The Working Cell

5

You can read these words because enzymes and membranes enable your cells to use energy. The light energy that bounces off the page enters your eyes and stimulates pigments held in special cell membranes. Enzymes make these pigments and convert them to a form that can absorb light. The eye cells can transmit signals through nerve cells to the brain because the membranes of these cells can selectively absorb and pump out charged particles. The energy for moving these particles comes from processes that make ATP. These processes take place through the action of enzymes on and between cell membranes. Every biological activity—not just reading, but walking, laughing, and thinking—depends on energy produced by processes that involve enzymes and membranes. Energy, enzymes, and membranes are the subjects discussed in this chapter.

Organizing Your Knowledge

Exercise 1 (Modules 5.1 - 5.5)

Web/CD Activity 5A *Energy Transformations*
Web/CD Activity 5B *Chemical Reactions and ATP*
Web/CD Activity 5C *The Structure of ATP*

After reading Modules 5.1–5.5, review energy, chemical reactions, and the function of enzymes by filling in the blanks in the following story.

If you were to stop eating, you would probably starve to death in weeks or months. If you were unable to breathe, you would die in minutes. Organisms need the energy that is released when food and oxygen combine. This energy is used not only to move the body but also to keep it from falling apart.

Energy is the ability to perform 1________________. The sun is the source of the energy that sustains living things. Sunlight is pure 2________________ energy, energy of movement that is actually doing work. In the process of photosynthesis, plants are able to use the energy of sunlight to produce food molecules. This process obeys the laws of 3________________, the principles that govern energy transformations. Plants do not make the energy in food. According to the 4________________ law of thermodynamics, energy can be 5________________ or transferred, but it cannot be created or destroyed. In photosynthesis, no energy is created. Rather, the plant transforms the energy of sunlight into stored energy, called 6________________ energy, stored in molecules of glucose.

No energy change is 100% efficient, and the changes that occur in photosynthesis are no exception to this rule. Some of the energy of sunlight is not stored in glucose, but rather is converted to 7________________, which is random molecular motion. The

[8]____________ law of thermodynamics says that energy changes are always accompanied by an increase in [9]_______________, a measure of disorder. One of the reasons living things need a constant supply of energy is to counter this natural tendency toward disorder.

The products of photosynthesis contain [10]_______________ potential energy than the reactants. This means that, overall, photosynthesis is an [11]_______________ reaction. Such a reaction consumes energy, which in photosynthesis is supplied by the sun.

Photosynthesis produces food molecules, such as glucose, which store energy. An animal might obtain this food by eating a plant or an animal that has eaten a plant. The food molecules enter the animal's cells, where their potential energy is released in the process of cellular respiration. The products of this chemical reaction (actually a series of reactions) contain less potential energy than the reactants. Therefore, cellular respiration is an [12]_____________ process; it [13]_____________ energy. In fact, this is the same overall change that occurs when glucose in a piece of wood or paper burns in air. When paper burns, the energy escapes as the heat and light of the flames. In a cell, the reaction occurs in a more controlled way, and some of the energy is captured for use by the cell.

Energy released by the exergonic "burning" of glucose in cellular respiration is used to make a substance called [14]_______________. A molecule of [15]____________ and a [16]_______________ group are joined to form each molecule of ATP. This is an endergonic reaction, because it takes energy to assemble ATP. The covalent bond connecting the phosphate group to the rest of the ATP molecule is unstable and easily broken. This arrangement of atoms stores [17]_______________ energy. The [18]_______________ of ATP is an exergonic reaction. When ATP undergoes hydrolysis, a [19]_______________ is removed, ATP becomes [20]_______________, and energy is released. Thus, ATP is a kind of energy "currency" that can be used to perform cellular [21]_______________. Most cellular activities depend on ATP energizing other molecules by transferring its phosphate group to them—a process called [22]_______________. It should be noted that energy is not destroyed when ATP is used to do work. When an ATP molecule is hydrolyzed to make muscles move, some of its energy moves the body, and some ends up as random molecular motion, or [23]_______________.

