Chapter 5: Cell Structure and Function

OVERVIEW

In this chapter, you will learn about the structure and function of the more primitive prokaryotic cells and the more evolutionarily advanced eukaryotic cells. In particular, the authors cover the organization of eukaryotic cells and emphasize the various organelles found in these cells. Although structurally simple in comparison to eukaryotic cells, bacterial cells have been found to withstand nearly three years exposure to the harsh environment on the surface of the moon.

1) What Are the Basic Features of Cells?

All living things are composed of one or more cells. In the 1850s, Rudolf Virchow proclaimed "All cells come from cells." Modern cell theory principles are: (1) every organism is made of at least one cell; (2) cells are the functional units of life; and (3) all cells arise from preexisting cells. All cells obtain energy and nutrients from their environment, make molecules necessary for growth and repair, get rid of wastes, interact with other cells, and reproduce. All cells share certain features.

The **plasma membrane** (phospholipid bilayer with embedded proteins) encloses the cell and mediates interactions between the cell and its environment. It (1) isolates cytoplasm from external environment, (2) regulates flow of materials between cytoplasm and its environment, and (3) allows interactions with other cells.

Cells use **DNA** as a hereditary blueprint to determine cell structure and function and allow cells to reproduce. In eukaryotic cells (plants, animals, fungi, and protists), DNA is found within the membrane-bound **nucleus**. In prokaryotic cells (bacteria and archaeans), DNA is in a non-membrane enclosed region of the cell.

All cells contain **cytoplasm** (all material inside the plasma membrane and outside the DNA-containing region). Cytoplasm includes water, salts, and organic molecules. Most of the cell's metabolic activities (biochemical reactions that underlie life) occur in the cell's cytoplasm. For instance, protein synthesis takes place on special cytoplasmic structures called **ribosomes**.

All cells obtain energy and nutrients from their environment, in order to maintain their incredible complexity. Cells that harness solar energy directly and incorporate it into high-energy molecules provide the source of energy for nearly all other life forms. The building blocks of biological molecules ultimately come from the environment.

Cell function limits cell size. Most cells are small (1 to 100 micrometers in diameter) because they need to exchange nutrients and wastes through their plasma membranes mainly by diffusion, a slow process especially over long distances. For instance, in a cell 8.5 inches in diameter, it would take over 200 days for oxygen molecules to diffuse to the middle of the cell. Larger cells have greater needs for exchange of molecules with the environment, but they have smaller surface area/internal volume ratio than do smaller cells. A cell that doubles in size becomes eight times greater in volume but only four times greater in surface area. Thus, cells tend to remain small.

2) What Are the Features of Prokaryotic ("before the nucleus") Cells?

Prokaryotic cells are small (less than 5 micrometers long) with simple internal features (no nucleus or membrane-bound organelles). Most are surrounded by a stiff cell wall that confers shape and protection. Some move using simple flagella. Surface protein projections, called **pili** (singular is **pilus**) are used to

attach some bacteria surfaces or to exchange genetic material. **Capsules** or **slime layers** are polysaccharide or protein coatings that some disease-causing bacteria secrete outside their cell wall to attach to their hosts and perhaps evade attack by immune cells. Prokaryotic cells have a single, circular strand of DNA in a cytoplasmic region called the **nucleoid**. Prokaryotic cells lack nuclei as well as other membrane-enclosed organelles, but some photosynthetic bacteria have cytoplasmic membranes which contain the light-capturing proteins and enzymes that catalyze the making of high-energy molecules. Bacterial cytoplasm contains ribosomes, made of **ribonucleic acid (RNA)** and proteins, on which proteins are made. The cytoplasm also may contain food granules.

3) What Are the Features of Eukaryotic Cells?

Eukaryotic cells are larger (greater than 10 micrometers in diameter) and contain **organelles** that perform specific functions within cells. They also have a **cytoskeleton** that provides a network of protein fibers for cellular shape and organization.

