecules (membrane proteins) that shuttle electrons during the redox reactions that release energy used to make ATP.
- breaks the fall of electrons to oxygen so that energy can be harvested at each step (instead of an "explosion")

8. Show the normal, downhill route most electrons follow in cellular respiration:

Glucose → NADH → electron transport chain → oxygen

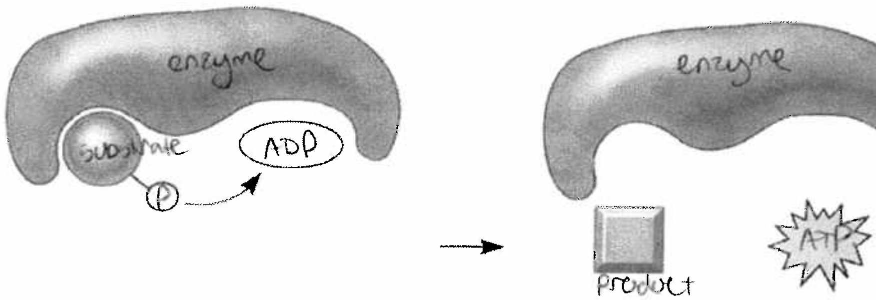
9. Understanding the overall map of how cellular respiration works will make the details easier to learn. Use Figure 9.2 to label the missing information in the figure below.



10. Three types of phosphorylation (adding a phosphate) are covered in the text, and two of these occur in cellular respiration. Explain how the electron transport chain is utilized in *oxidative phosphorylation.*

the steps of the electron transport chain releases energy; this energy is used to phosphorylate (add a phosphate to) ADP to synthesize ATP.

11. The second form of phosphorylation is *substrate level.* Label the figure below to show the direct transfer of a phosphate from a substrate to ADP to form ATP.



For each glucose molecule, 38 ATP are synthesized through the (3) stages of cellular respiration, 90% during oxidative phosphorylation

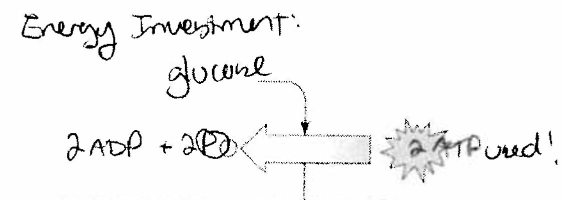
Concept 9.2 Glycolysis harvests chemical energy by oxidizing glucose to pyruvate

12. Why is glycolysis an appropriate term for this step of cellular respiration?

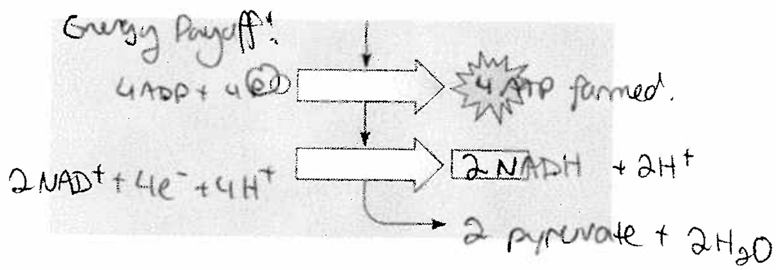
"sugar splitting" → this is what happens!

13. The starting product of glycolysis is the six-carbon sugar glucose, and the ending product is two three- carbon compounds termed pyruvate.

14. The ten individual steps of glycolysis can be divided into two stages: *energy investment* and *energy payoff.* Label the *energy investment stage* below; then use Figure 9.9 to find the two specific stages where ATP is used.



15. The second step in glycolysis is the *energy payoff phase.* Label this stage. Note that it provides both ATP and NADH. Look at Figure 9.9 to locate the two stages where ATP is formed and the one stage where NADH is formed.



16. This final figure shows the net gain of energy for the cell after glycolysis. Most of the energy is still present in the two molecules of pyruvate. Fill in the chart below and show the net energy gains.

