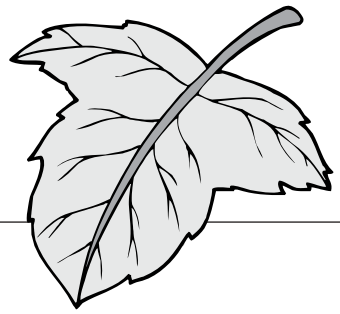
Cellular Energy
Section 4.2
Photosynthesis



Pre-View 4.2

- **Autotrophs** (also called ***producers***) – organisms such as plants that usually use energy directly from the sun to produce glucose and other carbohydrates
- **Calvin cycle** – the stage of photosynthesis that does not require light
- **Carbon fixation** – the process of converting the inorganic carbon found in carbon dioxide to organic carbon in glucose
- **Chlorophyll** – the green pigment found in the chloroplasts of plant cells that absorbs energy from the sun and uses that energy in the first stage of photosynthesis
- **Chloroplasts** – organelles found in plant cells (and photosynthetic autotrophs); where photosynthesis takes place
- **Granum** – a stack of thylakoids within a chloroplast (plural: grana)
- **Heterotrophs** (also called ***consumers***) – organisms such as animals that obtain energy by consuming plants and other animals
- **Photosynthesis** – process used by autotrophs that uses the sun's energy to convert water and carbon dioxide to glucose (simple sugar) and oxygen
- **Stroma** – the water-based fluid region outside of the thylakoid membranes where the Calvin cycle takes place
- **Thylakoids** – sac-like membranes found within chloroplasts that contain the photosynthetic pigments

You know that all living organisms need energy, but where does that energy come from? In Section 4.1, you saw how chemical potential energy in glucose (or simple sugar) is converted into chemical energy stored in and released from ATP, but where does the glucose come from? The sun is actually the main source of energy for living organisms although many organisms can't use that energy in its original form. All living organisms live by releasing energy found in chemical compounds such as glucose, but some can also use light energy directly from the sun to make glucose. This light energy from the sun is stored in the chemical bonds between atoms of the glucose molecule. Energy is released from glucose when these bonds are broken.

Living organisms can be divided into two main groups: autotrophs and heterotrophs. **Autotrophs** are organisms such as plants that can directly use the sun's energy to produce energy-containing chemical compounds such as glucose and other carbohydrates. Autotrophs are also called ***producers*** since they can produce their own food. **Heterotrophs** are organisms such as animals that get energy from the sun indirectly by consuming foods that have energy stored in them. Heterotrophs are also called ***consumers*** since they must consume food for energy.

Through the process of **photosynthesis**, most autotrophs use the energy in sunlight (called *solar energy*) to change water and carbon dioxide (CO_2) into glucose and oxygen. The light energy from the sun is converted to chemical energy that is stored in the bonds of the glucose molecules. The net equation for photosynthesis is shown in figure 4-4.

Photosynthesis

$$6CO_2 + 6H_2O \xrightarrow[\text{enzymes and chlorophyll}]{\text{light energy}} C_6H_{12}O_6 + 6O_2$$

carbon dioxide | water | glucose (simple sugar) | oxygen

Fig. 4-4

After glycolysis, there are two possibilities depending on whether or not oxygen is present. One possibility is aerobic respiration, and the other possibility is anaerobic respiration. The pathways for each are summarized below in figure 4-8.

Aerobic versus Anaerobic Respiration Pathways

Is oxygen present?