A less obvious but important function of ATP is supplying the energy for fighting the natural tendency for a system to become disordered. A cell constantly needs to manufacture molecules to replace ones that are used up or damaged. Building a large molecule from smaller parts is an [24]_______________ reaction. Energy released by the exergonic hydrolysis of ATP is used to drive essential endergonic reactions. The linking of exergonic and endergonic processes is called energy [25]_______________, and ATP is the critical connection between the processes that release energy and those that consume it.

What prevents a molecule of ATP from breaking down until its energy is needed? Molecules can break down spontaneously; that is why ATP energy is needed to repair them. Fortunately for living things, it takes some additional energy, called energy of [26]_________, to get a chemical reaction started. This creates an energy [27]_______________ that prevents molecules from breaking down spontaneously. Energy barriers exist for both exergonic and endergonic reactions. Most of the time, most molecules in a cell lack the extra energy needed to clear the barrier, so chemical reactions occur slowly, if at all.

So what enables the vital reactions of metabolism to occur when and where they are needed, at a rate sufficient to sustain life? This is where enzymes come in. An enzyme is a special [28] _________________ molecule that acts as a biological [29] _________________. It [30] _________________ the rate of a chemical reaction without being [31] _______________ by it. An enzyme holds reactants in such a way as to [32] _________________ the energy barrier that prevents them from reacting. Even though reactants would not normally possess the activation energy needed to start the reaction, the enzyme creates conditions that make the reaction possible. Enzymes enable the cell to carry out vital chemical changes when and where they are needed, enabling it to control the many chemical reactions that make up cellular [33] _________________ .

Exercise 2 (Modules 5.1 – 5.5)

Web/CD Activity 5A *Energy Transformations*
Web/CD Activity 5B *Chemical Reactions and ATP*
Web/CD Activity 5C *The Structure of ATP*

Briefly summarize the differences between the words or phrases in each of the following pairs.

1. Kinetic energy and potential energy

2. Exergonic reactions and endergonic reactions

3. Reactants and products

4. ATP and ADP

5. A reaction without an enzyme and a reaction with an enzyme

6. Photosynthesis and cellular respiration

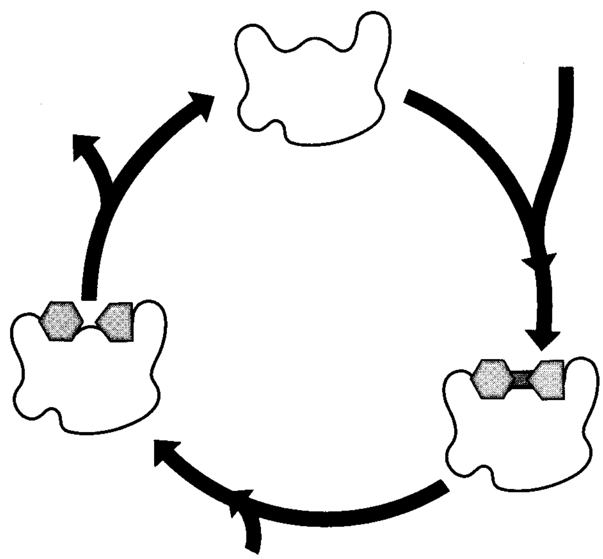
7. First and second laws of thermodynamics

Exercise 3 (Modules 5.6 – 5.9)

Web/CD Activity 5D *How Enzymes Work*

Review enzyme action by completing the activities below.

1. Complete the diagram below so that it shows the cycle of enzyme activity. Imagine that the reaction carried out by this enzyme is splitting a substrate molecule into two parts. Color the diagram as suggested, and label the items in **boldface** type. Color the **enzyme** purple. Sketch the **substrate** as a dark pink shape. Sketch the **products,** and color them light pink. Also label the **active site.**