The nucleus is usually the largest organelle in the cell, and functions as the cellular control center, containing genetic material (DNA). The DNA is used selectively by eukaryotic cells, depending on their stage of development and environmental conditions. Nuclear components are: (1) the **nuclear envelope** (two membranes perforated with pores to control flow of informational molecules), which separates nuclear material from the cytoplasm. Ribosomes line the outer nuclear membrane, which is continuous with membranes of the rough endoplasmic reticulum; (2) **chromatin** (DNA and associated proteins organized into **chromosomes**). DNA stays in the nucleus, but makes information molecules of RNA that are sent into the cytoplasm to direct the synthesis of cellular proteins; and (3) one or more **nucleoli** ("little nuclei"), containing ribosomal RNA, ribosomes in various stages of assembly, and DNA genes for making ribosomal RNA. Nucleoli are the sites of ribosome synthesis.

Eukaryotic cells contain a complex system of membranes, including the plasma membrane and several organelles including the nuclear envelope. The plasma membrane both isolates a cell and allows selective interactions between a cell and its environment. The **endoplasmic reticulum (ER)** forms interconnected membrane-bound tubes and channels within the cytoplasm and is continuous with the nuclear membrane. Numerous ribosomes stud the outside of the **rough ER** (site of protein synthesis), while **smooth ER** (major site of lipid synthesis) lacks ribosomes. Proteins made by ribosomes in rough ER move through ER channels and accumulate in regions that bud off to form vesicles (membrane-bound cytoplasmic sacs) that carry their protein cargo to the Golgi complex.

The **Golgi complex** (membranous sacs derived from smooth ER) has three functions: (1) it separates out lipids and proteins obtained from ER according to their destinations; (2) it chemically alters some molecules, for instance adding sugars to proteins to make glycoproteins; and (3) it packages molecules into vesicles for transport. **Lysosomes** are cellular digestive centers containing digestive enzymes to break down proteins, fats, and carbohydrates taken into cells as food. Many cells eat by phagocytosis, engulfing extracellular particles using extensions of the plasma membrane which form **food vacuoles**. Lysosomes fuse with food vacuoles and lysosomal enzymes then digest the food into small molecules. Lysosomes also digest defective organelles. Membranes flow through a cell in an orderly way, for example from ER to the Golgi complex to a vesicle which fuses with plasma membrane.

Vacuoles, which are fluid-filled membrane-bound sacs, serve many functions, including water regulation, support, and storage. **Contractile vacuoles**, found in freshwater microorganisms, use energy to pump out water constantly entering due to osmosis. **Central vacuoles**, found in plant cells, may: (1) collect cellular wastes; (2) store poisons that deter feeding animals; (3) store sugars and amino acids for cellular use; and (4) collect pigments that give flowers their colors. Central vacuole contents become hypertonic to cytoplasm and take in water through osmosis. The pressure of the expanding central vacuole, called **turgor pressure**, stiffens the cell, providing support for nonwoody plant parts. Houseplants stiffen when watered and wilt when sufficient water is lacking.

Mitochondria extract energy from food molecules and **chloroplasts** capture solar energy. Biologists believe that both mitochondria and chloroplasts evolved from prokaryotic ancestors that took up residence within the cytoplasm of ancestral eukaryotic cells. This is explained in the **endosymbiotic theory**. Both chloroplasts and mitochondria (1) are oblong and about 1–5 micrometers in diameter; (2) are surrounded by a double membrane; (3) have DNA; and (4) make **ATP**.

Mitochondria, the "powerhouses of the cell," are found in all eukaryotic cells and make ATP using energy stored in food molecules. **Anaerobic** (without oxygen) metabolism of sugar in the cytoplasm produces little ATP energy. Mitochondria use **aerobic** (with oxygen) metabolism to generate about 18 or 19 times as much ATP. The inner mitochondrial membrane loops back and forth to form deep folds (**cristae**) so that there are two regions: the **intermembrane compartment** between outer and inner membrane and the inner **matrix** region.

Chloroplasts (specialized **plastids**) are the sites of photosynthesis. Their inner membranes enclose semifluid **stroma**. The stroma contains **thylakoids** (interconnected stacks of hollow membranous discs) containing **chlorophyll** and other pigments; a stack of thylakoids is a **granum**. Chlorophyll captures sunlight energy and transfers it to other molecules that make ATP and other energy-carrier molecules. In the stroma, these energy molecules are used to combine carbon dioxide and water into sugars. Plastids store various types of molecules, including pigments in fruits and starch in potatoes.

