Chapter 4: Cell Membrane Structure and Function

OVERVIEW

This chapter introduces you to the characteristics and functions of cell walls and cell membranes. You will learn about the transport of molecules across cell membranes, especially the processes of diffusion and osmosis. You also will learn how cells are connected and how cells communicate with each other. The chapter begins with an account of two young hikers, one of which is bitten by a Western Diamondback rattlesnake, with initial symptoms of rapidly spreading bruising in the bitten area, dropping blood pressure, shortness of breath, dizziness and nausea.

1) How Is the Structure of a Membrane Related to Its Function?

The **plasma membrane** acts as a cellular gatekeeper, surrounding, protecting and isolating the cell while allowing it extensive communication with its surroundings. The three basic functions of a plasma membrane are to selectively isolate the cell's contents from the external environment, to regulate the exchange of essential substances between the cell's contents and the surrounding environment, and to communicate with other cells. The basic structure of membranes is a collection of proteins moving within a double layer of phospholipids (and, in animal cells, cholesterol). This is called the **fluid mosaic model** of cellular membrane structure; the proteins are like "tiles" moving within a double layer of phospholipids which acts as a viscous, fluid "grout." The overall distribution of proteins and various types of phospholipids can change over time within a plasma membrane.

Within membranes, phospholipids arrange themselves into a double layer called the **phospholipid bilayer** with the hydrophilic head forming the outer borders facing the watery extracellular fluid or the internal watery **cytoplasm**, and the hydrophobic tails facing each other inside the layers. Polar water-soluble molecules (salts, amino acids, sugars) cannot pass easily through the phospholipid bilayer. A variety of proteins are embedded within or attached to the phospholipid bilayer to regulate molecular movement through the membrane and to communicate with the environment. Some have carbohydrates attached, forming **glycoproteins**, which aid in cell communication. In most animal cells, the phospholipid bilayer also contains cholesterol, which makes the bilayer stronger, more flexible but less fluid, and less permeable to water-soluble substances such as ions and monosaccharides.

The three major categories of membrane proteins are transport proteins, receptor proteins, and recognition proteins. **Transport proteins** regulate movement of water-soluble molecules through the plasma membrane. Specifically, **channel proteins** form pores to allow small molecules and ions (Ca^{++}, K^{+}, Na^{+}) to pass through and **carrier proteins** bind molecules and, by changing shape, pass them across the membrane. **Receptor proteins** trigger cell responses and/or communication between cells when certain molecules (hormones or nutrients) bind to them. **Recognition proteins** often are glycoproteins on the outer membrane surface of certain cells (immune system cells, for instance) and serve as identification tags and attachment sites for other cells and molecules.

2) How Do Substances Move Across Membranes?

A **fluid** is any substance that can move or change shape in response to external forces without breaking apart. The **concentration** of molecules in a fluid is the number of molecules in a given amount of volume. A **gradient** is a physical difference between two regions of space that causes molecules to move from one region to the other. Cells frequently generate or encounter gradients of concentration,

pressure, and/or electrical charge. Molecules in fluids move randomly in response to **concentration gradients**, from regions of greater concentration (numbers of molecules in a given volume) to regions of lower concentration. Over time, random movement will produce a net movement of molecules from regions of high concentration to regions of low concentration, a process called **diffusion**. Eventually, diffusion will result in molecules becoming evenly dispersed throughout a fluid or the air, creating a dynamic equilibrium, since the molecules continue to move randomly. You can watch diffusion in action by pacing a drop of food coloring in a glass of water and looking at it every five minutes.

Movement across membranes occurs by both passive and active transport. During **passive transport,** substances move into and out of cells down concentration gradients, from regions of high concentration to regions of low concentration by diffusion and require no cell energy. The plasma membrane's lipid and protein pores regulate which molecules can cross, but they do not influence the direction of flow. During **active transport**, cells use energy to move substances against the concentration gradient, using membrane transport proteins to control the direction of flow. For example, when you ride a bike, if you don't pedal, you can only go downhill (like passive transport), but if you use energy to pedal, you can go uphill (like active transport). The greater the concentration gradient, the faster diffusion occurs, but diffusion cannot move molecules rapidly over long distances.

