Chapter 6

Biology and Society: Marathoners versus Sprinters

- Sprinters do not usually compete at short and long distances.
- Natural differences in the muscles of these athletes favor sprinting or long-distance running.
- The muscles that move our legs contain two main types of muscle fibers:
  - slow-twitch and
  - fast-twitch.
- Slow-twitch fibers
  - last longer,
  - do not generate a lot of quick power, and
  - generate ATP using oxygen (aerobically).
- Fast-twitch fibers
  - contract more quickly and powerfully,
  - fatigue more quickly, and
  - can generate ATP without using oxygen (anaerobically).
- All human muscles contain both types of fibers but in different ratios.

ENERGY FLOW AND CHEMICAL CYCLING IN THE BIOSPHERE

- Animals depend on plants to convert the energy of sunlight to
  - chemical energy of sugars and
  - other organic molecules we consume as food.
- **Photosynthesis** uses light energy from the sun to
  - power a chemical process and
  - make organic molecules.

Producers and Consumers

- Plants and other **autotrophs** (self-feeders)
  - make their own organic matter from inorganic nutrients.
- **Heterotrophs** (other-feeders)
  - include humans and other animals that cannot make organic molecules from inorganic ones.
- Autotrophs are **producers** because ecosystems depend upon them for food.
- Heterotrophs are **consumers** because they eat plants or other animals.

Chemical Cycling between Photosynthesis and Cellular Respiration

- The ingredients for photosynthesis are carbon dioxide (CO_2) and water (H_2O).
  - CO_2 is obtained from the air by a plant's leaves.
  - H_2O is obtained from the damp soil by a plant's roots.
- Chloroplasts in the cells of leaves use light energy to rearrange the atoms of CO_2 and H_2O, which produces
  - sugars (such as glucose),
  - other organic molecules, and
  - oxygen gas.
- Plant and animal cells perform **cellular respiration**, a chemical process that
  - primarily occurs in mitochondria,

- harvests energy stored in organic molecules,
  - uses oxygen, and
  - generates ATP.
- The waste products of cellular respiration are
  - CO_2 and H_2O,
  - used in photosynthesis.
- Animals perform *only* cellular respiration.
- Plants perform
  - photosynthesis *and*
  - cellular respiration.
- Plants usually make more organic molecules than they need for fuel. This surplus provides material that can be
  - used for the plant to grow or
  - stored as starch in potatoes.

CELLULAR RESPIRATION: AEROBIC HARVEST OF FOOD ENERGY

- **Cellular respiration** is
  - the main way that chemical energy is harvested from food and converted to ATP and
  - an **aerobic** process—it requires oxygen.
- Cellular respiration and breathing are closely related.
  - Cellular respiration requires a cell to exchange gases with its surroundings.
    - Cells take in oxygen gas.
    - Cells release waste carbon dioxide gas.
  - Breathing exchanges these same gases between the blood and outside air.

The Simplified Equation for Cellular Respiration

- A common fuel molecule for cellular respiration is glucose.
- Cellular respiration can produce up to 32 ATP molecules for each glucose molecule consumed.
- The overall equation for what happens to glucose during cellular respiration is
  - glucose & oxygen -> CO_2, H_2O, & a release of energy.

Redox Reactions

- Chemical reactions that transfer electrons from one substance to another are called
  - oxidation-reduction reactions or
  - **redox reactions** for short.
- The loss of electrons during a redox reaction is **oxidation**.
- The acceptance of electrons during a redox reaction is **reduction**.
- During cellular respiration
  - glucose is oxidized and
  - oxygen is reduced.
- Why does electron transfer to oxygen release energy?
  - When electrons move from glucose to oxygen, it is as though the electrons were falling.
  - This “fall” of electrons releases energy during cellular respiration.

- Cellular respiration is
  - a controlled fall of electrons and
  - a stepwise cascade much like going down a staircase.
- The path that electrons take on their way down from glucose to oxygen involves many steps.
- The first step is an electron acceptor called NAD^+.
  - NAD is made by cells from niacin, a B vitamin.
  - The transfer of electrons from organic fuel to NAD^+ reduces it to **NADH**.
- The rest of the path consists of an **electron transport chain**, which
  - involves a series of redox reactions and
  - ultimately leads to the production of large amounts of ATP.

