Chapter 5: The Working Cell

SOME BASIC ENERGY CONCEPTS

• Energy makes the world go around, but what is energy?
  • Energy is defined as the capacity to perform work.
    ▪ Kinetic energy is the energy of motion.
    ▪ Potential energy is stored energy.

• 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.
  – 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
  – Product of all energy conversions

• Scientists use the term **entropy** as a measure of disorder, or randomness.

• 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.

• Living cells and automobile engines use the same basic process to make chemical energy do work.

• Cellular respiration is the energy-releasing chemical breakdown of fuel molecules that provides energy for cells to do work.

• Humans convert about 40% of the energy in food to useful work, such as the contraction of muscles.
Food Calories

- A calorie is the amount of energy that raises 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.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Food Calories consumed per hour by a 150-pound person*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Running (7 min/mi)</td>
<td>979</td>
</tr>
<tr>
<td>Dancing (fast)</td>
<td>510</td>
</tr>
<tr>
<td>Bicycling (10 mph)</td>
<td>490</td>
</tr>
<tr>
<td>Swimming (2 mph)</td>
<td>408</td>
</tr>
<tr>
<td>Walking (3 mph)</td>
<td>245</td>
</tr>
<tr>
<td>Dancing (slow)</td>
<td>204</td>
</tr>
<tr>
<td>Playing the piano</td>
<td>73</td>
</tr>
<tr>
<td>Driving a car</td>
<td>61</td>
</tr>
<tr>
<td>Sitting (writing)</td>
<td>28</td>
</tr>
</tbody>
</table>

*Not including energy necessary for basic functions, such as breathing and heartbeat

<table>
<thead>
<tr>
<th>Food</th>
<th>Food Calories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheeseburger</td>
<td>295</td>
</tr>
<tr>
<td>Spaghetti with sauce (1 cup)</td>
<td>241</td>
</tr>
<tr>
<td>Baked potato (plain, with skin)</td>
<td>220</td>
</tr>
<tr>
<td>Fried chicken (drumstick)</td>
<td>193</td>
</tr>
<tr>
<td>Bean burrito</td>
<td>189</td>
</tr>
<tr>
<td>Pizza with pepperoni (1 slice)</td>
<td>181</td>
</tr>
<tr>
<td>Peanuts (1 ounce)</td>
<td>166</td>
</tr>
<tr>
<td>Apple</td>
<td>81</td>
</tr>
<tr>
<td>Garden salad (2 cups)</td>
<td>56</td>
</tr>
<tr>
<td>Popcorn (plain, 1 cup)</td>
<td>31</td>
</tr>
<tr>
<td>Broccoli (1 cup)</td>
<td>25</td>
</tr>
</tbody>
</table>

(b) Food Calories (kilocalories) we burn in various activities

(a) Food Calories (kilocalories) in various foods
ATP AND CELLULAR WORK

• Chemical energy is
  – Released by the breakdown of organic molecules during cellular respiration
  – Used to generate molecules of ATP

• ATP
  – Acts like an energy shuttle
  – Stores energy obtained from food
  – Releases it later as needed

The Structure of ATP
• ATP (adenosine triphosphate)
  – Consists of adenosine plus a tail of three phosphate groups
  – Is broken down to ADP and a phosphate group, releasing energy

[Diagram of ATP structure]
Phosphate Transfer
• ATP energizes other molecules by transferring phosphate groups.
• This energy helps cells perform
  – Mechanical work
  – Transport work
  – Chemical work

The ATP Cycle
• Cellular work spends ATP.
• ATP is recycled from ADP and a phosphate group through cellular respiration.

![ATP Cycle Diagram]

• A working muscle cell spends and recycles about 10 million ATP molecules per second.

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.

**Activation Energy**

• **Activation energy**
  – Activates the reactants
  – Triggers a chemical reaction

• Enzymes lower the activation energy for chemical reactions.

**Induced Fit**

• Every enzyme is very selective, catalyzing a specific reaction.

• 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**.
• Enzymes can function over and over again, a key characteristic of enzymes.

**Enzyme Inhibitors**

• **Enzyme inhibitors** can prevent metabolic reactions by binding to the active site.

• Other enzyme inhibitors
  – Bind at a remote site
  – Change the enzyme’s shape
  – Prevent the enzyme from binding to its substrate

• Some products of a reaction may inhibit the enzyme required for its production.
– This is called **feedback regulation**.

![Diagram of feedback inhibition](image)

– It prevents the cell from wasting resources.

- Many **antibiotics** work by inhibiting enzymes of disease-causing bacteria.

**MEMBRANE FUNCTION**

- Working cells must control the flow of materials to and from the environment.

- Membrane proteins perform many functions.

- **Transport proteins**
  - Are located in membranes
  - Regulate the passage of materials into and out of the cell
Passive Transport: Diffusion across Membranes

- Molecules contain heat energy that causes them to vibrate and wander randomly.

- **Diffusion** is the tendency for molecules of any substance to spread out into the available space.

- **Passive transport** is the diffusion of a substance across a membrane without the input of energy.

- Diffusion is an example of passive transport.
- Substances diffuse down their **concentration gradient**, from an area of high concentration to an area of low concentration.
- Some substances do not cross membranes spontaneously because of their size.
  - These substances can be transported via **facilitated diffusion**.
  - Specific transport proteins (channels) act as selective corridors.
− No energy input is needed.

Osmosis and Water Balance

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

  ![Osmosis Diagram](image)

  - A **hypertonic** solution has a higher concentration of solute.
  - A **hypotonic** solution has a lower concentration of solute.
  - 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.

• Most animal cells require an isotonic environment.

Water Balance in Plant Cells
• Plant have rigid cell walls.
• Plant cells require a hypotonic environment, which keeps these walled cells **turgid**.

• As a plant cell loses water,
  – It shrivels.
  – Its plasma membrane may pull away from the cell wall in the process of **plasmolysis**, which usually kills the cell.
Active Transport: The Pumping of Molecules Across Membranes

• **Active transport** requires energy to move molecules across a membrane.

Exocytosis and Endocytosis: Traffic of Large Molecules

• **Exocytosis** is the secretion of large molecules within vesicles.

• **Endocytosis** takes material into a cell within vesicles that bud inward from the plasma membrane.
There are three types of endocytosis:

- **Phagocytosis** ("cellular eating"); a cell engulfs a particle and packages it within a food vacuole
- **Pinocytosis** ("cellular drinking"); a cell "gulps" droplets of fluid by forming tiny vesicles
- **Receptor-mediated endocytosis**; a cell takes in very specific molecules

The Role of Membranes in Cell Signaling

- The plasma membrane helps convey signals between
  - Cells
  - Cells and their environment
• Receptors on a cell surface trigger **signal transduction pathways** that
  – Relay the signal
  – Convert it to chemical forms that can function within the cell

![Diagram of signal transduction pathways](image)

**Evolution Connection: The Origin of Membranes**

• Phospholipids
  – Are key ingredients of ALL cellular membranes- Prokaryotes & Eukaryotes
  – Were probably among the first organic compounds that formed before life emerged (Chemosynthesis Theory)
  – All membranes can fuse into another membrane.