Notes

Biology 102
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Chapter 8

Topic: Cellular Respiration

Main concepts:

- Overall equation for cellular respiration: $C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$
- While this equation is symmetrical with the equation for photosynthesis, photosynthesis is not "backwards cellular respiration." The two energy-related processes take place in different parts of a cell, and involve different chemical processes.
- The primary "goal" of Cellular Respiration is to harvest energy from glucose and other energy-rich carbon-based molecules and use it to make ATP, which is the universal energy molecule. Some energy is lost as heat in this conversion.
- Glycolysis is the first step in the breakdown of sugar, and takes place outside the mitochondria.
  - Glycolysis requires the input of two ATP molecules and produces 4 ATP molecules, for a net gain of 2 ATPs.
  - In addition, two electron carriers, called NADH, are formed. These will be used later in cellular respiration.
  - The sugar molecule breaks into two 3-carbon chains called pyruvate.
  - In anaerobic conditions (such as fermenting yeast, or muscle cells working in oxygen debt), fermentation may convert pyruvate into ethanol (yeast) or lactic acid (human muscle cells). This does not produce any more ATP.
  - Sugar that is not needed by the cells may be synthesized into fat for storage.
- Cellular respiration is a series of reactions inside of the mitochondria in which the products of glycolysis are further broken down and more ATP is manufactured. Oxygen is required.
  - Pyruvate that has been made by glycolysis is picked up by CoenzymeA and transported into the mitochondrion. One carbon is broken off in the process, and one NADH is made.
  - The two-carbon acetyl group detaches from Coenzyme A and is picked up by the Krebs cycle.
  - The Krebs cycle (also called the citric acid cycle) is a cyclic series of reactions. The 2-carbon acetyl group is picked up by a 4-carbon molecule (oxaloacetate) to form a 6-carbon molecule (citrate). An enzyme-driven series of chemical transformations then takes place. NADH, FADH, and a small amount of ATP are produced, and two carbons of the molecule are peeled off and expelled as carbon dioxide. The molecule is then transformed back to 4-carbon oxaloacetate, and is ready to pick up another acetyl group.
  - The final phase of cellular respiration involves the electron transport chain and chemiosmosis through a proton pump. The last H from NADH and FADH, is removed, and the H stripped of its electron. This highly charged electron is passed down a row of enzymes and coenzymes. This generates energy to pump the hydrogen ions (bare protons) across a membrane. The energy released as the ions drift back through ion channels drives ATP production.
  - At the end of the electron transport chain, oxygen picks up used electrons and hydrogen ions (protons), forming water. This is why we must breathe oxygen — to gather up the electrons and protons at the end of cellular respiration. If we lack oxygen, the whole system backs up.
- *All* Eukaryotic organisms carry out cellular respiration: all animals, plants, protists, and fungi.
- The end product of cellular respiration is ATP. The waste products are carbon dioxide and water.

Common misconceptions:

- Students often believe that photosynthesis and respiration are inverse reactions of one another. This may be because the overall equations appear to be inverse reactions. Both processes, however, involve a different set of reactions.
- Some students believe that in anaerobic fermentation, carbon dioxide is used instead of oxygen. However, carbon dioxide is the waste product of both reactions.
- Students often are confused about the word "respire." In the context of the respiratory system, the word refers to gas exchange in the lungs. In the context of cellular respiration, the word refers to the aerobic breakdown of glucose in the mitochondria.
- Students may believe that glucose is the product of cellular respiration.

- Students often confuse which gases are used and which are released in cellular respiration and photosynthesis. Respiration requires an intake of oxygen and releases carbon dioxide.
- Students often believe that ATP is an energy storage molecule. In fact, ATP is highly unstable, and the total amount of ATP in our cells is transformed from ADP to ATP and back again every few minutes.

Chapter study guide:

- Write out the overall equation of complete glucose metabolism.
- How efficient is glucose metabolism? How does this compare with a gasoline engine?
- Define *glycolysis*. State whether the process is aerobic or anaerobic.
- Each of the three phases of cellular respiration produces some ATP. List the three phases and how much ATP is produced in each (see figure 8.1, and notice where ATP is given off). State which two of these processes occur inside the mitochondria.
- The two phases of glycolysis are glucose activation and energy harvest. Describe how ATP is used and produced in these two processes (see figure 8.2).
- Examine Figure E8-1 (A Closer Look). You do not have to memorize all of these steps. Notice where ATP is used and where it is produced. Notice that when ATP is used or made, a phosphate is transferred to or from the carbon chain. Also notice the production of NADH, which is an electron carrier.
- Describe generally under what conditions pyruvate is converted to lactic acid, and what effects this has on humans. Also describe generally how lactic acid is converted to ethanol by yeast, and under what conditions.
- Describe how fats and proteins are metabolized. Describe how sugar that we consume can be synthesized into fat. (Remember that sugar does not contain fat, nor does fat contain sugar.)
- Give a definition of cellular respiration.
- State how pyruvate is transported into the mitochondria.
- List the products of the Krebs cycle (that is, what is made during the cycle). Carbon dioxide is the waste product — where does the carbon come from?
- State what NADH and FADH are used for in the electron transport chain.
- Hydrogen is stripped of its single electron and becomes a hydrogen ion. What is the electron used for in the electron transport chain, and what is the remaining ion (single proton) used for?
- What is chemiosmosis, and how is it used to manufacture ATP?
- Use Figures 8.9 and 8.10 to summarize the steps of glucose metabolism.
- State the role of oxygen at the end of the electron transport chain.
- Describe the effects of cyanide on cellular respiration.

Useful websites:

- “Glycolysis” http://instruct1.cit.cornell.edu/courses/biomi290/ASM/glycolysis.dcr is a self-running animation of the process, showing all of the molecular reactants. As in the reading notes, the important things to notice are where ATP is made and used, what happens to the phosphate groups, and where NADH is made.
- “Glycolysis: A Step-by-step Look at Respiration” http://www.northland.cc.mn.us/biology/Biology1111/animations/glycolysis.html is a Shockwave animation of glycolysis, with annotations explaining each step.
- “Citric Acid Cycle” http://www.wiley.com/legacy/college/boyer/0470003790/animations/tca/tca.htm is an interactive animation of the Krebs cycle.
- “Aerobic and Anaerobic Respiration” http://www.sp.uconn.edu/~terry/Common/respiration.html has a good animation of the electron transport chain.