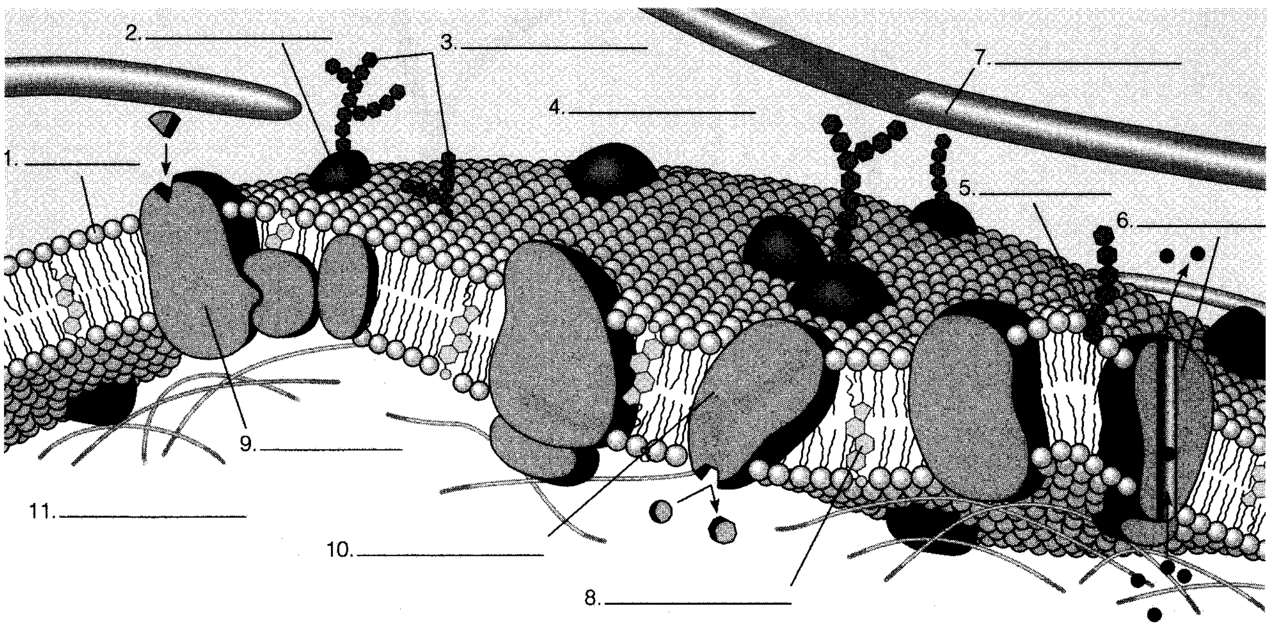
2. Make a sketch showing how heat or change in pH might change the above enzyme and alter its ability to catalyze its chemical reaction. Color and label the **enzyme,** its **active site,** and its **substrate,** as above.

3. On the left side of the space below, make a sketch showing how a competitive inhibitor might interfere with activity of the enzyme. Label the **competitive inhibitor,** and color it orange. On the right side, make a sketch showing how a noncompetitive inhibitor might interfere with activity of the enzyme. Label the **noncompetitive inhibitor,** and color it red.

Exercise 4 (Modules 5.10 - 5.13)

Web/CD Activity 5E *Membrane Structure*
Web/CD Activity 5F *Signal Transduction*
Web/CD Activity 5G *Selective Permeability of Membranes*

Review fluid mosaic membrane structure by coloring and labeling this diagram. It is a composite based on the figures in Modules 5.12 and 5.13. Label the items in **boldface** type: Start with the **cytoplasm, extracellular fluid,** and a **fiber of the extra cellular matrix.** In the membrane, color **phospholipids** gray, protein molecules purple, **carbohydrate I.D. tags** on **glycoprotein** and **glycolipid** molecules green, and **cholesterol** molecules yellow. Also show the functions of certain proteins by labeling them **enzyme, receptor protein,** and **transport protein.**



Exercise 5 (Modules 5.14 - 5.20)

Web/CD Activity 5H *Diffusion*
Web/CD Activity 5I *Osmosis and Water Balance in Cells*
Web/CD Activity 5J *Facilitated Diffusion*
Web/CD Activity 5K *Active Transport*
Web/CD Activity 5L *Exocytosis and Endocytosis*

Review diffusion and the function of cell membranes by matching each of the phrases on the right with the appropriate mechanisms from the list on the left. Two questions require more than one answer.