Passive transport includes simple diffusion, facilitated diffusion, and osmosis. Plasma membranes are **differentially permeable** to diffusion of molecules since they allow some molecules to pass across but prevent other molecules from passing across. Different molecules cross the plasma membrane at different locations and at different rates. In **simple diffusion**, water, dissolved gases, or lipid-soluble molecules pass freely through the phospholipid bilayer. In **facilitated diffusion**, most water-soluble molecules such as ions, amino acids, and small sugars, cross the membrane in a way that doesn't use energy; they are assisted by channel proteins (form pores or channels) and carrier proteins (that bind specific molecules, then change shape to allow the molecules to pass through). Facilitated transport is a slower process than simple diffusion.

Diffusion of water across differentially permeable membranes is called **osmosis**. Extracellular fluids in animals usually are equal in water concentration (**isotonic** or "having the same strength") to cellular fluids, so water diffuses equally into and out of cells. Pure water has the highest water concentration (100%). If a cell is placed in a concentrated salt solution, the salt solution has a lower water/higher dissolved salt concentration (is **hypertonic** or "having greater strength of dissolved molecules") than the cell (higher water/lower dissolved molecules concentration or **hypotonic**), water will diffuse down its concentration gradient and leave the cell faster than it enters and the cytoplasm will shrink. If, however, a solution is hypotonic to cells that are hypertonic, water will enter the cells faster than it leaves and the cytoplasm will expand. In protists that live in fresh water, cells have contractile vacuoles that pump the excess water out, while plant cells have central vacuoles which expand and allow those cells to become rigid. Examples of osmosis include water uptake by plant roots, absorption of dietary water in animal intestines, and reabsorption of water and minerals in kidneys.

Active transport uses energy to move substances against their concentration gradients into or out of cells. Digestive cells concentrate nutrients and brain cells get rid of excess ions by active transport. Active transport proteins, often called "pumps," span plasma membranes and use energy (usually from breaking down ATP molecules) to transport molecules across the membrane against the concentration gradient.

Many cells acquire particles too large to pass through membranes by **endocytosis** (using energy to surround the substance with plasma membrane and pinching it off internally to form a **vesicle**). In **pinocytosis**, a small area of membrane pinches inward to surround extracellular fluid and buds off into the cytoplasm to form a tiny vacuole. In **receptor-mediated endocytosis**, depressed areas of membrane called coated pits contain many copies of a receptor protein. These attach to specific extracellular molecules and the coated pit deepens into a U-shaped area that pinches off into the cytoplasm forming a coated vesicle. In **phagocytosis**, cells (such as *Amoeba* and white blood cells) can ingest entire microorganisms or large molecules by extending sections of plasma membrane to form **pseudopods** that surround the object and

