Chapter 5

The Working Cell

Biology and Society:
Harnessing Cellular Structures

- Cells control their chemical environment using
  - energy,
  - enzymes, and
  - the plasma membrane.
- Cell-based nanotechnology may be used to power microscopic robots.

Figure 5.0

SOME BASIC ENERGY CONCEPTS

- Energy makes the world go around.
- But what is energy?

Conservation of Energy

- **Energy** is defined as the capacity to cause change.
  - Some forms of energy are used to perform work.
  - Energy is the ability to rearrange a collection of matter.

Conservation of Energy

- **Kinetic energy** is the energy of motion.
- **Potential energy** is stored energy. It is energy that an object has because of its
  - location or
  - structure.

Figure 5.1

- Machines and organisms can transform kinetic energy to potential energy and vice versa.
- In all such energy transformations, total energy is conserved.
  - Energy cannot be created or destroyed.
  - Energy can be converted from one form to another.
  - This is the principle of **conservation of energy**.

Entropy

- Every energy conversion releases some randomized energy in the form of heat.
- **Heat** is a
  - type of kinetic energy and
  - product of all energy conversions.

Entropy

- Scientists use the term **entropy** as a measure of disorder, or randomness, in a system.
- All energy conversions increase the entropy of the universe.

Chemical Energy

- Molecules store varying amounts of potential energy in the arrangement of their atoms.
- Organic compounds are relatively rich in such **chemical energy**.

Chemical Energy

- Chemical energy
  - arises from the arrangement of atoms and
  - can be released by a chemical reaction.
- Living cells and automobile engines use the same basic process to make chemical energy do work.

Figure 5.2

- Cellular respiration is
  - the energy-releasing chemical breakdown of fuel molecules and
  - the storage of that energy in a form the cell can use to perform work.
- Humans convert about 34% of the energy in food to useful work, such as the contraction of muscles.
- About 66% of the energy released by the breakdown of fuel molecules generates body heat.

Food Calories

- A **calorie** is the amount of energy that can raise the temperature of one gram of water by 1 degree Celsius.
- Food Calories are kilocalories, equal to 1,000 calories.

- The energy of calories in food is burned off by many activities.

Figure 5.3
Figure 5.3a
Figure 5.3b

ATP AND CELLULAR WORK

- Chemical energy is
  - released by the breakdown of organic molecules during cellular respiration and
  - used to generate molecules of ATP.
- **ATP**
  - acts like an energy shuttle,
  - stores energy obtained from food, and
  - releases it later as needed.

The Structure of ATP

- ATP (adenosine triphosphate)
  - consists of an organic molecule called adenosine plus a tail of three phosphate groups and
  - is broken down to ADP and a phosphate group, releasing energy.

Figure 5.4

Phosphate Transfer

- ATP energizes other molecules by transferring phosphate groups.
- This energy helps cells perform
  - mechanical work,
  - transport work, and
  - chemical work.

Figure 5.5
Figure 5.5a
Figure 5.5b
Figure 5.5c

The ATP Cycle

- Cellular work spends ATP continuously.
- ATP is recycled from ADP and a phosphate group through cellular respiration.
- A working muscle cell spends and recycles up to 10 million ATP molecules per second.

Figure 5.6

ENZYMES

- **Metabolism** is the total of all chemical reactions in an organism.
- Most metabolic reactions require the assistance of **enzymes**, proteins that speed up chemical reactions.
- All living cells contain thousands of different enzymes, each promoting a different chemical reaction.

Activation Energy

- **Activation energy**
  - activates the reactants and
  - triggers a chemical reaction.
- Enzymes reduce the amount of activation energy required to break bonds of reactant molecules.

Figure 5.7
Figure 5.7a
Figure 5.7b

The Process of Science: Can Enzymes Be Engineered?

- **Observation**: Genetic sequences suggest that many of our genes were formed through a type of molecular evolution.
- **Question**: Can laboratory methods mimic this process through artificial selection?
- **Hypothesis**: An artificial process could be used to modify the gene that codes for lactase into a new gene coding for an enzyme with a new function.
- **Experiment**: Using the process of directed evolution, many copies of the lactase gene were randomly mutated and tested for new activities.
- **Results**: Directed evolution produced a new enzyme with a novel function.