The cytoskeleton provides shape, support, and movement. It includes several types of protein fibers: thin **microfilaments**, medium-sized **intermediate filaments**, and thick **microtubules**. Cytoskeleton functions include: (1) cell shape (especially in animal cells); (2) cell movement (through assembly, disassembly, and sliding of microfilaments and microtubules); (3) organelle movement (especially vesicles, by microfilaments and microtubules); and (4) cell division (microtubules move chromosomes into daughter nuclei, and division of the cytoplasm in animal cells results from contraction of a ring of microfilaments).

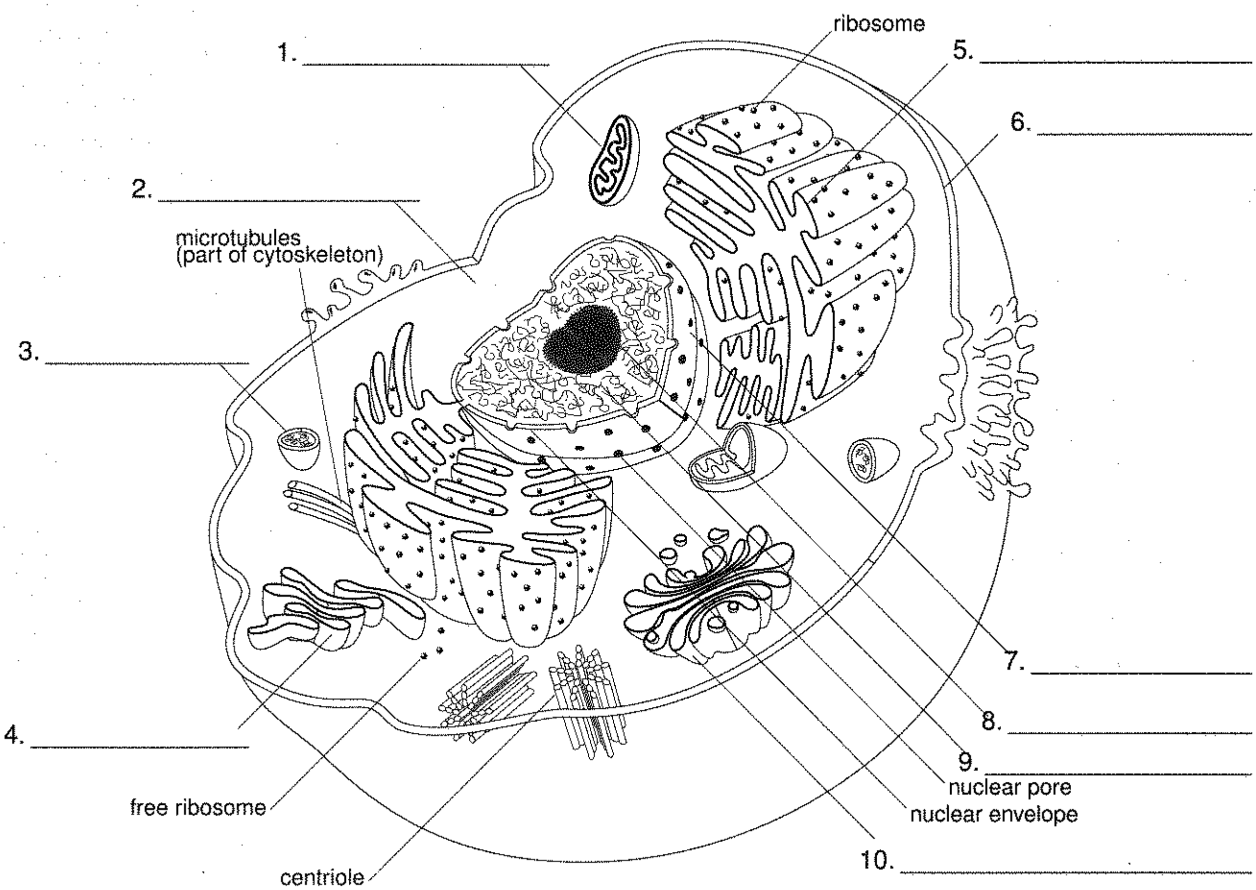
Cilia (short, with many per cell) and **flagella** (long, with few per cell) move cells or move fluid past cells. These are slender extensions of plasma membrane containing a ring of nine fused pairs of microtubules with an unfused pair in the center of the ring (a "9+2" arrangement). They are powered by ATP made by many mitochondria at their bases. Some prokaryotic cells have "flagella" but these do not contain microtubules. A **centriole** is a short, barrel-shaped ring consisting of nine microtubule triplets, but with no microtubules in the center (a "9+0" arrangement). Centrioles provide a basis for the formation of cilia or flagella. Once it begins forming the cilium or flagellum, the centriole is referred to as a **basal body**, since it is located at their base, anchoring them to the plasma membrane.