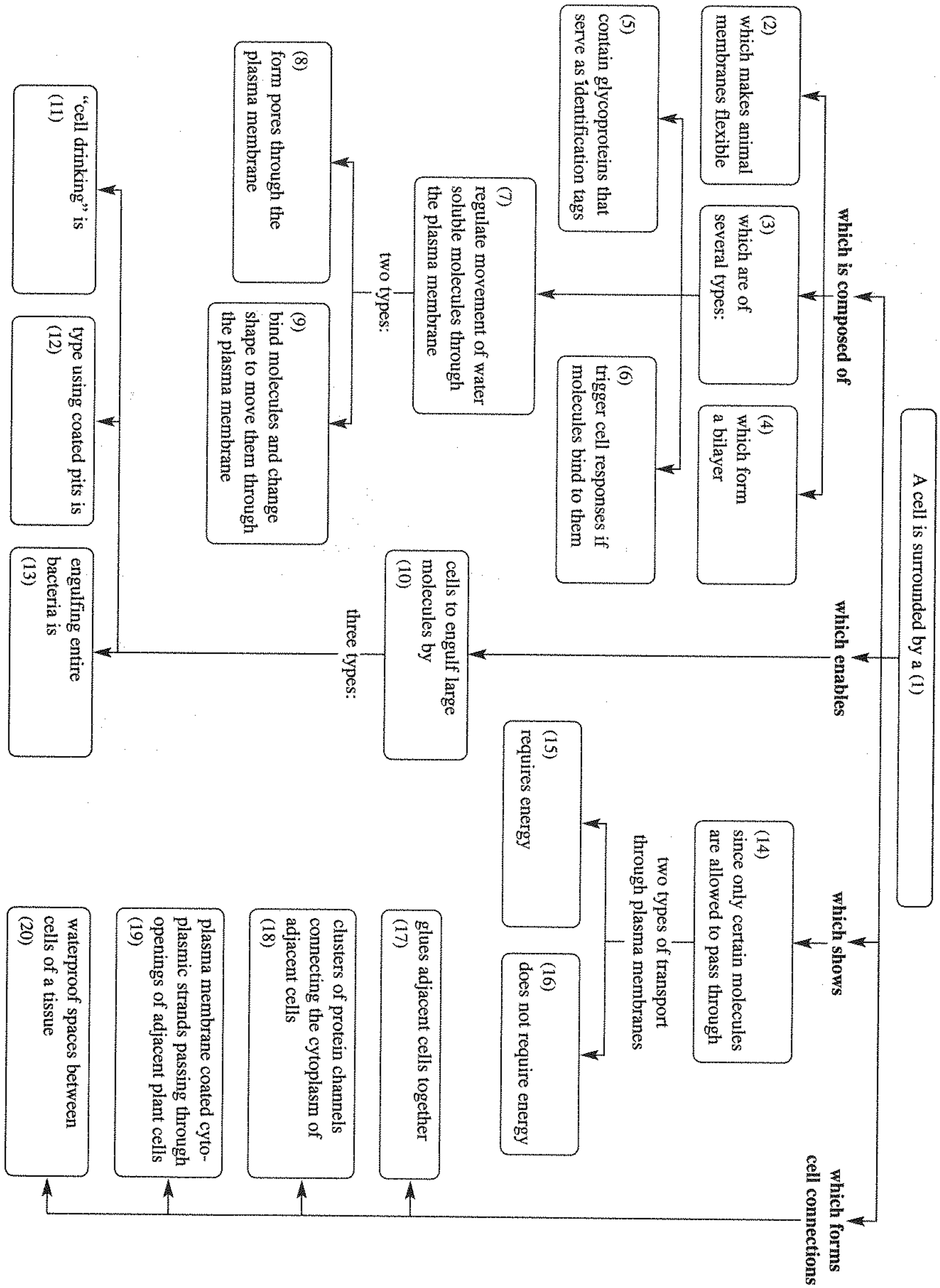
enclose it within a food vacuole in the cytoplasm for digestion. Through **exocytosis**, cells eliminate unwanted materials (like digestive waste) or secrete molecules (like hormones) into the extracellular fluid. A membrane-bound vesicle moves within the cytoplasm to the cell surface, where its membrane fuses with the plasma membrane, excreting the contents.

3) How Are Cells Specialized?

