Photosynthesis and Cellular Respiration: A Comparison

Aerobic cellular respiration and photosynthesis are the two main chemical processes that are essential to most of the life on Earth. They fit together like pieces of a puzzle, completing a cycle of energy transformation in living things. This cycle occurs both at the cellular level and on the scale of entire ecosystems. As you learned in this chapter, photosynthesis converts sunlight into chemical energy for use as food by the organisms themselves and by organisms at higher trophic levels. Photosynthesis occurs in the cells of autotrophs such as plants, algae, and cyanobacteria. As you learned in Chapter 4, aerobic cellular respiration is used by the vast majority of eukaryotic and many prokaryotic heterotrophs, and by all photosynthesizing organisms. Aerobic cellular respiration extracts chemical energy from food and converts it into chemical potential energy within ATP. This potential energy of ATP then supplies the free energy that is needed to drive all other cellular metabolic activities.

In eukaryotes, photosynthesis occurs in the chloroplast, while aerobic cellular respiration begins in the cytosol and is completed within the mitochondrion. These processes are complementary (**Figure 1**). Photosynthesis produces oxygen and sugars, which are the reactants for cellular respiration. In turn, the waste products of cellular respiration—water and carbon dioxide—are the reactants for photosynthesis.

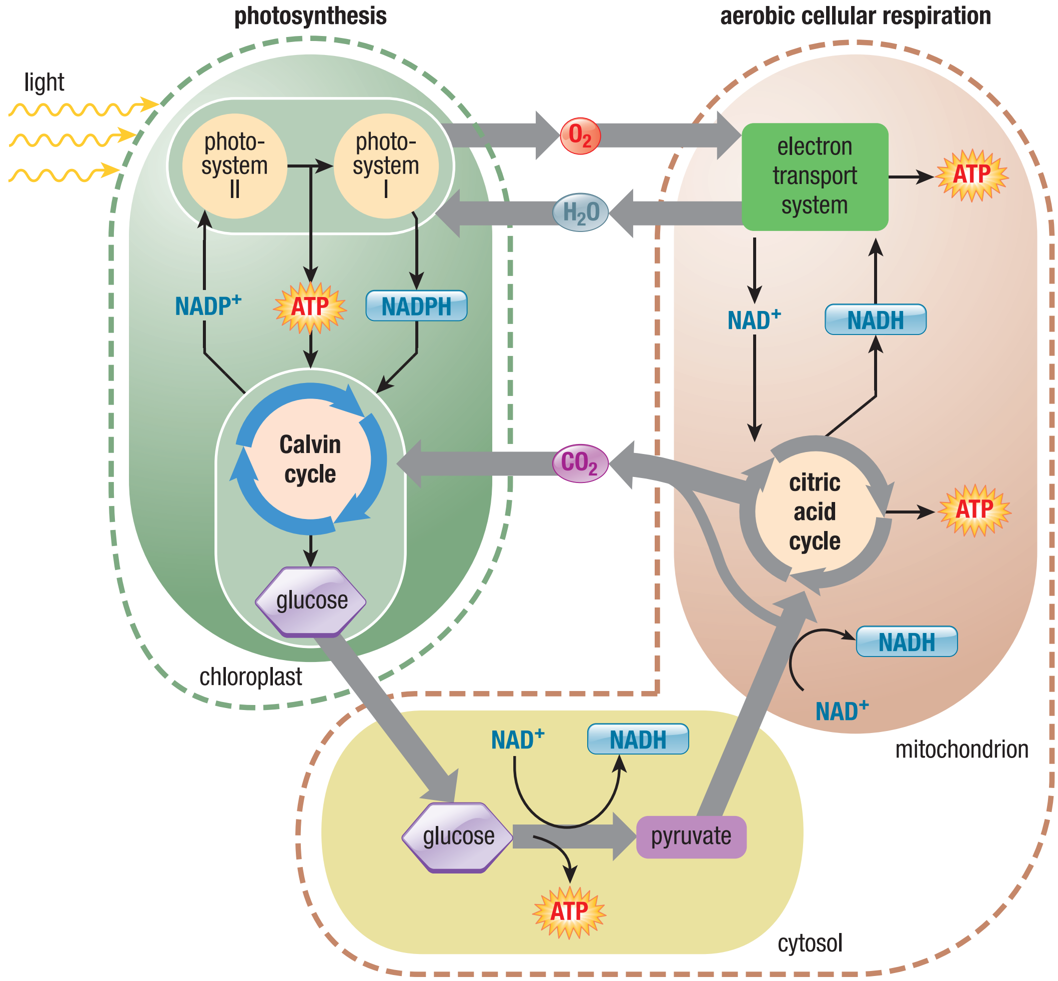

Figure 1 Photosynthesis (outlined in green) and aerobic cellular respiration (outlined in brown) are complementary—they use each other's products. The NAD^+ that are reduced to NADH in the cytosol and during pyruvate oxidation are also regenerated by the transfer of their hydrogens and high-energy electrons to the electron transport chain. For simplicity, H^+, ADP, and P_i are not shown in this diagram.

