Introduction

- Some organisms use energy-converting reactions to produce light in a process called bioluminescence.
  - Many marine invertebrates and fishes use bioluminescence to hide themselves from predators.
  - Scientists estimate that 90% of deep-sea marine life produces bioluminescence.
- The light is produced from chemical reactions that convert chemical energy into visible light.

Bioluminescence is an example of the multitude of energy conversions that a cell can perform.

- Many of a cell’s reactions
  - take place in organelles and
  - use enzymes embedded in the membranes of these organelles.
- This chapter addresses how working cells use membranes, energy, and enzymes.

MEMBRANE STRUCTURE AND FUNCTION
5.1 Membranes are fluid mosaics of lipids and proteins with many functions

- Membranes are composed of
  - a bilayer of phospholipids with
  - embedded and attached proteins,
  - in a structure biologists call a **fluid mosaic**.

- Many phospholipids are made from unsaturated fatty acids that have kinks in their tails.
- These kinks prevent phospholipids from packing tightly together, keeping them in liquid form.
- In animal cell membranes, cholesterol helps
  - stabilize membranes at warmer temperatures and
  - keep the membrane fluid at lower temperatures.

5.1 Membranes are fluid mosaics of lipids and proteins with many functions

- Membrane proteins perform many functions.
  1. Some proteins help maintain cell shape and coordinate changes inside and outside the cell through their attachment to the cytoskeleton and extracellular matrix.
  2. Some proteins function as receptors for chemical messengers from other cells.
  3. Some membrane proteins function as enzymes.

- Some membrane glycoproteins are involved in cell-cell recognition.
- Membrane proteins may participate in the intercellular junctions that attach adjacent cells to each other.
- Membranes may exhibit **selective permeability**, allowing some substances to cross more easily than others.
5.3 Passive transport is diffusion across a membrane with no energy investment

- **Diffusion** is the tendency of particles to spread out evenly in an available space.
  - Particles move from an area of more concentrated particles to an area where they are less concentrated.
  - This means that particles diffuse down their concentration gradient.
  - Eventually, the particles reach equilibrium where the concentration of particles is the same throughout.

- Diffusion across a cell membrane does not require energy, so it is called **passive transport**.
- The concentration gradient itself represents potential energy for diffusion.
5.4 Osmosis is the diffusion of water across a membrane

- One of the most important substances that crosses membranes is water.
- The diffusion of water across a selectively permeable membrane is called osmosis.

5.4 Osmosis is the diffusion of water across a membrane

- If a membrane permeable to water but not a solute separates two solutions with different concentrations of solute,
  - water will cross the membrane,
  - moving down its own concentration gradient,
  - until the solute concentration on both sides is equal.

5.5 Water balance between cells and their surroundings is crucial to organisms

- Tonicity is a term that describes the ability of a solution to cause a cell to gain or lose water.
- Tonicity mostly depends on the concentration of a solute on both sides of the membrane.

5.5 Water balance between cells and their surroundings is crucial to organisms

- How will animal cells be affected when placed into solutions of various tonicities? When an animal cell is placed into
  - an isotonic solution, the concentration of solute is the same on both sides of a membrane, and the cell volume will not change,
  - a hypotonic solution, the solute concentration is lower outside the cell, water molecules move into the cell, and the cell will expand and may burst, or
  - a hypertonic solution, the solute concentration is higher outside the cell, water molecules move out of the cell, and the cell will shrink.

- For an animal cell to survive in a hypotonic or hypertonic environment, it must engage in osmoregulation, the control of water balance.
5.5 Water balance between cells and their surroundings is crucial to organisms

- The cell walls of plant cells, prokaryotes, and fungi make water balance issues somewhat different.
  - The cell wall of a plant cell exerts pressure that prevents the cell from taking in too much water and bursting when placed in a hypotonic environment.
  - But in a hypertonic environment, plant and animal cells both shrivel.

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5.6 Transport proteins can facilitate diffusion across membranes

- Hydrophobic substances easily diffuse across a cell membrane.

- However, polar or charged substances do not easily cross cell membranes and, instead, move across membranes with the help of specific transport proteins in a process called **facilitated diffusion**, which
  - does not require energy and
  - relies on the concentration gradient.

- Because water is polar, its diffusion through a membrane’s hydrophobic interior is relatively slow.

- The very rapid diffusion of water into and out of certain cells is made possible by a protein channel called an **aquaporin**.
5.7 SCIENTIFIC DISCOVERY: Research on another membrane protein led to the discovery of aquaporins

- Dr. Peter Agre received the 2003 Nobel Prize in chemistry for his discovery of aquaporins.
- His research on the Rh protein used in blood typing led to this discovery.