A variety of junctions allow cells to connect and communicate. **Desmosomes** attach cells together, particularly within animal tissues, by gluing together the plasma membranes of adjacent cells with proteins or carbohydrates. Protein filaments run from the desmosomes into the interiors of each cell, adding additional strength to the attachment. **Tight junctions** waterproof the membranes of cells forming tubes or sacs that must remain watertight (like the urinary bladder). The membranes of adjacent cells nearly fuse along a series of ridges, forming leakproof gaskets. **Gap junctions** are clusters of protein channels directly connecting the cytoplasm of adjacent cells to help communication (via the flow of hormones, nutrients, ions, or electrical signals) among heart muscle cells, gland cells, or brain cells, for instance. **Plasmodesmata** are cytoplasmic strands, surrounded by plasma membrane, that pass through openings in the walls of adjacent plant cells, allowing water, nutrients, and hormones to pass freely from one cell to another.

Some cells are supported by **cell walls**. Cell walls cover the outer surfaces of many cells. In protists, cell walls are made of cellulose, protein, or glassy silica. In plants, they are made of cellulose and other polysaccharides, in fungi they are made of chitin, and in bacteria they are made of a chitin-like material. In plants, cells secrete a **primary cell wall** of cellulose through their plasma membranes, and later secrete a thicker **secondary cell wall** of cellulose and other polysaccharides beneath the primary wall. The primary cell walls of adjacent cells are joined by a **middle lamella** layer made of a polysaccharide called pectin. Cells walls are strong yet porous.

Case study revisited. The reason that Western Diamondback rattlesnake venom is dangerous, even deadly, is that it contains enzymes called phospholipases, which break down the phospholipids of the plasma membranes of cells, causing the cells to rupture and die. All of Karl's symptoms were the result of the action of phospholipases on his skin, blood cells and blood vessels, muscle, and blood clotting. Antivenom contains proteins that bind to and neutralize the various toxins in the snake venom.


A cell is surrounded by a (1)
which is composed of
(2) which makes animal membranes flexible
(3) which are of several types:
(4) which form a bilayer
(5) contain glycoproteins that serve as identification tags
(6) trigger cell responses if molecules bind to them
(7) regulate movement of water soluble molecules through the plasma membrane
two types:
(8) form pores through the plasma membrane
(9) bind molecules and change shape to move them through the plasma membrane
which enables
cells to engulf large molecules by (10)
three types:
"cell drinking" is (11)
type using coated pits is (12)
engulfing entire bacteria is (13)
which shows
(14) since only certain molecules are allowed to pass through
two types of transport through plasma membranes
(15) requires energy
(16) does not require energy
which forms cell connections
glues adjacent cells together (17)
clusters of protein channels connecting the cytoplasm of adjacent cells (18)
plasma membrane coated cytoplasmic strands passing through openings of adjacent plant cells (19)
waterproof spaces between cells of a tissue (20)

KEY TERMS AND CONCEPTS

Fill-In: From the following list of key terms, fill in all the boxes in the preceding concept map.

active transport
carrier proteins
channel proteins
cholesterol
desmosomes
differential permeability
endocytosis
gap junctions
passive transport
phagocytosis
phospholipid
pinocytosis
plasma membrane
plasmodesmata
proteins
receptor proteins
receptor-mediated endocytosis
recognition proteins
tight junctions
transport proteins

Key Terms and Definitions

active transport: the movement of materials across a membrane through the use of cellular energy, normally against a concentration gradient.

carrier protein: a membrane protein that facilitates the diffusion of specific substances across the membrane. The molecule to be transported binds to the outer surface of the carrier protein; the protein then changes shape, allowing the molecule to move across the membrane through the protein.

cell wall: a layer of material, normally made up of cellulose or cellulose-like materials, that is outside the plasma membrane of plants, fungi, bacteria, and some protists.

channel protein: a membrane protein that forms a channel or pore completely through the membrane and that is usually permeable to one or to a few water-soluble molecules, especially ions.

concentration: the number of particles of a dissolved substance in a given unit of volume.

concentration gradient: the difference in concentration of a substance between two parts of a fluid or across a barrier such as a membrane.

cytoplasm (sī´-tō-plaz-um): the material contained within the plasma membrane of a cell, exclusive of the nucleus.

desmosome (dez´-mō-sōm): a strong cell-to-cell junction that attaches adjacent cells to one another.