Net:

glucose ⟶ 2 pyruvate + $2H_2O$

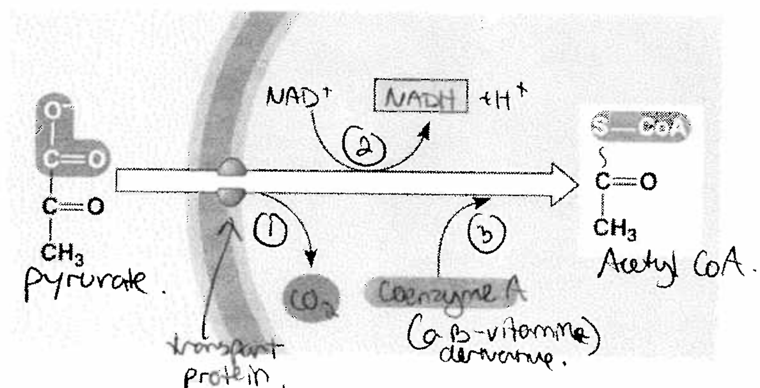
4 ATP formed − 2 ATP lost ⟶ 2 ATP

2 NAD^+ + $4e^-$ + $4H^+$ ⟶ 2 NADH + $2H^+$

17. Notice that glycolysis occurs in the Cytosol of the cell. What is the relationship concerning glycolysis and oxygen?

Concept 9.3 The citric acid cycle completes the energy-yielding oxidation of organic molecules

18. To enter the citric acid cycle, pyruvate must enter the mitochondria by active transport. Three things are necessary to convert pyruvate to acetyl CoA. Complete the missing parts of the chart below and then explain the three steps in the conversion process.



(1) The carboxyl group is removed from pyruvate, forming CO_2.

(2) electrons are transfered to NAD^+, forming NADH (as the carbon fragment is oxidized)

(3) Coenzyme A (CoA) is attached to carbon fragment, creating a very reactive chemical: acetyl coA.
↳ now ready for further oxidation.

19. How many times does the citric acid cycle occur for each molecule of glucose?

twice

20. Use Figure 9.11 to help you answer the following summary questions about the citric acid cycle:

a. How many NADHs are formed? 3

b. How many total carbons are lost as pyruvate is oxidized? 2

c. The carbons have been lost in the molecule carbon dioxide.

d. How many $FADH_2$ have been formed? 1

e. How many ATPs are formed? 1

21. The diagram covers only one pyruvate, although two pyruvates are formed from a single glucose. How many molecules of the following are formed from the breakdown of glucose?

a. NADH = 6

b. $FADH_2$ = 2

c. ATP = 2

} for citric acid cycle only. 10, 2, 4 } for everything so far.

22. The step that converts pyruvate to acetyl CoA at the top of the diagram also occurs twice per glucose. This step accounts for two additional reduced NADH. molecules and two carbon dioxide molecules.

23. Explain what has happened to the six-carbon molecules found in the original glucose molecule.

↳ each carbon has been released as CO_2. Hence $6CO_2$

Concept 9.4 During oxidative phosphorylation, chemiosmosis couples electron transport to ATP synthesis

24. Oxidative phosphorylation involves two components: the electron transport chain and ATP synthesis. Referring to Figure 9.13, notice that each member of the electron transport chain is lower in free energy than the preceding member of the chain, but higher in electronegativity The molecule at zero free energy, which is oxygen, is lowest of all the molecules in free energy and highest in electronegativity.

25. Explain why oxygen is the ultimate electron acceptor. Oxygen stabilizes the electrons by combining with two hydrogen ions to form what compound?

Oxygen is very electronegative ... it readily accepts electrons. In order to stabilize the electrons that it gains (reduction), every O atom combines with $2H^+$ ions to form H_2O (water)

26. The two electron carrier molecules that feed electrons into the electron transport system are NADH and $FADH_2$.

27. Using Figure 9.14, explain the overall concept of how ATP synthase uses the flow of hydrogen ions to produce ATP.

The flow of H^+ ions down their gradient (into the mitochondrial matrix) causes the protein ATP synthase to rotate. This rotation activates catalytic sites on the matrix-side of the protein to produce ATP from ADP and P_i.