Case study revisited. Bacteria from humans have survived on the moon surface for several years in a vacuum, at temperatures near absolute zero (-273 degrees, Celsius), without nutrients, energy, or water. Bacteria form sturdy resting structures, called endospores, and may survive in that state for millions of years. Perhaps they are hardy because their simple structure is similar to forms that first colonized Earth about 3.5 billion years ago under extremely harsh conditions.

KEY TERMS AND CONCEPTS

Fill-In: Fill in the names of the structures indicated in this diagram of an animal cell, identifying the following:

cytoplasm	mitochondrion	plasma membrane
chromatin	nucleolus	rough endoplasmic reticulum
Golgi complex	nucleus	smooth endoplasmic reticulum
lysosome		



Key Terms and Definitions

aerobic: using oxygen.

anaerobic: not using oxygen.

basal body: a structure resembling a centriole that produces a cilium or flagellum and anchors this structure within the plasma membrane.

capsule: a polysaccharide or protein coating that some disease-causing bacteria secrete outside their cell wall.

central vacuole: a large, fluid-filled vacuole occupying most of the volume of many plant cells; performs several functions, including maintaining turgor pressure.

centriole (sen´-trē-ōl): in animal cells, a short, barrel-shaped ring consisting of nine microtubule triplets; a microtubule-containing structure at the base of each cilium and flagellum; gives rise to the microtubules of cilia and flagella and is involved in spindle formation during cell division.

chlorophyll (klor´-ō-fil): a pigment found in chloroplasts that captures light energy during photosynthesis; absorbs violet, blue, and red light but reflects green light.

chloroplast (klor´-ō-plast): the organelle in plants and plantlike protists that is the site of photosynthesis; surrounded by a double membrane and containing an extensive internal membrane system that bears chlorophyll.

chromatin (krō´-ma-tin): the complex of DNA and proteins that makes up eukaryotic chromosomes.

chromosome (krō´-mō-sōm): a single DNA double helix together with proteins that help to organize the DNA.

cilium (sil´-ē-um; pl., cilia): a short, hairlike projection from the surface of certain eukaryotic cells that contains microtubules in a 9 + 2 arrangement. The movement of cilia may propel cells through a fluid medium or move fluids over a stationary surface layer of cells.

contractile vacuole: a fluid-filled vacuole in certain protists that takes up water from the cytoplasm, contracts, and expels the water outside the cell through a pore in the plasma membrane.

crista (kris´-tuh; pl., cristae): a fold in the inner membrane of a mitochondrion.

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

cytoskeleton: a network of protein fibers in the cytoplasm that gives shape to a cell, holds and moves organelles, and is typically involved in cell movement.

deoxyribonucleic acid (dē-ox-ē-rī-bō-noo-klā´-ik; DNA): a molecule composed of deoxyribose nucleotides; contains the genetic information of all living cells.

endoplasmic reticulum (ER) (en-dō-plaz´-mik re-tik´-ū-lum): a system of membranous tubes and channels within eukaryotic cells; the site of most protein and lipid syntheses.

endosymbiont hypothesis: the hypothesis that certain organelles, especially chloroplasts and mitochondria, arose as mutually beneficial associations between the ancestors of eukaryotic cells and captured bacteria that lived within the cytoplasm of the pre-eukaryotic cell.