5.8 Cells expend energy in the active transport of a solute

- In active transport, a cell
  - must expend energy to
  - move a solute against its concentration gradient.
- The following figures show the four main stages of active transport.
5.9 Exocytosis and endocytosis transport large molecules across membranes

- There are three kinds of endocytosis.
  1. **Phagocytosis** is the engulfment of a particle by wrapping cell membrane around it, forming a vacuole.
  2. **Pinocytosis** is the same thing except that fluids are taken into small vesicles.
  3. **Receptor-mediated endocytosis** uses receptors in a receptor-coated pit to interact with a specific protein, initiating the formation of a vesicle.

A cell uses two mechanisms to move large molecules across membranes.

- **Exocytosis** is used to export bulky molecules, such as proteins or polysaccharides.
- **Endocytosis** is used to import substances useful to the livelihood of the cell.

In both cases, material to be transported is packaged within a vesicle that fuses with the membrane.
ENERGY AND THE CELL

5.10 Cells transform energy as they perform work

- Cells are small units, a chemical factory, housing thousands of chemical reactions.
- Cells use these chemical reactions for
  - cell maintenance,
  - manufacture of cellular parts, and
  - cell replication.
5.10 Cells transform energy as they perform work

- **Energy** is the capacity to cause change or to perform work.

- There are two kinds of energy.
  1. **Kinetic energy** is the energy of motion.
  2. **Potential energy** is energy that matter possesses as a result of its location or structure.

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- **Heat**, or thermal energy, is a type of kinetic energy associated with the random movement of atoms or molecules.

- Light is also a type of kinetic energy, and can be harnessed to power photosynthesis.

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- Chemical energy is the potential energy available for release in a chemical reaction. It is the most important type of energy for living organisms to power the work of the cell.
5.10 Cells transform energy as they perform work

- **Thermodynamics** is the study of energy transformations that occur in a collection of matter.
- Scientists use the word
  - *system* for the matter under study and
  - *surroundings* for the rest of the universe.

5.10 Cells transform energy as they perform work

- Two laws govern energy transformations in organisms. According to the
  - **first law of thermodynamics**, energy in the universe is constant, and
  - **second law of thermodynamics**, energy conversions increase the disorder of the universe.
- **Entropy** is the measure of disorder, or randomness.

5.10 Cells transform energy as they perform work

- Cells use oxygen in reactions that release energy from fuel molecules.
- In **cellular respiration**, the chemical energy stored in organic molecules is converted to a form that the cell can use to perform work.

5.11 Chemical reactions either release or store energy

- **Exergonic reactions** release energy.
  - These reactions release the energy in covalent bonds of the reactants.
  - Burning wood releases the energy in glucose as heat and light.
  - Cellular respiration
    - involves many steps,
    - releases energy slowly, and
    - uses some of the released energy to produce ATP.
5.11 Chemical reactions either release or store energy

- **An endergonic reaction**
  - requires an input of energy and
  - yields products rich in potential energy.
- **Endergonic reactions**
  - begin with reactant molecules that contain relatively little potential energy but
  - end with products that contain more chemical energy.

5.11 Chemical reactions either release or store energy

- Photosynthesis is a type of endergonic process.
  - Energy-poor reactants, carbon dioxide, and water are used.
  - Energy is absorbed from sunlight.
  - Energy-rich sugar molecules are produced.

5.11 Chemical reactions either release or store energy

- A living organism carries out thousands of endergonic and exergonic chemical reactions.
- The total of an organism’s chemical reactions is called **metabolism**.
- A **metabolic pathway** is a series of chemical reactions that either
  - builds a complex molecule or
  - breaks down a complex molecule into simpler compounds.

5.11 Chemical reactions either release or store energy

- **Energy coupling** uses the
  - energy released from exergonic reactions to drive
  - essential endergonic reactions,
  - usually using the energy stored in ATP molecules.

5.12 ATP drives cellular work by coupling exergonic and endergonic reactions

- **ATP**, adenosine triphosphate, powers nearly all forms of cellular work.
- ATP consists of
  - the nitrogenous base adenine,
  - the five-carbon sugar ribose, and
  - three phosphate groups.
5.12 ATP drives cellular work by coupling exergonic and endergonic reactions

- Hydrolysis of ATP releases energy by transferring its third phosphate from ATP to some other molecule in a process called \textit{phosphorylation}.
- Most cellular work depends on ATP energizing molecules by phosphorylating them.

ATP: Adenosine Triphosphate

\[ \text{ATP} \rightarrow \text{ADP} + \text{P} + \text{Energy} \]

ADP: Adenosine Diphosphate

5.12 ATP drives cellular work by coupling exergonic and endergonic reactions

- There are three main types of cellular work:
  1. chemical,
  2. mechanical, and
  3. transport.
- ATP drives all three of these types of work.