differentially permeable: referring to the ability of some substances to pass through a membrane more readily than can other substances.

diffusion: the net movement of particles from a region of high concentration of that particle to a region of low concentration, driven by the concentration gradient; may occur entirely within a fluid or across a barrier such as a membrane.

endocytosis (en-dō-sī-tō´-sis): the process in which the plasma membrane engulfs extracellular material, forming membrane-bound sacs that enter the cytoplasm and thereby move material into the cell.

exocytosis (ex-ō-sī-tō´-sis): the process in which intracellular material is enclosed within a membrane-bound sac that moves to the plasma membrane and fuses with it, releasing the material outside the cell.

facilitated diffusion: the diffusion of molecules across a membrane, assisted by protein pores or carriers embedded in the membrane.

fluid: a liquid or gas.

fluid mosaic model: a model of membrane structure; according to this model, membranes are composed of a double layer of phospholipids in which various proteins are embedded. The phospholipid bilayer is a somewhat fluid matrix that allows the movement of proteins within it.

gap junction: a type of cell-to-cell junction in animals in which channels connect the cytoplasm of adjacent cells.

glycoprotein: a protein to which a carbohydrate is attached.

gradient: a difference in concentration, pressure, or electrical charge between two regions.

hypertonic (hī-per-ton´-ik): referring to a solution that has a higher concentration of dissolved particles (and therefore a lower concentration of free water) than has the cytoplasm of a cell.

hypotonic (hī-pō-ton´-ik): referring to a solution that has a lower concentration of dissolved particles (and therefore a higher concentration of free water) than has the cytoplasm of a cell.

isotonic (ī-sō-ton´-ik): referring to a solution that has the same concentration of dissolved particles (and therefore the same concentration of free water) as has the cytoplasm of a cell.

middle lamella: a thin layer of sticky polysaccharides, such as pectin, and other carbohydrates that separates and holds together the primary cell walls of adjacent plant cells.

osmosis (oz-mō´-sis): the diffusion of water across a differentially permeable membrane, normally down a concentration gradient of free water molecules. Water moves into the solution that has a lower concentration of free water from a solution with the higher concentration of free water.

passive transport: the movement of materials across a membrane down a gradient of concentration, pressure, or electrical charge without using cellular energy.

phagocytosis (fa-gō-sī-tō´-sis): a type of endocytosis in which extensions of a plasma membrane engulf extracellular particles and transport them into the interior of the cell.

phospholipid bilayer: a double layer of phospholipids that forms the basis of all cellular membranes. The phospholipid heads, which are hydrophilic, face the water of extracellular fluid or the cytoplasm; the tails, which are hydrophobic, are buried in the middle of the bilayer.

pinocytosis (pi-nō-sī-tō´-sis): the nonselective movement of extracellular fluid, enclosed within a vesicle formed from the plasma membrane, into a cell.

plasma membrane: the outer membrane of a cell, composed of a bilayer of phospholipids in which proteins are embedded.

plasmodesma (plaz-mō-dez´-muh; pl., plasmodesmata): a cell-to-cell junction in plants that connects the cytoplasm of adjacent cells.

primary cell wall: cellulose and other carbohydrates secreted by a young plant cell between the middle lamella and the plasma membrane.

pseudopod (sood´-ō-pod): an extension of the plasma membrane by which certain cells, such as amoebae, locomote and engulf prey.

receptor-mediated endocytosis: the selective uptake of molecules from the extracellular fluid by binding to a receptor located at a coated pit on the plasma membrane and pinching off the coated pit into a vesicle that moves into the cytoplasm.

receptor protein: a protein, located on a membrane (or in the cytoplasm), that recognizes and binds to specific molecules. Binding by receptor proteins typically triggers a response by a cell, such as endocytosis, increased metabolic rate, or cell division.