YES → **AEROBIC RESPIRATION**

- must have oxygen to occur
- takes place in mitochondria
- produces a net of approximately 34 ATP molecules from one glucose molecule (not considering glycolysis)

NO → **ANAEROBIC RESPIRATION**

- no oxygen needed
- takes place in cytoplasm
- produces 2 ATP molecules from one glucose molecule

Fig. 4-8

Aerobic Respiration

Aerobic respiration occurs only when oxygen is present. In order for aerobic respiration to proceed from the cytoplasm into the mitochondria, the pyruvate molecules formed from glycolysis must be further modified. The pyruvate reacts to form carbon dioxide and a molecule called acetyl CoA. The acetyl CoA molecule enters the mitochondrion and is used to begin another step to produce ATP called the **Krebs cycle**. The Krebs cycle takes place in a part of the mitochondrion called the mitochondrial matrix, and this process releases more carbon dioxide and produces a net gain of two more ATP. The Krebs cycle is sometimes called the citric acid cycle because citric acid is formed from the acetyl CoA at the beginning of the cycle.

Glycolysis and the Krebs cycle produce electrons that are carried by energy carrying molecules (NADH and $FADH_2$). These electrons are used in a third step of ATP production called the **electron transport chain** (**ETC**). The electron transport chain takes place across the inner mitochondrial membrane, and this step is by far the most efficient at producing ATP. The electron transport chain produces a net gain of between 32 and 34 ATP molecules. Mitochondrial membrane enzymes, hydrogen ions (H^+), and oxygen are used in this process. In addition to the ATP, water is also produced.

The Three Steps of ATP Production in Aerobic Respiration

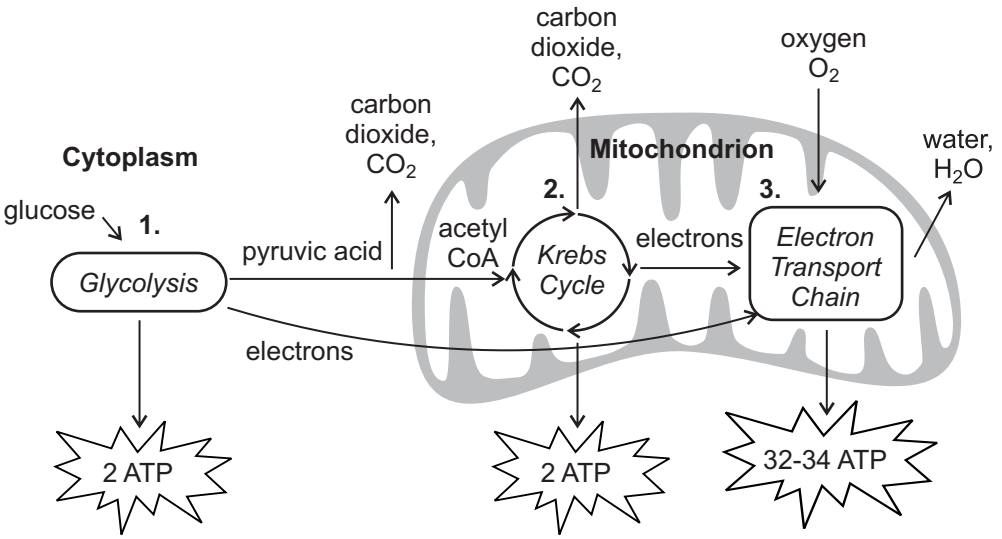


Fig. 4-9

Programmed cell death, or **apoptosis**, occurs when cells become damaged or worn. For example, if a cell encounters a problem at an internal checkpoint, proteins may signal for apoptosis. Apoptosis can occur when factors either outside or inside the cell signal for genes to produce self-destructive enzymes. The enzymes break the cell into parts without damaging surrounding cells. Apoptosis also plays a key role in the development of tissues and organs. For instance, a developing human embryo has webbed fingers and toes. Apoptosis is responsible for the disintegration of the webbing and the development of well-defined individual fingers and toes.

The Cell Cycle Checkpoints

Now consider the three specific internal cell cycle checkpoints a little more closely.

The ***G_1 checkpoint*** determines if the cell has reached an appropriate size and has adequate energy reserves and nutrients to proceed through the cell cycle. Additionally, the cell checks for any damage to the DNA and ensures that the cell is receiving signals from growth factors to indicate the cell should divide. If either is found insufficient, the cell will not progress to the S phase. If all requirements are met, the cyclins and cyclin-dependent kinases will signal for the cell to proceed.