ATP is a renewable source of energy for the cell.
- In the ATP cycle, energy released in an exergonic reaction, such as the breakdown of glucose, is used in an endergonic reaction to generate ATP.
5.13 Enzymes speed up the cell’s chemical reactions by lowering energy barriers

- Although biological molecules possess much potential energy, it is not released spontaneously.
  - An energy barrier must be overcome before a chemical reaction can begin.
  - This energy is called the activation energy ($E_A$).

- We can think of $E_A$ as the amount of energy needed for a reactant molecule to move “uphill” to a higher energy but an unstable state so that the “downhill” part of the reaction can begin.

- One way to speed up a reaction is to add heat, which agitates atoms so that bonds break more easily and reactions can proceed but could kill a cell.
5.13 Enzymes speed up the cell’s chemical reactions by lowering energy barriers

- Enzymes
  - function as biological catalysts by lowering the $E_A$ needed for a reaction to begin,
  - increase the rate of a reaction without being consumed by the reaction, and
  - are usually proteins, although some RNA molecules can function as enzymes.

5.14 A specific enzyme catalyzes each cellular reaction

- An enzyme
  - is very selective in the reaction it catalyzes and
  - has a shape that determines the enzyme’s specificity.

- The specific reactant that an enzyme acts on is called the enzyme’s **substrate**.

- A substrate fits into a region of the enzyme called the **active site**.

- Enzymes are specific because their active site fits only specific substrate molecules.

5.14 A specific enzyme catalyzes each cellular reaction

- The following figure illustrates the catalytic cycle of an enzyme.
5.14 A specific enzyme catalyzes each cellular reaction

- Many enzymes require nonprotein helpers called **cofactors**, which
  - bind to the active site and
  - function in catalysis.

- Some cofactors are inorganic, such as zinc, iron, or copper.

- If a cofactor is an organic molecule, such as most vitamins, it is called a **coenzyme**.

5.14 A specific enzyme catalyzes each cellular reaction

5.15 Enzyme inhibitors can regulate enzyme activity in a cell

- A chemical that interferes with an enzyme’s activity is called an inhibitor.

- **Competitive inhibitors**
  - block substrates from entering the active site and
  - reduce an enzyme’s productivity.
5.15 Enzyme inhibitors can regulate enzyme activity in a cell

- Noncompetitive inhibitors
  - bind to the enzyme somewhere other than the active site,
  - change the shape of the active site, and
  - prevent the substrate from binding.

5.15 Enzyme inhibitors can regulate enzyme activity in a cell

- Enzyme inhibitors are important in regulating cell metabolism.
- In some reactions, the product may act as an inhibitor of one of the enzymes in the pathway that produced it. This is called feedback inhibition.

5.16 CONNECTION: Many drugs, pesticides, and poisons are enzyme inhibitors

- Many beneficial drugs act as enzyme inhibitors, including
  - ibuprofen, inhibiting the production of prostaglandins,
  - some blood pressure medicines,
  - some antidepressants,
  - many antibiotics, and
  - protease inhibitors used to fight HIV.
- Enzyme inhibitors have also been developed as pesticides and deadly poisons for chemical warfare.
1. Describe the fluid mosaic structure of cell membranes.
2. Describe the diverse functions of membrane proteins.
3. Relate the structure of phospholipid molecules to the structure and properties of cell membranes.
4. Define diffusion and describe the process of passive transport.
5. Explain how osmosis can be defined as the diffusion of water across a membrane.
6. Distinguish between hypertonic, hypotonic, and isotonic solutions.
7. Explain how transport proteins facilitate diffusion.
8. Distinguish between exocytosis, endocytosis, phagocytosis, pinocytosis, and receptor-mediated endocytosis.
9. Define and compare kinetic energy, potential energy, chemical energy, and heat.
10. Define the two laws of thermodynamics and explain how they relate to biological systems.
11. Define and compare endergonic and exergonic reactions.
12. Explain how cells use cellular respiration and energy coupling to survive.
13. Explain how ATP functions as an energy shuttle.
14. Explain how enzymes speed up chemical reactions.
15. Explain how competitive and noncompetitive inhibitors alter an enzyme’s activity.
16. Explain how certain drugs, pesticides, and poisons can affect enzymes.
Figure 5.1: Molecules cross cell membranes by passive transport or by active transport. Passive transport may be diffusion or by polar molecules and ions.

(a) diffusion
(b) moving down a concentration gradient
(c) moving against a concentration gradient
(d) requires ATP

Table 5.2: Rate and Enzyme Concentration

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Table 5.3: Rate and Substrate Concentration

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