eukaryotic (ū-kar-ē-ot´-ik): referring to cells of organisms of the domain Eukarya (kingdoms Protista, Fungi, Plantae, and Animalia). Eukaryotic cells have genetic material enclosed within a membrane-bound nucleus and contain other membrane-bound organelles.

flagellum (fla-jel´-um; pl., flagella): a long, hairlike extension of the plasma membrane; in eukaryotic cells, it contains microtubules arranged in a 9 + 2 pattern. The movement of flagella propel some cells through fluids.

food vacuole: a membranous sac, within a single cell, in which food is enclosed. Digestive enzymes are released into the vacuole, where intracellular digestion occurs.

Golgi complex (gōl´-jē): a stack of membranous sacs, found in most eukaryotic cells, that is the site of processing and separation of membrane components and secretory materials.

granum (gra´-num; pl., grana): a stack of thylakoids in chloroplasts.

intermediate filament: part of the cytoskeleton of eukaryotic cells that probably functions mainly for support and is composed of several types of proteins.

intermembrane compartment: the fluid-filled space between the inner and outer membranes of a mitochondrion.

lysosome (lī´-sō-sōm): a membrane-bound organelle containing intracellular digestive enzymes.

matrix: the fluid contained within the inner membrane of a mitochondrion.

microfilament: part of the cytoskeleton of eukaryotic cells that is composed of the proteins actin and (in some cases) myosin; functions in the movement of cell organelles and in locomotion by extension of the plasma membrane.

microtubule: a hollow, cylindrical strand, found in eukaryotic cells, that is composed of the protein tubulin; part of the cytoskeleton used in the movement of organelles, cell growth, and the construction of cilia and flagella.

mitochondrion (mī-tō-kon´-drē-un): an organelle, bounded by two membranes, that is the site of the reactions of aerobic metabolism.

nuclear envelope: the double-membrane system surrounding the nucleus of eukaryotic cells; the outer membrane is typically continuous with the endoplasmic reticulum.

nucleoid (noo-klē-oid): the location of the genetic material in prokaryotic cells; not membrane-enclosed.

nucleolus (noo-klē´-ō-lus): the region of the eukaryotic nucleus that is engaged in ribosome synthesis; consists of the genes encoding ribosomal RNA, newly synthesized ribosomal RNA, and ribosomal proteins.

nucleus (cellular): the membrane-bound organelle of eukaryotic cells that contains the cell's genetic material.

organelle (or-guh-nel´): a structure, found in the cytoplasm of eukaryotic cells, that performs a specific function; sometimes refers specifically to membrane-bound structures, such as the nucleus or endoplasmic reticulum.

pilus (pil´-us; pl., pili): a hairlike projection that is made of protein, located on the surface of certain bacteria, and is typically used to attach a bacterium to another cell.

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

plastid (plas´-tid): in plant cells, an organelle bounded by two membranes that may be involved in photosynthesis (chloroplasts), pigment storage, or food storage.

prokaryotic (prō-kar-ē-ot´-ik): referring to cells of the domains Bacteria or Archaea. Prokaryotic cells have genetic material that is not enclosed in a membrane-bound nucleus; they lack other membrane-bound organelles.

ribonucleic acid (rī-bō-noo-klā´-ik; RNA): a molecule composed of ribose nucleotides, each of which consists of a phosphate group, the sugar ribose, and one of the bases adenine, cytosine, guanine, or uracil; transfers hereditary instructions from the nucleus to the cytoplasm; also the genetic material of some viruses.

ribosome: an organelle consisting of two subunits, each composed of ribosomal RNA and protein; the site of protein synthesis, during which the sequence of bases of messenger RNA is translated into the sequence of amino acids in a protein.

rough endoplasmic reticulum: endoplasmic reticulum lined on the outside with ribosomes.

slime layer: a sticky polysaccharide or protein coating that some disease-causing bacteria secrete outside their cell wall; helps the cells aggregate and stick to smooth surfaces.

smooth endoplasmic reticulum: endoplasmic reticulum without ribosomes.

stroma (strō´-muh): the semi-fluid material inside chloroplasts in which the grana are embedded.

thylakoid (thī´-luh-koid): a disk-shaped, membranous sac found in chloroplasts, the membranes of which contain the photosystems and ATP-synthesizing enzymes used in the light-dependent reactions of photosynthesis.

turgor pressure: pressure developed within a cell (especially the central vacuole of plant cells) as a result of osmotic water entry.

vacuole (vak´-ū-ōl): a vesicle that is typically large and consists of a single membrane enclosing a fluid-filled space.