A. Diffusion
B. Active transport
C. Osmosis
D. Phagocytosis
E. Passive transport
F. Facilitated diffusion
G. Pinocytosis
H. Receptor-mediated endocytosis
I. Exocytosis

_______ 1. Diffusion across a biological membrane
_______ 2. Moves solutes against concentration gradient
_______ 3. Any spread of molecules from area of higher concentration to area of lower concentration
_______ 4. Diffusion with help of transport protein
_______ 5. Three types of endocytosis
_______ 6. Engulfing of fluid in membrane vesicles
_______ 7. Diffusion of water across selectively permeable membrane, from hypotonic to hypertonic solution
_______ 8. Transport molecules need ATP to function
_______ 9. Enables cell to engulf bulk quantities of specific large molecules
_______ 10. How oxygen and carbon dioxide enter and leave cells
_______ 11. Two types of passive transport
_______ 12. Engulfing of particle in membrane vesicle
_______ 13. Fusion of membrane-bound vesicle with membrane, and dumping of contents outside cell
_______ 14. How a cell might capture a bacterium

Exercise 6 (Modules 5.15 - 5.16)

Web/CD Activity 5I *Osmosis and Water Balance in Cells*

Osmosis is an important process that has many effects on living things. Test your understanding of osmosis by predicting in each of the following cases whether water will enter the cell (*In*) or leave the cell (*Out*), or whether there will be no net movement of water (*None*). Assume that the plasma membrane is permeable to water but not solutes.

_______ 1. Cell is exposed to hypertonic solution.
_______ 2. Cell is placed in salt solution whose concentration is greater than cell contents.
_______ 3. Due to disease, solute concentration of body fluid outside cell is less than solute concentration of cells.
_______ 4. Cell is in isotonic solution.
_______ 5. Single-celled organism is placed in drop of pure water for examination under microscope.
_______ 6. Cell is immersed in solution of sucrose and glucose whose individual concentrations are less than concentration of solutes in cytoplasm, but whose combined concentration is greater than concentration of solutes in cytoplasm.
_______ 7. Solute concentration of cell is greater than solute concentration of surrounding fluid.
_______ 8. Cell is exposed to hypotonic solution.
_______ 9. Concentration of solutes in cytoplasm is equal to solute concentration of extracellular fluid.
_______ 10. Cytoplasm more dilute than surrounding solution.

Exercise 7 (Modules 5.10 – 5.20)

Web/CD Activity 5E *Membrane Structure*
Web/CD Activity 5F *Signal Transduction*
Web/CD Activity 5G *Selective Permeability of Membranes*
Web/CD Activity 5H *Diffusion*
Web/CD Activity 5I *Osmosis and Water Balance in Cells*
Web/CD Activity 5J *Facilitated Diffusion*
Web/CD Activity 5K *Active Transport*
Web/CD Activity 5L *Exocytosis and Endocytosis*

Try to picture membranes and their functions close up by completing the following story.

Your first mission as a Bionaut requires you to enter a blood vessel and observe the structure and functions of cell membranes. You step into the water-filled chamber of the Microtron, which quickly shrinks you to a size much smaller than a red blood cell.

You tumble through the tunnel-like needle and into a blood vessel in the arm of a volunteer. Huge, rubbery red blood cells slowly glide past. Floating in the clear, yellowish blood plasma, you switch on your headlamp and examine the epithelial cells of the vessel wall. Their plasma membranes seem made of millions of small balloons. These are the polar "heads" of the [1]____________________ molecules that make up most of the membrane surface. Through the transparent surface, you can see their flexible, [2]________________ tails projecting inward toward the interior of the membrane, and beyond them an inner layer of [3]________________ molecules with their tails pointing toward you. Here and there there are globular [4]________________molecules embedded in the membrane; some rest lightly on the surface, but most project all the way into the interior of the cell. The membrane is indeed a [5]________________ mosaic; the proteins are embedded like the pieces of a picture, but you can see that they are free to move around. You push on one of the proteins, and it bobs like an iceberg. Some of the phospholipids and proteins have chains of sugar molecules attached to them, forming [6]________________ and [7]________________. These are the molecules that act as cell [8]________________ tags. You notice that one of the proteins has a dimple in its surface. Just then a small, round molecule floating in the plasma nestles in the dimple. The molecule is a hormone, a chemical signal, and the dimpled protein is the [9]________________ that enables the cell to respond to it.