recognition protein: a protein or glycoprotein protruding from the outside surface of a plasma membrane that identifies a cell as belonging to a particular species, to a specific individual of that species, and in many cases to one specific organ within the individual.

secondary cell wall: a thick layer of cellulose and other polysaccharides secreted by certain plant cells between the primary cell wall and the plasma membrane.

simple diffusion: the diffusion of water, dissolved gases, or lipid-soluble molecules through the phospholipid bilayer of a cellular membrane.

tight junction: a type of cell-to-cell junction in animals that prevents the movement of materials through the spaces between cells.

transport protein: a protein that regulates the movement of water-soluble molecules through the plasma membrane.

vesicle (ves´-i-kul): a small, membrane-bound sac within the cytoplasm.

THINKING THROUGH THE CONCEPTS

True or False: Determine if the statement given is true or false. If it is false, change the <u>underlined</u> word(s) so that the statement reads true.

21. _____ As a cell increases in size, its surface area increases <u>more rapidly</u> than its internal volume.
22. _____ Red blood cells will <u>burst</u> when placed in fresh water.
23. _____ The water-loving portion of a compound is <u>hydrophobic</u>.
24. _____ The rate of diffusion is increased by <u>decreasing</u> the temperature.
25. _____ In diffusion, molecules move toward regions of <u>higher</u> concentration.
26. _____ More water will enter a cell if it is placed in a <u>hypotonic</u> solution.
27. _____ Solutions with higher salt concentrations than a cell are <u>hypertonic</u> when compared to the cell.
28. _____ Freshwater organisms deal with the tendency of their cells to <u>gain</u> water.
29. _____ Endocytosis is the movement of substances <u>into</u> cells.
30. _____ The movement of a solid substance into a cell is <u>pinocytosis</u>.

Identify: Determine whether the following statements refer to **cell walls** or **plasma membranes.**

31. _______________ contains cellulose in plants
32. _______________ isolates the cytoplasm from the external environment
33. _______________ regulates flow of materials into and out of cells
34. _______________ contains chitin in fungi
35. _______________ communicates with other cells
36. _______________ stiff, porous, and non-living
37. _______________ "fluid-mosaic model"
38. _______________ has a lipid bilayer

Identify: Determine whether the following statements refer to **diffusion** or specifically to **osmosis.**

39. ________________ effect of movement of all molecules down the concentration gradient
40. ________________ effect of water moving down its concentration gradient across a differentially permeable membrane
41. ________________ movement of O_2 into a cell and CO_2 out of a cell
42. ________________ a cell expands when placed in pure water
43. ________________ can cause cells to shrink

Identify: Determine whether the following statements refer to effect of osmosis on cells placed in a **hypertonic**, **hypotonic**, or **isotonic** solution.

44. ________________ Animal cells will expand.
45. ________________ Animal cells will shrivel up.
46. ________________ Red blood cells will burst.
47. ________________ Celery will wilt.
48. ________________ Lettuce leaves will become turgid (rigid, crisp) in fluid.
49. ________________ Red blood cells will neither shrivel up nor swell up.

Matching: Cell connections and communications

50. _____ clusters of protein channels for communication between cells
51. _____ waterproof gaskets between cells
52. _____ attachments between cells that are stretched, compressed, or bent as organisms move
53. _____ large, membrane-bound tubes for water passage between cells

Choices:

a. tight junctions
b. plasmodesmata
c. gap junctions
d. desmosomes

Multiple Choice: Pick the most correct choice for each question.