Chemical Steps and Reaction Processes

In addition to being complementary, photosynthesis and aerobic cellular respiration share many similar chemical steps and processes. Both reactions use electron transfer chains, along with ATP synthase complexes, to generate ATP by chemiosmosis. Both also use and regenerate carrier molecules. In photosynthesis, $NADP^+$ molecules are reduced during the light-dependent reactions to NADPH molecules, which then deliver hydrogens and their high-energy electrons to the Calvin cycle for use in carbohydrate synthesis. In aerobic cellular respiration, molecules of both NAD^+ and FAD (not shown in Figure 1) are used to carry hydrogens and their high-energy electrons to an electron transport chain. There, they are oxidized using oxygen to produce water and generate ATP.

Even the key organelles that are involved in each reaction share structural features. The chloroplasts used in photosynthesis and mitochondria used in cellular respiration have inner folded membranes that create separated fluid-filled spaces that allow proton gradients to be established (**Figure 2**). Both have complementary carbon-fixing (Calvin) and carbon-releasing (citric acid) cycles. Chloroplasts and mitochondria even possess their own unique DNA and replicate independently of cell division.

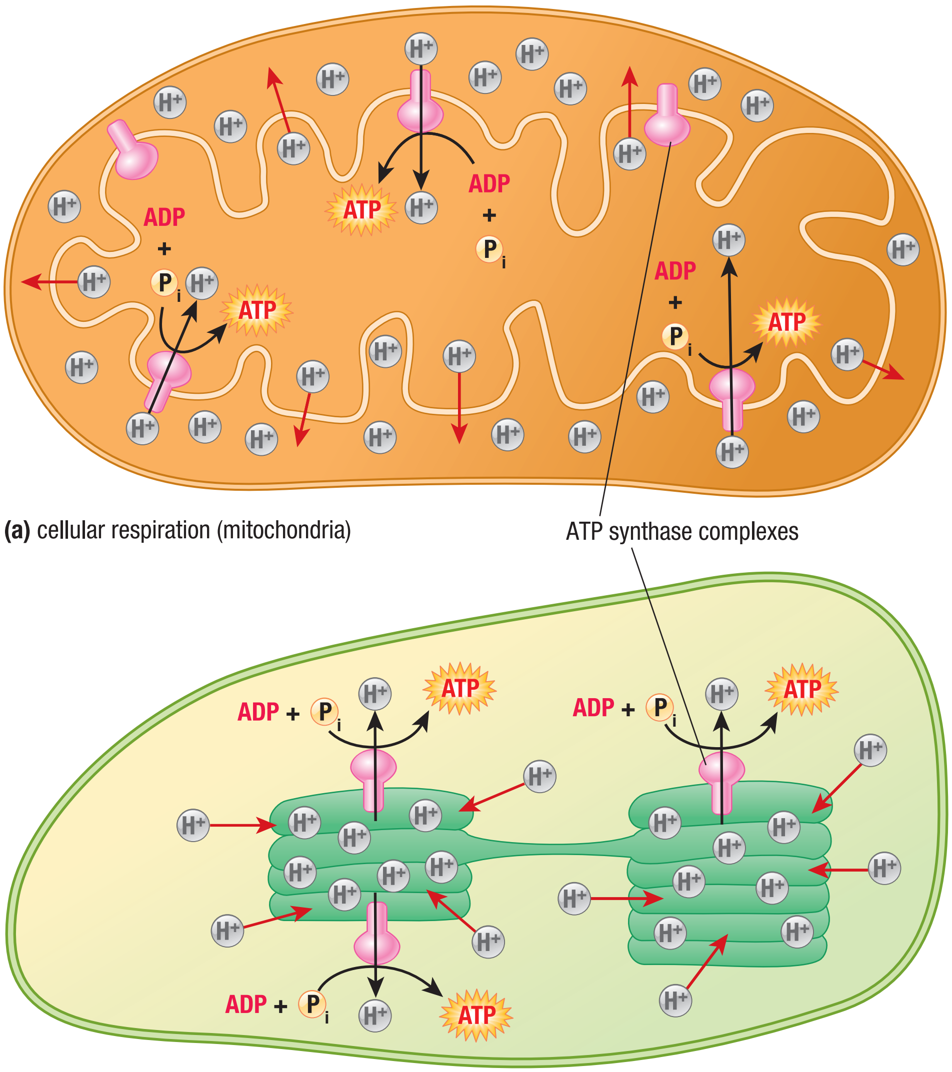

Figure 2 Comparison of chemiosmosis in mitochondria and in chloroplasts. (a) In mitochondria, the proton gradient is established by pumping hydrogens out of an internal space (the matrix). (b) In chloroplasts, the proton gradient is established by pumping hydrogens into an internal space (the thylakoid lumens).