28. What is the role of the electron transport chain in forming the H^+ gradient across the inner mitochondrial membrane?

The electron transport chain uses the exergonic flow of electrons from NADH and $FADH_2$ to pump H^+ ions across the membrane: from the mitochondrial matrix into the intermembrane space. This forms an H^+ gradient.

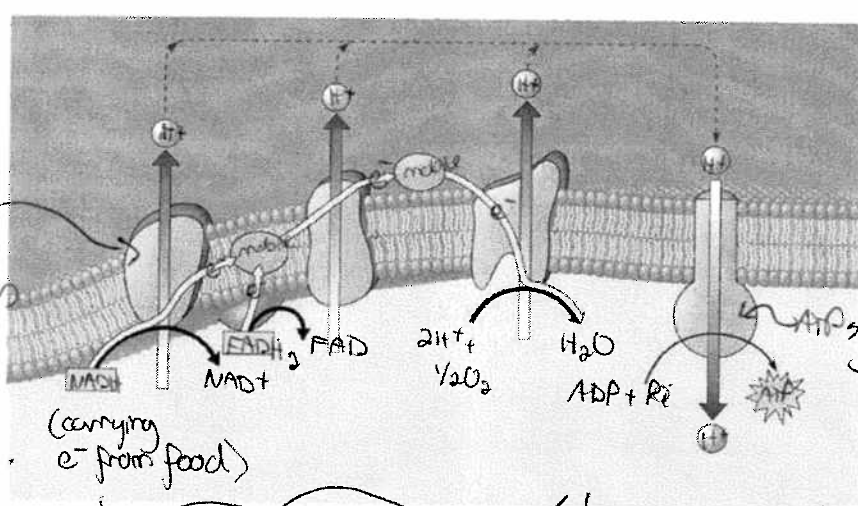
29. Two key terms are *chemiosmosis* and *proton-motive force*. Relate both of these terms to the process of oxidative phosphorylation.

In oxidative phosphorylation the electron transport chain creates an increase in potential energy as it creates the H^+ ion gradient. This potential energy creates proton-motive force that allows chemiosmosis to occur. The H^+ ions flow down their gradient through ATP synthase, driving the synthesis of ATP.

30. Figure 9.16 is a key to understanding the production of ATP in the mitochondria. In the figure below, label all locations and molecules. Then use one color to trace the flow of electrons and another color to show the flow of protons.

Proton-motive force = H^+ gradient

Chemiosmosis = drives cellular work by the energy stored in the proton-motive force (H^+ gradient)



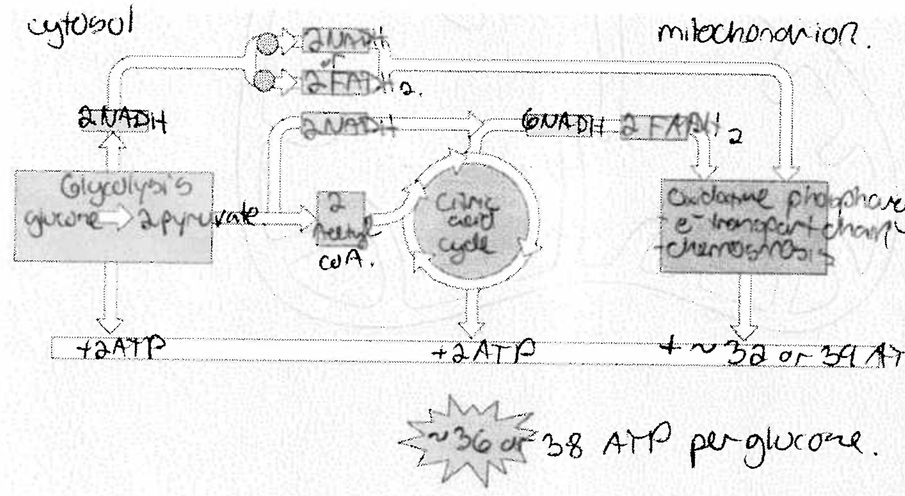
electron transport chain

chemiosmosis

Oxidative Phosphorylation

31. At this point, you should be able to account for the total number of ATPs that could be formed from a glucose molecule. To accomplish this, we have to add the substrate-level ATPs from glycolysis and the citric acid cycle to the ATPs formed by chemiosmosis. Each NADH can form a maximum of 3 ATP molecules. Each $FADH_2$, which donates electrons that activate only two proton pumps, makes 2 ATP molecules.