In your light beam, you can see the sparkle and shimmer of many molecules, large and small, in the blood and passing through the cell membrane. Oxygen is moving from the plasma, where it is more concentrated, to the cell interior, where it is less concentrated. This movement is [10]________________; when it occurs through a biological membrane, it is called [11]________________ transport. Similarly, carbon dioxide is flowing out of the cell, down its [12]________________ gradient, from the cell interior, where it is [13]________________ concentrated, to the blood, where it is [14]______________ concentrated.

You note that water molecules are passing through the membrane equally in both directions. The total concentration of solutes in the cell and in the blood must be equal; the solutions must be [15]_______________. You signal the control team to inject a small amount of concentrated salt solution into the blood, making the blood slightly [16]_______________ relative to the cell contents. This causes water to flow [17]_______________ the cell, until the two solutions are again in equilibrium. This diffusion of water through a [18]_______________ permeable membrane is called [19]_______________.

Some sugar molecules floating in the blood are simply too large to pass easily through gaps in the membrane like the much smaller water molecules can. The sugar molecules simply bounce off, unless they happen to pass through pores in special [20]_______________ proteins. This is a type of passive transport, because the molecules move down a concentration gradient without the expenditure of [21]_______________. Because transport proteins help out, it is called [22]_______________ diffusion.

Your chemscanner detects a high concentration of potassium ions inside the cell. Transport proteins here and there in the membrane are able to move potassium into the cell against the concentration gradient. This must be [23]_______________ transport; the cell expends [24]_______________ to provide energy to "pump" the potassium into the cell.

Suddenly there is a tug at your foot. You look down to see your flipper engulfed by a rippling membrane. A white blood cell the size of a building quickly pins you against the vessel wall. The phospholipids of its membrane are pressed against your face mask. The cell is engulfing you, protecting the body from a foreign invader! Taking in a substance in this way is called [25]_______________, more specifically [26]___________, if the substance is a solid particle. Suddenly the pressure diminishes, and you are inside the white blood cell, floating free in a membrane-enclosed bag, or [27]_______________. Another sac is approaching; it is a [28]_______________, full of digestive enzymes. You manage to get your legs outside of the vacuole and move it back toward the inner surface of the cell membrane. As the vacuole fuses with the membrane, you tear your feet free and swim away from the voracious cell, realizing that [29]_______________ expelled you almost as fast as endocytosis trapped you!

You swim to the exit point, and the control team removes you by syringe. This is quite enough adventure for one day.

Testing Your Knowledge

Multiple Choice

1. The movement of molecules from an area of higher concentration to an area of lower concentration is called
   a. diffusion.
   b. endocytosis.
   c. catalysis.
   d. active transport.
   e. osmosis.

2. Which of the following is *not* true of an enzyme? An enzyme
   a. is a protein.
   b. acts as a biological catalyst.
   c. supplies energy to start a chemical reaction.
   d. is specific.
   e. lowers the energy barrier for a chemical reaction.

3. Phospholipid molecules in a membrane are arranged with their____ on the exterior and their____ on the interior.
   a. hydrophobic heads . . . hydrophilic tails
   b. hydrophilic heads . . . hydrophobic tails
   c. nonpolar heads . . . polar tails
   d. hydrophobic tails . . . hydrophilic heads
   e. hydrophilic tails . . . hydrophobic heads

4. In osmosis, water always moves toward the ____ solution, that is, toward the solution with the ____ solute concentration.
   a. isotonic . . . greater
   b. hypertonic . . . greater
   c. hypertonic . . . lesser
   d. hypotonic . . . greater
   e. hypotonic . . . lesser

5. Which of the following enables a cell to pick up and concentrate a specific kind of molecule?
   a. passive transport
   b. diffusion
   c. osmosis
   d. receptor-mediated endocytosis
   e. pinocytosis

6. A cell uses energy released by ____ reactions to drive the ____ reaction that makes ATP. Then it uses the energy released by the hydrolysis of ATP, an ____ reaction, to do various kinds of work in the cell.
   a. exergonic . . . exergonic . . . endergonic
   b. endergonic . . . exergonic . . . endergonic
   c. exergonic . . . endergonic . . . exergonic
   d. endergonic . . . endergonic . . . exergonic
   e. exergonic . . . endergonic . . . endergonic

7. Energy of activation
   a. is released when a large molecule breaks up.
   b. gets a reaction going.
   c. is released by an exergonic reaction.
   d. is stored in an endergonic reaction.
   e. is supplied by an enzyme.