An Overview of Cellular Respiration
- Cellular respiration is an example of a metabolic pathway, which is a series of chemical reactions in cells.
- All of the reactions involved in cellular respiration can be grouped into three main stages:
  1. **glycolysis**,
  2. the **citric acid cycle**, and
  3. **electron transport**.

The Three Stages of Cellular Respiration
- With the big-picture view of cellular respiration in mind, let's examine the process in more detail.

Stage 1: Glycolysis
- A six-carbon glucose molecule is split in half to form two molecules of pyruvic acid.
- These two molecules then donate high energy electrons to NAD+, forming NADH.

Stage 2: The Citric Acid Cycle
- In the citric acid cycle, pyruvic acid from glycolysis is first "groomed."
  - Each pyruvic acid loses a carbon as CO_2.
  - The remaining fuel molecule, with only two carbons left, is acetic acid.
- Oxidation of the fuel generates NADH.
- Finally, each acetic acid is attached to a molecule called coenzyme A to form acetyl CoA.
- The CoA escorts the acetic acid into the first reaction of the citric acid cycle.
- The CoA is then stripped and recycled.
- The citric acid cycle
  - extracts the energy of sugar by breaking the acetic acid molecules all the way down to CO_2,
  - uses some of this energy to make ATP, and
  - forms NADH and $FADH_2$.

Stage 3: Electron Transport
- Electron transport releases the energy your cells need to make the most of their ATP.
- The molecules of the **electron transport chain** are built into the inner membranes of mitochondria.
- The chain

    - functions as a chemical machine, which
    - uses energy released by the “fall” of electrons to pump hydrogen ions across the inner mitochondrial membrane, and
    - uses these ions to store potential energy.
- When the hydrogen ions flow back through the membrane, they release energy.
    - The hydrogen ions flow through **ATP synthase**.
    - ATP synthase
        - takes the energy from this flow and
        - synthesizes ATP.
- Cyanide is a deadly poison that
    - binds to one of the protein complexes in the electron transport chain,
    - prevents the passage of electrons to oxygen, and
    - stops the production of ATP.

The Results of Cellular Respiration
- Cellular respiration can generate up to 32 molecules of ATP per molecule of glucose.
- In addition to glucose, cellular respiration can “burn”
    - diverse types of carbohydrates,
    - fats, and
    - proteins.

FERMENTATION: ANAEROBIC HARVEST OF FOOD ENERGY
- Some of your cells can actually work for short periods without oxygen.
- **Fermentation** is the **anaerobic** (without oxygen) harvest of food energy.

Fermentation in Human Muscle Cells
- After functioning anaerobically for about 15 seconds, muscle cells begin to generate ATP by the process of fermentation.
- Fermentation relies on glycolysis to produce ATP.
- Glycolysis
    - does not require oxygen and
    - produces two ATP molecules for each glucose broken down to pyruvic acid.
- Pyruvic acid, produced by glycolysis,
    - is reduced by NADH,
    - producing NAD^+, which
    - keeps glycolysis going.
- In human muscle cells, lactic acid is a by-product.

The Process of Science: What Causes Muscle Burn?
- **Observation**: Muscles produce lactic acid under anaerobic conditions.
- **Question**: Does the buildup of lactic acid cause muscle fatigue?
- **Hypothesis**: The buildup of lactic acid would cause muscle activity to stop.
- **Experiment**: Tested frog muscles under conditions when lactic acid
    - could and
    - could not diffuse away.

- **Results**: When lactic acid could diffuse away, performance improved greatly.
- **Conclusion**: Lactic acid accumulation is the primary cause of failure in muscle tissue.
- However, recent evidence suggests that the role of lactic acid in muscle function remains unclear.

Fermentation in Microorganisms

- Fermentation alone is able to sustain many types of microorganisms.
- The lactic acid produced by microbes using fermentation is used to produce
  - cheese, sour cream, and yogurt,
  - soy sauce, pickles, and olives, and
  - sausage meat products.
- Yeast is a microscopic fungus that
  - uses a different type of fermentation and
  - produces CO_2 and ethyl alcohol instead of lactic acid.
- This type of fermentation, called **alcoholic fermentation**, is used to produce
  - beer,
  - wine, and
  - breads.

Evolution Connection: Life before and after Oxygen

- Glycolysis could be used by ancient bacteria to make ATP
  - when little oxygen was available, and
  - before organelles evolved.
- Today, glycolysis
  - occurs in almost all organisms and
  - is a metabolic heirloom of the first stage in the breakdown of organic molecules.