32. Use the figure to account for all the ATP molecules formed during cellular respiration. Use the text to be sure you understand how each subtotal on the bar below the figure is reached.



33. Why is the total count about 36 or 38 ATP molecules rather than a specific number?

1) ratio of NADH to ATP is not whole # (due to ~3-4H+ needed per ATP)
2) depends on NADH vs FADH2 use to transport e⁻ from cytosol to mitochondrion
3) proton-motive force can be used to drive work other than ATP synthesis.

Concept 9.5 Fermentation enables some cells to produce ATP without the use of oxygen

34. Fermentation allows for the production of ATP without using either oxygen or any electron transport chain.

35. For aerobic respiration to continue, the cell must be supplied with oxygen—the ultimate electron acceptor. What is the electron acceptor in fermentation?

Pyruvate → indirectly in alcohol fermentation via acetylaldehyde to ethanol
→ directly in lactic acid fermentation

* Anaerobic respiration is not the same as fermentation. Anaerobic respiration involves the use of an electron transport chain; however instead of O_2 as the final electron acceptor, other less electronegative substances are used such as sulfate : ex. (sulfur-reducing

36. Explain how alcohol fermentation starts with glucose and yields ethanol. Be sure to stress how NAD^+ is recycled. As glucose is broken down to pyruvate, 2 NAD^+ are reduced to 2 NADH. (A net of 2 ATP is generated at this time.) In order to recycle the NAD^+, to generate more ATP from glucose, pyruvate is converted to acetylaldehyde (releasing CO_2). Acetylaldehyde is then reduced to ethanol, gaining electrons from NADH. This oxidizes 2NADH back to 2NAD^+ so that glycolysis can continue.

37. Explain how lactic acid fermentation starts with glucose and yields lactate. Be sure to stress how NAD^+ is recycled.

As glucose is broken down to pyruvate, 2 NAD^+ are reduced to 2NADH, generating a net of 2ATP. In order to continue the breakdown of more glucose molecules, pyruvate is reduced to lactic acid by gaining electrons from 2NADH. This oxidizes 2NADH back to 2NAD^+ so that it can be reused in further glycolysis.

38. Using Figure 9.19 as a guide, draw and explain why pyruvate is a key juncture in metabolism.

Fermentation, anaerobic respiration, and aerobic respiration all use glycolysis to convert glucose to pyruvate (generating a net of 2ATP). Pyruvate represents a "fork" in metabolic pathways. From here, it can be oxidized via fermentation and/or cellular respiration depending on the organism or cell type. Ex.) human muscle cells can do both, brain only resp. Yeast both.

Concept 9.6 Glycolysis and the citric acid cycle connect to many other metabolic pathways

39. What three organic macromolecules are often utilized to make ATP by cellular respiration?

Proteins, Carbohydrates, Fats

40. Explain the difference in energy usage between the catabolic reactions of cellular respiration and anabolic pathways of biosynthesis.

In cellular respiration, energy is used to synthesize ATP
In biosynthesis, energy is used from ATP to synthesize more complex molecules.

41. Explain how AMP stimulates cellular respiration while citrate and ATP inhibit it.

If ATP increases in concentration, it will inhibit an important enzyme within the glycolysis pathway (phosphofructokinase). If, however, ATP is being used up by the cell, some will be converted to AMP. AMP stimulates the same enzyme in glycolysis, ultimately producing more ATP. (This is an example of feedback inhibition.)

TestingYour Knowledge: Self-Quiz Answers

Now you should be ready to test your knowledge. Place your answers here:

1.______ 2.______ 3.______ 4.______ 5.______ 6.______ 7.______ 8.______ 9.______

DO THIS ON THE WEBSITE/CDROM!

☆ Cellular respiration releases energy from molecules; It does NOT produce energy.