The ***G_2 checkpoint*** is a second gatekeeper that can prevent a cell's entry into mitosis if certain conditions are not met. The cell's appropriate size is evaluated again at this checkpoint. But more importantly, this checkpoint is in place to ensure that all of the chromosomes were duplicated correctly. Any DNA mutations or DNA damage will halt the cell cycle in an attempt to repair the mutated or damaged DNA. If the DNA is found to be correctly duplicated, the cyclin-dependent kinases initiate the beginning of mitosis.

The ***M checkpoint*** is the last cell cycle checkpoint, and it takes place near the end of metaphase. This checkpoint ensures that all of the sister chromatids are adequately attached to the spindle microtubules, so it is also known as the spindle assembly checkpoint or simply the spindle checkpoint. Once again, if mistakes are found, such as the sister chromatids are not firmly attached to the spindle fibers, the cell cycle will be halted.

Figure 5-7 shows each of these cell cycle checkpoints.

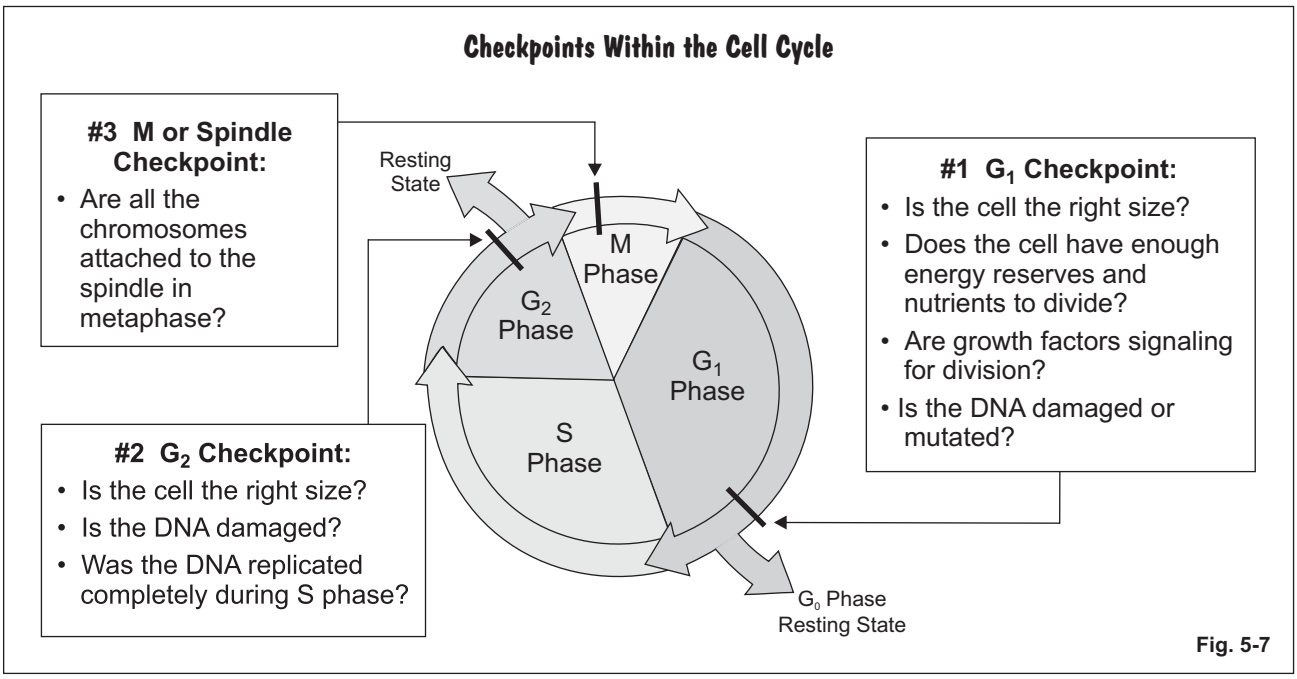


Fig. 5-7

Example 1: Red blood cells carry oxygen to other cells in the body. When oxygen levels in the body become low, specialized cells in the kidneys release a protein called *erythropoietin*, or *EPO*. EPO signals bone marrow cells to create more red blood cells. In what way does EPO signal bone marrow cells to create red blood cells?