Figure 5.8
Figure 5.8a
Figure 5.8b
Figure 5.8c

Induced Fit

- An enzyme is very selective in the reaction it catalyzes.
- Each enzyme recognizes a **substrate**, a specific reactant molecule.

- The **active site** fits to the substrate, and the enzyme changes shape slightly.
- This interaction is called **induced fit** because the entry of the substrate induces the enzyme to change shape slightly.

- Enzymes can function over and over again, a key characteristic of enzymes.
- Many enzymes are named for their substrates, but with an *–ase* ending.

Figure 5.9-1
Figure 5.9-2
Figure 5.9-3
Figure 5.9-4

Enzyme Inhibitors

- **Enzyme inhibitors** can prevent metabolic reactions by binding
  - to the active site or
  - near the active site, resulting in changes to the enzyme's shape so that the active site no longer accepts the substrate.

Figure 5.10
Figure 5.10a
Figure 5.10b
Figure 5.10c

- Some products of a reaction may inhibit the enzyme required for its production.
  - This is called **feedback regulation**.
  - It prevents the cell from wasting resources.
- Many beneficial drugs work by inhibiting enzymes.
  - Penicillin blocks the active site of an enzyme that bacteria use in making cell walls.
  - Ibuprofen inhibits an enzyme involved in sending pain signals.
  - Many cancer drugs inhibit enzymes that promote cell division.

MEMBRANE FUNCTION

- Cells must control the flow of materials to and from the environment.
- Membrane proteins perform many functions.
- **Transport proteins**
  - are located in membranes and
  - help move substances across a cell membrane.

Figure 5.11

Passive Transport: Diffusion across Membranes

- Molecules contain heat energy that causes them to vibrate and wander randomly.
- **Diffusion** is the movement of molecules so that they spread out evenly into the available space.

Figure 5.12
Figure 5.12a
Figure 5.12b

- Some substances do not cross membranes spontaneously or cross slowly.
  - These substances can be transported via **facilitated diffusion**.
  - Specific transport proteins act as selective corridors.
  - No energy input is needed.

Osmosis and Water Balance

- The diffusion of water across a selectively permeable membrane is **osmosis**.

Figure 5.13-1
Figure 5.13-2

- Compared to another solution,
  - a **hypertonic** solution has a higher concentration of solute,
  - a **hypotonic** solution has a lower concentration of solute, and
  - an **isotonic** solution has an equal concentration of solute.

Water Balance in Animal Cells

- **Osmoregulation** is the control of water balance within a cell or organism.

Water Balance in Plant Cells

- Plants have rigid cell walls.
- Plant cells are healthiest in a hypotonic environment, which keeps their walled cells turgid.

Figure 5.14
Figure 5.14a

Figure 5.14b
Figure 5.14c

- As a plant cell loses water,
  - it shrivels and
  - its plasma membrane may pull away from the cell wall in the process of plasmolysis, which usually kills the cell.

Figure 5.15

Active Transport:
The Pumping of Molecules across Membranes

- **Active transport** requires that a cell expend energy to move molecules across a membrane.

Figure 5.16-1
Figure 5.16-2

Exocytosis and Endocytosis:
Traffic of Large Molecules

- **Exocytosis** is the secretion of large molecules within transport vesicles.

Figure 5.17

- **Endocytosis** takes material in via vesicles that bud inward from the plasma membrane.

Figure 5.18

- In the process of **phagocytosis** ("cellular eating"), a cell engulfs a particle and packages it within a food vacuole.
- Other times a cell "gulps" droplets of fluid into vesicles.
- Endocytosis can also be triggered by the binding of certain external molecules to specific receptor proteins built into the plasma membrane.
- The plasma membrane helps convey signals
  - between cells and
  - between cells and their environment.
- Receptors on a cell surface trigger **signal transduction pathways** that
  - relay the signal and
  - convert it to chemical forms that can function within the cell.

Figure 5.19
Figure 5.19a

Evolution Connection:
The Origin of Membranes

- Phospholipids
  - are key ingredients of membranes,
  - were probably among the first organic compounds that formed from chemical reactions on early Earth, and
  - self-assemble into simple membranes.

Figure 5.20
Figure 5.UN01
Figure 5.UN02
Figure 5.UN03
Figure 5.UN04