THINKING THROUGH THE CONCEPTS

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

11. _____ More primitive types of cells are called eukaryotic cells.
12. _____ The presence of large numbers of ribosomes is characteristic of rough endoplasmic reticulum.
13. _____ In eukaryotic cells, the majority of the hereditary material is found in the cytoplasm.
14. _____ Mitochondria are associated with release of energy from sugar.
15. _____ Mitochondria are associated with the storage of energy in sugar.
16. _____ Lipid-producing enzymes are more common in rough endoplasmic reticulum.
17. _____ Animals store food in the form of starch.
18. _____ Animal cells are more likely to have vacuoles.
19. _____ Higher plants lack ciliated or flagellated cells.
20. _____ Cilia are longer than flagella.

Identify: Determine whether the following statements refer to **eukaryotic** or **prokaryotic** cells or **both**.

21. _______________ lack a membrane-bound nucleus
22. _______________ have many chromosomes with DNA and protein
23. _______________ lack most cytoplasmic organelles
24. _______________ larger and more complex
25. _______________ have nucleoid regions in the cytoplasm
26. _______________ have DNA
27. _______________ have flagella with 9+2 structure

Identify: Determine whether the following statements refer to **mitochondria**, **chloroplasts**, or **both**.

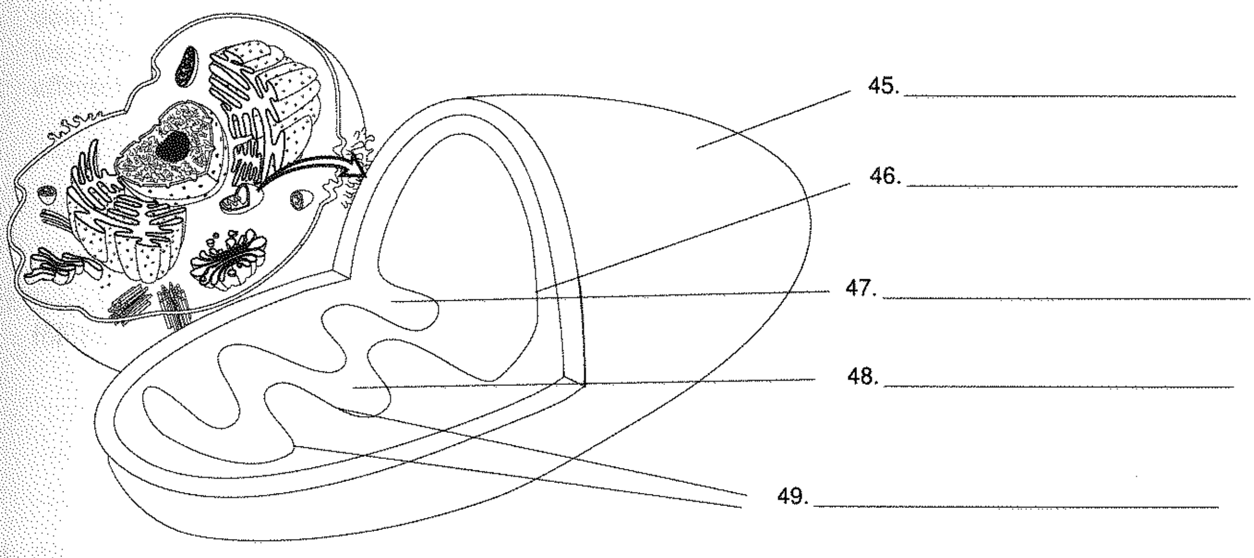
28. _______________ make ATP using solar energy
29. _______________ capture sunlight energy to make sugar
30. _______________ convert food energy into ATP energy
31. _______________ have DNA
32. _______________ have thylakoid membranes and semi-fluid stroma
33. _______________ extract energy from food molecules
34. _______________ found in plants
35. _______________ have cristae membranes and semi-fluid matrix
36. _______________ have chlorophyll
37. _______________ function in photosynthesis
38. _______________ use oxygen

Identify: Determine whether the following statements refer to **cilia**, **flagella**, or **both**.