EPO acts as an external growth factor. It binds to receptor sites on the surface of bone marrow cells to signal those cells to produce more red blood cells. It acts as a "go" signal for the cell cycle to begin.

Disruption of the Cell Cycle

What happens if an abnormal cell or a cell with DNA mutations gets past one of the checkpoints as the cell proceeds through the cell cycle? If an abnormal cell is not destroyed at the checkpoints, internal growth factors may not be suppressed, and the cell cycle may continue and result in uncontrolled cell growth and division. This situation is considered a disruption of the normal cell cycle. Cells may grow and divide uncontrollably. A mass of cells that is growing out of control is called a **tumor**. Some tumors are benign (noncancerous). Benign tumors form a mass, but they do not invade and destroy healthy tissues. These tumors may be called cysts. Malignant (cancerous) tumors, however, do invade and destroy healthy tissues.

Cancer results from cells growing and dividing abnormally and then invading healthy tissues. Cancer can be caused by environmental exposure to substances called **carcinogens** that damage the DNA in cells and transform the cells into cancer cells. Common examples of carcinogens are asbestos, UV radiation, x-rays, some viruses, and cigarette smoke.

Carcinogens can cause a **mutation** in a gene, which is a permeant change in its DNA sequence. If a gene that controls the cell cycle becomes mutated, it can become an **oncogene**, a gene that has the potential to cause cancer. For example, a gene may contain the code to create a protein that causes cells to grow and divide. If a mutation occurs in that gene that changes its instructions, the mutated gene may produce too much of the protein and cause cells to divide too quickly. Cancer may then result from uncontrolled cell division.

Metastasis is the spread of cancer to other areas in the body and occurs when cancer cells grow aggressively, break off from their home tissues, and travel through either the blood or the lymph vessels as seen in figure 5-8. These portable cancer cells are soon able to form new tumors in new locations. One way of treating cancer is by using chemotherapy drugs. These drugs work by disrupting the cell cycle in cancer cells, but they can often disrupt the cell cycle in normal cells as well.

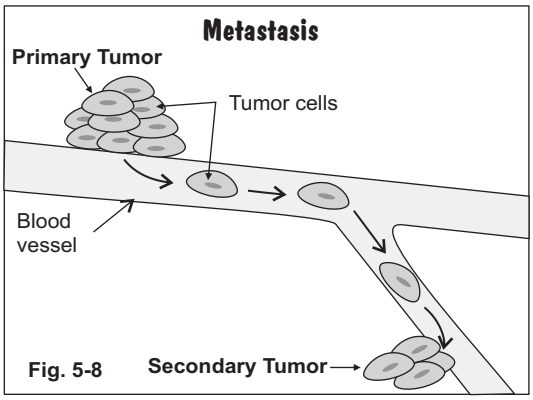


Fig. 5-8

Example 2: A chemotherapy drug named Pacitaxel prevents microtubules from forming the mitotic spindles necessary for cell division. A common side effect of Pacitaxel is low immunity due to neutropenia, which is a decrease in the number of white blood cells. Why does Pacitaxel have this side effect?

Most chemotherapy drugs disrupt the cell cycle in all rapidly dividing cells whether the cells are cancerous or not. Pacitaxel, as well as many other chemotherapy drugs, negatively affects bone marrow cells. Since bone marrow creates white blood cells, chemotherapy drugs also decrease the number of white blood cells found in the blood. Low white blood cell counts decrease immunity and increase the chances for infection.