8. The laws of thermodynamics state that whenever energy changes occur, ____ always increases.
   a. disorder
   b. order
   c. kinetic energy
   d. potential energy
   e. energy of activation

9. Living things transform kinetic energy into potential chemical energy in the ____, when ____ is made.
   a. mitochondrion . . . ADP
   b. chloroplast . . . ADP
   c. chloroplast . . . an enzyme
   d. mitochondrion . . . glucose
   e. chloroplast . . . glucose

10. Why does heating interfere with the activity of an enzyme?
    a. It kills the enzyme.
    b. It changes the enzyme's shape.
    c. It increases the energy of substrate molecules.
    d. It causes the enzyme to break up.
    e. It kills the cell, so enzymes can't work.

11. An enzyme is specific. This means
    a. it has a certain amino acid sequence.
    b. it is found only in a certain place.
    c. it functions only under certain environmental conditions.
    d. it speeds up a particular chemical reaction.
    e. it occurs in only one type of cell.

12. Diffusion of water across a selectively permeable membrane is called
    a. active transport.
    b. osmosis.
    c. exocytosis.
    d. passive transport.
    e. facilitated diffusion.

Essay

1. Describe the kinds of molecules that cannot easily diffuse through cell membranes. How do proteins facilitate diffusion of these substances?
2. Make a sketch showing why an enzyme acts only on a specific substrate.
3. Most enzyme-catalyzed chemical reactions in humans occur most readily around body temperature, 37°C. Why do these reactions slow down at lower temperatures? Why do they slow down at higher temperatures?
4. Which contains more potential energy, a large, complex molecule like a protein, or the smaller amino acid subunits of which it is composed? Is the joining of amino acids to form a protein an exergonic or endergonic reaction? Why must this be the case? Where does the cell obtain energy to carry out such reactions?
5. Describe the circumstances under which plant and animal cells gain and lose water by osmosis. Which of the following is the least serious problem: water gain by a plant cell, water loss by a plant cell, water gain by an animal cell, or water loss by an animal cell? Why?

Applying Your Knowledge

Multiple Choice

1. If a cell is like a factory, then enzymes are like
   a. the plans for the factory.
   b. the machines in the factory.
   c. the power plant for the factory.
   d. the raw materials used by the factory.
   e. the walls of the factory.
2. A molecule that has the same shape as the substrate of an enzyme would tend to
   a. speed metabolism by guiding the enzyme to its substrate.
   b. speed metabolism by acting as a cofactor for the enzyme.
   c. speed metabolism because it would also be a catalyst.
   d. save the cell energy by substituting for the substrate.
   e. slow metabolism by blocking the enzyme's active site.
3. A plant cell is placed in a solution whose solute concentration is twice as great as the concentration of the cell cytoplasm. The cell membrane is selectively permeable, allowing water but not the solutes to pass through. What will happen to the cell?
   a. No change will occur because it is a plant cell.
   b. The cell will shrivel because of osmosis.
   c. The cell will swell because of osmosis.
   d. The cell will shrivel because of active transport of water.
   e. The cell will swell because of active transport of water.
4. A white blood cell is capable of producing and releasing thousands of antibody molecules every second. Antibodies are large, complex protein molecules. How would you expect them to leave the cell?
   a. active transport
   b. exocytosis
   c. receptor-mediated endocytosis
   d. passive transport
   e. pinocytosis
5. Which of the following would be *least* likely to diffuse through a cell membrane without the help of a transport protein?
   a. a large polar molecule
   b. a large nonpolar molecule
   c. a small polar molecule
   d. a small nonpolar molecule
   e. Any of the above would easily diffuse through the membrane.
6. Red blood cells shrivel when placed in a 10% sucrose solution. When first placed in the solution, the solute concentration of the cells is ____ the concentration of the sucrose solution. After the cells shrivel, their solute concentration is ____ the concentration of the sucrose solution.
   a. less than . . . greater than
   b. greater than . . . less than
   c. equal to . . . equal to
   d. less than . . . equal to
   e. greater than . . . equal to

7. A nursing infant is able to obtain disease-fighting antibodies, which are large protein molecules, from its mother's milk. These molecules probably enter the cells lining the baby's digestive tract via
   a. osmosis.
   b. passive transport.
   c. exocytosis.
   d. active transport.
   e. endocytosis.

