Chapter 3

Cell Structure and Taxonomy

Learning Objectives

Chapter 3 introduces the structure of prokaryotic and eukaryotic cells and explains the differences between these two categories of cells. It also introduces taxonomy, binomial nomenclature, and the Five-Kingdom and Three-Domain Systems of Classification. The information in Chapter 3 is considered essential in an introductory microbiology course.

Terms Introduced in This Chapter

After reading Chapter 3, you should be familiar with the following terms. These terms are defined in Chapter 3 and in the Glossary.

Amphitrichous bacterium
Asexual reproduction
Autolysis
Axial filaments
Bacteria
Binary fission
Capsule
Cell
Cell membrane
Cell theory
Cell wall
Cellulose
Chitin
Chloroplast
Chromosomes
Cilium
Conjugation
Cytokinesis
Cytology
Cytoplasm
Cytoskeleton
Deoxyribonucleic acid (DNA)
Diploid cells
Domain *Archaea*
Domain *Bacteria*
Endoplasmic reticulum (ER)
Endospore

***Eukarya* (Domain)**
Eukaryotic cells
Fimbriae
Flagella
Flagellin
Gene
Gene product
Generation time
Genotype
Genus
Glycocalyx
Golgi complex
Haploid cells
Life cycle
Lophotrichous bacterium
Lysosome
Meiosis
Metabolism
Microtubules
Mitochondria
Mitosis
Monotrichous bacterium
Negative stain
Nuclear membrane
Nucleolus
Nucleoplasm
Nucleus
Organelles
Peptidoglycan
Peritrichous bacterium
Peroxisome
Phagocyte
Phagocytosis
Phenotype
Photosynthesis
Pili
Plasmid
Plastid
Polyribosomes
Prokaryotic cells
Protists
Protoplasm
Ribonucleic acid (RNA)

Ribosomes
Rough endoplasmic reticulum (RER)
Selective permeability
Sex pilus
Sexual reproduction
Slime layer
Smooth endoplasmic reticulum (SER)
Species
Specific epithet
Spirochetes
Sporulation
Taxa
Taxonomy
Tyndallization

Review of Key Points

- The cell is the fundamental unit of any living organism. It exhibits the basic characteristics of life. All living organisms are composed of one or more cells.
- Cellular microbes are also called microorganisms.
- Eukaryotic cells contain a "true nucleus," whereas prokaryotic cells do not. Eukaryotic cells also possess a complex system of membranes and membrane-bound organelles, whereas prokaryotic cells do not.
- A "true nucleus" consists of nucleoplasm, chromosomes, and a nuclear membrane.
- Genes are located along chromosomes. An organism's complete collection of genes is referred to as its genotype or genome.
- Each gene codes for one or more gene products. Most gene products are proteins.
- Both eukaryotic and prokaryotic cells possess a cell membrane. Cell membranes have selective permeability, allowing only certain substances to pass through them.
- Ribosomes are the sites of protein synthesis.
- Golgi complexes can be considered "packaging plants," for it is here that proteins are packaged into small, membrane-enclosed vesicles.
- Eukaryotic cells contain mitochondria, whereas prokaryotic cells do not.
- Mitochondria can be considered "power plants" or "energy factories," for it is within mitochondria that much energy is produced. Energy-producing reactions occur at the cell membranes of prokaryotic cells.
- Plastids are the sites of photosynthesis. Plastids are found within plant cells and algae.
- Some eukaryotic cells have cell walls, which provide rigidity, shape, and protection; these simple cell walls may contain cellulose, pectin, lignin, chitin, or mineral salts. Prokaryotic bacterial cell walls are more complex, containing peptidoglycan and, in some cases, lipopolysaccharides.
- Motile eukaryotic cells possess either cilia or flagella. Motile prokaryotic cells possess

flagella. Eukaryotic flagella are structurally more complex than prokaryotic flagella.

