AP Biology Reading Guide *Julia Keller 12d*

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Chapter 9: Cellular Respiration and Fermentation

1. Explain the difference between fermentation and cellular respiration.

Fermentation is a partial degradation of sugars or other organic fuel that occurs without the use of oxygen, while cellular respiration includes both aerobic and anaerobic processes, but is often used to refer to the aerobic process, in which oxygen is consumed as a reactant along with the organic fuel.

2. Give the formula for the catabolic degradation of glucose by cellular respiration.

glucose ($C_6H_{12}O_6$) + oxygen gas ($6O_2$) → carbon dioxide ($6CO_2$) + water ($6H_2O$) + energy (ATP + heat)

3. Both cellular respiration and photosynthesis are redox reactions. What is the difference between oxidation and reduction?

Oxidation is the loss of electrons from one substance, while reduction is the addition of electrons to another substance.

4. Consider the redox reaction $Xe^- + Y \rightarrow X + Ye^-$.

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

5. When compounds lose electrons, they lose energy.

When compounds gain electrons, they gain energy.

6. The hydrogens are held in the cell temporarily by what electron carrier? What is a coenzyme?

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. NAD^+, a coenzyme, is the electron carrier that temporarily holds the hydrogens in the cell. Coenzymes are organic nonprotein helpers for catalytic activity that may be bound tightly to the enzyme as permanent residents, or loosely and reversibly along the substrate.

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

The electron transport chain breaks the fall of electrons to oxygen into several energy-releasing steps.

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

glucose → NADH → electron transport chain → oxygen

10. Explain how the electron transport chain is utilized in oxidative phosphorylation.

In the third stage of respiration, the electron transport chain accepts electrons from the breakdown products of the first two stages (most often via NADH) and passes these electrons from one molecule to another. At the end of the chain, the electrons are combined with molecular oxygen and hydrogen ions, forming water. The energy released at each step of the chain is stored in a form the mitochondrion can use to make ATP from ADP. This mode of ATP synthesis is called oxidative phosphorylation because it is powered by the redox reactions of the electron transport chain.

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

During glycolysis ("sugar-splitting"), glucose, a six-carbon sugar, is broken into two three-carbon sugars.

13. The starting product of glycolysis is…

…the six-carbon sugar glucose, and the ending product is two three-carbon compounds called pyruvate.

17. Glycolysis occurs in the cytoplasm of the cell. What is the relationship between glycolysis and oxygen?

Glycolysis occurs whether or not oxygen is present. However, if oxygen is present, the chemical energy stored in pyruvate and NADH can be extracted by pyruvate oxidation, the citric acid cycle, and oxidative phosphorylation.

18. Explain the three steps in the conversion of pyruvate to acetyl CoA. ✐

First, pyruvate's carboxyl group ($–COO^–$), which is already fully oxidized and thus has little chemical energy, is removed and given off as a molecule of CO_2. (This is the first step in which CO_2 is released during respiration.) Second, the remaining two-carbon fragment is oxidized, forming acetate ($CH_3COO^–$, the ionized form of acetic acid). The extracted electrons are transferred to NAD^+, storing energy in the form of NADH. Thirdly, coenzyme A (CoA), a sulfur-containing compound derived from a B vitamin, is attached via its sulfur atom to the acetate, forming acetyl CoA, which has a high potential energy due to the instability of the bond.

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

The citric acid cycle occurs twice for each molecule of glucose.

20. Summarize the citric acid cycle.

Three NADHs, 1 $FADH_2$, and 1 ATP are formed, while 2 total carbons are lost in the molecule CO_2 as pyruvate is oxidized.

21. How many molecules of NADH, $FADH_2$, and ATP are formed from the breakdown of glucose?

Six NADHs, 2 $FADH_2$s, and 2 ATP molecules are formed.

22. The step that converts pyruvate to acetyl CoA at the top of the diagram, which occurs twice per glucose…

…accounts for two additional reduced NADH molecules and two CO_2 molecules.

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

They have been released as CO_2. Molecules of NADH and $FADH_2$ account for most of the energy extracted from the glucose.

24. Oxidative phosphorylation involves two components: the electron transport chain and ATP synthesis.

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 0 free energy, O_2, is lowest of all the molecules in free energy and highest in electronegativity.

26. Explain why oxygen is the ultimate electron acceptor.

The *highly* electronegative oxygen stabilizes the electrons by combining with two hydrogen ions to form water.

27. Explain the overall concept of how ATP synthase uses the flow of hydrogen ions to produce ATP.

H^+ ions flowing down their gradient enter a half channel in a stator, which is anchored in the membrane. H^+ ions then enter binding sites within a rotor, changing the shape of each subunit so that the rotor spins within the membrane. Each H^+ ion makes one complete turn before leaving the rotor and passing through a second half channel in the stator into the mitochondrial matrix. Spinning of the rotor causes an internal rod to spin as well. This rod extends like a stalk into the knob below it, which is held stationary by part of the stator. Turning of the rod activates catalytic sites in the knob that 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 chain is an energy converter, using the exergonic flow of electrons from NADH and $FADH_2$ to pump H^+ from the mitochondrial matrix into the intermembrane space. The H^+ has a tendency to move back across the membrane, diffusing down its gradient, and the ATP synthases are the only sites that provide a route through the membrane for H^+.

29. Relate chemiosmosis and proton-motive force to the process of oxidative phosphorylation.

The electron transport chain pumps protons from the mitochondrial matrix into the intermembrane space. During chemiosmosis, the protons flow back down their gradient via ATP synthase, which is built into the membrane nearby.

The ATP synthase harnesses the proton-motive force to phosphorylate ADP, forming ATP. Together, electron transport and chemiosmosis make up oxidative phosphorylation.

31. To account for the total number of ATPs that could be formed from a glucose molecule, 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.

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

Since phosphorylation and the redox reactions aren't directly coupled to each other, the ratio of the number of NADH molecules to the number of ATP molecules is not a whole number. Also, the ATP yield varies slightly depending on the type of shuttle used to transport electrons from the cytosol into the mitochondria.

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.

The electron acceptor in fermentation is an organic molecule such as pyruvate (in lactic acid fermentation) or acetaldehyde (in alcohol fermentation).

36. Explain how alcohol fermentation starts with glucose and yields ethanol.

First, CO_2 released from the pyruvate is converted to the two-carbon compound acetaldehyde, which is reduced by NADH to ethanol. This regenerates the supply of NAD^+ needed for the continuation of glycolysis. Then, pyruvate is converted to ethanol, releasing CO_2 and oxidizing NADH in the process to form more NAD^+.

37. Explain how lactic acid fermentation starts with glucose and yields lactate.

Pyruvate is reduced directly by NADH to form lactate as a final product with no release of CO_2. The reduction of pyruvate by NADH leads to the formation of NAD^+, and lactate is formed as a waste product.

38. Explain why pyruvate is a key juncture in metabolism.

Pyruvate represents a fork in the catabolic pathways of glucose oxidation. In a facultative anaerobe, which is capable of both aerobic cellular respiration and anaerobic fermentation, pyruvate is committed to one of those two pathways, usually depending on whether or not oxygen is present.