54. The hydrophobic tails of a phospholipid bilayer are oriented toward the
    a. interior of the plasma membrane
    b. extracellular fluid surrounding the cell
    c. cytoplasm of the cell
    d. nucleus of the cell

55. Molecules that permeate a plasma membrane by facilitated diffusion
    a. require the use of energy
    b. require the aid of transport proteins
    c. move from areas of low concentration to areas of high concentration
    d. do so much more quickly than those crossing by simple diffusion
    e. are water molecules

56. A molecule that can diffuse freely through a phospholipid bilayer is probably
    a. water-soluble
    b. positively charged
    c. nonpolar
    d. negatively charged
    e. a membrane-spanning protein

57. The preferential movement of water molecules across a differentially permeable membrane is termed
    a. facilitated diffusion
    b. osmosis
    c. active transport
    d. exocytosis
    e. a concentration gradient

58. If red blood cells are placed in a hypotonic solution, what happens?
    a. The cells swell and burst.
    b. The cells shrivel up and shrink.
    c. The cells remain unchanged in volume.
    d. The cells take up salt molecules from the hypotonic solution.
    e. The cells release salt molecules into the hypotonic solution.

59. Solutions that cause water to preferentially enter cells by osmosis are called
    a. hypertonic
    b. isotonic
    c. hypotonic
    d. endosmotic
    e. exosmotic

60. What does snake antivenom do to alleviate the effects of a snakebite?
    a. it kills the snake
    b. it cuts off circulation to the bitten body part
    c. it neutralizes the various toxins in the snake venom
    d. it contains new cells to take the place of the affected ones
    e. it provides vitamins to strengthen the victim

61. Most snakes are aggressive and seek out humans to attack.
    a. true
    b. false

62. Which of the following is NOT an initial symptom of being bitten by a Western Diamondback rattlesnake?
    a. a sudden burst of energy
    b. rapidly spreading bruising in the bitten area
    c. dropping blood pressure
    d. shortness of breath
    e. dizziness and nausea

63. Which enzymes contained in rattlesnake venom are especially dangerous?
    a. polymerases
    b. endonucleases
    c. lipases
    d. phospholipases
    e. lactases

APPLYING THE CONCEPTS

These practice questions are intended to sharpen your ability to apply critical thinking and analysis to biological concepts covered in this chapter.

64. Suppose you are taking a cruise from San Francisco to Hawaii. About halfway there, the ship begins to sink and all passengers and crew board lifeboats and are floating around in the ocean waiting to be rescued. After several days, you are so thirsty that you bend over the side of your life boat and drink some of the seawater. Did you do a wise thing? Explain what you think will happen to your body within a few hours of drinking the ocean water, and explain the biological basis for your reactions.

65. Usually, lipids and water do not mix. However, soap allows us to remove greasy dirt from our hands by washing it down the drain with water. What molecules in membranes allow lipids and water to "mix" and what does that suggest to us about the chemical composition of soap?

66. An organism that lives in fresh water is almost always hypertonic to its watery environment. Why is this a serious problem for such organisms? How do these organisms cope with the problem?

67. An organism that lives in the ocean is almost always hypotonic to its salt water environment. Why is this a serious problem for such organisms? How do these organisms cope with the problem?

68. Membranes have phospholipid, protein, and carbohydrate components. Discuss how their chemical properties are related to their functions within cell membranes.

69. Compare simple diffusion, facilitated diffusion, and active transport, including the source of energy that drives each process and use the terms "concentration gradient" and "carrier proteins" in your response.

70. In the human body, the ways cells are attached to each other usually indicates something about the function of the cells involved. Relate the three ways that cells are attached to each other with a specific function in each case.

71. Describe the differences in membrane structure in the upper and lower parts of the legs of arctic caribou that allow their lower legs to reach freezing temperatures in the winter without loss of membrane function.

72. Both humans and snakes have phospholipase enzymes. Explain their functions in these organisms.

73. Why is it important for cells to be capable of active transport?

Use the Case Study and Web sites for this chapter to answer the following question.

74. Many people are afraid of snakes. A person bitten by a poisonous snake might die without anti-venom treatment, yet venom components can also be life-saving drugs. This exercise takes a closer look at snake bites and venom. What are the three major functions of snake venom? What are the major components of venom? Why does it takes several weeks to produce snake anti-venom, used to treat snake bites?