- Eukaryotic cells reproduce by either mitosis or meiosis. Prokaryotic cells reproduce by binary fission—the simple division of one cell into two cells.
- The length of time it takes for one bacterial cell to split into two cells is referred to as the organism's generation time.
- Most bacteria possess only one chromosome.
- Bacteria may possess plasmids—small, circular molecules of DNA that are not part of the bacterial chromosome; they are said to be extrachromosomal.
- A plasmid may contain anywhere from fewer than 10 genes up to several hundred genes.
- A bacterial cell may not contain any plasmids, or it may contain one plasmid, multiple copies of the same plasmid, or more than one type of plasmid.
- Most bacteria possess cell walls. Exceptions include bacteria in the genus *Mycoplasma*.
- External to the cell wall, some bacteria have either a capsule or a slime layer. Capsules serve an antiphagocytic function and have been used in the production of certain vaccines (e.g., Hib vaccine). Determining whether a bacterium possesses a capsule is sometimes of value when attempting to identify (speciate) the organism.
- Many bacteria have flagella that enable motility, and some produce spores to enable them to survive adverse conditions. Determining whether a bacterium possesses flagella is sometimes of value when attempting to identify the organism, as are the number and location of the flagella. Likewise, the presence or absence of spores and their location within cells can be of value when identifying bacteria.
- Fimbriae (Pili) are organelles of attachment; they enable bacteria to adhere to surfaces.
- A sex pilus enables the transfer of genetic material from one bacterial cell (the donor cell) to another (the recipient cell).
- An organism's physical characteristics are collectively known as the organsim's phenotype. An organism's phenotype is determined by that organism's genotype.
- In the binomial system of nomenclature, the first name is the genus, the second name is the specific epithet, and the two names together are referred to as a species.
- Taxonomic classification of organisms separates them into kingdoms, divisions, classes, orders, families, genera, and species, based on their characteristics, attributes, properties, and traits.
- In the Five-Kingdom System of Classification, microorganisms are found in the first three kingdoms—Prokaryotae (bacteria), Protista (algae and protozoa), and Fungi. In the Three-Domain System of Classification, microorganisms are found in all three domains—*Archaea*, *Bacteria*, and *Eukarya.*
- Viruses are not included in either the Five-Kingdom System or the Three-Domain System of Classification because they are acellular and, therefore, are not considered to be organisms.
- Relatedness among organisms is determined by analysis of genes that code for small-subunit ribosomal RNA. The more similar the gene sequences, the more closely related are the organisms. The less similar the sequences, the less related are the organisms.

A Closer Look

• Asexual versus Sexual Reproduction

In ***asexual reproduction***, a single organism is the sole parent. It passes copies of all of its genes (i.e., its entire genome) to its offspring. Some single-celled eukaryotic organisms can reproduce asexually by mitotic cell division (mitosis; described later), a process by which their chromosomes are copied and allocated equally to two daughter cells. The genomes of the offspring are identical to the parent's genome. Prokaryotic organisms reproduce asexually by a process known as binary fission (described later).

In ***sexual reproduction***, two parents give rise to offspring that have unique combinations of genes inherited from both parents. The alternation of meiosis (described later) and fertilization is common to all organisms that reproduce sexually. In sexual reproduction, a zygote (fertilized egg) is formed by the fusion of gametes.

Most **protists** can reproduce asexually. Some protists are exclusively asexual, whereas others can also reproduce sexually (involving meiosis and the fusion of gametes). Fungi (other than yeasts) reproduce by releasing conidia or spores, which are produced either sexually or asexually. Most yeasts reproduce asexually, either by simple cell division or by the process of budding. Budding, a type of mitosis, involves the formation of a small cell (called a bud), which then pinches off from the parent cell. Some yeasts reproduce sexually.

• Life Cycles

A ***life cycle*** can be defined as the generation-to-generation sequence of stages that occur in the reproductive history of an organism. The human life cycle (which is also the life cycle of most animals and some protists) involves production of haploid gametes by meiosis, fusion of gametes to produce a diploid zygote, and mitotic division of the zygote to produce a multicellular organism, composed of diploid cells. (***Haploid cells*** contain only one set of chromosomes, whereas ***diploid cells*** contain two sets of chromosomes.)

Another type of life cycle that occurs in most fungi and some protists, including some algae, involves fusion of haploid gametes to form a diploid zygote, meiosis to produce haploid cells, and then division of the haploid cells by mitosis to give rise to a multicellular adult organism that is composed of haploid cells. Gametes are then produced from the haploid organism by mitosis (rather than by meiosis). Thus, the only diploid stage is the zygote.

