Chapter 6

Cellular Respiration: Obtaining Energy from Food

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.

Figure 6.0

- 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.

Producers and Consumers

- Autotrophs are **producers** because ecosystems depend upon them for food.
- Heterotrophs are **consumers** because they eat plants or other animals.

Figure 6.1

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.

Figure 6.2

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.

Figure 6.3

Figure 6.3a

Figure 6.3b

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.

Figure 6.UN01

Redox Reactions

- Chemical reactions that transfer electrons from one substance to another are called
  - oxidation-reduction reactions or
  - **redox reactions** for short.

Redox Reactions

- 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.

Figure 6.UN02

- 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.

Figure 6.4

- 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.

Figure 6.5

Figure 6.5a

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**.

Figure 6.6
Figure 6.6a

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.

Figure 6.7
Figure 6.7a
Figure 6.7b-1
Figure 6.7b-2
Figure 6.7b-3

- Glycolysis

Figure 6.8

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.

Figure 6.9
Figure 6.9a
Figure 6.9b

- 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 $FADH_2$.

Figure 6.10
Figure 6.10a
Figure 6.10b

- 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.

Figure 6.11
Figure 6.11a
Figure 6.11b
Figure 6.11c

- 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.

Figure 6.12
Figure 6.12a

- In addition to glucose, cellular respiration can "burn"

- diverse types of carbohydrates,
- fats, and
- proteins.

Figure 6.13

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.

Figure 6.14
Figure 6.14a
Figure 6.14b

**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?

**The Process of Science:
What Causes Muscle Burn?**

- **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.

Figure 6.15

- **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.

Figure 6.16
Figure 6.16a
Figure 6.16b

**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.

Figure 6.17
Figure 6.17a
Figure 6.17b
Figure 6.UN03
Figure 6.UN04
Figure 6.UN05
Figure 6.UN06
Figure 6.UN07
Figure 6.UN08
Figure 6.UN09