Comparison of Animals and Plants

Although we associate plant cells with photosynthesis, we know that photosynthesis requires the presence of the green pigment chlorophyll. Most plant cells, however, are not green and, like animal cells, are incapable of performing photosynthesis. These non-green cells form the roots, inner parts of stems, and various reproductive parts of a plant (**Figure 3**). All green plants contain at least some chlorophyll-bearing cells, typically within the leaves and green stems. These cells perform photosynthesis, producing energy-rich food molecules to be distributed throughout the plant. Herbivores then eat the plant, passing on the energy from photosynthesis. In this way, life is sustained at higher and higher trophic levels. Within chloroplasts, therefore, light's energy really does become life's energy.

All growing plant and animal cells require a non-stop supply of energy in the form of energy-rich ATP. They also require a supply of organic building materials, which they use to construct membranes, fibres and filaments, flagella and cilia, chromosomes, and all other cellular structures (**Table 1**). To meet these needs, organisms consume food for use both as a fuel and as raw building materials. When the food is used as a fuel, it enters the aerobic respiration pathway. When the food is used as building materials, the food molecules are disassembled and enter a variety of different metabolic pathways. Of these pathways, protein synthesis is particularly significant. In the next unit, you will examine the relationship between the genetic information you inherit from your parents and the control of protein synthesis.

Figure 3 While we think of most plants as being green, only certain cells of the above-ground structures are actually green.

Table 1 Comparison of Plant and Animal Demands for Energy and Materials

	Plants	Animals
Primary energy source	light	food
Method of obtaining primary energy source	photosynthesis	consumption of other living organisms
Energy storage	carbohydrates and other energy-rich molecules, such as fats and lipids	
Immediate source of free energy	ATP	
Primary source of ATP	aerobic cellular respiration	
Primary organic materials for growth, reproduction, and repair	carbohydrates, lipids, proteins, and nucleic acids	
Source of carbon in organic materials	carbon fixation during photosynthesis	consumption of other living organisms

5.6 Review

Summary

- Aerobic cellular respiration and photosynthesis create a cycle. Some of the products of one process serve as the reactants for the other process, and vice versa.
- Photosynthesis occurs in the chloroplasts of cells, while part of aerobic cellular respiration occurs in the mitochondria.
- The chemical processes and physical structures that are associated with photosynthesis and aerobic cellular respiration have many similarities.
- Plants and most other producers perform both photosynthesis and aerobic cellular respiration.
- Most consumers perform aerobic cellular respiration; however, they must rely on producers for the synthesis of the organic molecules they use as energy and as building materials for growth.

Questions

1. Which organelles are the sites of photosynthesis in eukaryotes? Do all plant cells contain these organelles? K/U
2. Which organelles are the sites of the oxygen-requiring stages of aerobic cellular respiration in eukaryotes? Do all plant and animal cells contain these organelles? K/U
3. The following equation is aerobic cellular respiration from left to right and photosynthesis from right to left. K/U T/I A

   $C_6H_{12}O_6 + 6O_2 \leftrightarrow 6\ CO_2 + 6\ H_2O$

   (a) Explain why this equation is misleading about the complexity of the interrelationship of photosynthesis and respiration.

   (b) Describe why the photosynthesis respiration equation is easily understood in terms of heterotrophs but often leads to misconceptions about energy use in plants.

   (c) From the photosynthesis and respiration equation, many people think that O_2 is created from CO_2. What does the CO_2 actually get converted to, and what does the O_2 in respiration become?
4. Compare the structure and function of chloroplasts and mitochondria. Do all the reactions of photosynthesis take place in the chloroplasts? Do all the reactions of aerobic cellular respiration take place in the mitochondria? K/U T/I
5. Make a Venn diagram to compare photosynthesis and aerobic cellular respiration. Consider their location within the cell, their primary energy source, and their reactants and products. T/I C
6. What is the relationship between autotrophs and heterotrophs in terms of photosynthesis and aerobic respiration? T/I
7. Compare and contrast the electron transport chains in photosynthesis with electron transport in cellular respiration. T/I
8. Contrast the source of electrons for aerobic cellular respiration and photosynthesis. K/U
9. Describe the roles of NADPH and NADH in the processes of photosynthesis and aerobic cellular respiration. T/I
10. Use Figure 1 (page 237) to explain the pathway of a carbon atom, beginning in a molecule of carbon dioxide, as it undergoes photosynthesis and then aerobic cellular respiration. T/I C
11. Both chloroplasts and mitochondria carry their own DNA. Do online research to find out the function of this DNA. How is the DNA in your own mitochondria inherited? Do you have a mix of your father's and mother's mitochondrial DNA? T/I A

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