39. ______________ microtubular extensions through the cell membrane
40. ______________ shorter and more numerous per cell
41. ______________ have a "9 + 2" arrangement of microtubular pairs
42. ______________ move in a wavelike motion
43. ______________ move substances across a surface
44. ______________ used for food gathering and for movement

Fill-In: Fill in the names of the structures indicated in the following figure.

cristae	intermembrane compartment	outer membrane
inner membrane	matrix	



Matching: Organelles that manufacture or digest proteins and lipids.

50. _____ digest food particles
51. _____ interconnected membrane tubes and channels in the cytoplasm
52. _____ stacks of membranes in the cytoplasm
53. _____ made of RNA and proteins
54. _____ function in the nucleus
55. _____ membrane-bound vesicles
56. _____ "workbenches" for protein synthesis
57. _____ sort out various lipids and proteins
58. _____ may be rough or smooth in appearance
59. _____ sites of lipid synthesis
60. _____ large and small subunits are assembled in the nucleolus
61. _____ packages proteins and lipids into vesicles for transport out of the cell
62. _____ digests defective organelles

Choices:

a. ribosomes
b. endoplasmic reticulum
c. Golgi complexes
d. lysosomes
e. none of these

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

63. Which of the following is not a similarity of mitochondria and chloroplasts?
    a. both make ATP
    b. both capture solar energy and convert it into chemical energy
    c. both possess their own DNA
    d. both have a double membrane
    e. both probably evolved from bacteria long ago

64. Which type of organism is most likely to survive on the lunar surface for years at a time?
    a. plants
    b. bacteria
    c. fungi
    d. animals
    e. algae

65. All cells possess all of the following except:
    a. cytoplasm
    b. genetic material
    c. nuclear membrane
    d. chromosome
    e. plasma (cell) membrane

66. Both prokaryotic and eukaryotic cells possess:
    a. mitochondria
    b. chloroplasts
    c. cytoskeleton
    d. ribosomes
    e. lysosomes

67. Which organelle extracts energy from food molecules and uses it to make ATP?
    a. mitochondrion
    b. chloroplast
    c. ribosome
    d. centriole
    e. nucleus

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.

68. Why do cells seldom grow large enough to be seen without the aid of a microscope?

69. Suppose you discovered a chemical that had all of the following effects on a cell: cell growth slowed down, the movement of cilia slowed down, cell divisions occurred less frequently, proteins were made less often, and endocytosis occurred less often. Which of these organelles do you think the chemical affected most severely: lysosomes, Golgi complex, or mitochondria? Briefly explain your answer.

70. Why is it not surprising that simple bacteria have been shown to be able to survive on the lunar surface for long periods of time?

71. Although it appears that plants and animals are very different types of organisms, their cells have much more in common than you would guess. List the organelles common in plants and animals, and the organelles unique to each.

72. Why do scientists think that chloroplasts and mitochondria arose from prokaryotic cells?

73. Vigorous exercise, repeated regularly, may result in larger and firmer muscles. What organelles within the muscle cells might also increase (in number) as a result of the exercise regimen?

74. Suppose a cell is shaped like a cube, 4 micrometers long on each side. Calculate the surface area (length x width x 6 sides) and the volume (length x width x height). Also, compare the surface area to the volume of the cell (divide the surface area by the volume). Now, compare those calculations to similar ones for a cube-shaped cell 8 micrometers long on each side. What does this comparison indicate about the functioning of smaller and larger cells? What conclusion can you draw about why cells seldom grow very large?

75. Estimate the number of cells in your little finger. Assume your finger is a cylinder, for which the volume is 3 x [(radius)^2] x height; assume that average size of a body cell is 1000 μm^3 (cubic micrometers).

76. Why are scientists so interested in studying lysosomes?