A third type of life cycle that occurs in plants and some species of algae is called alternation of generations. In this type of life cycle, there are both diploid and haploid multicellular stages. The multicellular diploid stage is called the sporophyte. Meiosis in the sporophyte produces haploid cells called spores. Unlike a gamete, a spore gives rise to a multicellular organism without fusing with another cell. A spore divides mitotically to generate a multicellular haploid stage called the gametophyte. The gametophyte makes gametes by mitosis. Fertilization results in a diploid zygote, which develops into the next sporophyte generation. Thus, the sporophyte and gametophyte generations take turns reproducing each other.

• Eukaryotic Cell Reproduction

Eukaryotic cells may reproduce either by mitosis or by meiosis. Mitosis results in two cells (called daughter cells), which are identical to the original cell (the parent cell). Meiosis results in four cells, each of which contains half the number of chromosomes as the parent cell.

Mitosis

The word *mitosis* comes from the Greek word *mito*, meaning “thread.” When cells are observed microscopically, threadlike structures can be seen during mitosis. Technically speaking, **mitosis** refers to nuclear division—the equal division of one nucleus into two genetically identical nuclei. Mitosis is preceded by replication of chromosomes, which occurs during a part of the cell’s life cycle known as interphase. During mitosis, the nuclear material of the parent cell shifts, reorganizes, and moves around, leading some people to refer to mitosis as “the dance of the chromosomes.” After mitosis occurs, the cytoplasm divides (a process known as ***cytokinesis***), resulting in two daughter cells. Either haploid or diploid cells can divide by mitosis.

Meiosis

Only diploid cells can undergo meiosis. As with mitosis, meiosis is preceded by replication of chromosomes. In **meiosis,** diploid cells are changed into haploid cells. Human diploid cells, for example, contain 46 chromosomes, whereas human haploid cells (sperm cells and ova) contain 23. Meiosis is the process by which gametes are produced. Many steps are involved in meiosis—too many to discuss in detail here. Suffice it to say that meiosis involves two divisions (called meiosis I and meiosis II). The end result is four daughter cells, each of which contains only half as many chromosomes as the parent cell. Recall that mitosis, on the other hand, produces two daughter cells that are genetically identical to the parent cell.

• The Origin of Mitochondria and Chloroplasts

Symbiosis is the living together or close association of two dissimilar organisms, usually two different species. In such a relationship, each party is referred to as a symbiont. Endosymbionts are organisms that live inside of other organisms, the latter of which are referred to as hosts.

Many scientists believe that the mitochondria and chloroplasts of eukaryotic cells were originally derived from bacterial endosymbionts—bacteria that once led a free-living, independent existence. The theory known as the serial endosymbiosis hypothesis proposes that, at some point in time (perhaps 1.5 billion years ago), certain bacteria were engulfed (phagocytized) by other prokaryotic cells. At first, the engulfed bacteria continued to live an independent existence within the host cells. But, in time, an interdependence developed between the two organisms, and the endosymbionts developed into the organelles known as mitochondria and chloroplasts.

Most of the evidence for the serial endosymbiosis theory is based on similarities between these organelles and bacteria. Mitochondria possess a circular chromosome, a specific type of RNA, and ribosomes (which are very much like those of bacteria), and similar to bacteria, mitochondria arise only from preexisting mitochondria. Chloroplasts are very much like photosynthetic bacteria. They contain DNA and ribosomes quite similar to those found in bacteria, and they too arise independently of other organelles. This theory becomes even more plausible when one considers that many simple marine animals and protists existing today contain photosynthetic endosymbionts. Based on 16S rRNA sequence data, the most likely candidates to have evolved into mitochondria and chloroplasts are alpha purple bacteria and cyanobacteria, respectively. (See the book for information on 16S sequences.)

Not all scientists agree with the serial endosymbiosis theory, however. Another theory—the autogenous hypothesis—states that mitochondria and chloroplasts, as well as other membranous structures found within eukaryotic cells, were derived from the cytoplasmic membrane. Undoubtedly, additional research will determine which of these hypotheses is correct.

Increase Your Knowledge

1. Information about the 600+ bacterial genomes that have been sequenced to date can be found at the following Wikipedia link: en.wikipedia.org/wiki/List_of_sequenced_bacterial_genomes. (Note that different strains of the same species—e.g., *E. coli*—contain different numbers of genes.) The first complete microbial genomic sequence—that of *Haemophilus influenzae*—was published in 1995.