8. Some enzymes involved in the hydrolysis of ATP cannot function without the help of sodium ions. Sodium in this case functions as
   a. a substrate.
   b. a cofactor.
   c. an active site.
   d. a noncompetitive inhibitor.
   e. a vitamin.

9. The relationship between an enzyme's active site and its substrate is most like which of the following?
   a. a battery and a flashlight
   b. a car and a driver
   c. a key and a lock
   d. a glove and a hand
   e. a hammer and a nail

10. In which of the following do both examples illustrate kinetic energy?
   a. positions of electrons in an atom—a ball rolling down a hill
   b. heat—arrangement of atoms in a molecule
   c. a rock resting on the edge of a cliff—heat
   d. a ball rolling down a hill—heat
   e. light—arrangement of atoms in a molecule

11. Which of the following is a difference between active transport (AT) and facilitated diffusion (FD)?
   a. AT involves transport proteins, and FD does not.
   b. FD can move solutes against a concentration gradient, and AT cannot.
   c. FD requires energy from ATP, and AT does not.
   d. FD involves transport proteins, and AT does not.
   e. AT requires energy from ATP, and FD does not.

12. An enzyme and a membrane receptor molecule are similar in that they
   a. are always attached to membranes.
   b. act as catalysts.
   c. require ATP to function.
   d. supply energy for the cell.
   e. bind to molecules of a particular shape.

Essay

1. The burning of glucose molecules in paper is an exergonic reaction, which releases heat and light. If this reaction is exergonic, why doesn't the book in your hands spontaneously burst into flame? You could start the reaction if you touched this page with a burning match. What is the role of the energy supplied by the match?

2. Seawater is hypertonic in comparison to body tissues. Explain what would happen to his stomach cells if a shipwrecked sailor drank seawater.

3. The laws of thermodynamics have imaginatively been described as the house rules of a cosmic energy card game: "You can't win, you can't break even (and to stay alive, you can't get out of the game)." State the law that says living things can't win the energy game. State the law that says they can't break even.

4. A farm worker accidentally was splashed with a powerful insecticide. A few minutes later he went into convulsions, stopped breathing, and died. The insecticide acted as a competitive inhibitor of an enzyme important in the function of the nervous system. Describe the structural relationship between the enzyme, its substrate, and the insecticide.

5. Lecithin is a substance used in foods such as mayonnaise as an emulsifier, which means that it helps oil and water mix. Lecithin is a phospholipid; a lecithin molecule has a polar "head" and a nonpolar "tail." How might the structure of lecithin allow water to surround fat droplets? Sketch a microscopic view of some fat droplets in mayonnaise, and show how you think the fat, surrounding water, and lecithin molecules might be arranged.

Extending Your Knowledge

1. Soap bubbles have many of the physical and chemical properties of cell membranes. Several books are available in bookstores and libraries that describe the physics and chemistry of bubbles. You might want to blow some bubbles, observe their behavior, and learn about the scientific principles that shape them.

2. Are you reading this under an electric light? Recall that energy cannot be created or destroyed, but only changed from one form into another. In what form was the light energy coming from the lamp before the light bulb changed it into light? Where did it come from? Trace the steps in the transformation of this energy as far back as you can. What happens to the light energy after it shines on you and the book?

3. Enzyme names usually end in the suffix"-ase," and the name of the enzyme often describes its substrate and the kind of reaction the enzyme catalyzes. For example, DNA polymerase catalyses the building of a DNA polymer from smaller nucleotide building blocks. Lactase breaks down the sugar lactose. Look for other enzyme names (in the text and elsewhere—see question 4) and try to imagine what the enzymes do.

4. Various household products contain enzymes—cleaners, laundry detergent, meat tenderizer, and so on. See if you can find products containing enzymes. Where are the enzymes in these products obtained? What are their substrates?