2. J. Craig Ventner is one of the leading scientists of the 21st century. Among his other accomplishments, in 2001, he published the complete sequence of the human genome. Learn more about this remarkable scientist in his book entitled *A Life Decoded: My Genome, My Life*.

3 Check out www.cellsalive.com for interactive information on cell structure, mitosis, meiosis, the cell cycle, and other cell-related topics.

4. Numerous videos on bacterial flagella and eukaryotic cilia can be viewed at www.youtube.com. Search for either “cilia” or “flagella.”

5. Identify bacteria in a virtual lab at the Howard Hughes Medical Institute Web site: http://www.hhmi.org/biointeractive/vlabs/bacterial_id/index.html
(This site has numerous excellent videos, animations, and interactive activities related to microbiology!)

6. Check “Dr. Lynn Margulis” on Wikipedia for information on the endosymbiotic theory and the origin of certain cell organelles.

Critical Thinking

1. Draw a picture of a eukaryotic cell from memory, labeling as many structures as possible. Use the outline below to represent the cell membrane. When you are finished, compare your drawing to Figure 3-2 in the book.

2. Draw a picture of a prokaryotic cell from memory, labeling as many structures as possible. Use the outline below to represent the cell membrane. When you are finished, compare your drawing to Figure 3-6 in the book.

3. Draw diagrams which illustrate the major differences between Gram-positive and Gram-negative cell walls.

Additional Chapter 3 Self-Assessment Exercises

(Note: Do not peek at the answers before you attempt to solve these self-assessment exercises.)

Matching Questions

A. Plastids
B. Mitochondria
C. Ribosomes
D. Endoplasmic reticulum
E. Golgi complex

_____ 1. Membrane-bound organelles where photosynthesis occurs.

_____ 2. The sites of protein synthesis in prokaryotic cells.

_____ 3. Considered a "packaging plant," where proteins are packaged into membrane-bound vesicles.

_____ 4. Membrane-bound organelles where energy is produced by the Krebs cycle and electron transport chain.

_____ 5. Found in prokaryotic cells as well as eukaryotic cells.

A. Pili
B. Cilia
C. Eukaryotic flagella
D. Capsules
E. Prokaryotic flagella

_____ 1. Short, hairlike projections used as organelles of locomotion by some eukaryotic cells.

_____ 2. Found on some bacteria; they serve an antiphagocytic function.

_____ 3. Found on some bacteria; they enable the bacteria to adhere to surfaces.

_____ 4. Composed of a protein called flagellin.

_____ 5. Long, whiplike structures having an internal organization that is described as a "9+2" arrangement of microtubules.

True/False Questions

_____ 1. The internal structure of prokaryotic flagella is the same as the internal structure of eukaryotic flagella.

_____ 2. The internal structure of eukaryotic cilia is the same as the internal structure of eukaryotic flagella.

_____ 3. The production of endospores by bacteria is a reproductive mechanism.

_____ 4. Bacteria never have cilia and eukaryotic cells never have pili.

_____ 5. The Three-Domain System of classification is based on differences in the structure of transfer RNA (tRNA) molecules.

_____ 6. One way that archaea differ from bacteria is that archaea possess more peptidoglycan in their cell walls.

_____ 7. Chitin is found in the cell walls of algae, but is not found in the cell walls of any other types of microorganisms.

_____ 8. Tyndallization is a process that kills spores as well as vegetative cells.

_____ 9. Prokaryotic cells do not contain endoplasmic reticulum, Golgi bodies, mitochondria, plastids, or membrane-bound vesicles.

_____ 10. In eukaryotic cells, ribosomal RNA (rRNA) molecules are manufactured in the nucleolus.

Answers to the Additional Chapter 3 Self-Assessment Exercises

Matching Questions

1. A
2. C
3. E
4. B
5. C

1. B
2. D
3. A
4. E
5. C

True/False Questions

1. False (Eukaryotic flagella contain microtubules, whereas prokaryotic flagella do not.)
2. True
3. False (Production of endospores is a survival mechanism.)
4. True
5. False (The Three-Domain System is based on differences in the structure of ribosomal RNA [rRNA].)
6. False (The cell walls of archaea do not contain peptidoglycan.)
7. False (Chitin is found in the cell walls of fungi.)
8. True
9. True
10. True